Hybrid Storage Technology

Initial assessment of the greenhouse gas reduction and economic savings from Hybrid EGT® adoption in California

July 2018

Gridwell
CONSULTING

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1 Executive Summary

Hybrid storage technology was pioneered by General Electric and Wellhead Power Solutions in 2016,[1] leading to the co-development of an electric gas turbine (EGT®). This technology was put into commercial use by Southern California Edison (SCE) in Q1, 2017. SCE energized two Hybrid EGT® systems, which integrated existing 50-MW combustion turbines with new 10-MW/4.3 MW-hour battery energy storage systems (BESS). SCE recently presented to the California Public Utilities Commission (CPUC), and then publicized, the lowered emissions and increased reliability that resulted from these Hybrid EGT® installations, as summarized below.[2]

- *Without* any fuel consumption—provision of 50 MWs of operating reserves[3], primary frequency response, voltage support, and the potential for black-start services.
- *With* fuel consumption—provision of instant-peaking energy for local contingencies and high-speed regulation.
- *Overall*—increased ancillary service participation (primarily spinning reserve and much higher frequency response use than before hybridizing), lower fuel gas use, lower emissions, higher capacity use, and higher market revenues.

Given these very positive initial findings, Wellhead has asked Gridwell Consulting to take the next step and independently evaluate greenhouse gas (GHG) reduction and potential economic savings to be gained from additional hybridizing of the California gas fleet. This study is intended as the first step toward understanding whether there are such benefits, before moving forward with more specialized modeling that can accommodate the unique characteristics of hybrid storage and the hybridizing option.

In general, Gridwell finds obvious benefits to hybridizing at least a subset of the existing gas fleet. These expected benefits are consistent with SCE's initial experience with the Hybrid EGT®s. This suggests that there are clearly benefits to additional hybridizing and earlier procurement of hybrid storage resources may produce additional benefits. Furthermore, we consistently verified several key findings across multiple evaluation methods:

- The optimal use for a hybrid storage resource is for spinning and regulation reserves, as well as quick response to emergency or near-emergency grid energy needs.
- Emission savings come primarily through fleet-wide re-dispatch, as hybrid storage resources take on more ancillary services and other resources can shut down or operate at their most efficient use. Secondary emission savings come from the battery responding instantaneously to unexpected, short-duration energy needs, without the resource needing to burn fuel.

[1] This report is sponsored by Wellhead.

[2] Notice of SCE of ex parte communication with the office of Commission President Michael Picker; April 13, 2018.

[3] Operating reserves refer to both spinning and non-spinning reserves.

- Early procurement of Hybrid EGT®s – in 2018, 2019, and 2020 – should reduce annual emissions even more than procurement after 2022 due to higher near-term ability to displace gas resources.
- Enabling storage hybridizing as part of the storage target leads to significant load payment savings by reducing fleet operating costs and storage build-out costs as California increases renewable energy on the grid to meet its renewable and GHG target.

Each evaluation method (described below) considers the potential benefits of hybridizing within the context of California GHG reduction and renewable resource target. California is in the process of reducing its reliance on natural gas resources in order to reduce GHG emissions and operate primarily with renewable energy and storage capacity. The movement away from natural gas limits the pool of potential gas plants to hybridize because a basic tenet of California resource planning is that natural gas plants not needed for reliability purposes should retire.

Additionally, Gridwell had to consider the fact that hybrid energy storage technology is only commercially in use to hybridize General Electric LM6000 combustion turbine engines. Currently, there are only theoretical benefits to hybridizing larger gas resources, such as combined-cycle plants. You will find a summary of the quantity of combustion turbine located in the California ISO that could benefit from hybridizing in section 8.2. This is a high level, total quantity that Gridwell recommends be further refined with additional analysis and modeling.

Gridwell uses three distinct methodologies to evaluate the initial potential for hybrid storage technology: (1) an analytical assessment of long-term GHG reduction and economic benefits using the capacity expansion model RESOLVE, (2) the conceptual and observed benefits of existing Hybrid EGT® resources in service, and (3) a review of previous PLEXOS modeling work done on hybrid storage resources prior to their activation.[4]

Gridwell applied the latest RESOLVE model used in the CPUC integrated resource planning (IRP) process to explore the long-term economic benefits and potential GHG reduction of installing additional Hybrid EGT®s. Gridwell modified the model to allow the Hybrid EGT®s to be considered as a resource option. Because the model would need additional, more significant optimization changes to perfectly model hybrid storage, the RESOLVE modelling results should be taken as directionally indicative, rather than an exact prediction of the future. The enhancements to the model that allow hybrid storage as a part of California's IRP yielded the following model results:

- Hybrid storage resources are part of the optimal resource mix under all planning scenarios considered, providing a significant proportion of required spinning reserves.

[4] Gridwell uses the following nomenclature: the technology used to combine natural gas plants and Battery Energy Storage Systems is "hybrid storage technology"; the commercialized and installed technology by SCE are the "Hybrid EGT® units" and any potential or theoretical hybrid units are "hybrid storage resources."

- Hybrid storage resources provide additional cost savings and GHG reductions if the model is forced to procure hybrid resources in the near-term.
    a. Hybrid Storage resources enable California to reach its GHG target at a lower cost, *ceteris paribus*. **Based on the model results, each hybrid storage resource can reduce GHG emissions by almost 30,000 tons of CO_2 per year.**
    b. Hybrid storage resources significantly reduce revenue requirements over the long-run. The model results show that under the existing storage target, **each hybrid resource has the potential to reduce ratepayer costs by a net present value of over $26.4 million through 2030.**

The figure below summarizes the highlights of the resulting benefits of hybrid storage resources selected by RESOLVE from a California capacity expansion perspective based on modeling by Gridwell to date.

Figure 1: Resolve Modeling Results Summary

Energy Storage Target Assumed in RESOLVE (MW)	Hybrid Storage (MW)	Battery Component (MW)	Annual Average GHG Savings Per Hybrid Resource (Metric Tons CO2)	Total Average Annual CAISO GHG Savings (Metric Tons CO2)	Net Present Value Rev Req't Savings Thru 2030 (Millions)	Net Present Value Rev Req't Savings Per Hybrid Resource (Millions)
1,325	704 (700 by 2022)	140	29,928	418,998	$369	$26.4
1,825	2,500	500	17,643	882,147	$589	$11.8

Under the 1,325 MW case above, Gridwell evaluated the potential savings of procuring at least 700 MWs of Hybrid EGT resources by 2022, representing an "early procurement" case. The 1,825 MW case evaluates if 500 MWs of the 1,825 MW energy storage target was met by Hybrid EGTs.

Gridwell also conceptually explored the benefits of hybrid storage technology, both to reduce emissions and provide additional grid services. Gridwell finds that:

- There are significant potential emission savings from adding battery storage to a gas turbine engine. If Hybrid EGT®s provide spinning reserves, emissions are significantly reduced across the entire fleet, as compared to spinning reserves being provided by combined-cycle or combustion turbines.[5] The GHG reduction value of hybridizing is to

[5] In 2017, approximately 34% of spinning reserves were provided by gas resources. http://www.caiso.com/Documents/2017AnnualReportonMarketIssuesandPerformance.pdf, page 146.

make gas plants needed for reliability as low-emission as possible, while concurrently enhancing their reliability and flexibility benefits to the grid.

- Hybrid EGT®s are a low-cost, high-benefit option for load-serving entities to meet their storage target.[6] Hybridizing the existing LM6000 peaking facilities in local areas will have a positive benefit-cost ratio, and higher net present value than BESS alone, will be extremely cost-competitive, and could help disadvantaged communities reduce emissions while maintaining local jobs and the property tax base.
- Additional analysis is needed to determine the optimal adoption rate and quantity. This is more fully explored in section 7.

Finally, Gridwell reviewed previous PLEXOS® modeling on the predicted benefits done prior to Hybrid EGT® energization to determine if the predicted benefits aligned with Gridwell's independent findings. All studies were aligned with conceptual and observed benefits and the RESOLVE modeling using actual operating characteristics. The PLEXOS® modeling, using expected characteristics, showed extremely similar results.

- The PLEXOS® production cost modeling efforts show the primary use of hybrid storage resources is to provide a significant portion of spinning reserves.
- Hybrid storage resources provide energy and spinning reserves at a lower heat rate than alternatives, thus reducing overall GHG emissions and cost.
- The modeled market realized significant cost savings due to the hybrid storage resources displacing higher-cost resources.

Overall, Gridwell finds positive indications that adopting hybrid storage technology in California will lower emissions (including GHG) and costs to load as well as provide significant reliability benefits. As noted above, additional study is needed to estimate more precise cost and GHG reduction savings, as well as optimal adoption timing and amounts. Furthermore, Gridwell focused exclusively on proven technology applicable only to hybridizing LM6000 turbines. Therefore, Gridwell believes that further theoretical and modeling work would be beneficial to explore the benefits on other technology types, particularly combined-cycle resources.[7]

2 Hybrid Battery Storage Technology

Hybrid storage technology combines a battery energy storage system (BESS) with a gas turbine to provide greater operational flexibility than a gas turbine alone. This technology was pioneered by General Electric and Wellhead Power Solutions in 2016. It is frequently referred to as a Hybrid EGT®, hybrid energy storage resource, or sometimes just as hybrid storage.

[6] Target as authorize by CPUC Resolution E-4791 and consistent with D.13-10-040.

[7] Initial modeling of combined-cycle hybridizing is very promising but requires additional RESOLVE model enhancements for more conclusive results.

SCE hybridized two of their LM6000 gas turbines in Q1 2017.[8] They are now reporting on the first year of the Hybrid EGT's® operational benefits and have found increased fuel savings, along with decreased emissions, water consumption, and need for maintenance.[9] The two hybridized gas turbine plants also meet California's strict environmental requirements by reducing overall water consumption. The Hybrid EGT®s can reduce the sites water usage by approximately 45 percent, due to lower fuel burn.

Figure 2 summarizes the resource characteristics of a generic hybrid storage resource.

Figure 2: Hybrid Storage Resource Characteristics

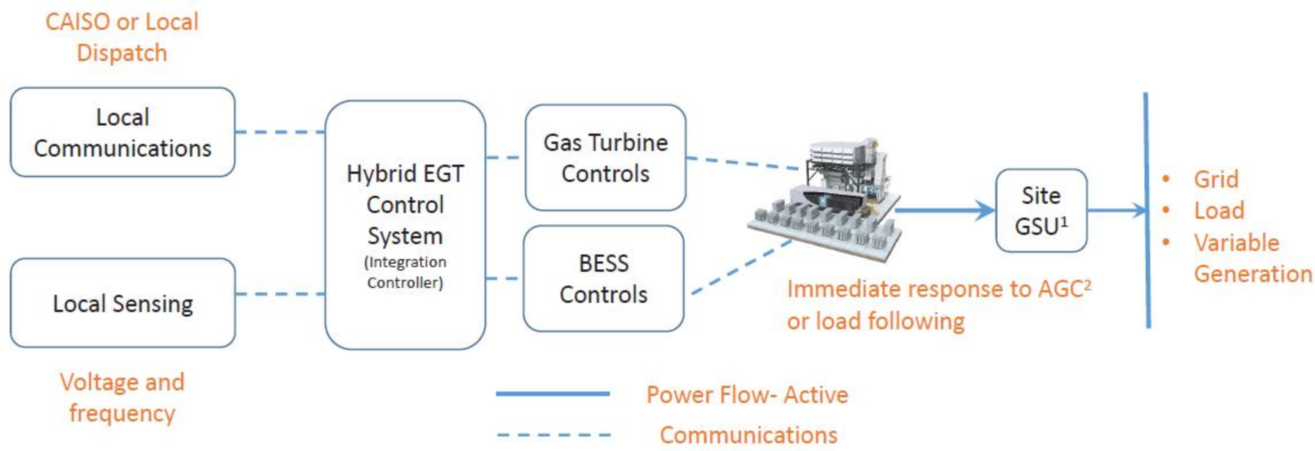
Resource Pmin	0 MW
Resource Pmax	50 MW
Battery Size	10 MW/4.3 MWh
Duration	20 minute battery, unlimited resource

The Hybrid EGT® resources are fully integrated and have both individual resource components and a total system component that optimally controls the entire resource. Figure 3 shows a control diagram for the hybrid storage technology. While the diagram is specifically from an SCE presentation showing their controls for the Hybrid EGT®, the controls would be the same for any hybridized gas resource. The diagram shows that a hybrid storage resource would be completely controlled by the California ISO (or other local dispatching agency). Additionally, the diagram shows how the resource can automatically respond to voltage and frequency events, and can provide regulation services through automatic grid control.

[8] SCE hybridized both their Center Peaks located in Norwalk, CA and their Grapeland Peaker, located in Rancho Cucamonga, CA.

[9] NOTICE OF SOUTHERN California EDISON COMPANY (U 338-E) OF EX PARTE COMMUNICATION WITH THE OFFICE OF COMMISSION PRESIDENT MICHAEL PICKER, April 13, 2018.

Figure 3: Hybrid EGT® Control Diagram



[1]Generator step-up transformer

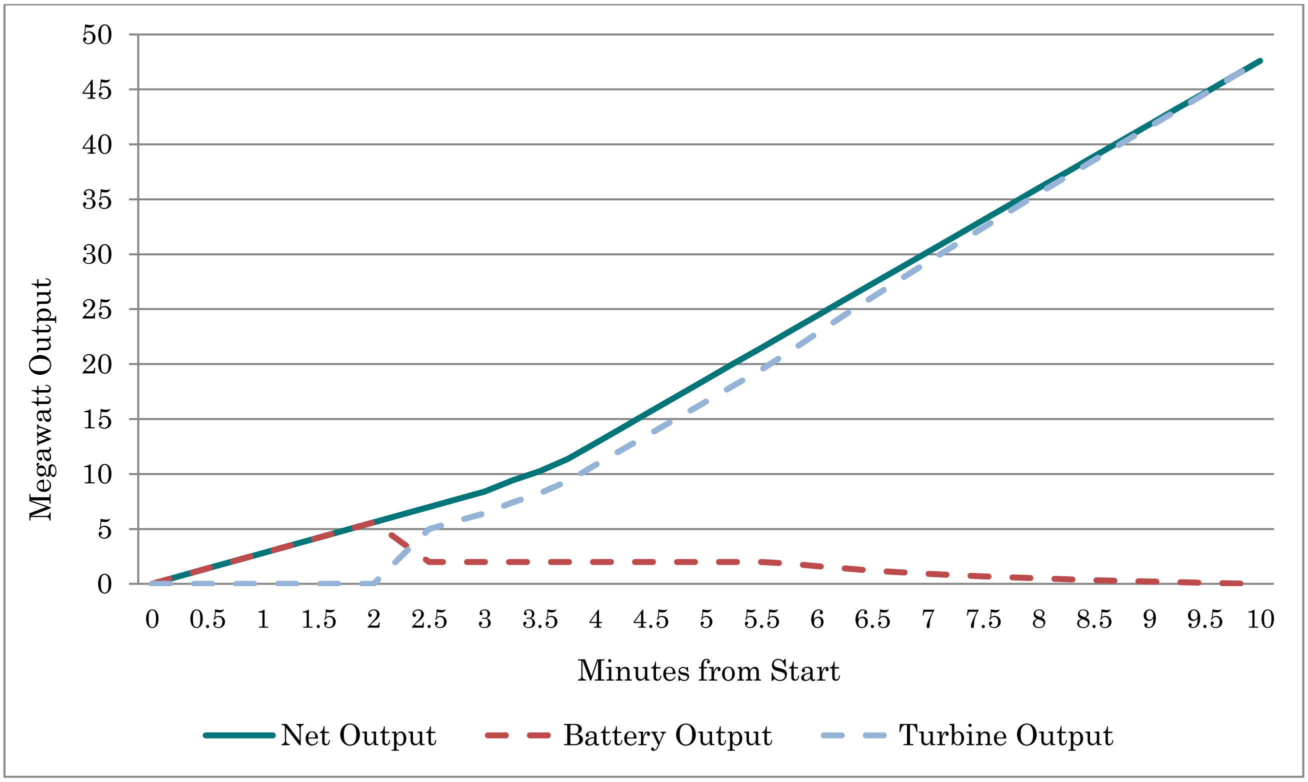
[2]Automatic generation control

Source: SCE ex parte communications on April 13, 2018

As the diagram shows, the entire unit operates under a single interconnection point. This allows a hybrid storage resource to use a gas plant's existing interconnection without upgrades or extensive studies. Currently the California ISO allows a battery of up to 50 percent the size of the interconnection to be added without going through the potentially costly and lengthy interconnection process.

Figure 4 illustrates how the BESS and gas turbine work together upon start-up instruction from the California ISO or distribution system operator. While the gas turbine is starting up, the BESS begins to immediately output energy onto the grid. After only a short period, just over 2 minutes, the gas turbine begins to output energy at a high ramp rate. The BESS continues to output energy in order for the resource to maintain a linear and extremely precise ramp toward full output. Depending upon the ramp rate selected, 5 minutes to 10 minutes after the start-up instruction, the hybrid storage resource can reach its maximum output level. Figure 4 illustrates a 10 – minute ramp rate selection.

Figure 4: Hybrid EGT® output from start-up instruction (0-MW Pmin to 48-MW Pmax)

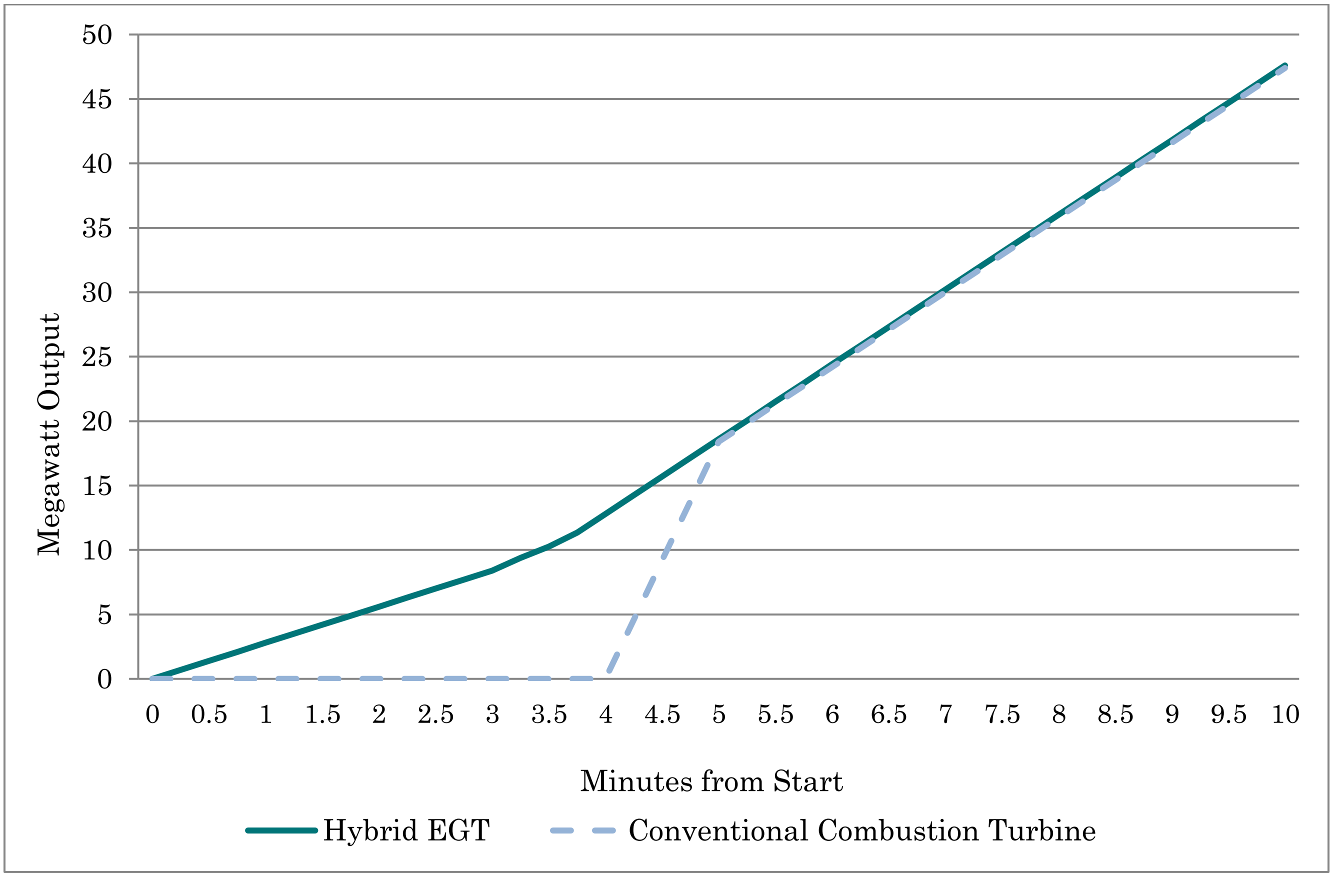


The Hybrid EGT® combustion turbine can put out energy faster onto the grid than many other combustion turbine stand-alone engines because of improvements made during the hybridizing process.[10] Figure 5 compares the Hybrid EGT® start-up to a conventional combustion turbine unit start-up. The main difference is that a conventional combustion turbine takes up to 5 minutes to begin putting energy on the grid. While this is a short period of time, it has a significant impact on a resource's ability to provide emergency energy and spinning reserves, which in turn impact resource emissions.[11]

[10] The new Hybrid EGT® control system uses adaptive synchronization to monitor plant conditions and synch the turbine to the grid as quickly as possible. This technology could also be used on a standard combustion turbine, but the unit would need a new control system and so typically it is not cost-effective as a standalone upgrade.

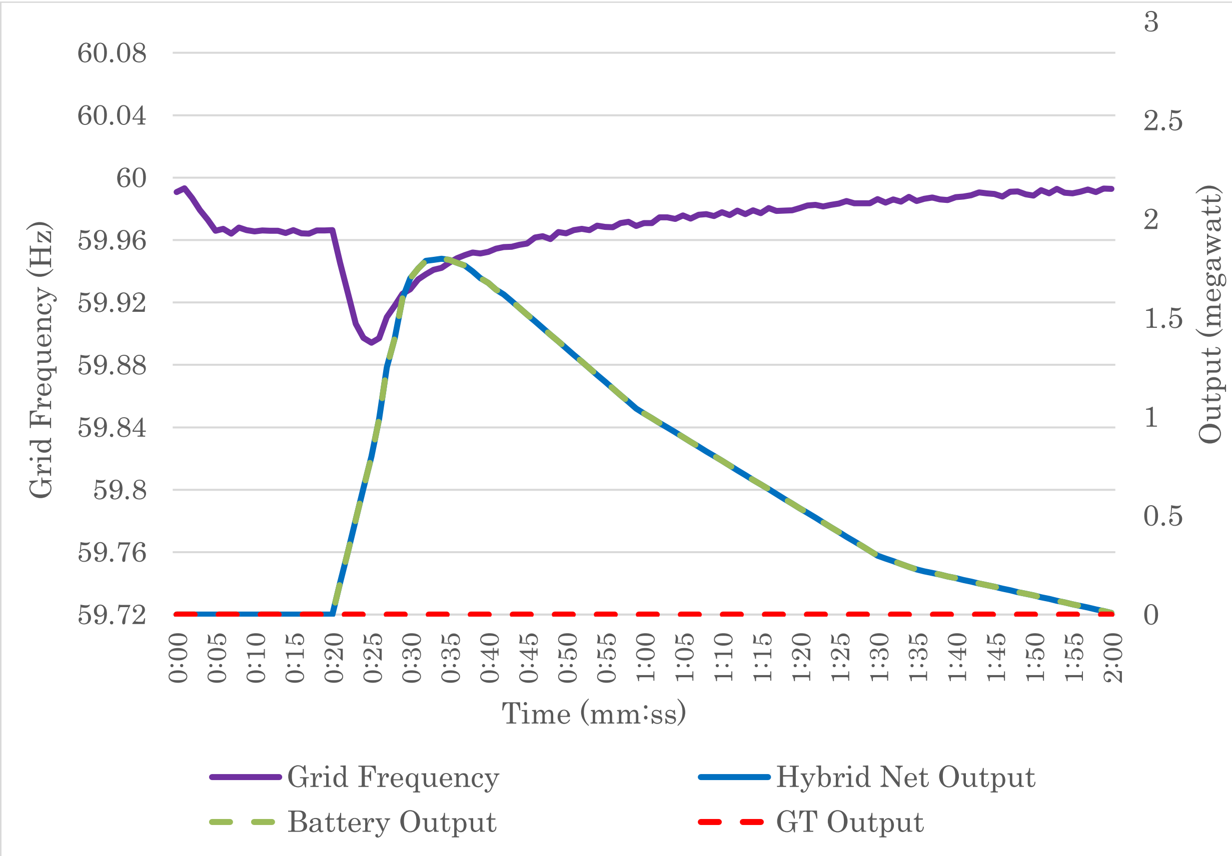
[11] A conventional gas plant must operate at Pmin (typically around 40% of their Pmax) in order to provide spinning reserves. These rules are described in detail in section 0.

Figure 5: Start-up of Hybrid EGT® compared to conventional combustion turbine



The hybrid storage resource does not act like a stand-alone storage facility that charges and discharges from the grid according to energy price differences. However, just like stand-alone storage, **a Hybrid EGT® can provide instant energy to the grid for short duration bursts to provide primary frequency response**. This is illustrated in Figure 6, below. The key difference between a hybrid storage resource and convention gas resource is that the hybrid storage can respond to frequency events while not emitting or using its gas turbine ("GT", red dashed line). The response is entirely provided by the BESS component (dashed green line).

Figure 6: Hybrid EGT® Primary Frequency Response



For full benefits, the BESS must be a minimum of 20 percent of the size of the gas unit. For example, a 50 MW gas turbine would be optimally paired with a 10 MW BESS. At these levels, hybrid storage is always synchronized to the grid and can reach 100 percent of its maximum capacity, within 5 minutes, at its highest ramp rates.

The storage device also enables the hybrid to be completely flexible and start, stop, or change directions within a single energy market dispatch instruction. For example, within 10 minutes, a hybrid storage resource can ramp up to 50 MWs and then turn completely off. It can then stay off until the next market interval and then ramp right back to 50 MWs - all without increasing the emissions rate of the resource. This extreme flexibility contrasts with most combustion turbines that must stay online for at least 30 minutes and then, when shut down, must again stay off for 30 minutes.

While there are only two Hybrid EGTs® energized so far, the technology itself is innovative rather than radical. The technology combines the upgraded grid controls, BESS, and gas turbine enhancements to create incremental flexibility improvements, and emission and water-use reductions. Importantly, the technology allows the plant to remain synchronized to the grid without any fuel use. The benefits of these improvements are discussed further in sections 5.1 and 5.2.

3 Background

This section provides a brief background on the current and future activities related to renewable integration in California's energy market. The state has targeted first through executive order, then codified through legislation, a requirement to reduce the state's GHG emissions 40 percent below 1990 levels by 2030. Senate Bill 350 additionally targeted a 50 percent renewables target and set direction for energy improvements in five major policy areas:

- Integrated Resource Planning
- Energy Efficiency
- Renewable Energy
- Transportation Electrification
- Disadvantaged Communities

The bill specifically required policies and tracking to ensure all Californians benefit from the transition to a greener grid. Therefore, the disadvantaged community goals in Senate Bill 350 are cross-cutting and integrated into all policy areas. Finally, Governor Brown has identified additional key climate change goals, which are in various phases of the legislative process.[12]

To support these targets and goals, both the state and the California ISO have pursued a suite of policies and programs aimed at advancing and integrating renewable energy in the California energy market. Already, the movement toward a green grid is causing the power grid to undergo rapid changes, including the integration of large amounts of wholesale variable energy, significant changes to the daily pattern of energy use (load), and an increase in quantity and role of distributed energy resources. It is widely acknowledged by California energy planners and stakeholders that the transformation of the physical power grid requires a paradigm shift for electric system planning and regulatory practices.

In 2018, record-breaking solar and wind production has led to energy grid conditions that require immediate attention from both the CPUC and the California ISO. As the amount of behind-the-meter and wholesale variable energy resources increases, the system faces a mismatch between the daily peak of renewable generation and daily peak demand. This has led to an increase in need for system flexibility and ancillary services, simply to maintain grid reliability and additionally prevent renewable curtailment on a massive scale.

Many solutions are being considered and enacted, including:

- Improved centralized resource procurement through integrated resource planning
- Increased energy storage targets to advance and maximize the value of energy storage technology

[12] https://www.arb.ca.gov/cc/pillars/pillars.htm

- Procurement and energy market changes in response to the Aliso Canyon natural gas storage facility well failure
- Improvements to the day-ahead and real-time energy market optimizations as well as resource adequacy rules

The sections below summarize just a few of the many programs and policies being put in place by the CPUC and California ISO to aid in the state's renewable transformation.

3.1 California Public Utilities Commission (CPUC)

Among California energy state agencies, the CPUC has led the planning and policy efforts for renewable integration policy. At the end of 2015 they published a white paper describing the magnitude and scope around coming to a common understanding of the challenges and solutions for grid integration of renewables beyond 33 percent.[13] Since then the CPUC has opened proceedings and held numerous meetings. Below we describe key items that specifically impact the need for or benefits of hybrid storage technology.

3.1.1 Integrated Resource Planning

In response to Senate Bill 350, the CPUC opened an "umbrella" planning proceeding to consider the CPUC's electric procurement practices and implement a process for integrated resource planning that would better enable load-serving entities to, in aggregate, meet California's statewide GHG goal of no more than 42 million metric tons of GHG in 2030 from the electric sector. The IRP proceeding has a mission to achieve the state's GHG goals at the lowest reasonable cost and to establish a process for load-serving entities to do individual procurement and have resource plans consistent with the first goal. Within the IRP, the CPUC has set up an analytical framework, using capacity expansion modeling (primarily with the model RESOLVE) in order to develop recommendations, guidelines, and benchmarks for load-serving entities in their procurement processes.

3.1.2 Storage Target

In October 2013, the CPUC implemented AB 2514 by adopting an energy storage procurement framework and established an energy storage target of 1,325 MWs in its energy storage rulemaking (R.10-12-007) collectively for Pacific Gas & Electric, SCE, and San Diego Gas & Electric by 2020, with installations required no later than the end of 2024.

In April 2017, the Commission issued a Track 2 Decision in its successor rulemaking (R.15-03-011) which addressed, among other things, energy storage procurement targets, the rules regarding the treatment of station power for energy storage devices, and implementation of AB 2868. In the Commission's Track 2 Decision, the investor-owned utilities were directed to comply with AB 2868 by proposing programs and investments for up to 500 MWs of distributed

[13] http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=9141

energy storage programs, systems, and investments above and beyond the original 1,325 MW target into their 2018 storage procurement and investment plans, resulting in a combined total target of 1,825 MWs.

The 2018 utility storage plans currently pending Commission approval would add a minimum of 302 MWs, plus an additional potential 168.5 MW.[14] Although the total amount cannot be predicted with certainty, it appears likely that the 1,825 MW target can be considered a reasonable planning figure.

3.1.3 Response to Aliso Canyon Natural Gas Storage Facility Well Failure

In response to Governor Brown's January 6, 2016 proclamation of a state of emergency in Los Angeles County due to the Aliso Canyon Natural Gas Storage Facility (Aliso Canyon) well failure, and subsequent restrictions imposed on gas injections into the Aliso Canyon facility, the CPUC issued Resolution E-4791 in May 2016 authorizing SCE to hold a solicitation and file an application for a reasonableness review by the CPUC for procurement of any utility-owned energy storage facilities. The Commission granted SCE the authority to recover costs for the solicitation, site assessment, and construction of four utility-owned energy storage systems, two of which were Hybrid EGT® projects, in June 2018.

3.2 California Independent System Operator (ISO)

The California ISO is ultimately responsible for the reliability of California's power grid throughout the state's renewable transformation. It must manage the flow of electricity across the high-voltage, long-distance power lines that make up 80 percent of California's (and a small part of Nevada's) grid and ensure the lights stay on. They do this, in part, by running a day-ahead and real-time market which procure energy and ancillary services necessary to meet energy demand.

Until recently, the naturally occurring characteristics of California's existing grid infrastructure, such as large amounts of hydro and import capacity, have allowed for integration of significant amounts of wind and solar generation with only minor changes to grid operations. That said, the California ISO is already experiencing challenges related to over-generation and maintaining frequency response years ahead of their original "duck curve" predictions.[15]

The increasing penetration of intermittent wind and solar resources, combined with additional load uncertainty due to rooftop solar, has left the California ISO with the need for higher amounts of ramping capability and increased need for ancillary services in their real-time market. Given that California is only 60 percent of the way to a grid made up of 50 percent

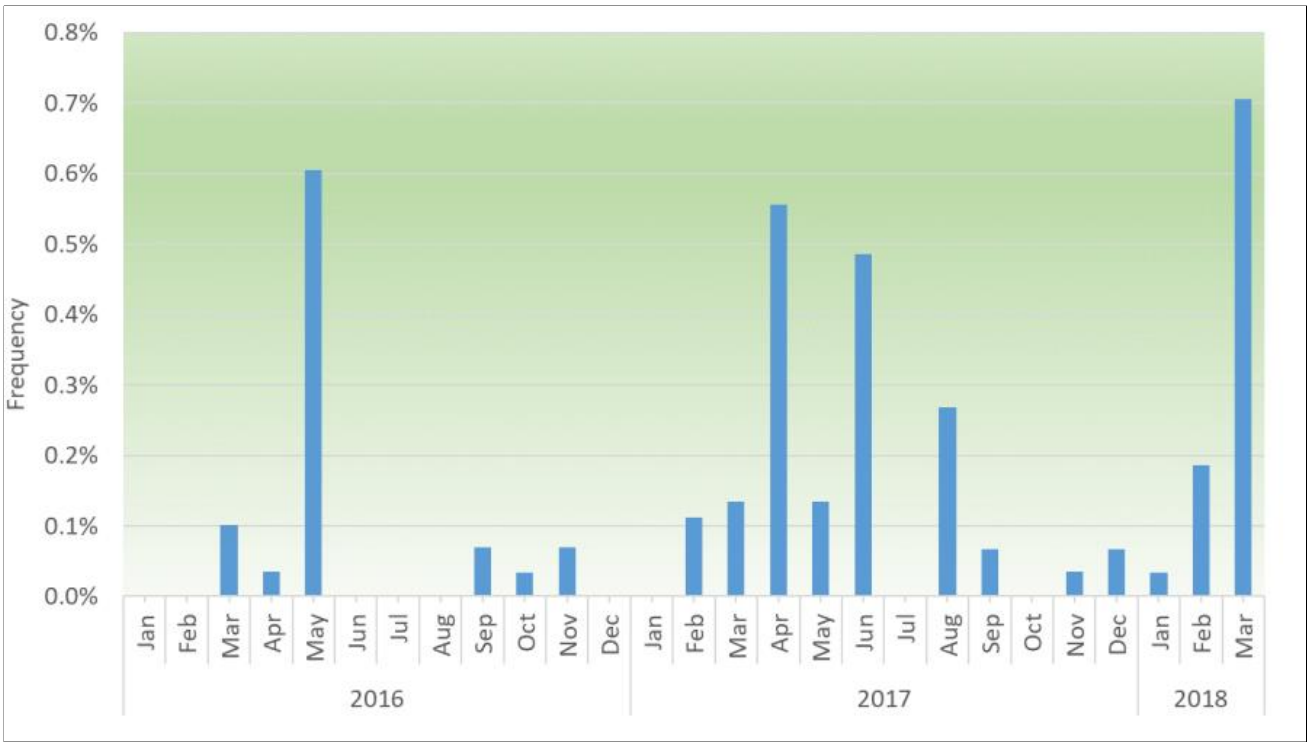
[14] Outside of the storage procurement framework, Pacific Gas and Electric Company has also recently submitted 567.5 MWs of storage projects for Commission approval in response to Resolution E-4909 resulting from desired avoidance of backstop procurement related to operating gas power plants.

[15] http://www.caiso.com/Documents/Agenda-Presentation-MarketPerformance-PlanningForum-Dec18_2017.pdf

renewables, it is not surprising the California ISO has announced substantial changes to its day-ahead and real-time markets to be implemented prior to 2020.

One of the most significant areas of concern to the California ISO relates to the procurement and dispatch of ancillary services. The California ISO has recently seen a significant increase in ancillary service scarcity events in real time, as shown in Figure 7. A scarcity event is triggered when the energy market is unable to procure sufficient ancillary service capacity to meet its demand.[16] There are several reasons why this may occur, but it is predominately due to additional capacity being unavailable in the real-time market to meet incremental ancillary service needs. When scarcity events occur, the California ISO is does not have sufficient capacity on-hand to dispatch in the event the reserves are needed for reliability.

Figure 7: Increase in Ancillary Service Scarcity Events[17]



Source: California ISO; April 19, 2018

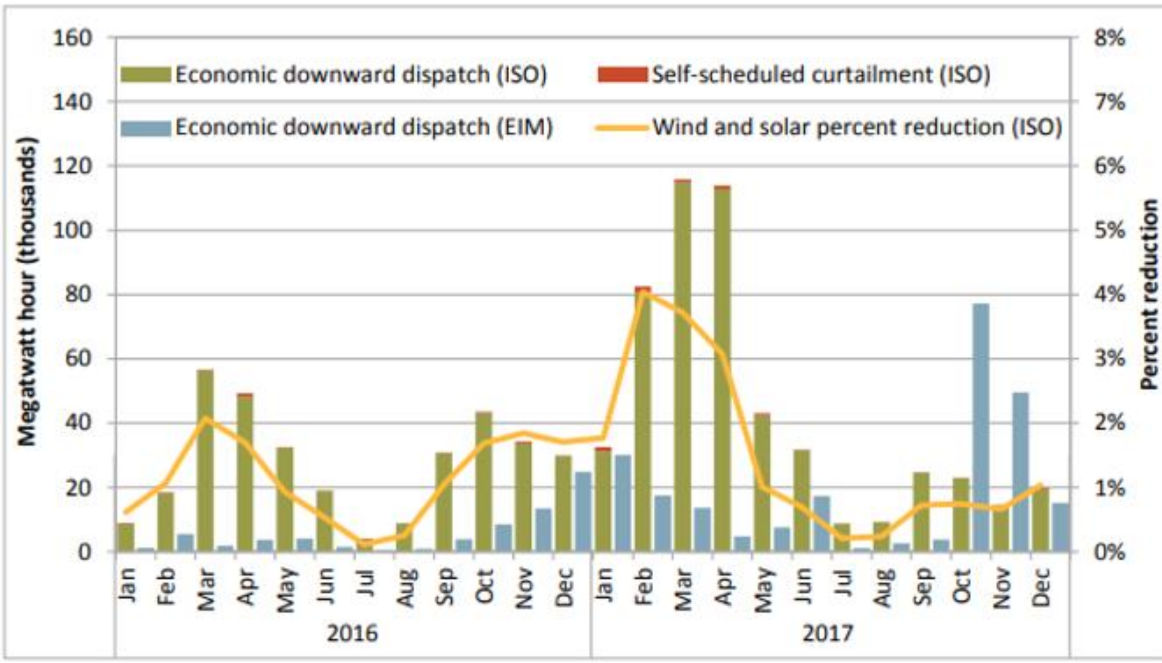
Additionally, the California ISO increasingly needs to curtail renewable energy to preserve market reliability, as shown in Figure 8. Reliability concerns can arise when renewable generation is transmission-constrained and, but for curtailment, could result in transmission failure events. Furthermore, over-generation (when supply of energy exceeds demand at any

[16] The ISO procures 100 percent of its ancillary service requirements in the day-ahead market. Ancillary service capacity is procured in real time, generally, when day-ahead capacity is no longer available, or the requirement is increased in real time, relative to the day ahead.

17 Market Performance Planning Forum slide 32: http://www.California ISO.com/Documents/Agenda-Presentation-MarketPerformance-PlanningForum-Apr192018.pdf

given point) can also contribute to reliability concerns. With the abundance of renewable generation in California, this is occurring at increasing rates. This is particularly the case in the spring months when favorable hydro conditions are combined with both solar and wind generation during low load periods. In order to preserve reliability, the market and operators will curtail generation from renewable resources. Given the targeted increase in the renewable portfolio standard to 50% by 2030 in California, this curtailment concern will only increase over the years to come.

Figure 8: Curtailment of wind and solar generation in California ISO[18]



Source: California ISO, Department of Market Monitoring, February 2018

[18] 4th Quarter Report page 51 http://www.California ISO.com/Documents/2017FourthQuarterReport-MarketIssues-PerformanceFebruary2018.pdf. Economic dispatch (ISO or EIM) refers to the market absorbing over generation by paying wholesale customers to take energy at "negative prices." Self-scheduled curtailment refers to the CAISO instructing generators to suspend generation when the wholesale market cannot dispose of over generation through negative prices.

4 Analysis of Hybrid Storage in CPUC Integrated Resource Plan

This section evaluates hybrid storage technology in the context of California's GHG and renewable energy targets, using CPUC's latest RESOLVE model used in the IRP Process. As discussed in section 3.1.1, in response to Senate Bill 350, the CPUC opened an umbrella planning proceeding to consider the CPUC's electric procurement practices and implement a process for IRP that would better enable load-serving entities to, in aggregate, meet California's GHG goals. A main goal of the IRP is to develop and operationalize a model to generate an optimal portfolio of resources over a 20-year planning horizon that achieves Senate Bill 350 GHG goals.

The CPUC currently uses a capacity-expansion model, RESOLVE, that determines the most cost-effective generation portfolio over a long-term planning horizon to meet load conditions, reliability, capacity, and selected policy constraints, including no more than 42 MMT of GHG from the electric sector in 2030. Part of the capacity expansion functionality is the ability to select the optimal quantity of new generation types to expand during the long-term planning horizon. Thus, capacity expansion models can be used to identify and evaluate the optimal portfolio mix under various load futures and scenarios.

The CPUC uses RESOLVE to establish the optimal portfolio or "Reference System Plan," which is one of many portfolios of resources produced under a variety of scenarios and futures evaluated by the capacity expansion model. This plan is intended to be a benchmark for individual and aggregate load-serving entity resource procurement. The CPUC endorses a steady approach to ongoing procurement of zero-carbon resources over the planning horizon to 2030, which subjects consumers to less financial risk. Within the RESOLVE capacity expansion model, this is accomplished by including renewable generation goals and energy storage targets that need to be met by a given year within the planning horizon. At this time, the CPUC has not assessed hybrid storage technology within RESOLVE, primarily for two reasons. First, modeling hybrid storage introduces some modeling complexities. Secondly, when the model was being created, hybrid storage was still a theoretical technology as it had not yet been commercialized. Gridwell expects that future updates to the RESOLVE model will include the ability to assess modification of existing resources to hybrid storage resources, but that this will likely take a while given the regulatory schedule and complexity in updating the model.

Therefore, to do this initial evaluation of hybrid storage potential, Gridwell set up the RESOLVE model using the CPUC's IRP Reference System Plan assumptions, but additionally changed the model so that the capacity expansion functionality would be able to choose hybrid storage as an option to include in the optimal solution set.

Gridwell used the CPUC IRP assumptions in the model set-up, including the following key inputs:

- A CO_2 reduction target of 42 million metric tons by 2030[19]
- Updated 2017 demand assumptions from the CEC Integrated Energy Policy Report
- 50 percent Renewable Portfolio Standard target by 2030
- Mid-case electric vehicle, behind-the-meter solar, energy efficiency, and demand response

To make hybrid storage an option for the capacity expansion functionality, Gridwell modified the resource characteristics and costs of a candidate resource type[20] already provided for in the model. Candidate resource types are pre-defined resources that the model can select as being optimal for generation expansion (i.e. invest in new build of these resource types) during the planning horizon.

There are several notable challenges to correctly modeling the cost of hybridizing. The model is not able to choose to hybridize an existing gas resource, and only has the option to add a new hybrid resource to the grid. In order to prevent double counting costs, Gridwell allowed the model to choose a new hybrid resource at the cost to hybridize existing gas, as described below.

Most of the challenges with modeling Hybrid EGTs in the current RESOLVE model stem from the fact that the model does not contemplate the new technology and that when "procured" its augmenting existing resources. Specifically, some of the challenges include:

- RESOLVE does not have a built-in new candidate resource type with the characteristics of Hybrid EGTs
- RESOLVE does not recognize the energy storage portion of the Hybrid EGTs as meeting the energy storage target in each case.
- RESOLVE does not recognize that when a Hybrid EGT is procured, it augments an existing gas-fired resource. Thus, RESOLVE has access to both the existing gas-fired and Hybrid EGT capacity.

The hybrid storage assumptions include[21]:

- 50 MW maximum output (Pmax) and 0 MW minimum output (Pmin)
- Ability to reach maximum output within 10 minutes
- The following all-in fixed costs, as with most new technology capacity costs, the cost is site specific and will evolve over time

[19] http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M209/K878/209878964.PDF; http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M195/K910/195910921.PDF

[20] Gridwell modified the resource characteristics of the California ISO_AERO_CT resource candidate type in RESOLVE to match the those of the Hybrid EGT.

[21] Additional resource characteristics and assumptions are provided in the appendix.

Figure 9: Cost of hybridizing an existing gas resource

Year	EGT Kit and Installation	PV of 20 Year O&M	Total EGT Price	Price $kW-yr on 50 MW EGT Kit for 20 years @ 10%
2018	$14,000,000	$1,460,856	$15,460,856	$36.32
2019	$13,408,863	$1,490,073	$14,898,936	$35.00
2020	$12,770,346	$1,519,875	$14,290,221	$33.57
2021	$12,089,260	$1,550,272	$13,639,532	$32.04
2022	$11,342,050	$1,581,278	$12,923,328	$30.36
2023	$10,757,173	$1,612,903	$12,370,076	$29.06
2024	$10,151,293	$1,645,162	$11,796,455	$27.71
2025	$9,694,413	$1,678,065	$11,372,478	$26.72
2026	$9,396,532	$1,711,626	$11,108,158	$26.10
2027	$9,157,649	$1,745,859	$10,903,508	$25.61
2028	$8,977,766	$1,780,776	$10,758,542	$25.27
2029	$8,756,881	$1,816,391	$10,573,272	$24.84
2030	$8,594,996	$1,852,719	$10,447,715	$24.54

- $5 per MW hours variable O&M
- Ability to provide regulation reserves, spinning reserves, load following, and frequency response
- 10 MMBTU heat rate at maximum measured power, and a zero-heat rate at Pmin

Gridwell then had to account for the BESS portion of the hybrid storage ability to count toward the storage target. Gridwell evaluated the hybrid storage resources under each of RESOLVE's storage scenarios:[22]

- *Current minimum* – 1,325-MW storage target
- *Total authorized* – 1,825-MW storage target

The scenarios evaluated by Gridwell to assess the hybrid storage technology within the capacity expansion model are shown in the figure below. Gridwell first allowed the model to choose hybrid storage as an option under both energy storage target scenarios to see what that did to total costs and emissions. Gridwell then forced-in 2,500 MW of hybrid storage to

[22] The 1,325 MW and 1,825 MW storage target scenarios include a constraint in the model requiring the capacity expansion functionality to select sufficient energy storage capacity to meet the total target by 2024. These are further described on page 27 of the CPUC IRP documentation. http://cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/irp/AttachmentB.RESOLVE_Inputs_Assumptions_2017-09-15.pdf

meet a portion of the energy storage target to see if there is a point at which the point of diminishing returns of the technology would start to incrementally reduce cost and emission savings. Lastly, Gridwell forced the model to procure 700 MW of hybrid storage by 2022 to evaluate potential benefits of early procurement. For comparison purposes, Gridwell also generated results for each storage target scenario without any modifications. Figure 10 summarizes each modeled scenario.

Figure 10: Hybrid Storage RESOLVE Scenarios

	No Storage Hybrid	***With Storage Hybrid***	***Section***
1: Optional hybrid storage (1,325-MW)	*1,325 MW mandate with no hybrid storage*	*1,325 MW mandate with optional hybrid storage*	*Section 4.2*
2: Optional hybrid storage (1,825-MW)	*1,825 MW mandate with no hybrid storage*	*1,825 MW mandate with optional hybrid storage*	*Section 4.3*
3: High procurement target (1,825-MW)		*1,825 MW mandate with 2,500 MW forced hybrid storage*	*Section 4.4*
4: Early procurement target (1,325-MW)		*1,325 MW mandate with 700 MW forced in 2022*	*Section 4.5*

The potential benefits of hybrid storage resources were evaluated based on cost and emission savings as well as their preferred use by the model.

- Cost savings were looked at in terms of net present value of total revenue requirement reductions. The net present value revenue requirement, as determined by the RESOLVE model, is the total of the levelized weighted annual cost of each modeled year. This includes Capex, variable costs to operate the California ISO system, fixed costs for new transmission and generation, as well as embedded costs in the energy system that drives retail rate increases.
- Emission savings were looked at in terms of California's GHG reductions[23]. These are measured by comparing average annual metric tons of CO2 emissions by generation within California ISO between two scenarios, one with and one without optional storage hybrid.
- Preferred use of the hybrid storage technology was determined by looking at the energy and ancillary service market products the hybrid storage provided in each scenario[24].

[23] GHG reductions were assessed only on CAISO internal generation which does not include imports.
[24] RESOLVE models thirty-seven representative days per year, thus the total MWhs summarized in each scenario for energy and ancillary services are based on thirty-seven days per year.

4.1 Hybrid Storage Resources Result Summary

A key metric in this evaluation that Gridwell considered was if, and at what quantity, the RESOLVE model would procure hybrid storage resources under the two different targets (i.e. 1,325 MW and 1,825 MW). Figure 11 summarizes the amount of hybrid storage capacity the RESOLVE model procured.[25] In both the current and expected storage target scenarios, the model procured around 700 MWs of hybrid storage, 20 percent of which counts toward the storage target (indicated by the dotted orange line).

Figure 11: Battery and Hybrid Storage Procurement Summary[26]

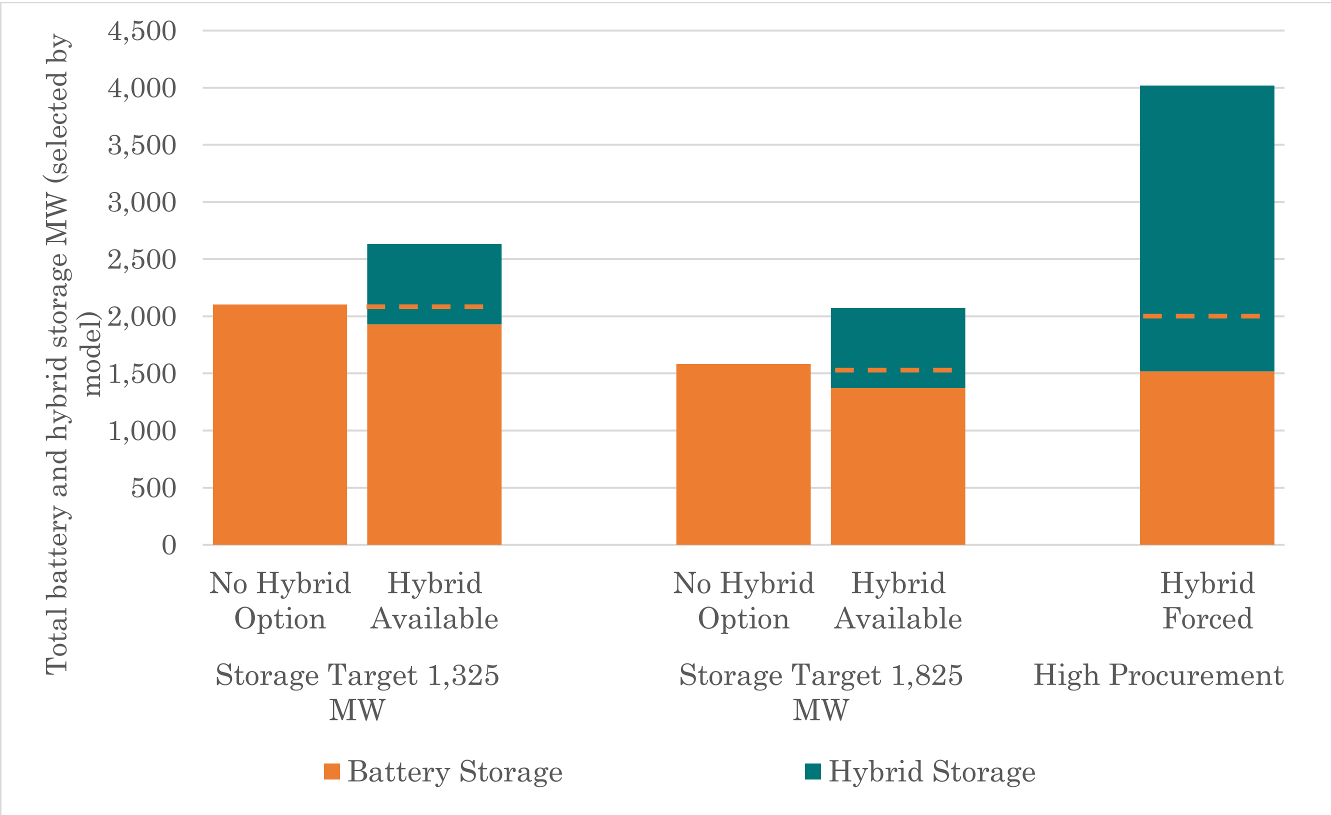


Figure *12* summarizes the total cost to ratepayers of meeting California's GHG goals and storage target with and without hybrid storage technology available to satisfy those goals. Additionally, Figure 13 summarizes the total cost to ratepayers under an earlier procurement scenario. Gridwell believes more modeling needs to be done to determine the exact savings but supports the below chart as directionally accurate.

[25] The battery storage capacity selected by the model is incremental to the storage target quantities. Thus, even without hybrid storage technology, RESOLVE results indicate that additional BESS is efficient in amounts greater than the storage targets.
26 Early procurement results are not included as the results 2030 procurement levels are the same as the 1,325 MW Storage Target case with hybrid available

Figure 12: Hybrid Storage Cost Savings Summary

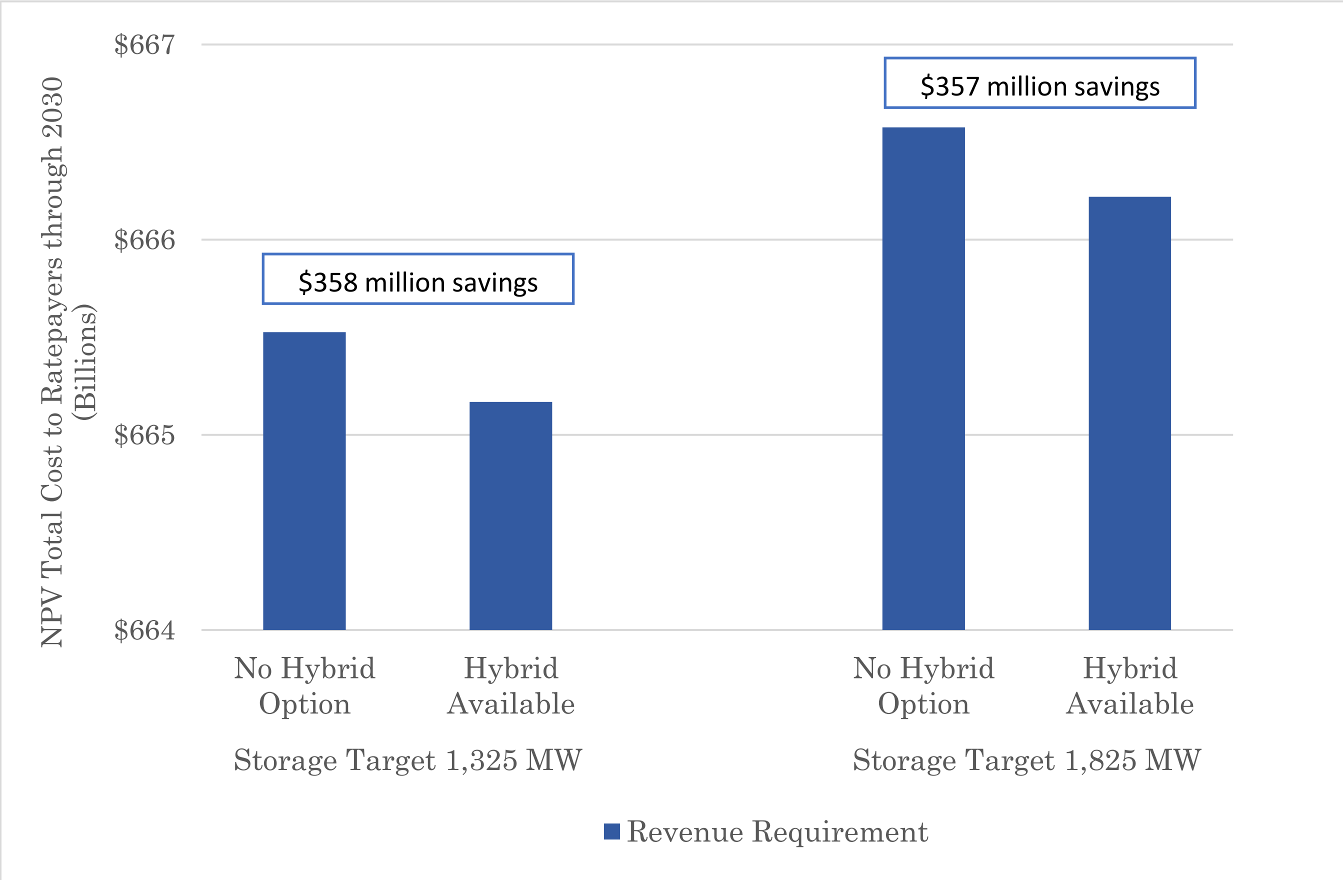
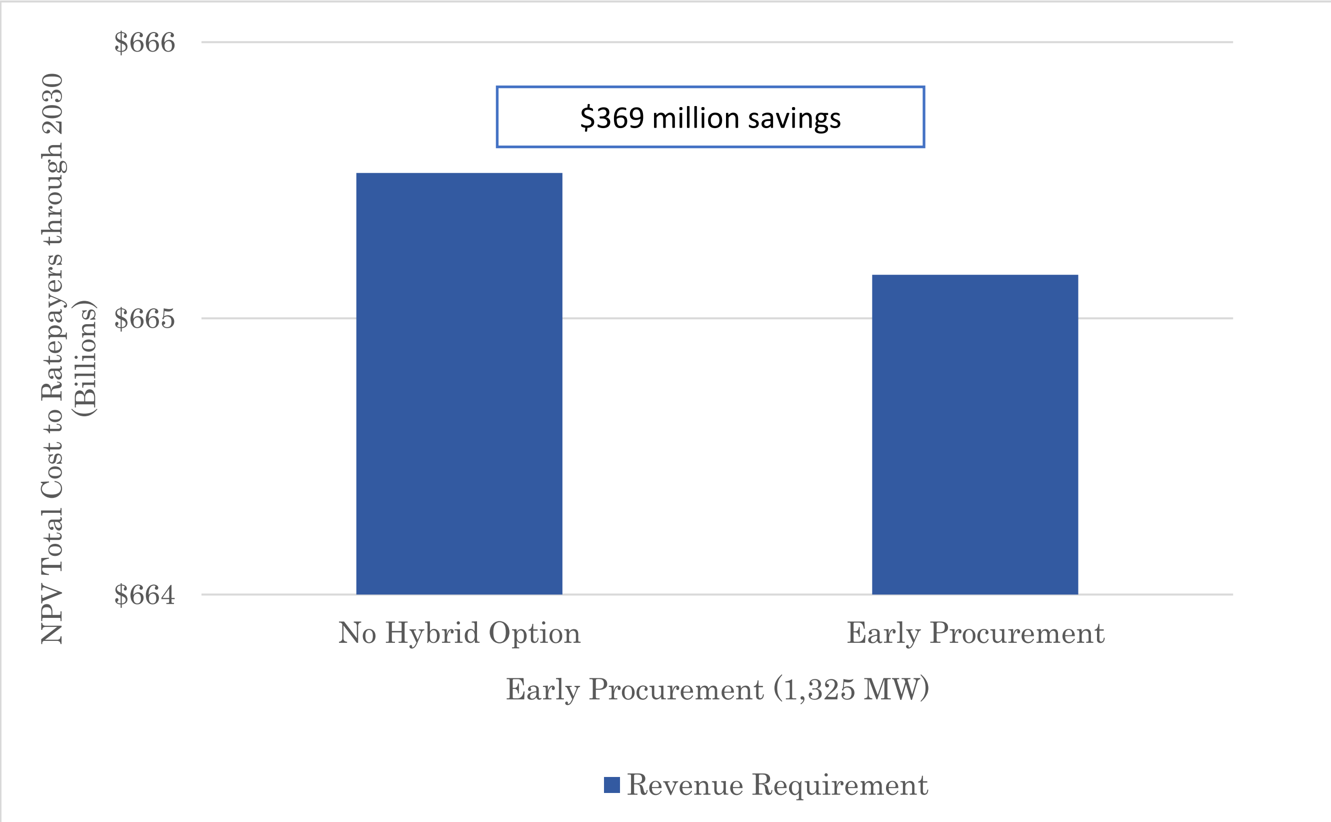


Figure 13: Hybrid Storage Early Procurement Cost Savings Summary



The detailed results in the following sections compare a before and after scenario that summarize what happens to costs, emissions, and fleet-wide use of different resource types when hybrid storage technology is added to RESOLVE. As noted in the introduction, the proffered results are not intended to be a prediction or recommendation on a precise amount of hybrid technology that should be procured. Instead they are intended solely as a preliminary evaluation as to whether additional hybridizing should be considered within the many options the state has as means to reduce GHG and meet energy storage targets.

4.2 1,325-MW Energy Storage Target Results

As previously noted, the latest RESOLVE model provides energy storage scenarios for the current storage target amount of 1,325 MWs. The model assumes the storage capacity will be installed by 2024 and then selects optimal resources around each storage target. The current RESOLVE model does not have the capability to directly account for a percentage of each hybrid resource's capacity to meet the energy storage target. Therefore, in order for the RESOLVE model to evaluate the 10 MWs of each 50 MW hybrid resource as able meet the storage target, Gridwell had to simulate this model functionality. This was done by making two model runs in each scenario.[27]

- In the first model run, Gridwell first allowed the RESOLVE model to exceed the storage target by modifying the model to include hybrid storage as a candidate resource. In the 1,325 MW storage target case, the RESOLVE model chose an additional 709 MW of hybrid storage.
- In the second model run, Gridwell took the 709 MW hybrid storage procurement results from the first run and reduced the energy storage target by the 140 MW so that the 1,325 MW energy storage target in RESOLVE was reduced to 1,185 MW. 140 MW is equivalent to 20 percent of the 709 MW hybrid storage capacity, which is the amount of battery capacity on the hybrid and therefore the amount that can count toward the storage mandate.

Ideally RESOLVE would be directly account for 20% of hybrid capacity being able to count toward the storage mandate; however, modifications to the RESOLVE optimization code was beyond the scope of this preliminary study.

The results shown in section 4.2.1 below compare the 1,325-MW base case run (i.e. the baseline run without hybrid storage) and the final 1,325-MW run with hybrid technology available and counted toward the storage target.

4.2.1 Cost and Emission Savings from Hybrid Storage

RESOVLE shows a reduction in revenue requirements and GHG emissions when hybrid storage is added as an option in the 1,325 MW RESOLVE model case, as shown in Figure 14, and illustrates the directional impact of adding a hybrid storage as a candidate resource option. Total costs to meet the energy target decreases.

The results indicate that when a hybrid storage resource can count toward meeting the energy storage target, **each of these resources can provide a cost savings net present value of approximately $25.6 million through 2030 in terms of revenue requirement**.

Figure 15 shows that in addition to the reduced costs, GHG emissions are also reduced compared to the base case. The results indicate average annual GHG reductions[28] from California ISO generation of approximately 28,000 metric tons of CO_2 emissions.

While not presented, Gridwell notes that the total costs of the system went down when hybrid storage resources were selected as candidate resources, even without being able to contribute to the storage target. It is unknown at what penetration level this stops occurring but was observed in both the 1,325-MW and 1,825-MW model runs.

[27] The baseline runs used the CPUC's IRP Reference System Plan to establish a baseline of emissions and costs for each storage target case.

[28] The average annual GHG reductions are based on modeled years that have procured hybrid storage capacity (2022,2026, and 2030) and only look at internal CAISO generation as the model does not identify specific resources outside the CAISO ISO and only generically looks at imports.

Figure 14: Optimal selected capacity counting hybrid storage towards 1,325-MW storage target

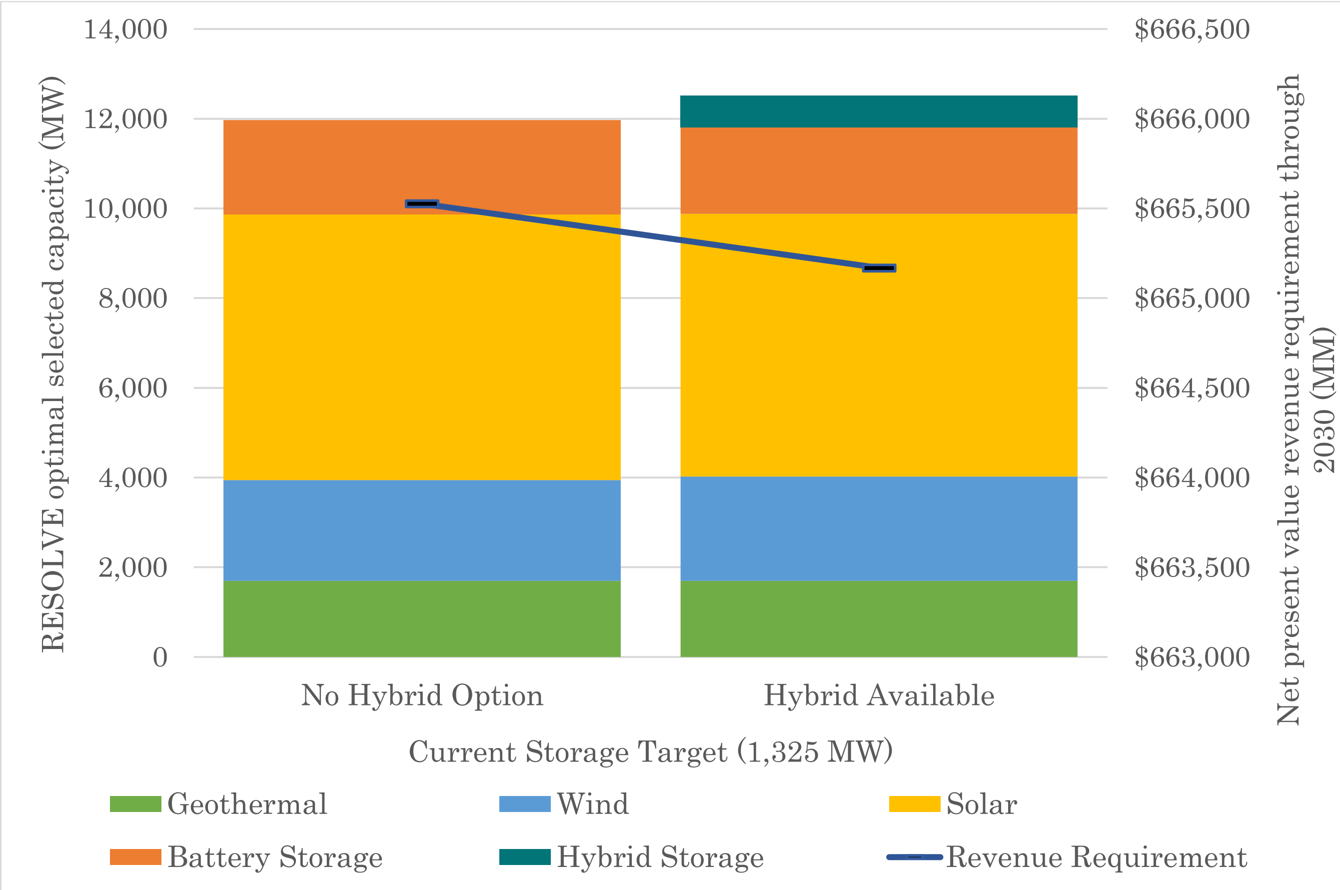


Figure 15: Cost and GHG savings counting hybrid storage towards 1,325-MW target[29]

1,325 MW energy storage target	Net present value revenue requirement through 2030	Average annual emission (metric tons CO2)
No Hybrid Option	$665.53 billion	28,678,687
Hybrid Available Option	$665.17 billion	28,398,622
Total System Savings	***$358 million***	***280,065***
Avg Savings per Hybrid Unit	***$25.6 million***	***20,005***

[29] Average annual values are based on modeled years 2022,2026, and 2030.

4.2.2 Preferred Use of Hybrid Storage

One of the features of the RESOLVE model is that it provides as an output how the model uses each resource type, in terms of energy and ancillary service market products. The market products within RESOLVE include energy, operating reserves (spinning, regulation-up, regulation-down), load following, and frequency response. Each product requires resources to be able to operate in a certain way and RESOLVE will model an estimate cost for resource types to provide different products, thus some resource types are better able to provide one product over another.

For example, a resource providing regulation must be able to respond to automatic-generation dispatch instructions every 4 seconds. Gridwell evaluated the model's optimal use of the hybrid storage technology by assessing which products hybrid storage provide. As shown in Figure 16, hybrid storage primarily provides spinning reserves with a small percentage of its use being to provide regulation services (barely seen yellow bar). The totals provided are based on the thirty-seven representative days per year modeled in RESOLVE.

Figure 16: Preferred use of hybrid storage towards 1,325-MW storage target

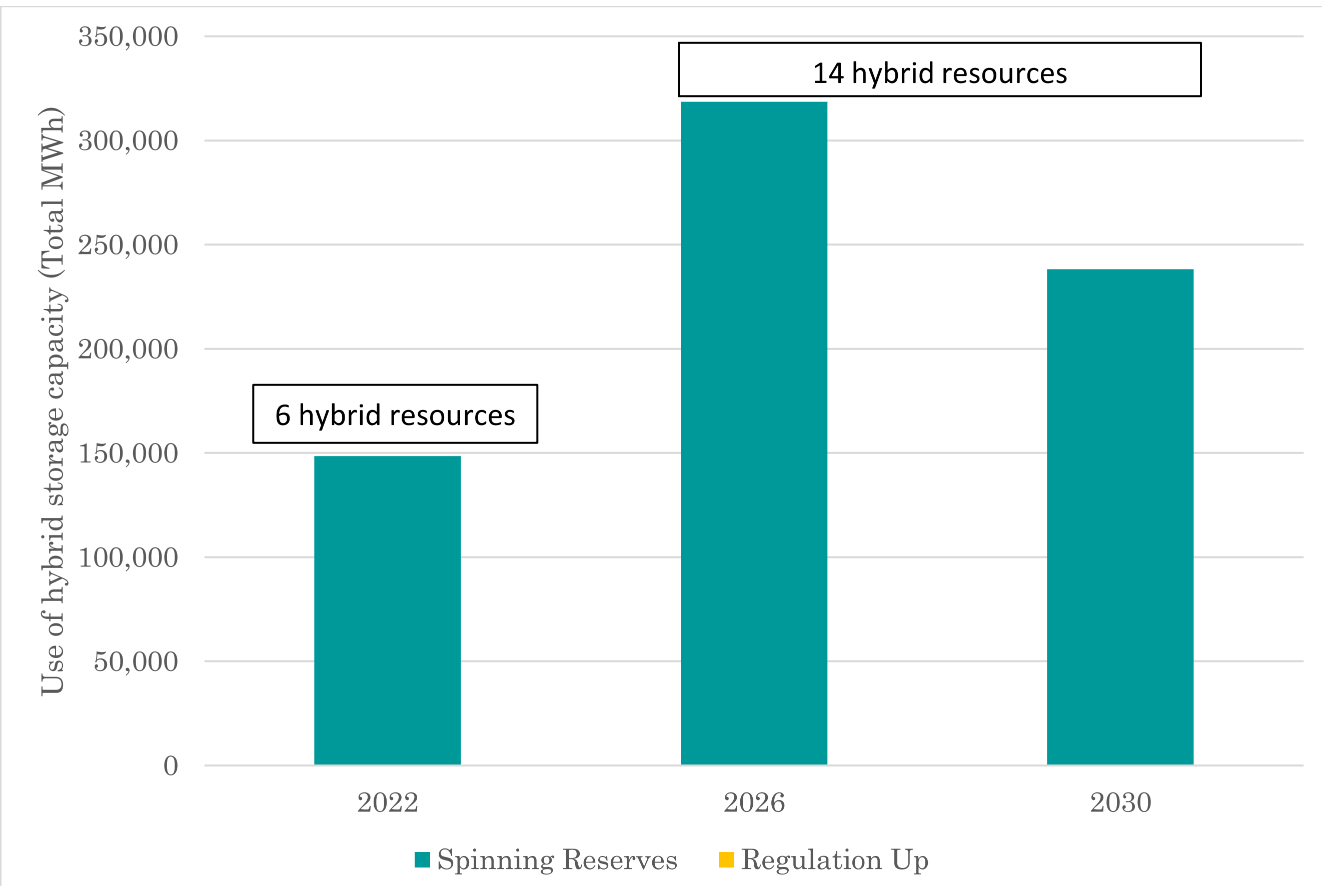


Figure 16 shows use during the modeled days by year, which indicate that hybrid storage resources are predominately being used to provide spinning reserves. The lower megawatts in year 2022 is because the model only procured six EGTs in year 2022 and then an additional eight EGTs by 2026. Additionally, there is a shuffling of resource use amongst various resource types. As noted above, hybrid resources are providing spinning reserves, which in turn shifts some of the use of battery storage and pumped hydro storage towards regulation up.

4.2.3 Hybrid Storage Impact Energy Procurement

One of the gaps in the RESOLVE model is its inability to choose between either keeping the existing resource or converting that resource to a hybrid resource. Due to RESOLVE's modeling limitations, Gridwell was only able to include hybrid as another optional resource type, which left the un-hybridized resources still available to be used within the model. When hybrid resources were made available, the model does reduce the production of energy (and GHG) from the existing gas-fired generation fleet by about 28,000 MWhs during the modeled days in 2030[30].

4.3 1,825-MW Energy Storage Target Results

We conducted a similar analysis for the 1,825-MW energy storage target. The following results are from modeled scenarios in which the 1,825-MW energy storage target was reduced to 1,685 MWs. The 140-MW reduction represents approximately the 20 percent battery portion of the procured 730 MWs of hybrid storage technology from an initial sensitivity run of 1,825-MW energy storage target, which we rounded down to 700 MW[31]. We conducted the initial sensitivity run of the 1,825-MW energy storage target solely in order to determine the amount by which to reduce the energy storage target within the model used to evaluate hybrid storage. All the results shown below include the 1,825-MW base case run (without hybrid storage) and the 1,825-MW run with hybrid technology available for comparison.

4.3.1 Cost and Emission Savings

The RESOLVE model selected nearly the same amount of hybrid storage technology when the energy storage target assumptions were reduced to 1,685 MWs by 2024, relative to the 1,825-MW case with hybrid storage available (the initial sensitivity). As shown below, there was a significant reduction in revenue requirements and GHG emissions. These results indicate that it is more optimal in terms of cost savings when hybrid storage technology is available and able to meet energy storage target. **When hybrid storage resources can count towards meeting the**

[30] Given the modeling limitations, the unhybridized gas resources are potentially being double counted in the model. This can only be avoided through direct modeling improvements that were outside the scope of this paper.
[31] The initial sensitivity run of the 1825-MW energy storage target case procured 730 MWs of hybrid storage technology, representing 14.6 50 MW units. Similar to the 1,325-MW case. Gridwell conducted another sensitivity with the year 2024 included to confirm procurement by 2024. Not all the hybrid storage capacity was procured by 2024 likely due to the higher pre-determined levels of storage relative to the 1,325-MW case and the model not recognizing the battery portion of the hybrid storage resource. Updating the RESOLVE model to recognize the battery storage portion of each hybrid storage resource will address this gap. For this evaluation Gridwell rounded down to 14 units (700 MWs) and given the 1,325-MW case procured all the capacity by 2024, found it reasonable to assume this amount would also be procured as well under the 1,825-MW case.

energy storage target, each hybrid storage resource can provide a cost savings present value of approximately $25.5 million through 2030 in terms of revenue requirement. Similar to the 1,325-MW energy storage case, the results indicate average annual GHG reductions from California ISO generation of approximately 17,500 metric tons of CO2 emissions per hybrid storage unit, **as well as a net present value of revenue requirement savings through 2030 of $357 million** from 700 MWs of hybrid storage (14 units) installed by 2024.[32].

Figure 17: Optimal selected capacity counting hybrid storage towards 1,825-MW storage target

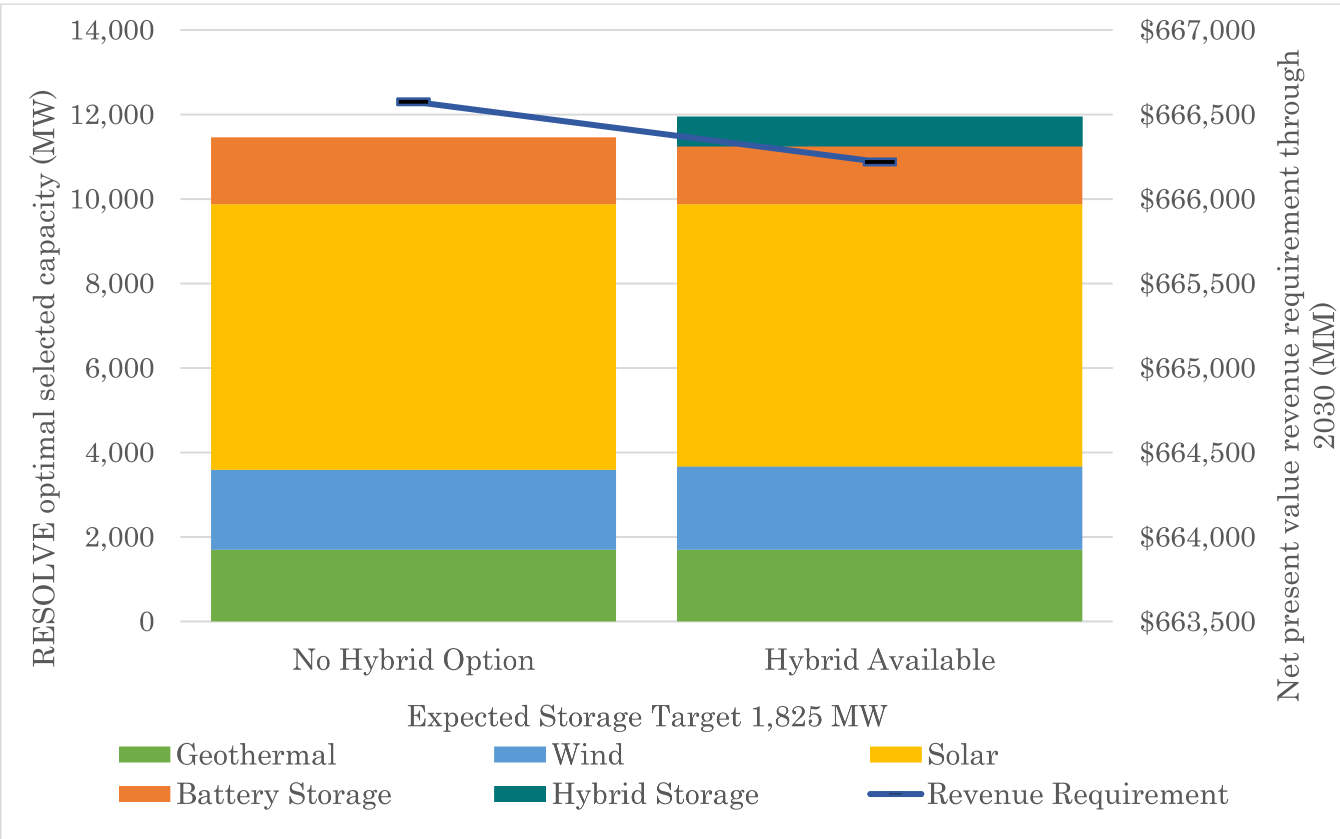


Figure 18: Cost and GHG savings counting hybrid storage towards 1,825-MW storage [33]

1,825 MW energy storage target	Net present value revenue requirement through 2030	Average annual emission (metric tons CO2)
No Hybrid Option	$666.58 billion	28,449,772
Hybrid Available Option	$666.22 billion	28,204,898

[32] Similar to the 1,325 MW results, the average annual metrics include years 2022, 2026, and 2030.
[33] Average annual values are based on modeled years 2022,2026, and 2030.

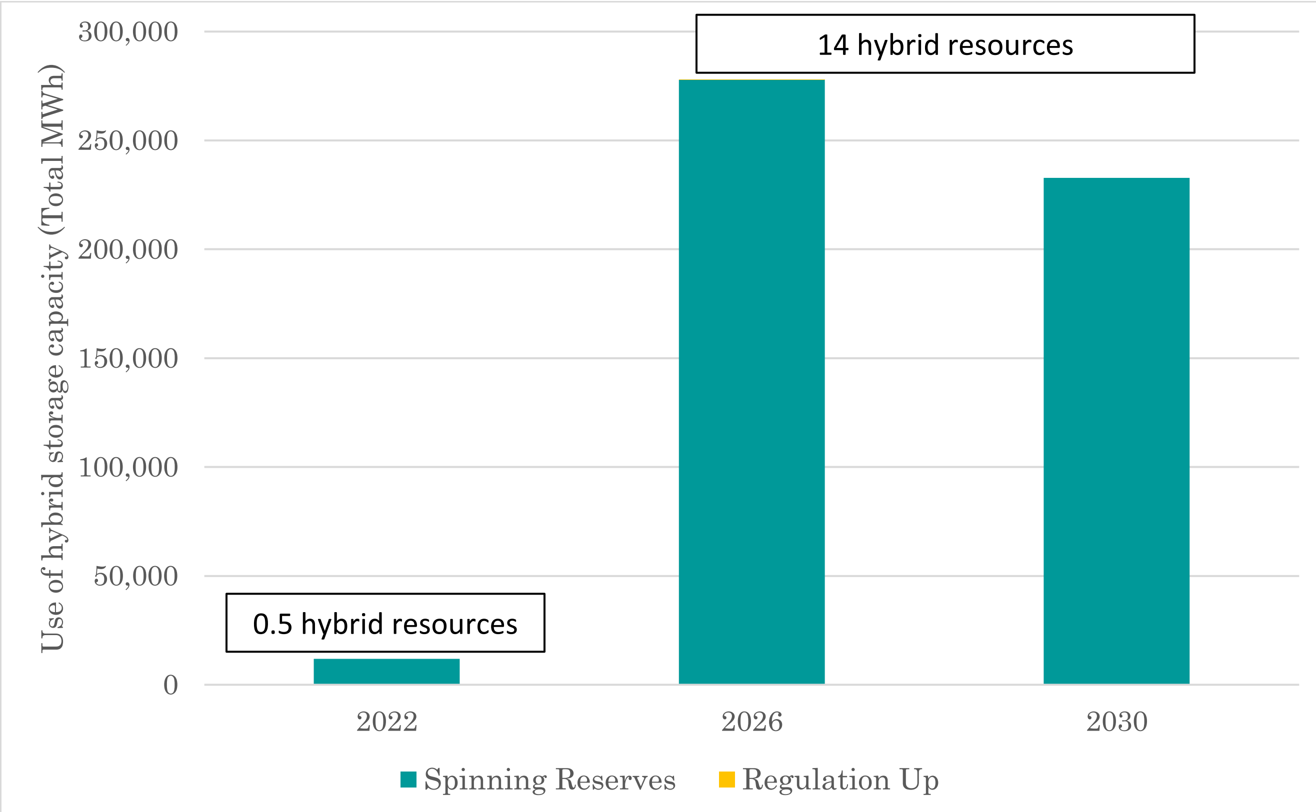
Total System Savings	***$357 million***	***244,874***
Avg Savings per Hybrid Unit	***$25.5 million***	***17,491***

Similar to the 1,325-MW target case, Gridwell finds that the addition of hybrid resources under an energy storage target of 1,825 MWs by 2024, the hybrid storage technology offers a cost-effective solution from all aspects—cost savings and GHG reductions—and is highly competitive, compared to other candidate resources within the RESOLVE model.

4.3.2 Preferred Use of Hybrid Storage

As discussed in the 1,325-MW case, the RESOLVE model determines the preferred use of the resource in terms of providing various energy products within the model. Even under the 1,825-MW storage target case, the results indicate the optimal use of the hybrid storage is to provide spinning reserves, and only in rare instances to provide regulation-up. This is likely a factor of the resource being able to provide spinning reserve capacity without having to generate any energy, given its minimum operating point of zero MWs. Again, year 2022 is showing lower spinning reserve capacity provided by hybrid storage resources in the thirty-seven representative days but is due to the fact that the model procured less than one hybrid storage resource in 2022. Additionally, its ability to provide spinning reserves while sitting at zero-MW dispatch point is also likely contributing to reduced GHG emissions from the California ISO generation fleet.

Figure 19: Preferred use of hybrid storage towards 1,825-MW storage target



As discussed in the 1,325-MW scenario, the RESOLVE model is currently unable to choose between either keeping the existing gas resource or converting that resource to a hybrid resource. Thus, Gridwell was only able to include hybrid as another optional resource type, which left the un-hybridized resources available to be used within the model. Similar to the 1,325-MW storage mandate scenario, under the expected 1,825-MW storage mandate scenario, the model reduces the use of the existing gas-fired generation for energy and does not use hybrid storage for energy[34]. These results continue in the same direction as the previous storage mandate scenario, in that the model would rather use the hybrid storage technology for spinning reserves rather than the un-hybridized existing combined-cycle gas turbine resources.

The hybrid storage technology continues to be competitive relative to other candidate resource types within the RESOLVE model, even under the 1,825-MW energy storage target. The results indicate the technology has the potential to provide savings all around—reduced revenue requirement and GHG reductions—while still meeting California's GHG and renewable energy goals.

[34] As noted under the 1,325 MW energy storage target case, there may be double counting of available capacity that is unable to avoid without further enhancing the RESOLVE model.

4.4 Hybrid Storage High Procurement Target Results

An additional sensitivity was run to assess if there is a point at which the market could become saturated with hybrid storage, such that benefits start to diminish. Given that the preferred use of the technology is to provide spinning reserves, there could be a point at which too much penetration of hybrid storage technology would saturate the market and reduce the incremental benefits of each additional hybrid storage resource.

Gridwell conducted another sensitivity to evaluate if the market would reach a saturation point if, for example, 2,500 MWs of hybrid storage were procured. To evaluate a potential saturation point, Gridwell used the 1,325-MW storage build-out scenario and forced the model to procure 2,500 MWs of hybrid technology. As discussed earlier, 20 percent of each resource's capacity can count towards meeting the energy storage target (10-MW BESS on a 50-MW unit). Thus, by forcing the model to procure 2,500 MWs (i.e. 50 units) of hybrid technology using the 1,325-MW energy storage target scenario, the model was essentially forced to meet the 1,825-MW energy storage target, 500 MW of which came from the battery portion of the hybrid storage resources (i.e. 20% of 2,500 MW).

All the results shown below include the 1,825-MW run with hybrid technology available, and the 1,325-MW run with forced 2,500-MW hybrid procurement, for comparison.

4.4.1 Cost and GHG Emissions Savings

Despite the significant amount of additional capacity procured, the results indicate continued cost savings even at higher levels of procurement. As noted earlier, this is not meant to be a recommended level of procurement but was intended as a benchmark to determine any obvious limitations to the technology. These are preliminary results that indicate the directional benefits of investing in the technology at various levels.

The model results shown in Figure 20 and Figure 21 continue to indicate the potential for GHG and cost savings with the inclusion of hybrid storage technology, even at high levels of procurement. Again, Gridwell is not recommending 2,500-MW hybrid storage procurement, especially considering there are likely only 1,000 MW of potential LM6000 resources that *could* be hybridized in California. The results indicate significant potential benefits even at high levels and thus Gridwell believes that hybrid storage technology should be further evaluated as an option to aid California in meeting its GHG and renewable generation targets.

Figure 20: Optimal selected capacity and cost savings with 2,500-MW hybrid storage under 1,825-MW energy storage target

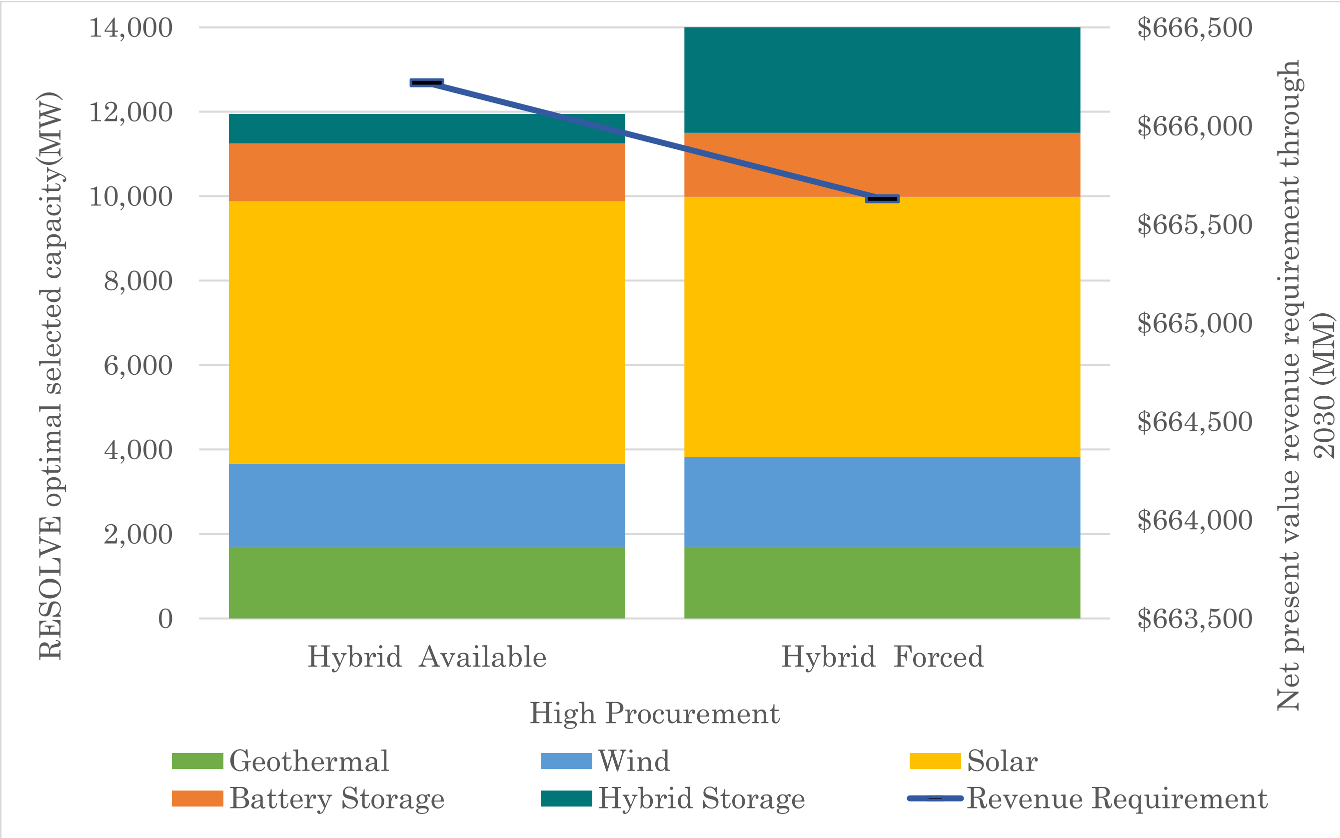


Figure 21: Cost and GHG savings with 2,500-MW hybrid storage towards 1,825-MW energy storage target [35]

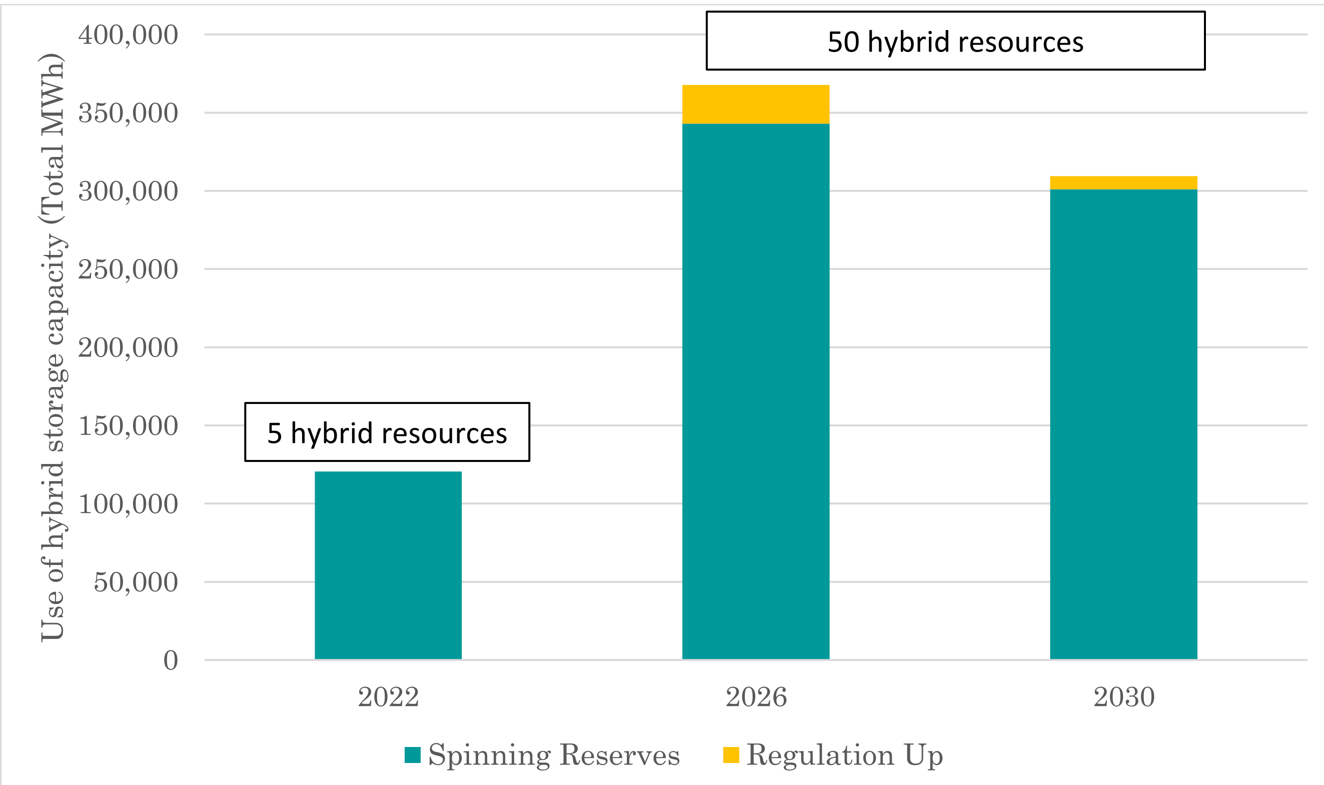
1,825 MW energy storage target	Net present value revenue requirement through 2030	Average annual emission (metric tons CO2)
Hybrid Available Option	$666.22 billion	28,204,898
High Procurement of Hybrid Option	$665.63 billion	27,322,751
Total System Savings	***$589 million***	***882,147***
Avg Savings per Hybrid Unit	***$12 million***	***17,643***

[35] Average annual values are based on modeled years 2022,2026, and 2030.

4.4.2 Preferred Use of Hybrid Storage

Even at higher levels of procurement, the hybrid storage technology primarily provides spinning reserve capacity. Yet, at this level of procurement, the model results do indicate a slight increase in the quantity of regulation-up provided by the hybrid storage resource as shown in Figure 22[36]. Furthermore, the model continues to rely less on existing gas-fired generation to provide energy.

Figure 22: Preferred use of 2,500-MW hybrid storage under 1,825-MW storage target



At higher levels of penetration, there does seem to be shift in the energy products provided by the hybrid storage technology. Based on these preliminary results, at 2,500 MWs of hybrid storage, the additional hybrid capacity is used for regulation-up services, as opposed to providing more of the spinning reserve capacity. Additionally, there is a reduction in the energy provided by gas-fired generation of almost 105,000[37] MWhs in 2030 under this scenario. These results suggest a level at which additional hybrid storage capacity would no longer provide spinning reserves but start providing more regulation services. However, Gridwell

[36] As with the other scenarios, the total spinning reserve values are based on the thirty-seven days per year modeled in RESOLVE.
[37] The reduction is relative to the 1,825-MW storage target case with hybrid available and based on the thirty-seven representative days modeled for 2030.

believes further modeling efforts need to be conducted to better evaluate if, and at what quantity, the saturation point is reached.

4.5 Early Procurement Results

Gridwell conducted a fourth scenario to evaluate if early procurement of hybrid storage resources could provide additional benefits relative to what the model was procuring in the earlier years under the 1,325 MW and 1,825 MW energy storage target cases. The impetus for this scenario stemmed from the observation that under the saturation scenario there were significant benefits at higher levels of procurement in 2022 compared to the 1,825 MW storage target case that delayed procuring the majority of hybrid storage capacity beyond 2022[38]. Under the 1,325 MW energy storage target case, only a fraction of the total procured hybrid storage resources was procured in 2022 (i.e. 315 MWs in 2022 of the total 700 MWs procured by 2030). Gridwell wanted to assess if the early procurement benefits observed under the saturation scenario continued under the 1,325 MW storage target case by forcing the model to procure the 700 MWs by 2022 under the 1,325 MW energy storage target case.

All the results shown below include the 1,325 MW run without hybrid technology available, the 1,325 MW run with hybrid technology available, and the 1,325 MW run with forced 700 MW hybrid procurement by 2022, for comparison. This scenario also highlights the importance of conducting further evaluations using a model that has built into the capacity expansion functionality the ability to not only hybridize existing resources but also recognize the battery portion of each hybrid storage resource as meeting the storage target. Updating the capacity expansion functionality may then result in higher levels of procurement earlier on, similar to those shown below[39]. Thus, these results could be considered a more reasonable representation of the timing and quantity of procurement and the benefits from hybrid storage resources under the current 1,325-MW storage target with an updated capacity expansion model.

The potential savings from procurement in 2018 are discussed in section 8.1.

4.5.1 Cost and GHG Emission Savings

The results show additional cost and GHG emission savings concentrated in the year during which the additional early procurement occurs despite procuring some of the hybrid storage resources at higher prices. Procuring an additional 385 MWs of hybrid storage technology (700

[38] The high procurement scenario procured four more hybrid storage resources in 2022 than the 1,825-MW storage target case with hybrid available, resulting in an additional revenue requirement savings of $45MM and 28,000 metric tons of CO_2 in 2022.

[39] RESOLVE sets the energy storage target amount for each year prior to 2024 based on the 2024 storage target value used in the model. Under the 1,325 MW case, the target in 2022 is 1,113 MWs of energy storage. When Gridwell reduces the 1,325 MW energy storage target in 2024 to 1,185 MWs, the model sets the 2022 energy storage target at 1008 MWs, a 105 MW difference. Thus the 315 MW of hybrid procured in 2022 under the 1,325 MW hybrid available option case is less energy storage (20% of 315 MWs is 63 MWs) than what would be procured if the model was updated and maintained the 2022 target set at 1,113 MWs while recognizing the 20% energy storage portion of each hybrid storage resource.

MW total) in 2022 results in additional savings of $11MM in net present value revenue requirements for the system, making the total net present value revenue requirement savings per procured resource increase to $26.4MM through 2030[40]. The average annual GHG reductions significantly increase as well when procuring 700 MW in 2022 compared to only procuring 315 MWs of hybrid storage in 2022.

Figure 23: Optimal resource mix and cost savings with early procurement of hybrid storage under 1,325 MW storage target

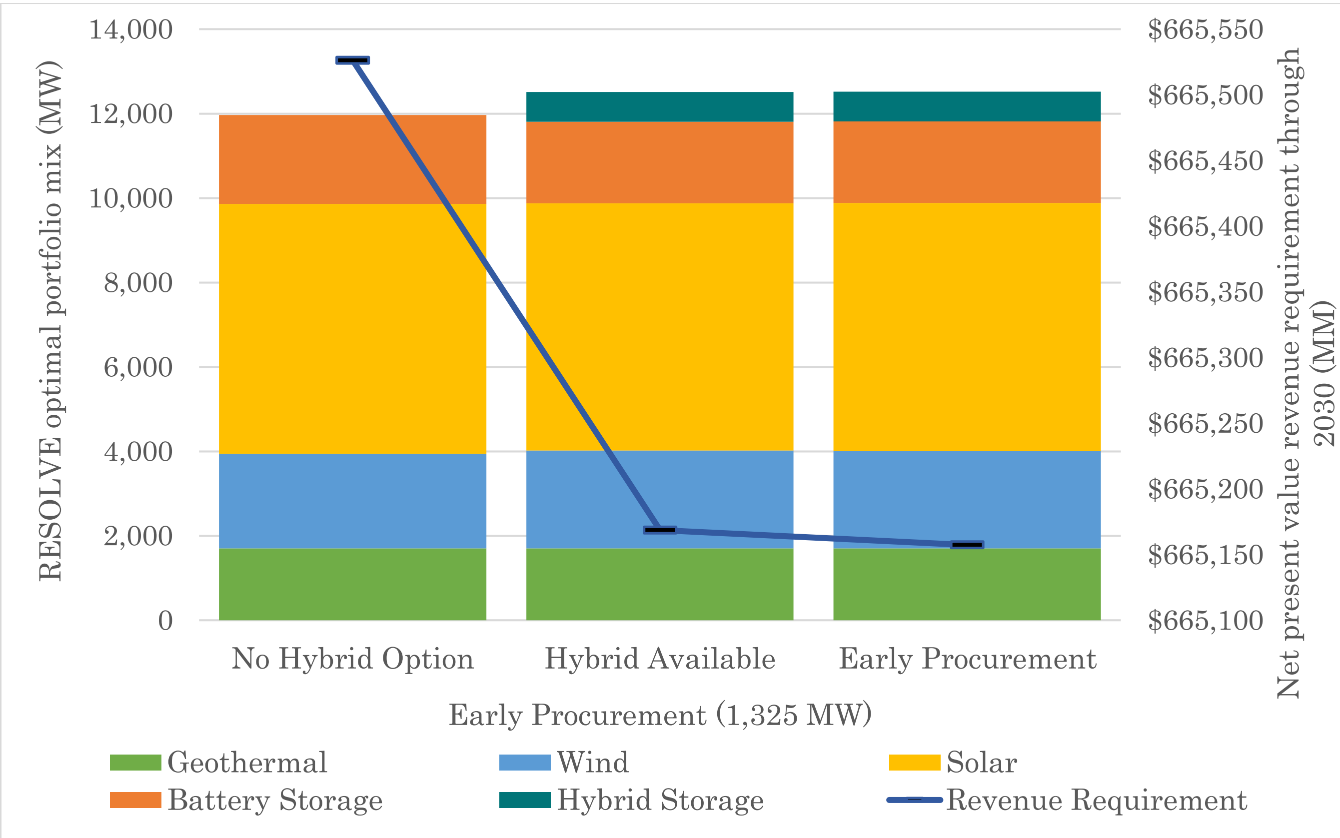


Figure 24: Cost and GHG savings with 700-MW hybrid storage procured in 2022 under 1,325-MW energy storage target

1,325 MW energy storage target	Net present value revenue requirement through 2030	Average annual emission (metric tons CO2)
No Hybrid Option	$665.53 billion	28,678,687
Hybrid Available Option	$665.17 billion	28,398,622

[40] The early procurement scenario procured a total of 703.65 MWs of hybrid storage by 2030 compared to 703.22 MWs by 2030 under the hybrid available scenario.

Total System Savings	***$358 million***	***280,065***
Avg Savings per Hybrid Unit	***$25.6 million***	***20,005***
Early Procurement Option	$665.16 billion	28,259,700
Additional Total System Savings	***$11 million***	***138,923***
Additional Avg Savings per Hybrid Unit	***$0.8 million***	***9,923***
Total Avg Savings per Hybrid Unit	***$26.4 million***	***29,928***

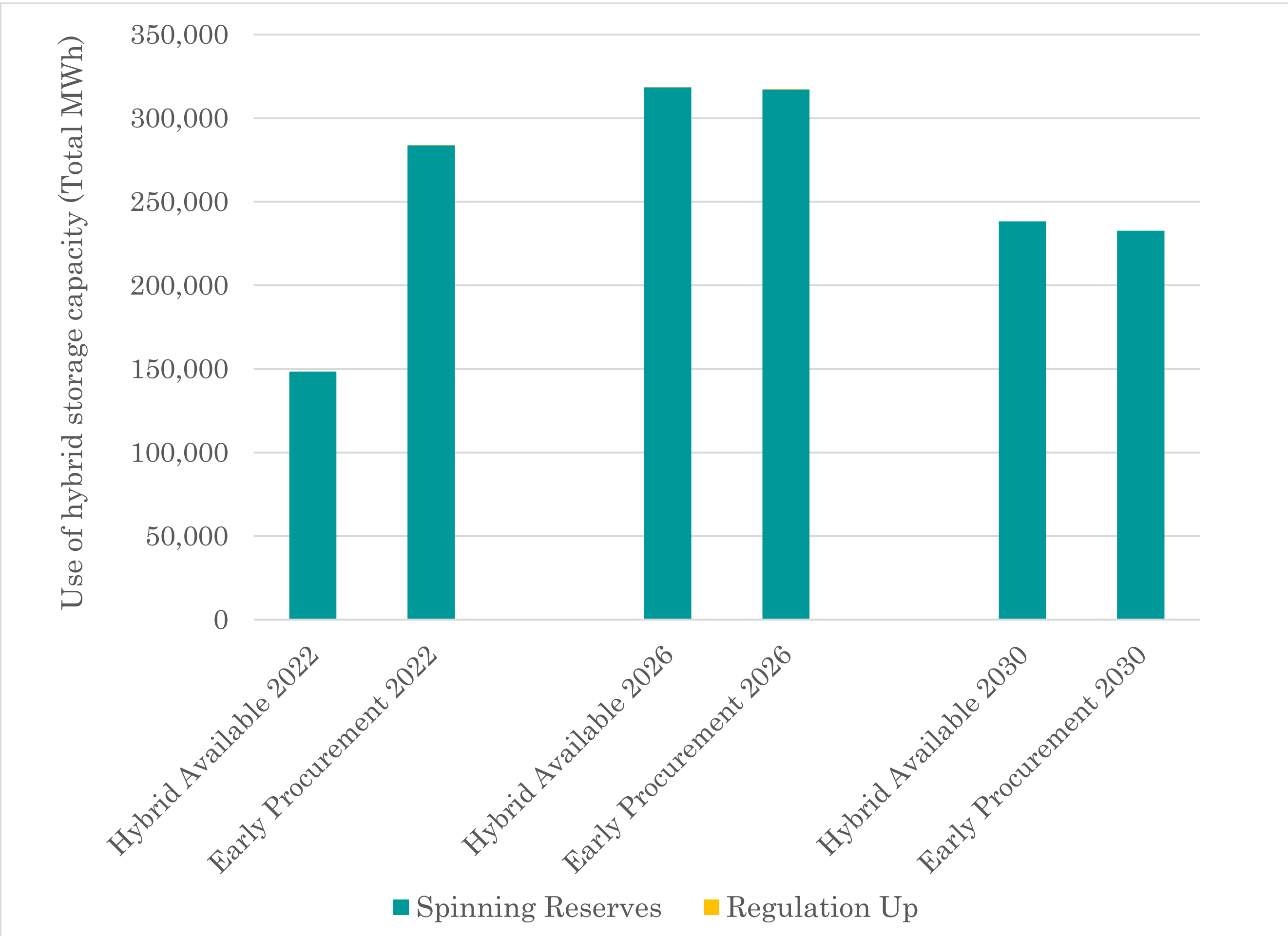
As noted earlier, these results indicate that procuring higher levels of hybrid storage earlier may produce additional benefits than those shown under the 1,325 MW storage target case where only 315 MWs were procured by 2022. Gridwell believes that using a capacity expansion model that accurately captures the hybrid storage resources may produce results more aligned with the early procurement scenario as it would recognize the battery portion of each hybrid resource to meet the 2024 target and potentially procure more resources prior to 2024, i.e. 2022. Given the way Gridwell had to modify the model, these results may be over- or under-estimating the additional benefits of early procurement.

As previously noted some of these benefits may be due to more gradual adoption to meet the 2024 energy storage target, which at this point is difficult to separate out given the current set of up RESOLVE model. Gridwell believes the results directionally indicate that procuring higher levels of hybrid storage earlier than 2024 may be beneficial, however additional studies will need to be conducted to accurately determine the optimal level of early procurement, and if that optimal level is above what would naturally occur under an updated capacity expansion model.

4.5.2 Preferred Use of Hybrid Storage

Earlier procurement of the hybrid storage technology is being used to provide additional spinning reserve capacity in the near term (i.e. 2022) with a slight increase in the amount of regulation provided during the thirty-seven representative days in the early year. Under the early procurement scenario there is an additional 385 MWs of hybrid storage resource capacity available, and being utilized, by the model to provide spinning reserves. These results indicate that even in earlier years, its optimal to have hybrid storage resources providing spinning reserves. Gridwell has provided additional discussion around potential benefits of procurement in 2018 in Section 8.1. Additionally, the model results also indicate that earlier procurement enables the market to rely less on existing gas-fired resources sooner than if procurement were to occur in later years. In year 2022 energy provided by gas fired generation reduced by 88,000 MWhs over the thirty-seven representative days when 700 MWs of hybrid storage resources were available in 2022.

Figure 25: Preferred use of hybrid storage technology with early procurement (1,325 MW energy storage target)



The additional capacity procured earlier in the planning horizon is still primarily used to provide spinning reserve capacity, albeit at higher levels, which in turn contributes to the additional cost and GHG savings observed. These preliminary results continue to indicate that hybrid storage technology is an optimal candidate resource under all scenarios evaluated. Given that the RESOLVE model was not initially set up to account for a percentage of hybrid storage technology as contributing to the energy storage target, the earlier procurement and its corresponding benefits may be the optimal adaptation rate under a capacity expansion model that incorporates this feature of hybrid storage technology. Thus, Gridwell recommends additional studies be conducted using a revised capacity expansion model to produce more conclusive results in terms of the additional benefits of early procurement above what would optimally be procured to meet the energy storage target.

5 Hybrid EGT® Conceptual and Observed Benefits

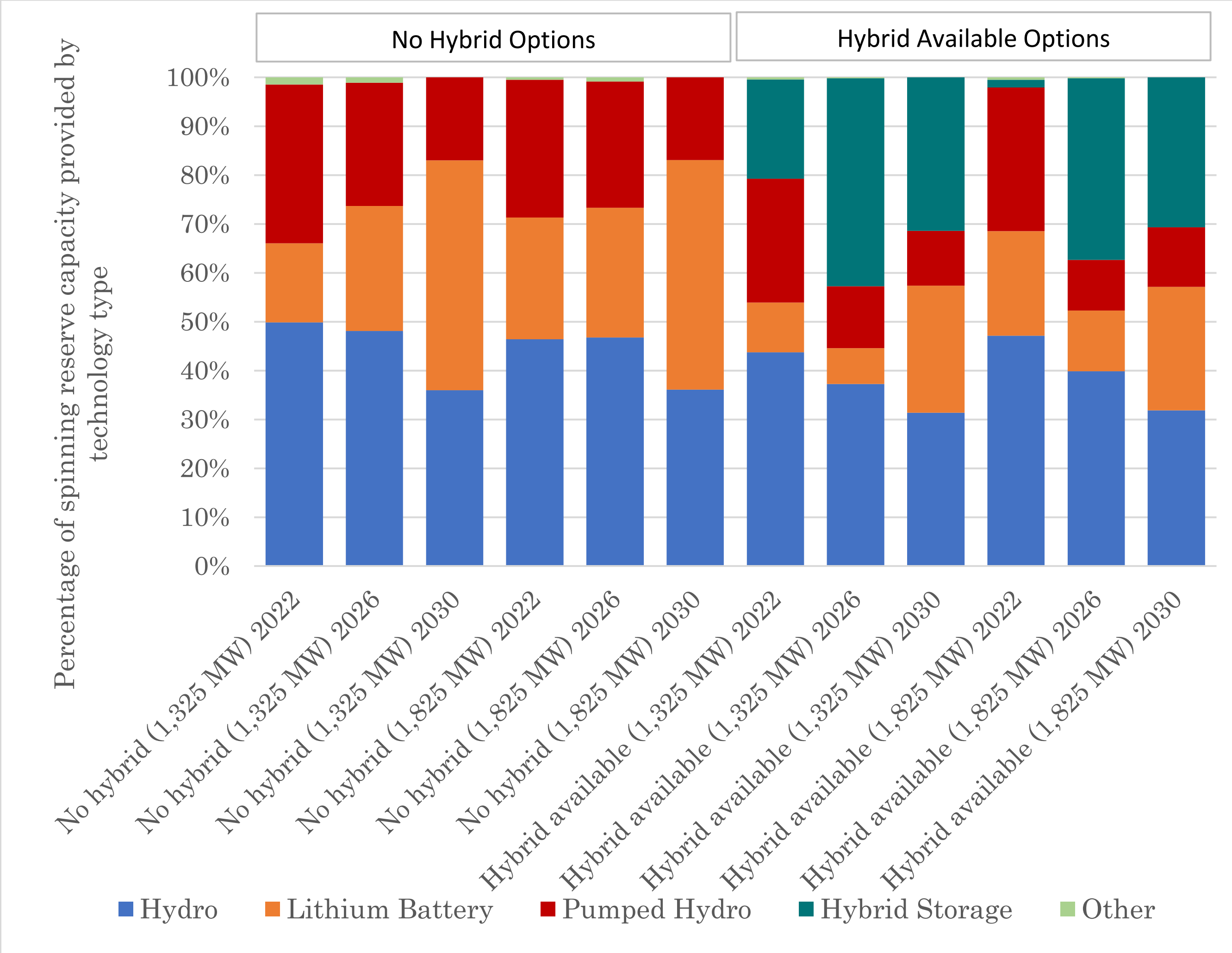
This section describes the conceptual and observed benefits of a 50-MW Hybrid EGT® with 10-MW/4.3-MWh BESS that Gridwell believes capacity expansion modeling will not be able to capture and should be explored with production cost modeling and continued observation of the existing SCE hybrids.

As noted in the previous section on RESOLVE modeling, there are some gaps between the RESOLVE model and actual grid conditions and flexibility needs. One of the more significant potential benefits of hybrid storage resources is their ability to provide spinning reserve capacity without putting any energy onto the grid or emitting GHG. This characteristic, in theory, would enable the market to decommit other emitting resources and rely upon the hybrid storage resources to provide most of the spinning reserve capacity. In turn, this would allow California to reach its GHG goals at a lower cost than a scenario without hybridizing.

In fact, the RESOLVE model results indicate that the optimal use of hybrid storage resources is to provide spinning reserve capacity. As shown in Figure 26 below, hybrid storage resources provide, on average, nearly 30 percent of the annual spinning reserves[41]. However, the results also indicate that hybrid storage resources will primarily replace spinning reserves that would otherwise be provided by pumped hydro and lithium batteries. This is because the model results have gas-fired resources providing less than one percent of spinning reserve capacity when hybrid storage resources are not available.

[41] Only 2022-2030 are shown in the chart as hybrid storage resources were not selected in 2018.

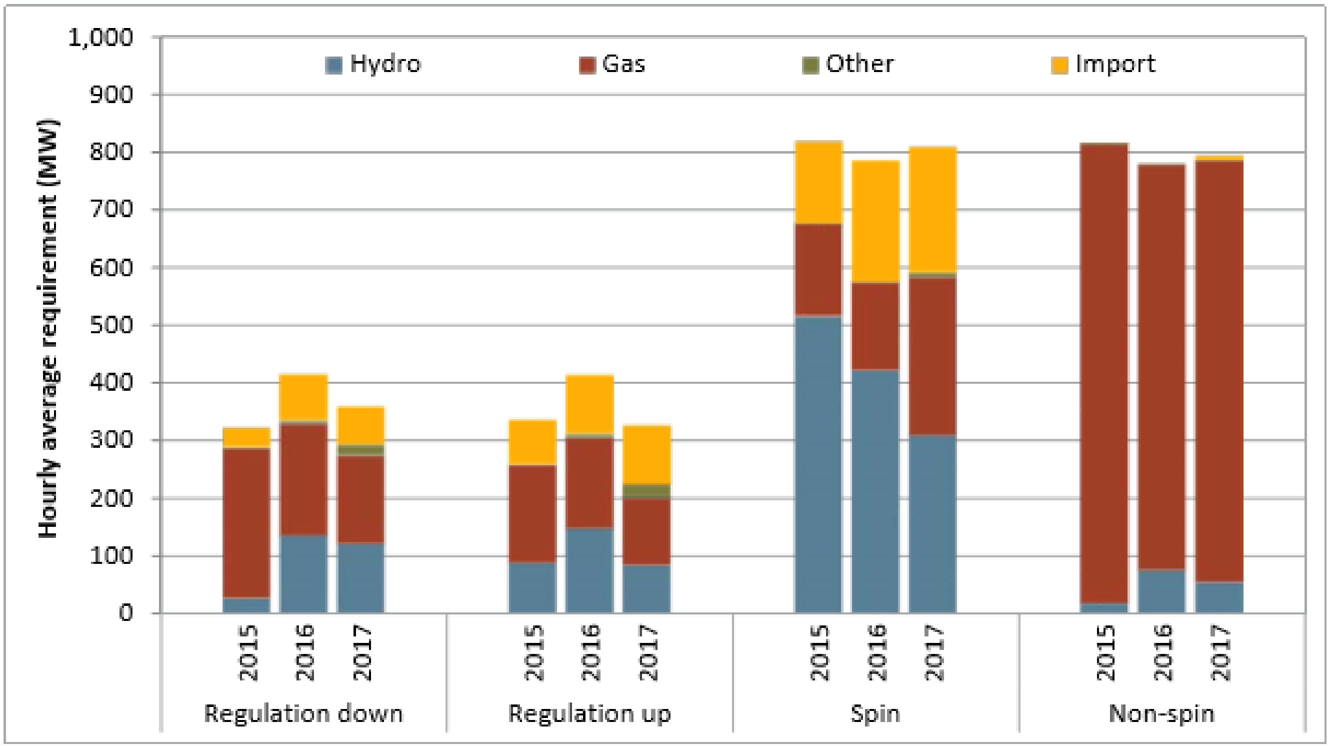
Figure 26: Percentage of spinning reserve capacity by technology type[42]



These results are in strong contrast to actual California ISO grid operations. As shown in Figure 27, the California ISO's 2017 Annual Report states that gas-fired resources have been providing an increasing percentage of spinning reserve capacity, most recently 34 percent in 2017. Thus, hybrid storage resources would likely replace spinning reserve capacity from gas-fired generation, further reducing GHG emissions.

[42] Only 0.5 of a hybrid storage resource was procured in 2022 under the 1,825 MW case, thus only providing a fraction of the spinning reserve capacity.

Figure 27: Average hourly procurement of ancillary services by fuel type[43]



Because RESOLVE's use of gas for spinning reserves (at 1%) is so significantly different than California ISO observations (34%), Gridwell feels confident in the conclusion that the GHG reductions due to the addition of hybrid storage are directionally accurate and conservative.

This section therefore focuses on benefits observed from the SCE Hybrid EGT® first year of service and conceptual benefits, like the one described above, which would benefit from additional consideration and improved modeling.

5.1 Greenhouse Gas (GHG) Reduction from the Hybrid EGT

Gridwell evaluated the difference in Hybrid EGT® emission output under different plausible scenarios in order to understand conceptually the potential for GHG reduction. In each scenario, Gridwell calculates the possible emissions saved in one day from hybridizing a 50-MW combustion turbine. These calculations assume a heat rate of 10,000 Btu/kWh for combustion turbines and 6,800 – 7,500 Btu/kWh for combined-cycle resources.

Figure 28 shows the simplest example—the small difference in CO_2 emissions from a Hybrid EGT® compared to a conventional combustion turbine resource. While most emission savings theoretically will come from the Hybrid EGT® providing spinning reserves, it is important to note that even when used like a traditional combustion turbine resource, it can provide the same amount of energy at a slightly lower emission rate, due to the addition of the BESS.

[43] Figure 6.6 in California ISO's 2017 Annual Report

Figure 28: Saved Emissions from Hybrid EGT Compared to Conventional Combustion Turbine during Morning and Evening Ramp

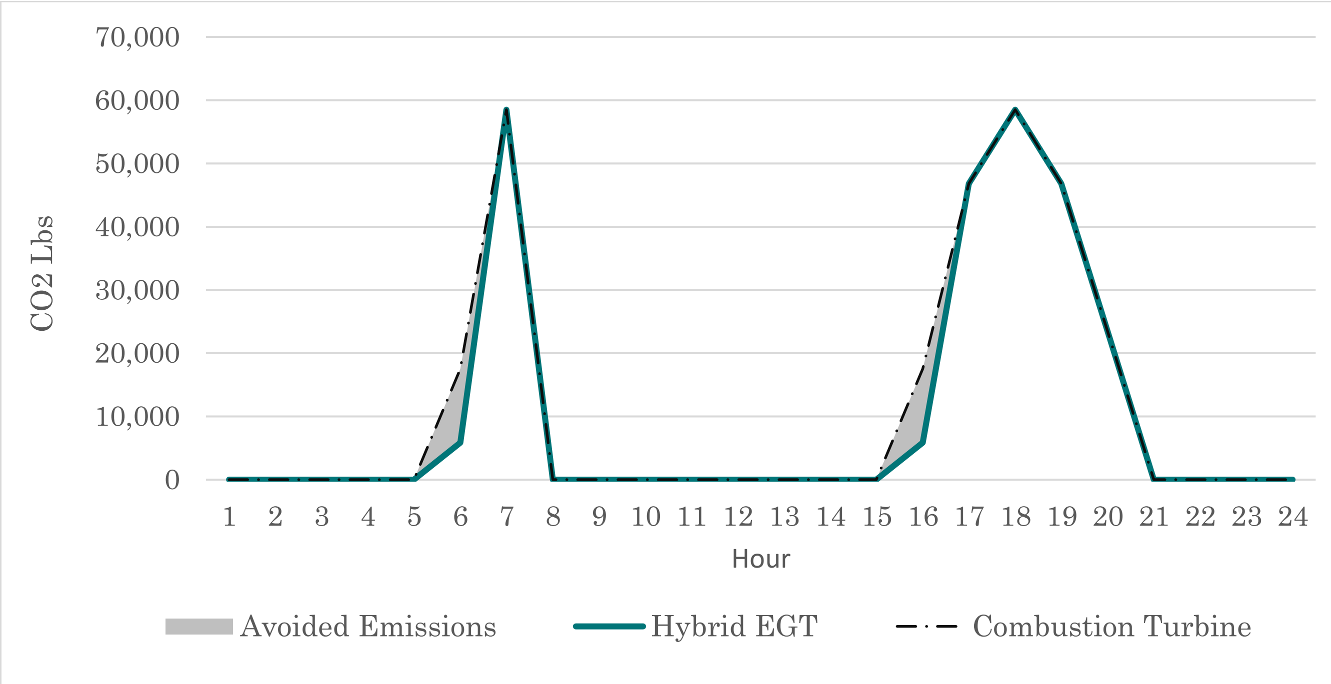


Figure 29 shows the potential emission savings of a Hybrid EGT®, compared to a traditional combined-cycle that is sitting at (even a very low) Pmin, in order to provide flexible energy on a cloudy day. The Hybrid EGT® is able to turn fully off and fully on and provide small amounts of energy at reduced emissions, again due to the BESS.

Figure 29: Saved Emissions from Hybrid EGT Compared to Conventional Combustion Turbine during Cloudy Day

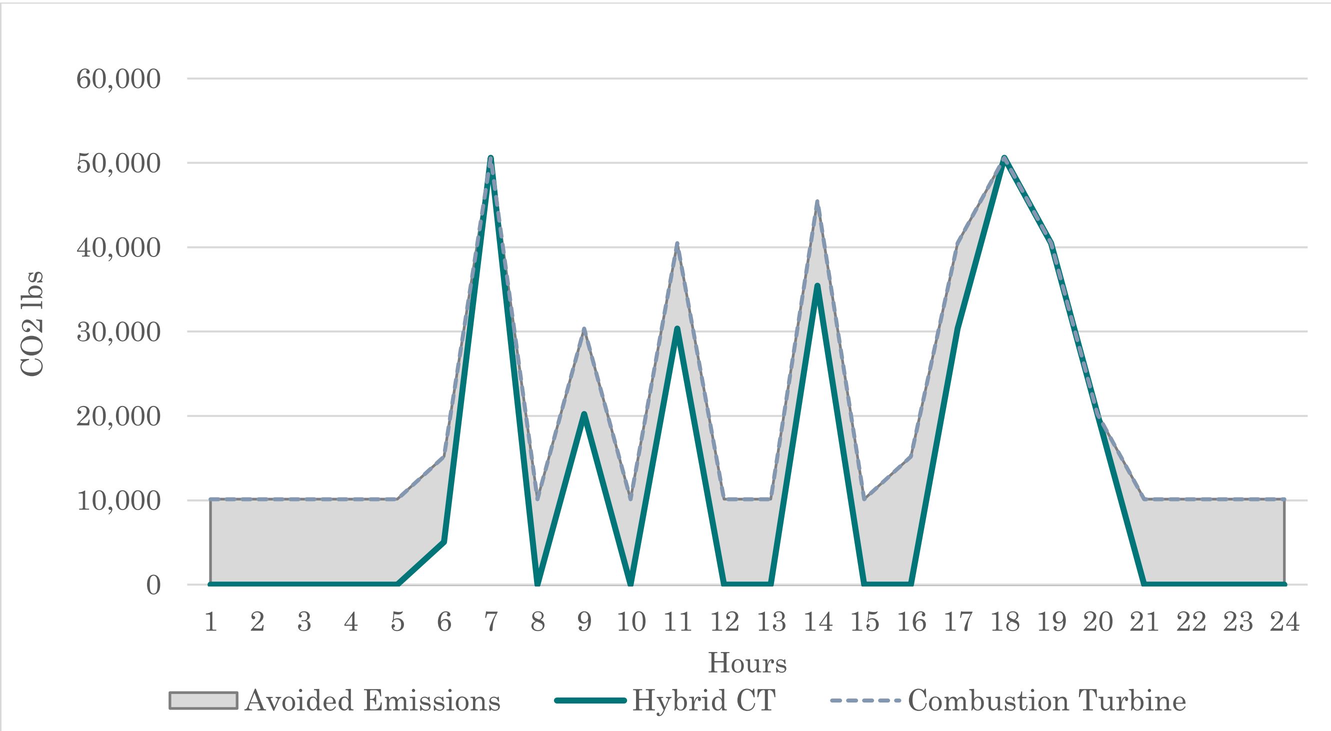
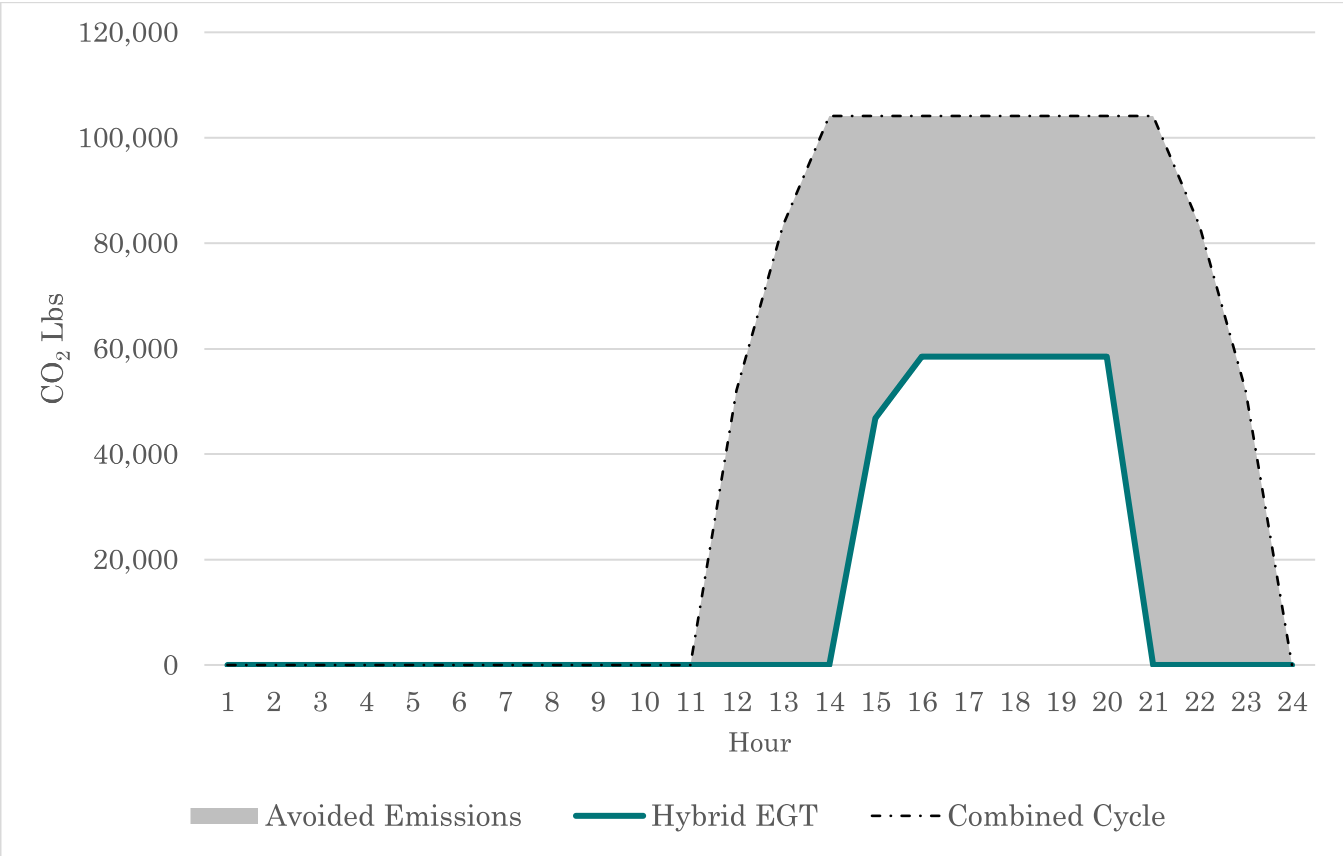


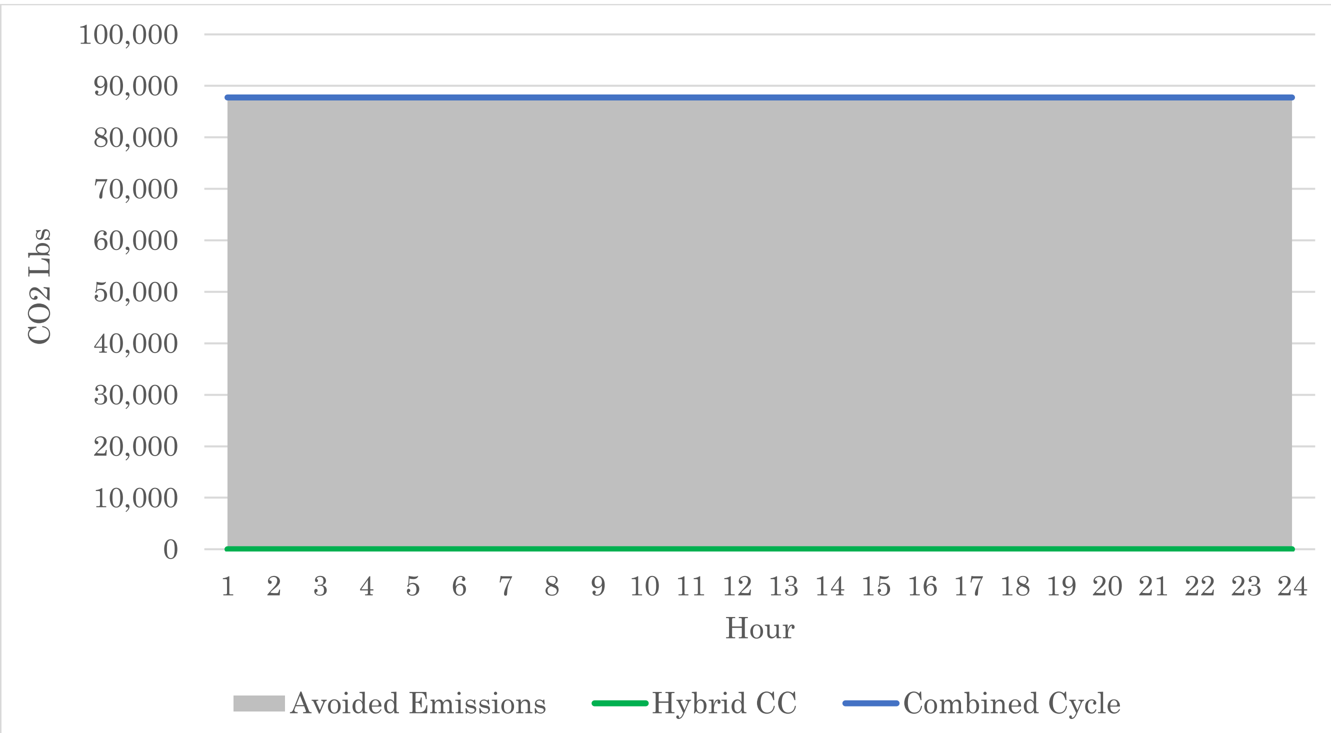
Figure 30 compares the Hybrid EGT® to a long-start combined-cycle dispatched to a 50-MW Pmin to provide potential flexible ramping during the evening peak. Rather than maintain a combined-cycle at Pmin, the California ISO could rely on the Hybrid EGT®. Assuming that at some point, 50 MWs of energy are actually needed, the Hybrid EGT® still saves hours of emissions by remaining offline while the California ISO relies on Solar or Wind energy.

Figure 30: Saved Emissions from Hybrid EGT Compared to Long-Start Combined Cycle during Evening Ramp



Finally, *Figure 31* shows how the expected emission savings from the best-use case for Hybrid EGT® resources. It shows the difference in emissions from a combined-cycle resource sitting at a Pmin of 100 MWs, in order to provide spinning reserve. This is compared to the Hybrid EGT®, which can provide spinning reserves at zero Pmin. Because spinning energy is only dispatched in an emergency or near-emergency, on most days, being able to provide 50 MWs of spinning reserve capacity while emitting no emissions whatsoever, is the greatest conceptual emission savings from hybridizing a combustion turbine engine.

Figure 31: Saved Emissions from Hybrid EGT Compared to Combined Cycle as Spinning Reserves



To put the emissions savings of this last example in context, a typical (non-SUV) passenger vehicle emits about 4.6 metric tons of carbon dioxide per year.[44] Hybridizing a single combustion turbine would be like taking more than 6,500 vehicles off the road every year.

5.2 Reliability Services

Hybrid storage technology is well suited to provide reliability services, which refer to fast-acting mechanisms for maintaining reliable operations of an interconnected transmission system.

[44] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

5.2.1 Ancillary Services

A hybrid storage technology plant is more effective than a traditional combustion turbine or combined-cycle plant at providing the most common market ancillary services--regulation-up, regulation-down, spinning reserve, and non-spinning reserve.[45] A plant using hybrid storage technology is always online and synchronized with the grid and only needs to burn fuel if the needed output is beyond the capability of the plant's battery storage system. Providing the same level of on-demand service with a traditional thermal plant would entail additional burdens, such as burning more fuel. This would increase emissions and its associated charges. It would also increase wear and maintenance costs from either continuously running the thermal generator or keeping it hot and primed for immediate start and managing the lead time necessary to prepare the generator to provide the ancillary service.

Regulation-up and regulation-down are provided by online and synchronized resources on automatic generation control. Resources providing regulation services respond to the minute-to-minute fluctuations in system load and adjust for unintended fluctuations in system generation output. Regulation services are necessary for compliance with the North American Electric Reliability Council (NERC) real power balancing control performance standard (BAL-001-2).[46]

Spinning reserves are provided by online and synchronized resources that can increase output immediately in response to a major generator or transmission outage and can reach full output within 10 minutes, to comply with NERC's disturbance control standard (BAL-002-2).[47] Non-spinning reserves are the same as spinning reserves, but the resources do not have to respond immediately and can be offline as long as they are still capable of reaching full output within the required 10 minutes.[48] Hybrid storage technology can be off-line, from a fuel-burn standpoint, yet still offer both spinning and non-spinning reserve services.

Traditional thermal plants need to burn fuel prior to offering the same spinning reserve service as the Hybrid EGT without fuel burn. Many traditional thermal plants don't have quick-start capabilities and would simply not be able to provide non-spinning reserve service. Additionally, in reality, when thermal plants provide spinning reserve capacity, they are operating at a non-zero minimum operating point. This further contributes to reliability concerns during over generation conditions because the generator must remain on line at its

[45] http://www.consultkirby.com/files/Ancillary_Services_-_Technical_And_Commercial_Insights_EXT_.pdf

[46] https://www.nerc.com/_layouts/PrintStandard.aspx?standardnumber=BAL-001-2&title=Real%20Power%20Balancing%20Control%20Performance

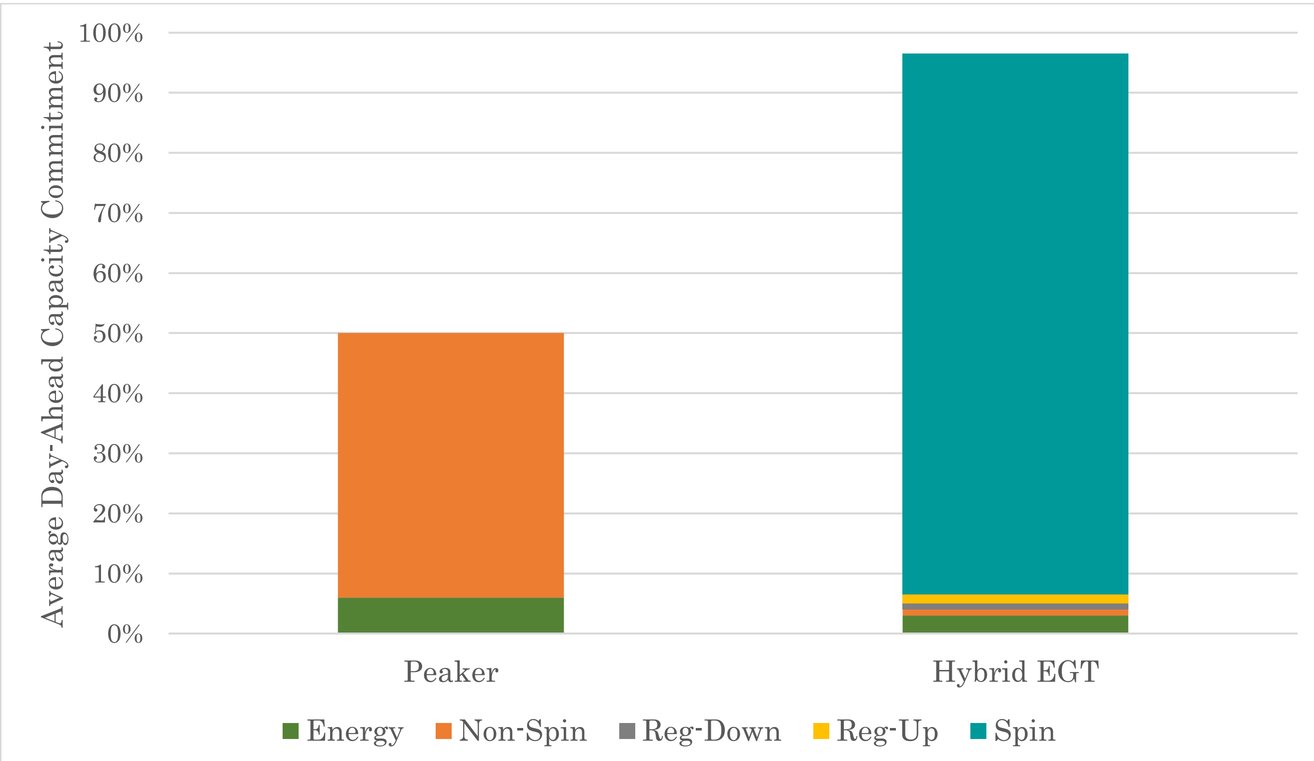
[47] https://www.nerc.com/_layouts/PrintStandard.aspx?standardnumber=BAL-002-2(i)&title=Disturbance%20Control%20Standard%20%E2%80%93%20Contingency%20Reserve%20for%20Recovery%20from%20a%20Balancing%20Contingency%20Event

[48] These rules are further described in section 0.

PMin. Hybrid storage technology, with its zero PMin, enables the resource to provide spinning reserves without putting any additional energy onto the grid[49].

SCE's experience to date confirms the market's recognition of the spinning reserve benefit of hybrid storage, as *Figure 32* shows the average day-ahead commitment for SCE's Center Peaker before and after hybridizing. Most of the Hybrid EGT commitments are spinning reserve and the small portion of energy is directly attributable to the battery energy underlying the regulation awards.

Figure 32: Observed increase in Spinning Reserve Awards after Hybridization



5.2.2 Frequency Response

Frequency response reflects the ability of the power system to restore and settle system frequency following a large disturbance. Frequency response compliance used to be part of spinning reserve requirements, but it is now more specifically called out in NERC standards (BAL-003-1.1).[50] Development of frequency response procurement and compensation mechanisms have begun (e.g., the California ISO's frequency response phase 2 process[51]). Hybrid storage technology is well suited to systems with frequent or even continuous need for

[49] The California ISO often refers to this as a Pmin burden; the market is unable to further reduce generation during over supply conditions from thermal plants positioned at a non-zero minimum load operating point that are providing spinning reserves.
[50] https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=BAL-003-1.1&title=Frequency%20Response%20and%20Frequency%20Bias%20Setting&jurisdiction=United%20States
[51] http://www.California ISO.com/informed/Pages/StakeholderProcesses/FrequencyResponsePhase2.aspx

frequency response because they can provide frequency response with less fuel burn, less emissions, and less wear and tear than a traditional thermal plant.

SCE has observed that the two Hybrid EGT®s have far exceeded expectations and at times responded to frequent frequency drops in a single day, helping to maintain stable electric system frequency. The ability of resources to respond to frequency drops is not trivial for reliability nor is it trivial in the amount of money the California ISO must pay for other balancing authorities to take on some of the California ISO's share. In 2018, the California ISO initiated a competitive solicitation to request offers for transferred frequency response for the 2017-2018 compliance year under NERC reliability standard BAL-003.1.1. This is because the California ISO anticipated that they would not be able to meet their balancing area's share of Western Interconnection's frequency response obligation. In 2017, $638,314 was paid to compensate the transferor balancing authority for any and all costs in connection with such performance. In 2016 this amount was even higher at $2,220,000.

5.2.3 Black start and voltage services

Black start generation is able to start itself without support from the grid and has sufficient real and reactive capability and control to be useful in energizing pieces of the transmission system and starting additional generators. Recently this was demonstrated with Imperial Irrigation District's new BESS and the combined-cycle natural gas turbine at the El Centro Generating Station[52]. As demonstrated there, a BESS can black-start a gas turbine and then have the battery system smoothly absorb the energy produced by the generator to make the plant into a microgrid that's ready to reconnect to the main grid, helping restore power to the system. A plant with hybrid storage technology couples together an energy storage system and gas turbine, using advanced controls and power electronics. This is all the equipment necessary to black-start the plant when needed.

The above-mentioned advanced controls and power electronics used in the hybrid storage technology provide superior reactive power adjustments, with more capability than a traditional thermal plant. This enables fast, tight voltage regulation to ensure transmission system voltages within the ranges required to maintain system stability and robustness.

5.3 Resource Adequacy Value

The CPUC and California ISO both run resource adequacy programs. These programs ensure that load-serving entities have procured sufficient local, system, and flexible capacity to meet the California ISO's operational needs.[53] The addition of a battery to an existing 50 MW combustion turbine plant will increase the resource adequacy of the entire Hybrid EGT® by 1.075 MWs.[54] While this is only a small portion of the 10-MW battery, at an average local

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[52] https://www.iid.com/Home/Components/News/News/557/30?backlist=%2F

[53] http://www.caiso.com/planning/Pages/ReliabilityRequirements/Default.aspx & http://www.cpuc.ca.gov/RA/

[54] Decision 18-06-009; June 21, 2018: Finding of Fact at 11 and 14.

resource adequacy price of $3/kW-month, the additional resource adequacy provides a net present value of about $330,000 over the next 10 years.

6 Review of Previous Modeling Efforts

Wellhead provided two separate independent production cost modeling studies that use the PLEXOS® integrated energy model to simulate the operation of hybrid storage resources in the California ISO grid and to evaluate the potential economic benefits of hybridizing using a 2017 study year. The model results and findings generally align with the results of the RESOLVE modeling efforts and observed SCE Hybrid EGT®s.

Production cost modeling differs from the RESOLVE capacity expansion modeling efforts discussed in section 4. Production cost models focus on how a given resource may operate in the energy and ancillary service markets in a single year. Capacity expansion models evaluate how competitive a resource would be, relative to other resource types over changing load and resource conditions over a longer time horizon. While a comparison between the two model type results should not be done directly, we observe that the predicted benefits from the PLEXOS modeling are aligned with the RESOLVE model results and have already begun to be realized by SCE as it operates two hybrid storage resources within the California ISO today.

The production cost modeling done suggests an overall cost savings. This is driven primarily from the hybrid storage resources displacing higher-cost, higher-emitting resources, to provide both energy and ancillary services. Additionally, the results show that having the hybrid storage resources in the supply stack reduces GHG emissions from dispatching the fleet lower on the system wide heat rate curve than without the hybrid storage resources. These results are similar to the RESOLVE model results. Specifically, hybrid storage resources produce significant cost savings and reduce overall GHG emissions. This provides a more cost-effective and efficient solution not only for meeting demand and maintaining reliability, but also for meeting California GHG and energy storage targets.

Another common result of both production cost modeling efforts noted the hybrid storage resources were primarily used to provide spinning reserves. The results show the hybrid storage resources providing spinning reserve capacity in about 90 percent of hours. While the RESOLVE modeling has the hybrid storage resources providing spinning reserves in about 50 percent of hours, the hybrid storage resources are competing against significantly more energy storage capacity in the RESOLVE model.

The underlying objective of a production cost model differs from that of a capacity expansion model. One cannot make a clean comparison between cost savings reported from each model result. However, all modeling efforts clearly identify the optimal use of the hybrid storage resources as providing spinning reserves and GHG emissions savings, due to displacing higher-cost and higher-emitting resources with hybrid storage technology. So, one can reasonably conclude that the findings reached from all three modeling efforts (RESOLVE included) should be the basis for future modeling and analytical efforts.

7 Conclusion and Recommendations

Gridwell finds that the RESOLVE model results confirm that the expected benefits of hybridizing additional gas resources are consistent with SCE's initial experience with the Hybrid EGT®s. This suggests that there are clearly benefits to additional hybridizing and earlier procurement of hybrid storage resources may produce additional benefits. Further study is needed to quantify the extent of these benefits and optimal penetration and timing of hybridizing. A number of key findings were consistently verified across multiple evaluation methods:

- There are benefits to early procurement of Hybrid Energy Storage and the optimal amount should be determined through additional modeling that identifies existing CTs that are particularly needed for reliability. Gridwell considers hybridizing any existing CT that has been shown to be needed for local reliability a no-regrets decision from an environmental and economic perspective.
- The optimal use for a hybrid storage resource is for spinning reserves and quick response to negative and positive price spikes in the real-time market[55].
- Emission and cost savings come primarily through fleet-wide re-dispatch, as hybrid storage resources take on more ancillary services and other resources can shut down or run at their most efficient load point. Secondary emission savings come from the battery responding instantaneously to unexpected, short-duration energy needs, without the resource needing to burn fuel.
- Because the BESS only makes up 20 percent of the total hybrid resource output, only a small portion of the storage target, 150-210 MWs would need to be reserved for hybrid storage technology for the full existing technology potential to be realized.

Based on the report findings, Gridwell has the following recommendations on areas of future focus:

- In order to understand the full benefits of hybrid technology in a high renewable and storage environment, hybrids should be evaluated in a production cost model in the near term and after significant BESS built-out. This would demonstrate how the benefits of providing spinning reserve capacity continue to occur throughout the life of the hybrid resource.
- The production cost modeling would also allow analysis of increasing amounts of hybridizing to determine the cost-benefit ratio for each additional resource hybridized. This would indicate the optimal adoption quantities in California.

[55] Currently, hybrid storage resources cannot charge from the grid at wholesale prices, but this could potentially change in the future.

- In order to understand the full benefits and optimal timing of penetration of hybrid technology, hybrids should be evaluated in a capacity expansion model that is able to directly model the decision to hybridize existing gas-fired resources. Gridwell believes the current RESOLVE model can be updated with moderate effort.
- Stand-alone BESS and hybrid technology should be considered within local areas as alternatives to transmission and other generation. Gridwell notes that the CAISO has begun work to understand the duration of capacity needed in different local areas and at times, the amount needed is beyond the capability of most battery energy storage resources. In these particular areas, the cost and emission savings considered together from hybridizing may be better than installing stand-alone storage.
- The benefits of hybridizing combined-cycle resources should be explored through conceptual and practical modeling to determine if it would be worthwhile to develop the technology for a CCGT hybrid storage use case.

Additional findings and answers to common questions about this report and hybrid technology can be found in the FAQ in section 8.5.

8 Appendix

8.1 Hybrid Storage Procurement in 2018

Gridwell conducted an additional early procurement study to evaluate potential benefits of procuring hybrid storage resources in 2018 under the 1,325 MW energy storage target case by forcing the model to procure 700 MWs of hybrid storage by 2018. The early procurement case discussed in the report was based on procurement in 2022. Procuring 700 MWs, or 14 EGTs, in 2018 results in net present value cost savings of $226.98 million and an average annual GHG emission savings of 477,161 metric tons relative to the 1,325 MW energy storage target case without hybrids available.

Procuring the EGTs in 2018 rather than 2022 comes with increased costs, as would be expected, but provides for additional reduction of GHG emissions. The costs of procuring hybrid storage resources used in the model decline over time, thus procuring the EGTs in 2018 is more expensive than procuring them at a lower cost in 2022. The net present value of revenue requirement in the 2018 early procurement case is $142 million higher than that of the 2022 early procurement case. However, the higher costs come with the ability for the market to realize additional GHG reduction. The average annual GHG emissions under the 2018 early procurement shows a reduction of 394,686 metric tons relative to the 2022 early procurement case[56].

As noted in the report, there may be some additional cost savings and GHG emission savings not accurately accounted for in the model due to differences between the model and observed CAISO dispatch of resources. Gridwell has highlighted the differences between the resource types providing spinning reserves in the CAISO's market relative to what the model is showing. Thus, additional GHG and cost savings could come from the fact that in reality hybrid storage resources are more likely to displace gas-fired resources from providing spinning reserves.

[56] The average annual GHG emissions reduction was based on years 2018, 2022, 2026, and 2030.

8.2 Resources for Hybridization Summary

The section show the resources Gridwell recommend be at a minimum specifically considered as potential hybrid storage resources in any future production cost or capacity expansion modeling. The resources are LM6000 turbines capable of being hybridized. They are all located in the California ISO and have a commercial operating date (COD) of 2001 or later. and summarized by potential in *Figure 33*. Gridwell is initially qualifying potential based on the location of the resource and the current predicted need for capacity in that local area in 2023.[57] If the resource was located outside a local area (system capacity) or if the California ISO in their latest local area study has found significant amounts of excess capacity in a local area, then Gridwell did not include the resource on the list. This is not to say that the grid could not benefit from hybridizing resources not on this list. Instead it shows an initial list to specifically do further modeling on.[58]

Figure 33: Summary of Top Resources Eligible for Hybridization in the California ISO

Hybrid Potential	Total California ISO MWs	Total Battery MWs
Existing or contracted	241	48
LM6000 Potential in CA	1,195	240

57 http://www.California ISO.com/Documents/Final2023Long-TermLocalCapacityTechnicalReport.pdf
58 The highest potential resources are ones already being considered for hybridizing.

8.3 California ISO Spinning and Non-Spinning Qualifications

Spinning Reserve Certification & Testing Requirements

Dispatchable generating units may be certified for spinning reserve if they can respond to five-minute dispatch instructions and are synchronized to the California ISO grid. Their maximum spinning reserve capacity is limited to their operating range from minimum load to maximum capacity, or their 10-minute ramping capability with their best operational ramp rate, whichever is lower.

Non-Spinning Reserve Certification & Testing Requirements

Generating units may be certified for non-spinning reserve if they can respond to five-minute dispatch Instructions.

- The maximum non-spinning reserve capacity for fast-start units that can start and synchronize with the grid within 10 minutes are limited to the output level they can reach from offline status in 10 minutes, or their 10-minute ramping capability with their best operational ramp rate, whichever is higher, but not greater than their maximum capacity.

- The maximum non-spinning reserve capacity for other resources that cannot start and synchronize with the grid within 10 minutes are limited to their operating range from minimum load to maximum capacity, or their 10-minute ramping capability with their best operational ramp rate, whichever is lower. In the integrated forward market, non-spinning reserve can be procured from all on-line resources (whether self-committed or committed in the market) and from offline fast-start units.

8.4 RESOLVE Inputs

In all modeled scenarios, the RESOLVE model used the input and assumptions for the CPUC's IRP Reference System Plan, including the updated 2017 CEC Integrated Energy Policy Report load assumptions, as shown below. To run all scenarios presented in this report, Gridwell toggled between the energy storage target scenario on the dashboard tab, as well as making modifications to RESOLVE's aero-CT conventional candidate and its related operating characteristics resource tabs and, in some cases, the storage input tab.

8.4.1 Dashboard Tab

The only input provided on the dashboard tab table below that Gridwell modified was the partial fulfillment of the energy storage target with the battery component of hybrid storage resources to generate the different sensitivities in this assessment.

Load Assumptions	
Electric Vehicle Adoption	CEC 2017 IEPR - Mid Demand
Behind-the-meter PV	CEC 2017 IEPR - Mid PV
AAPV	CEC 2017 IEPR - Mid-Mid AAPV
Energy Efficiency	CEC 2017 IEPR - Mid AAEE
Existing Shed DR	Mid
TOU Adjustment	CEC 2017 IEPR
Workplace Charger Availability	Mid
EV Charging Flexibility	Low
EV Charging Shape	2017 IEPR
Renewable Assumptions	
RPS Target	50% by 2030
GHG Target	Large
Energy Storage Target Scenarios	
0 MW by 2024	
1,325 MW by 2024	
1,825 MW by 2024	

8.4.2 Hybrid Storage Availability

As discussed throughout the report, hybrid storage was not a technology already reflected in the RESOLVE model. Therefore, Gridwell had to modify resource characteristics of a pre-defined candidate resource already in the model to reflect the characteristics and costs of a hybrid storage resource, as described below.

The hybrid storage resource was modeled as the California ISO_Aero_CT candidate resource type with the following characteristics as provided for on the CONV_Candidate and CONV_OpChar tabs in the RESOLVE User Interface. The characteristics not shown in the table below were left at their default value. Highlighted values indicate those modified to represent the hybrid storage resource from the default values.

Input	Default Value	Hybrid Value
Dispatchable	1	1
Must Run	0	0
Regulation?	0	1
Spin?	0	1
Load Following Reserves?	1	1
Min Commit	0	0
Freq. Resp. Total?	1	1
Freq. Resp. Partial?	1	1
Freq. Resp. Contrib.	0.08	0.08
Pmax (MW)	100	50
Pmin (MW)	30	0
Pmin (% of Pmax)	30%	0%
Max Ramp Up (%Pmax/Hr)	100%	600%
Hr at Pmax (Btu/MWh)	9.572	10
HR at Pmin (Btu/MWh)	17.63	0
Min. up- and min. down-time		
Startup Cost ($/MWh)	10	0
Slope (MMBtu/MWh)	6.117	10
Intercept (MMBtu/MWh)	345	0

VOM ($/MWh)	5	5

8.4.3 Hybrid-Optional Scenarios

When assessing the impact of allowing the RESOLVE model to optimally select hybrid storage technology, Gridwell manually adjusted the storage target in the storage inputs tab within the RESOLVE model to reflect the portion of the target satisfied by the battery component of the hybrid storage technology.

Specifically, for the 1,325-MW hybrid available scenario, Gridwell adjusted the storage starting in 2024 to 1,185 MWs through the modeled horizon, again to reflect 140 MW of batteries provided by hybrid storage resources. The RESOLVE model then automatically determined the storage capacity, from 2018 through 2023, needed to reach the 1,175-MW level by 2024.

The same was done for the 1,825-MW hybrid available scenario, by adjusting the storage target to 1,685 MWs by 2024 to account for the battery component of hybrid storage.

8.4.4 Saturation Scenario

For the scenario in which 2,500-MW hybrid storage was forced, Gridwell leveraged the model's use-specified build functionality. This enabled Gridwell to tell the model it must select a specified quantity of hybrid storage. Gridwell specified that the model must select 2,500 MWs of CAISO_Aero_CT candidate resource type, which is the candidate resource type modified by Gridwell to reflect the operating characteristics of the hybrid storage technology. Gridwell used the 1,325 MW energy storage mandate case without lowering the 2024 target thus the result being 1,825 MWs of energy storage procured by 2024 since 20% of 2,500 MWs is 500 MWs of additional energy storage provided by the hybrid storage resources

8.4.5 Early Procurement Scenario

Similar to the saturation scenario, tor the scenario in which 700 MWs of hybrid storage was forced to be procured by 2022, Gridwell leveraged the model's user-specified build functionality. This enabled Gridwell to tell the model it must select 700 MWs by 2022 of CAISO_Aero_CT candidate resource type. The 700 MWs were determined based on the 1,325 MW energy storage target case with hybrids available; Gridwell lowered the 1,325 MW energy storage target by 2024 to 1,185 MW energy storage by 2024 again to reflect the fact that 140 MWs of the 700 MWs procured hybrid storage resource is energy storage. Under that scenario, the model optimally selected 700 MWs but waited to procure those resources until later in the planning horizon. Thus, knowing it was the resulting optimal level of procurement, Gridwell forced that level to be reached earlier in the planning horizon.

8.5 FAQ

1. Who is Gridwell Consulting?

Gridwell Consulting is a boutique California consulting firm that provides expert analysis and strategic advice to companies that operate or transact in the wholesale energy market. This includes evaluation and development of high voltage transmission, conventional power plants, and new resource technologies. Gridwell provides top-of-the-line analytics that accurately model how resources, including battery storage, can optimally participate in the California energy and capacity markets. Our consultants additionally represent the Western Power Trading Forum, a non-profit, member-backed company, at the California ISO and FERC, on all policy initiatives. Our comprehensive knowledge of both market rules and policy processes enable us to provide high value-added insights and strategic advice to wholesale energy market participants.

2. What is the difference between a hybrid storage resource and a hybrid solar or co-located solar resource?

A hybrid storage resource is a fully integrated BESS and gas turbine engine. The BESS literally makes the combustion turbine a more flexible plant. A hybrid solar resource or co-located solar resource with storage are non-integrated facilities that either use the same interconnection or potentially operate by the solar powering the storage resource, prior to or instead of, producing output onto the grid.

3. What resources have already been hybridized and are there plans for more?

SCE has hybridized two LM6000 peaking plants—Center Peaker (Norwalk, CA) and Grapeland Peaker (Rancho Cucamonga, CA)—and has made public that they are actively analyzing the customer value of additional Hybrid EGT® upgrades at its three remaining GE LM6000 peakers---Mira Loma Peaker (Ontario, CA), Barre Peaker (Stanton, CA) and McGrath Peaker (Oxnard, CA). In addition, Stanton Energy Reliability Center has commenced construction activities for two LM6000s Hybrid EGTs in Stanton, CA, with an expected COD in 2020.

4. Why not just build more Battery Energy Storage Systems (BESS)?

Gridwell Consulting does not believe that Hybrid EGT®s are a replacement for building additional BESS. Both standalone BESS and Hybrid EGT® are options that will help California meet its GHG and Renewable Energy goals. Hybridizing existing peaking plants is particularly beneficial when the original facility is not only needed for local reliability, but also the local area has been demonstrated to need very long duration capacity.

The California ISO has found that while some areas only need intermittent emergency resources (with a duration of 4 hours or less), some local areas are more prone to disruptions and need capacity that can produce energy for 12 hours during emergency conditions. There is therefore a BESS/Hybrid duration efficiency point where it is vastly less expensive and only creates small amounts of incremental emissions for a peaking plant to be hybridized, compared to sufficient BESS to be installed to meet the local reliability needs.

Additionally, a Hybrid EGT frequently can be implemented at a lower initial cost that standalone BESS for comparable functionality because the site typically already exists and has interconnection capability. It also offers the ability to be added onto and have standalone BESS structure as well as the hybrid system over time.

5. **Does the BESS portion of the Hybrid EGT® count as resource adequacy capacity?**

Yes. For example, consider the SCE Hybrid EGT® resources with a 4.3 MWh BESS provided an incremental resource adequacy value of 1.075 MWs, independent of the 50-MW peakers.[59]

6. **Does the BESS portion of the Hybrid EGT® count toward the storage target?**

Yes. In June 2018 the CPUC granted cost recovery for SCE's two Hybrid EGT® projects and determined that the Hybrid EGT® should count toward the procurement target.[60]

7. **Does it make sense to hybridize LM6000 peaker plants located in disadvantaged communities[61]?**

While Gridwell Consulting believes that hybridizing should be looked at on a case-by-case basis, generally, there could be significant benefits to hybridizing resources in disadvantaged communities. A Hybrid EGT® has the potential to only use its BESS and still provide valuable operating reserves, frequency response, and voltage support to the grid, all at zero emissions. Indeed, SCE has forecast that the retrofit of their peakers at Center and Grapeland as Hybrid EGTs will reduce annual emissions by more than 60%, compared to the peaker emissions prior to hybridizing. Hybridizing, rather than simply retiring the resource, should be a win-win for most disadvantaged communities that are in constrained load pockets, because it maintains local property taxes, jobs and emergency capacity where they are most needed. Total emissions of both criteria pollutants and GHG from a Hybrid EGT compared to a combustion turbine used as a peaker are forecasted to be reduced by as much as 90%.

8. **How does the California ISO model Hybrid EGT® resources?**

The California ISO treats Hybrid EGT® resources like any other thermal resource. The California ISO can fully model all BESS enhancements within the energy market optimization, including the 0-MW Pmin. Any start-up costs can either be included in the energy bid, or as a transition cost under the multistage generating model.

[59] Decision 18-06-009; June 21, 2018: Finding of Fact at 11 and 14.
[60] ibid
[61] http://www.cpuc.ca.gov/discom/

9. What is often over-looked as a benefit of hybrid storage technology?

Increased renewable capacity has both economic and reliability impacts on the grid. Large and often unexpected swings in solar and wind production can negatively affect grid reliability in a variety of ways, including the grid's ability to maintain normal frequency. For example, the immediate effect of over-generation is higher-than-normal system frequency (typically 60 Hz, +/- ~ .02 Hz) and higher-than-normal balancing authority area control error. The more severe effects of over-generation include grid facility overloads, potential generator damage and placing a balancing authority area at risk of non-compliance with NERC's control performance standard 1 (CPS1) and NERC standard BAL-001-1.

The California ISO has had significant issues maintaining compliance with NERC's frequency response standards and this is a known challenge going forward. Hybrid EGT®s are able to provide frequency response and fast frequency response services without having to put additional emissions on the grid.

10. Can the same technology be used for combined-cycle resources?

Yes. But there will be significant differences in how the resource can operate. Further research and subsequent modeling is needed to understand the potential benefits.

11. How can I learn more?

To learn more about RESOLVE, go to: CPUC IRP RESOLVE MODEL with 2017 IEPR.

To learn more about Wellhead, go to: http://wellhead.com/wphome/wps-advantage/.

To learn more about California ISO market enhancements, go to: California ISO Stakeholder Processes.

12. Still have questions?

Contact Carrie Bentley at cbentley@gridwell.com