Application: A.18-02-___

Exhibit SDGE-

Witness: Evan M. Bierman

DIRECT TESTIMONY OF

EVAN M. BIERMAN

ON BEHALF OF SAN DIEGO GAS & ELECTRIC COMPANY

**BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA**

FEBRUARY 28, 2018

Corrected July 27, 2018

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DIRECT TESTIMONY OF
EVAN M. BIERMAN

I. INTRODUCTION

My direct testimony describes the potential wholesale market benefits from the seven utility-owned energy storage resource investments proposed by San Diego Gas & Electric Company ("SDG&E") designed to accelerate the widespread deployment of distributed energy storage systems based on the goals and priorities directed by California Assembly Bill ("AB") 2868. My direct testimony describes illustrative wholesale market benefits, including how a 10 megawatt ("MW") one- or two-hour[1] energy storage system could generate benefits for SDG&E's customers, and describes potential greenhouse gas ("GHG") emissions reductions, which align with the AB 2868 statutory criteria.

While all seven investments will primarily focus on providing backup power to public sector critical customers using microgrid designs as described in Stephen T Johnston's testimony,[2] these energy storage resources will also benefit SDG&E's customers in other ways, such as reducing GHG emissions directly, allowing more renewables to be integrated onto the grid, providing key ramping support to the California Independent System Operator ("CAISO") during periods of steep changes in renewable generation, reducing the amount of procurement necessary to meet SDG&E's Track 4 Local Capacity Requirement ("LCR"), and generating

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[1] Energy storage systems are generally described in terms of their nameplate power rating andtheir energy storage capacity. For example, a 10 MW/10 MWh storage system can deliver 10 awatts of AC power for onehour (*i.e.,* "a one hour energy storage system"), for a total of 10 megawatt-hours of energy delivered to the grid (10 MW x 1 hour = 10 MWh). A 10 MW/20 MWh energy storage system (*i.e.*, "a two hour energy storage system") can deliver 10 megawatts of AC power for two hours, for a total of 20 megawatt-hours of energy delivered to the grid (10MW x 2 hours = 20 MWh).

[2] References to testimony herein are to the prepared direct testimony served in support of this application.

wholesale market revenues[3] to reduce project costs. Similar to the wholesale market revenue sharing mechanism outlined in the testimony of Norma G. Jasso, SDG&E requests that any resource adequacy ("RA") capacity credits would also be shared amongst the other load-serving entities ("LSEs") in SDG&E's service territory. By optimizing these aspects, SDG&E is uniquely situated to provide the best energy storage resources for AB 2868, maximizing customer benefits, and reducing GHG emissions.

II. WHOLESALE MARKET BENEFITS OF PROPOSED PROJECTS

SDG&E's customers are connected to the CAISO grid, which transmits electricity to all customers from an assortment of in-state and out-of-state generating sources determined by an hourly clearing price auction. The clearing price represents the market price of power paid to generators (resources that generate electricity such as solar farms and natural gas plants) by customers (resources that use energy). Currently, natural gas units set the clearing price for the auction, as they are most commonly the marginal units on the cost-based dispatched. As such, the price of natural gas is often used as a proxy for the market price of power. To deliver reliable power to customers, SDG&E must procure enough generation (third-party or utility-owned) to meet customers' needs at all times throughout the year. Generation resources are dispatched on a day-ahead, hourly, 15-minute, and 5-minute interval by the CAISO to balance generation and load. Before the recent advent of substantial renewable generation, there were very few intermittent resources, and the ability to balance generation and load was relatively straightforward. However, with the addition of a significant amount of intermittent renewable resources, the task of balancing generation and load became more complicated and will continue

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3 Wholesale market revenues are those revenues received from the CAISO less charging costs and variable operations and maintenance costs (*i.e.*, net revenues or gross margin).

to get more complicated as the penetration of renewables increases. This will place a premium on resources that can both deliver power when renewables cannot and can quickly change the amount of power they deliver to integrate renewables.[4] The two services - load and generation shifting, and ancillary services such as regulation energy - are the basis for the wholesale market and GHG benefits of these energy storage resources.

A. Wholesale market revenues will benefit customers by reducing investment costs

The seven proposed energy storage systems will be offered into the CAISO[5] to help deliver clean, safe, and reliable electricity to our customers. Successful participation by these energy storage systems in the CAISO market can lead to wholesale market revenues, and the revenues received will go into the Distribution Energy Storage Balancing Account ("DESBA").[6] These revenues will help to reduce the overall costs of the energy storage systems. Costs for the energy storage systems will be included in the distribution rate, and thus any wholesale market revenue offsets will be shared by all benefiting customers. SDG&E requests that the Commission make an upfront determination on reasonableness of the wholesale market revenues, such that actual wholesale market revenues generated through the market participation of these energy storage systems are not subject to retroactive reasonableness review.

B. The proposed projects offer three types of wholesale market benefits

Currently, tthese energy storage resources can provide three main market benefits:

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[4] This benefit is sometimes referred as the "smoothing"of intermittent renewables. *See* Cal. Energy Comm'n, Energy Research and Development Division, *Final Project Report – Microgrid Assessment and Recommendation(s) to Guide Future Investments* (July 2015) at 7. Available at: http://www.energy.ca.gov/2015publications/CEC-500-2015-071/CEC-500-2015-071.pdf

[5] Resources will be offered into the CAISO market most of the time, except when they are needed for other use cases as described in the testimony of Stephen T Johnston.

[6] As described in the testimony of Norma G. Jasso.

1. Energy arbitrage and GHG reduction

Energy storage systems have the ability to store energy from periods of excess renewable generation when market prices are low. Such energy storage systems can then discharge this energy during high-priced market periods where the marginal generating unit is a low-efficiency natural gas unit. The arbitrage during high-priced times - where high demand and a high proportion of fossil generation mean high GHG output - and low-priced lower-demand hours with lower GHG intensity due to a high proportion of renewable generation, can lead to both wholesale market revenues and a net reduction in GHG emissions. This energy arbitrage revenue and GHG savings is affected by the round-trip efficiency of the battery, the Variable Operating Maintenance Cost, and the exact times and market prices when the battery dispatches. In addition, SDG&E will consider the timing of discharge relative to the potential need for resiliency services, *e.g.*, during a Santa Ana weather event, which often coincides with SDG&E's system peak, and high wildfire risk.[7]

2. Ancillary Services

SDG&E supplies clean, safe, and reliable energy to its customers. Ancillary services are those that help provide the "reliable" component of the statement above. The two main categories are:

Regulation: Regulation is defined by the CAISO as a resource that can increase ("Reg Up") or decrease ("Reg Down") its energy production, or decrease (Reg Up) or increase (Reg Down) its energy consumption, in response to a direct electronic signal from the CAISO.[8] The

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[7] Such times usually include high temperatures, and would give priority to supporting public health and safety infrastructure such as fire stations and cool zones.

[8] *See* CAISO, *Fifth Replacement Electronic Tariff* (February 15, 2018) at 151. Available at: http://www.caiso.com/Documents/AppendixA_MasterDefinitionSupplement_asof_Feb15_2018.pdf

CAISO uses these resources to both help maintain the proper grid frequency and to help balance generation and load during periods of fast changing conditions.

Spinning Reserve: The CAISO defines spinning reserve as "the portion of unloaded synchronized resource capacity that is immediately responsive to system frequency and that is capable of being loaded in ten (10) minutes, and that is capable of running for at least thirty (30) minutes from the time it reaches its award capacity."[9] This generation provides for additional generation in case of emergency situations, unplanned generator outages, and unforeseen load swings.

As the amount of renewables on the grid have increased, the demand for, and price of, ancillary services has increased. The CAISO's annual market report[10] on the state of the market reflects these trends:

> Ancillary service costs increased to $119 million, nearly doubling from $62 million in 2015. This represents an increase from 0.7 percent of total wholesale energy costs in 2015 to about 1.6 percent in 2016. This was primarily driven by the increased regulation requirements to manage variability of renewable resources.
>
> However, between February and June 2016 the ISO roughly doubled the regulation requirements to manage increased variability of renewable resources. During these months, regulation costs were about six times higher than the same months in 2015.
>
> Average day-ahead requirements for regulation up and down increased by about 19 and 28 percent from 2015, respectively. The average day-ahead requirements were 412 MW for regulation up and 417 MW for regulation down.[11]

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9 *Id*. at 178.

10 *See* CASIO, *2016 Annual Report on Market Issues & Performance* (May 2017). Available at http://www.caiso.com/Documents/2016AnnualReportonMarketIssuesandPerformance.pdf

11 *Id*. at 141.

The key to having a reliable and resilient grid is to have flexible resources to meet the changing dynamics of a grid that is integrating more and more renewable resources. Energy storage devices, such as those proposed here, are uniquely suited to accomplish this. Renewable energy benefits the environment and our society, but it is inherently difficult to manage from a reliability perspective due to intermittency. The sun rises and sets every day, however clouds (or even the moon) will intermittently and erratically block the sun, and wind will gust strongly and then stop without warning. These intermittencies place a premium on having resources that can deliver flexible ancillary services to help manage the grid during times of highly variable generation and load. With the expectation that the penetration of renewables will only increase, the amount and premium for these services are also expected to increase.

3. Resource adequacy

California's RA program is managed both by the California Public Utilities Commission ("Commission") and the CAISO. This program is designed to ensure that LSEs, such as SDG&E, have procured enough generation ahead of time, so there is no scarcity when that power is needed. It can take many years to build a generating facility, and so it is impractical to procure them the day that they are needed, thus a robust planning process is paramount. SDG&E, in conjunction with the Commission and the CAISO, forecasts load and projects the resources necessary to meet this load, plus a reserve margin. For example, due to the retirement of the San Onofre Nuclear Generating Station ("SONGS"), the Commission via the Track 4 decision in the long-term procurement planning ("LTPP") proceeding authorized SDG&E to procure 500 – 800 MW of new local capacity (*i.e.*, SDG&E's LCR).[12] SDG&E intends to seek

[12] *See* D.14-03-004, ordering paragraph 2 at 143. *See also* testimony of Jennifer W. Summers and Don Balfour.

local RA qualification for these energy storage systems and, to the extent they qualify, their capacity will contribute towards the remaining Track 4 LCR obligation of 56 MW, offsetting the need to purchase additional resources for Track 4 LCR purposes.[13] By doing so, these energy storage systems provide direct savings to customers and fulfill Commission and CAISO RA requirements.

The LCR obligation is for all of SDG&E's local territory, not specifically for SDG&E's bundled customers. Since the AB 2868 mandate applies to all customers and these resources could benefit all customers, SDG&E proposes that any RA capacity credits[14] would also be shared amongst the other LSEs in SDG&E's service territory by share of coincident peak, adjusted monthly. The Commission implemented the cost allocation mechanism methodology pursuant to Cal. Pub. Util. Code § 365.1 and Decision ("D.") 06-07-029, to allocate RA capacity credits to all benefiting customers. SDG&E seeks a similar mechanism to allocate the RA capacity from these energy storage systems.

C. Illustrative wholesale market benefits and GHG impacts from a representative energy storage project

SDG&E commissioned a third-party study[15] by Enovation Partners[16] to illustrate the benefits that SDG&E's proposed energy storage projects may provide to our customers. The

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[13] *See* testimony of Jennifer W. Summers at 8: "To the extent the AB 2868 investments proposed within this application provide LCR, SDG&E requests that the Commission authorize SDG&E to count up to 27.5 MW of LCR resources toward SDG&E's 56 MW of LCR resource authorization needed online by the end of 2021."

[14] SDG&E expects this to be ~27.5 MW under the current RA rules, all counted toward the remaining 56 MW obligation.

[15] *See* Enovation Partners, *SDG&E IFM Storage Revenue Assessment* (February 13, 2018), attached hereto as Appendix A.

[16] Enovation Partners is a strategy and analytics consultancy focused entirely on the energy transition, with offices in Chicago, London, San Francisco, and Washington. It is particularly active in energy

study shows that the energy storage projects are likely to result in wholesale market revenues, GHG emissions reductions, and displace the need to purchase RA from alternate resources. However, given that the market is volatile and the ability of the proposed projects to participate in the market will vary with the demands of the projects' primary purpose of providing distribution resiliency, it is not possible to reliably estimate precise future benefits. This illustrative study describes what potential future market dynamics may look like, how these energy storage resources will operate, and how they will benefit our customers from each market product. I believe this study provides a reasonable outlook for the performance of SDG&E's proposed energy storage projects, and is useful for understanding the scope of the market opportunity for the proposed energy storage projects.

Enovation Partners' forecasted amount of revenues and GHG reductions were modeled using a representative in-front of the meter, 10 MW/10 MWh Lithium-Ion battery energy storage system[17] (*i.e.*, a one-hour system), with an in-service duration of 20 total years (with the energy storage system being under a long-term service agreement ("LTSA") for the first 10 years, and the remaining 10 years with no LTSA and a storage module degradation of 2.67%/year).[18] Only operational and commercially feasible combinations of revenue streams were simulated, the energy storage resource could only participate in one revenue stream at a time during each 15-minute interval, and some level of forecasting error was assumed when bidding into the CAISO market.

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storage, including supporting Lazard in its annual "Levelized Cost of Storage" survey. *See* Appendix A at 29-30.

[17] A 10 MW/20 MWh (*i.e.,* two-hour system) was also modeled.

[18] *See* Appendix A.

Enovation Partners used the Itron method[19] to calculate the GHG emissions or reductions from the representative energy storage system. The Itron Method was used because it is the Commission-approved method for measuring GHG in the Self-Generation Incentive Program ("SGIP"), which subsidizes new energy storage resources that are installed at customer locations.

1. GHG benefits

SDG&E's proposed energy storage projects will help reduce GHG emissions in the state both directly and indirectly. For the representative in-front of the meter, 10 MW/10 MWh energy storage system, the total direct GHG emissions reduction over the 20-year period is forecasted to be 4,843 metric tons.[20] For the representative in-front of the meter, 10 MW/20 MWh energy storage system, the total GHG emissions reduction over the 20-year period is forecasted to be 13,786 metric tons.[21]

These amounts of GHG reductions may be conservative and reflect the conservative energy price forecasting approach adopted by Enovation Partners. I would expect that with increased renewable penetration and fossil generation retirements, the share of hours where gas sets the marginal price will fall. In those hours, the price could be significantly lower than projected, or even negative, while peak times would still be set by a marginal gas unit as projected. This is not something captured in the Itron model currently. If so, the potential value of storage from energy arbitrage and total GHG reduction provided by energy storage systems could increase significantly. It is important to note that the GHG benefits increase when going from a one hour duration (4,843 metric tons) to a two hour duration (13,786 metric tons) due to

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[19] Itron, *2016 SGIP Advanced Energy Storage Impact Evaluation* (August 31, 2017). Availabe at http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442454964

[20] *See* Appendix A at 2.

[21] *Id*. at 16.

increased participation in the energy market versus reserve markets.[22] While each energy storage system will not operate in the exact same manner across the seven proposed energy storage project locations, when using the modeled representative energy storage projects as a proxy, total GHG emissions reductions over the 20 year period are 57,376 metric tons of GHG.[23]

Therefore, based upon the modeling, in terms of direct GHG emissions reductions, the energy storage devices can charge at periods of relatively low GHG intensity and discharge that energy at relatively high times of GHG intensity. This can reduce GHG emissions and save our customers money. For example, by discharging at peak times, this may allow some of SDG&E's conventional generation to back down or not turn on at all. If these resources do not turn on, or reduce their running, SDG&E will not have to pay carbon compliance obligations for running these resources under the California Air Resources Board ("CARB") cap and trade program.[24]

Indirectly, the energy storage devices will provide the necessary support to add further renewables to the grid. For example, one of the large areas of renewable growth in San Diego is rooftop solar. While these resources produce GHG free energy, they do not necessarily produce that energy when the customer needs it. Further, this type of resource cannot be curtailed during periods of excess renewable generation on the grid. Therefore, by adding these energy storage

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[22] Reserve revenues are limited by the power rating of the unit(MW), while the energy arbitrage revenues are mainly limited by the energy rating(MWh).

[23] SDG&E is proposing seven substation locations for the proposed energy storage projects, with energy storage systems on ten circuits. Nine of the circuits will have energy storage systems of 10 MW/10 MWh, and one circuit will be a 10 MW/20 MWh energy storage system. When calculated: (9 10 MW/10 MWh systems x 4,843 MT of GHG emission reductions/system) + (1 10 MW/20 MWh system x 13,786 MT of GHG emission reductions/system) = 57,376 metric tons of GHG emissions reductions.

[24] *See* https://www.arb.ca.gov/cc/capandtrade/capandtrade.htm

systems to SDG&E's distribution circuits, these circuits will be more resilient and able to absorb higher levels of rooftop solar generation.

The Itron method in the SGIP program showed energy storage resources increasing GHG emissions rather than decreasing them.[25] This is likely because SGIP energy storage resources are deployed for the benefit of an individual customer alone and will be optimized for an individual customer's financial gain, not necessarily the system as a whole or for GHG reduction purposes. A customer's financial gain is set by rates, which are not granular enough and not flexible enough to capture the full nature of the market. This means those energy storage units will inherently act differently than market resources. In contrast, when bid into the market, SDG&E's proposed energy storage projects will respond directly to market signals and conditions, thereby being better situated to respond to periods of excess renewable generation and high GHG intensities. This means that they provide a more efficient way to deploy energy storage to reduce GHG emissions.

2. Wholesale market revenues

a. 10 MW/10 MWh energy storage system

Based on the simulation for the representative in-front of the meter, 10 MW/10 MWh energy storage system, Enovation Partners estimated the combined value streams (*e.g.*, energy arbitrage, ancillary services, and local RA) from the CAISO market for 2018 to 2038 average ~ $112/kW-year[26] in gross margin, or an average gross margin of $1.12 million per year for a 10 MW system. Over the 20 year life of the 10 MW/10 MWh energy storage system, the net

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25 *See*, Itron, *2016 SGIP Advanced Energy Storage Impact Evaluation* (August 31, 2017), Executive Summary at 1-24, Figure 1-22. Available at: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442454964

26 *See* Appendix A at 2.

present value of the gross margin of the CAISO market revenues would be ~$11 million.[27] Table 1 below summarizes the average gross margin generated by each of the value streams for an average year in nominal dollars:

Table 1: 10 MW/10 MWh Market Revenue Summary

Wholesale Market Value Streams	Percent of Total Value Streams	Average Gross Margin per Year
Energy Arbitrage	17%	$190,000
Ancillary Services	60%	$670,000
Resource Adequacy	23%	$260,000
Total	100%	$1,120,000

b. 10 MW/20 MWh energy storage system

For the representative in-front of the meter, 10 MW/20 MWh energy storage system, the estimated combined value streams from the CAISO market for 2018 to 2038 average ~$170/kW-year in gross margin, or an average gross margin of $1,660,000 million per year.[28] Over the 20 year life of the 10 MW/20 MWh energy storage system, the net present value of the gross margin of the CAISO market revenues would be ~$16 million.[29] Table 2 below summarizes the average gross margin generated by each of the value streams for an average year in nominal dollars:

27 *Id*. at 4. Net present value based on a 7.5% discount rate.

28 *Id*. at 2.

29 *Id*. at 4. Net present value based on a 7.5% discount rate.

Table 2: 10 MW/20 MWh Market Revenue Summary

Wholesale Market Value Streams	Percent of Total Value Streams	Average Gross Margin per Year
Energy Arbitrage	17%	$280,000
Ancillary Services	53%	$880,000
Resource Adequacy	30%	$500,000
Total	100%	$1,660,000

c. Total benefits of all systems

While it is unlikely these resources will operate exactly as modeled because there are so many assumptions using in forecasting and modeling, using the modeled representative energy storage projects as a proxy, the total discounted gross margin for the entire set of 100 MW of energy storage systems over the 20 year period based on the Enovation Partners study is ~$115 million.[30]

Due to the inherently uncertain nature of the proposed projects' future market participation, however, SDG&E does not intend to identify a specific forecasted amount of market revenues to offset the revenue requirement described in other testimony. Most importantly, given that the primary purpose of these assets is distribution resiliency, SDG&E must have the operational flexibility to give priority to distribution resiliency service, so committing to a specific market revenue forecast would create perverse incentives. Accordingly,

[30] SDG&E is proposing seven substation locations for the proposed energy storage projects, with energy storage systems on ten circuits. Nine of the circuits will have energy storage systems of 10 MW/10 MWh, and one circuit will be a 10 MW/20 MWh energy storage system. When calculated: (nine 10 MW/10 MWh systems x $11 M/system) + (one 10 MW/20 MWh system x $16 M/system) = $115 M.

SDG&E proposes a mechanism to give effect to a dollar-for-dollar offset of the program costs for market revenues earned.[31]

III. CONCLUSION

SDG&E's AB 2868 application focuses on multiple benefits and uses for customers. This testimony has outlined how the resources can potentially benefit customers by bringing in market revenues to offset the costs of the energy storage resources themselves, offset resource adequacy requirements, and reduce GHG emissions. As the third-party report from Enovation Partners shows, there is a significant amount of market revenues available from different revenue streams offering a chance to offset a significant portion of the costs. While this is not the primary purpose of AB 2868, these benefits should not be ignored. Indeed, the energy storage resources can generate revenue while helping integrate renewables during critical times when renewable resources are intermittently coming on or turning off. SDG&E is committed to clean, safe, and reliable energy and has proposed these energy storage resources to meet both our goals, and the goals of the state.

This concludes my direct testimony.

[31] *See* testimony of Norma G. Jasso.

IV. STATEMENT OF QUALIFICATIONS

My name is Evan M. Bierman, Ph.D. and I have been a Principal Analyst in the Energy Procurement department at San Diego Gas & Electric Company since June 2017. My business address is 8315 Century Park Court, San Diego, California 92123.

In my current job, I analyze and procure long-term and short-term energy resources. My responsibilities include running the procurement process and analyzing the bids received within solicitations, including the 2016 Preferred Resources LCR RFO, Distributed Energy Resources, Demand Response Auction Mechanism, Resource Adequacy, Renewable Auction Mechanism and Green Tariff Shared Renewables.

I have been with the Sempra Energy family of companies since 2011. Prior to taking my current position, I was a Senior Analysist in the group for two years. Before that I was a Senior Financial Analyst Sempra US Gas & Power, analyzing renewable and conventional energy projects. Before that I was a renewable energy performance engineer for Sempra US Gas & Power, building and analyzing renewable energy facilities.

I received a Ph.D. in Physics and Astronomy from the University of California at San Diego and a bachelor's degree in Physics and Astronomy from the University of California at Berkeley.

I have previously sponsored prepared testimony submitted to the California Public Utilities Commission.

APPENDIX A

SDG&E IFM Storage Revenue Assessment

February 13, 2018

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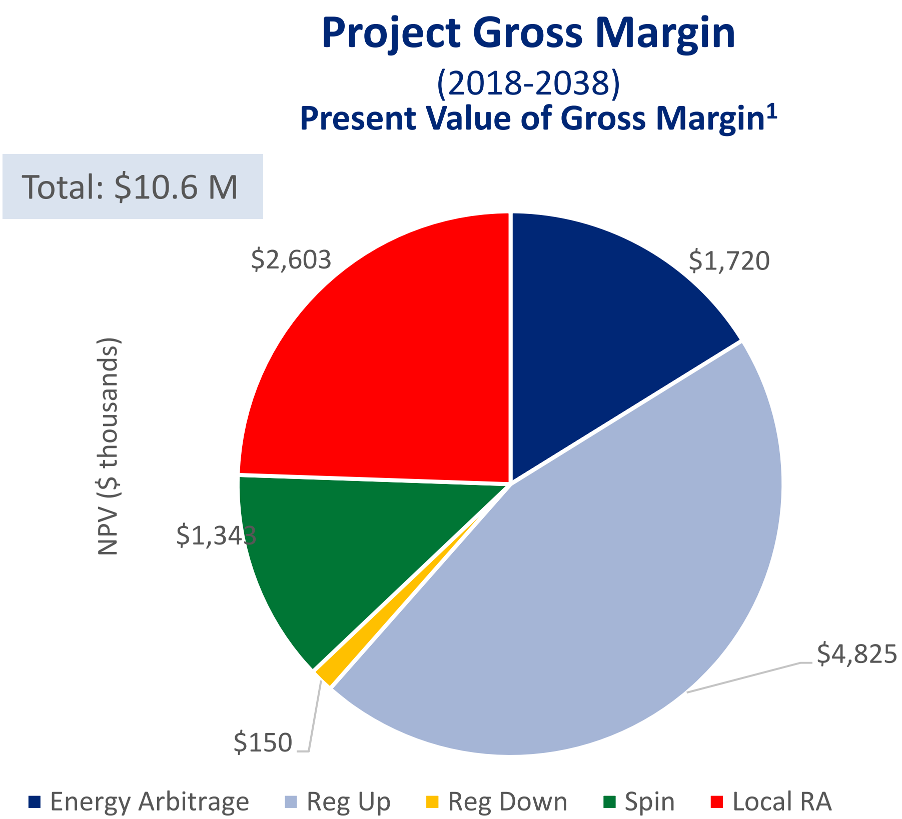
Summary of findings

- SDG&E is assessing the potential value of revenue sources available to a number of potential energy storage projects to be sited in its service territory
- Potential revenue sources are available for SDG&E's proposed energy storage projects assessed include: Energy arbitrage, Regulation (Reg Up and Reg Down), Spinning reserve and Local Resource Adequacy
- Based on simulation of a representative project (a 10 MW, 10 MWh Li-ion energy storage system), we estimate the combined value streams from 2018 to 2038 to average ~ $112/kW-year in revenue less charging less variable O&M (gross margin)
  - Regulation up and spin represent ~ 59% of the gross margin, with spin contributing an increasing share (from 7% to 17%)
  - Energy arbitrage represents a relatively constant portion of the gross margin, around 16%
  - Local RA represents 23% of gross margin, but with a decreasing share over time (from 33% to 19%)
  - Reg down revenues make up the balance, ~ 1%
- Total GHG reduction over the 20 year period was 4,843 Metric tons, for an average value of $8,486 ($0.85/ kw-yr)
  - Relatively modest impact reflects the conservative energy price forecasting approach adopted
- The revenue and GHG reduction impacts of the project simulated are conservative
  - Forecasted energy price assumes natural gas continues to set peak power prices
  - It is possible that with increased renewable penetration and fossil generation retirements, share of hours where gas sets marginal price will fall
  - If so, potential value of storage from energy arbitrage and total GHG reduction provided by units could increase significantly
- Based on simulation of a representative project (a 10 MW, 20 MWh Li-ion energy storage system), we estimate the combined value streams from 2018 to 2038 to average ~ $166/kW-year in revenue less charging less variable O&M (gross margin)
  - Regulation up and spin represent ~ 52% of the gross margin
  - Energy arbitrage represents a relatively constant portion of the gross margin, around 17%
  - Local RA represents ~ 30% of gross margin
  - Reg down revenues make up the balance, ~ 1%

Overview of methodology applied to revenue assessment

- Scope of revenue assessment
  - Limited to direct, pecuniary revenue streams produced by project
  - Included: Energy arbitrage, regulation (up and down), spinning reserve, local capacity revenue
  - Only operational and commercially feasible combination of revenue streams were simulated
  - Economic cost of GHG reflected in energy prices applied to simulation, and total GHG impact (volumetric and economic) estimated but not included in revenue estimate
  - Potential value of resiliency for local ratepayers not assessed
- Overall approach emphasized simplicity, transparency, conservatism
  - Simulated revenue streams based on a single, representative project site
  - Given the very high level of uncertainty associated with future evolution of regional electricity market, applied simple regressions – based on well understood underlying drivers of electricity prices – to forecast future ancillary service and energy arbitrage values
  - Local capacity revenues based on sample of recent values realized at actual regional projects
  - Future level and mix of revenues available to same storage project based on relatively simple optimization algorithm to ensure underlying dispatch logic is transparent and logical…
  - …. While fully reflecting practical operating constraints of storage system and of electricity products
- Implications of altering some of the key assumptions applied in the assessment are discussed below

Overview of illustrative 10MW/10MWh SDG&E energy storage simulation



Additional Performance Data

- Total Charge (MWh) – 191,286
- Total Discharge (MWh) – 170,436
- Full Depth of Discharge (DOD) Cycles[2] – 17,528
- Total GHG Reduction (metric tons) – 4,843

SDG&E Representative Project Inputs

- Size: 10 MW / 10 MWh
- AS Zone: SP-15
- Project Life: 10y with warranty + 10y post-warranty
- Storage Module Degradation Post-Warranty: 2.67%/year
- Power Conversion System (PCS) Degradation Post-Warranty: 2.00%/year
- VOM Escalation Post-Warranty: 1.79%/year

1. NPV based on 7.5% discount rate. The illustrative 10 MW/20 MWh energy storage system had a gross margin NPV for 2018-2038 of $15.95 M.
2. Full DOD Cycles equivalent is total discharge divided by battery MWh rating

Source: Enovation Partners analysis

Enovation Partners

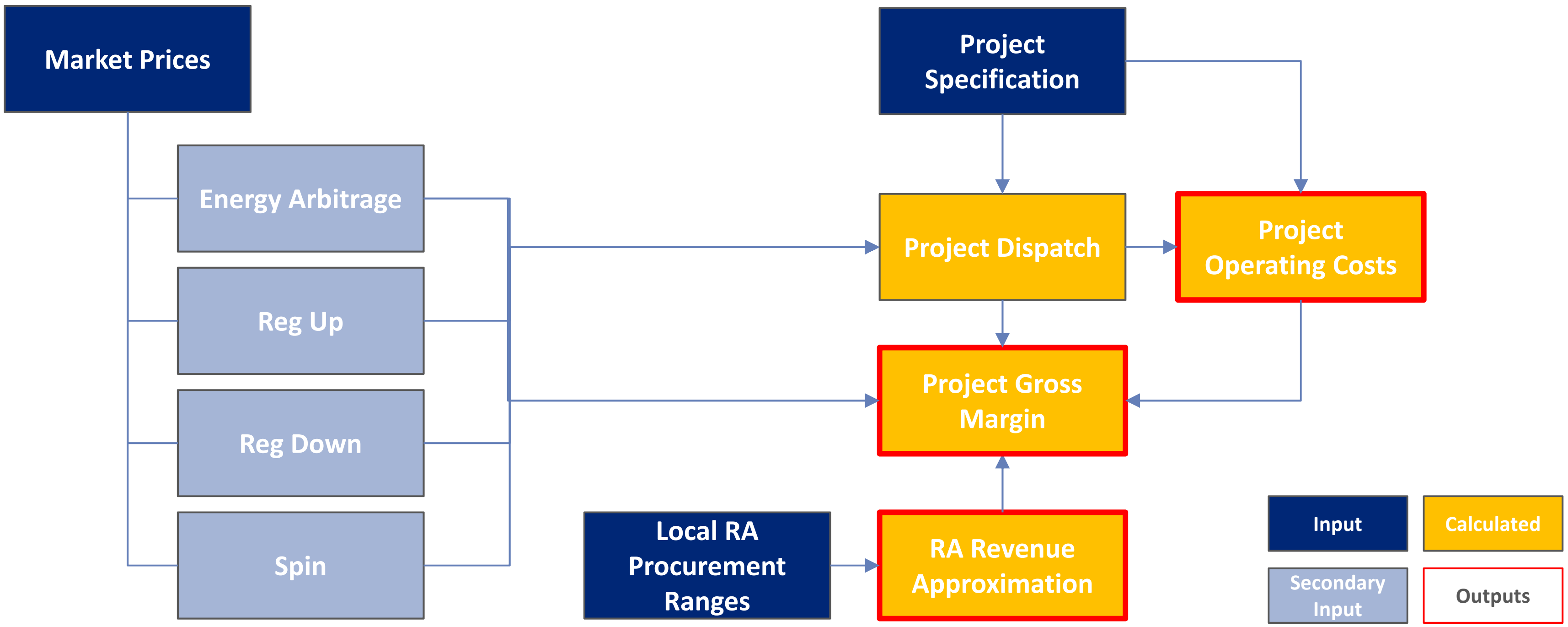
SDG&E intends to offset project costs with revenues received

Revenue Sources Included in Assessment

Source	Market Size (2017)	Gross Margin 2011- 2017 ($/kW-yr)[1]	Participation Mode	Rules	Penalties
Energy Arbitrage	N/A	12-62	Purchasing and selling energy into the RT and DA market	None	None
Regulation Up	Hundreds of MW	0-55[2]	• Bid into the DA market mainly to obtain capacity payment to be ready for quick discharge of energy in 4 second increments (compensated for energy also). • No simultaneous bidding into other markets	Must be synchronized and able to receive AGC signals, minimum 25% accuracy required for reg up measured over a calendar month	Reg up capacity payments rescinded if resource awarded it does not fulfill the requirements associated with that payment
Regulation Down	Hundreds of MW	0-55[2]	• Bid into the DA market mainly to obtain capacity payment to be ready for quick charge of energy in 4 second increments (compensated for energy also). • No simultaneous bidding into other markets	Must be synchronized and able to receive AGC signals, minimum 25% accuracy required for reg down measured over a calendar month	Reg down capacity payments rescinded if resource awarded it does not fulfill the requirements associated with that payment
Spinning Reserve	Hundreds of MW	12-32	• Bid into the DA market mainly to obtain capacity payment to be ready after regulation resources are exhausted (compensated for energy also). No simultaneous bidding into other markets	Must be synchronized, be available in 10 minutes, and be maintainable for two hours	Spinning reserve capacity payments rescinded if resource awarded it does not fulfill the requirements associated with that payment
Local Resource Adequacy	386 MW[2]	50-350	Offsets SDG&E Track 4 requirement for procurement of local RA	Must perform as specified by participation type; local peak reduction through dispatch	The Scheduling Coordinator of a resource who fails a performance audit is subject to the financial penalties provided for in the CAISO Tariff

Note: 1) Data source from analysis in subsequent pages 2) Coupled reg up and reg down
Source: CAISO

Revenues were estimated by simulating the dispatch of the battery to maximize revenue sources, subject to operating constraints

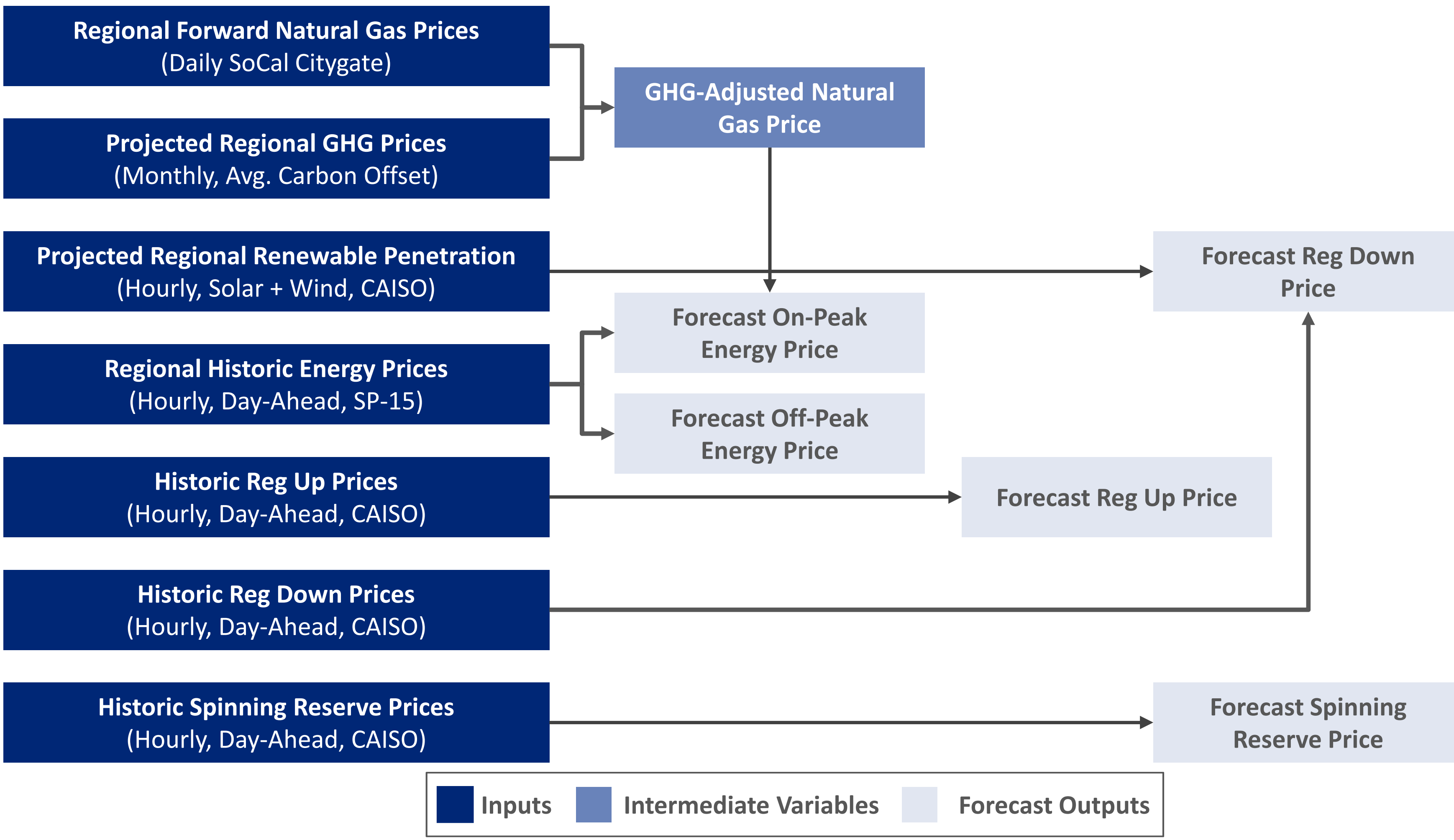


Selected Critical Assumptions

- Simulation assumes perfect foresight of future prices and when called to dispatch into AS markets
- Impacts on revenue estimates due to uncertainty of future prices and AS events not modeled, but expected to be moderate and to decrease through ongoing improvements in forecasting methods applied to energy storage
- Simulation of charging and discharging at "strike prices" is used to obtain realistic depiction of operation. Substantial increase to actual project revenue may be possible by applying more rigorous optimization techniques
- Frequency and duration of dispatch into spinning reserve and regulation markets are based on recent history
- Results depend on the forecast value of energy and ancillary prices, based on historic relationships. Changes in market design (i.e., how ancillary services must be offered by market participants), shifts in gas pricing fundamentals, and evolving patterns of regional electricity demand and generation supply could alter results

Forecast of the prices of ancillary services and energy arbitrage were based on regression analysis of historic prices

High-level Forecasting Process Flow



Summary of forecasting approach

<table>
<tr><th>Forecast Method</th><th>Energy</th><th>Reg Up</th><th>Reg Down</th><th>Spinning Reserve</th></tr>
<tr><td>Regression Dependent Variables</td><td>SP-15 DA Daily Average Peak</td><td>CAISO DA Hourly</td><td>CAISO DA Hourly</td><td>CAISO DA Hourly</td></tr>
<tr><td>Regression Independent Variables</td><td>SoCal Citygate DA Daily</td><td>SP-15 DA Energy Hourly</td><td>SP-15 DA Energy Hourly, CAISO Renewable Generation MW (Hourly)</td><td>SP-15 DA Energy Hourly</td></tr>
<tr><td>Regression for On and Off Peak?</td><td>Separate Regressions for On and Off Peak</td><td>On Peak Only</td><td>Off Peak Only</td><td>On Peak Only</td></tr>
<tr><td>Forecast Independent Variables</td><td>SoCal Citygate Monthly Futures</td><td>Energy Forecast Hourly</td><td>Energy Forecast Hourly, CAISO Renewable Generation MW Forecast</td><td>Energy Forecast Hourly</td></tr>
<tr><td>Future Hourly Price Forecast</td><td>On Peak:
$E_f = E_h + r_{e_p}(NG_f - NG_h)$

Off Peak:
$E_f = E_h + r_{e_{op}}(NG_f - NG_h)$</td><td>On Peak:
$RU_f = RU_h + r_{ru}(E_f - E_h)$

Off Peak:
$RU_f = RU_h * inflation$</td><td>On Peak:
$RD_f = RD_h * inflation$

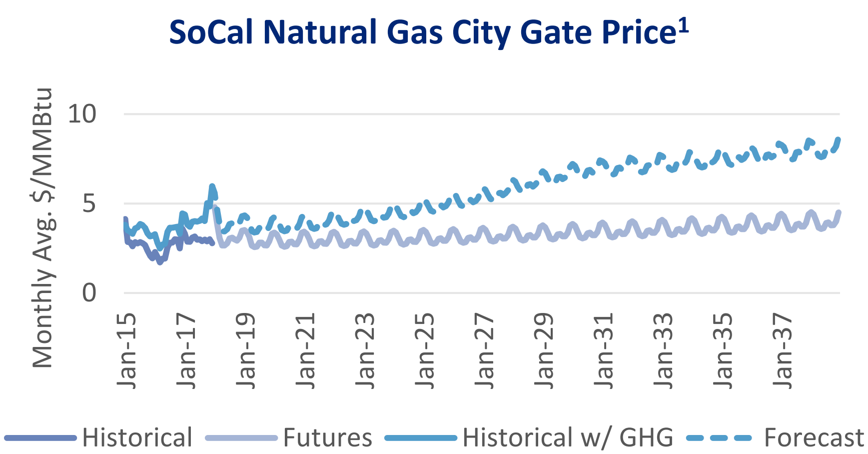
Off Peak:
$RD_f = RD_h + r_{rd}(E_f - E_h)$
$+s_{rd}(G_f - G_h)$</td><td>On Peak:
$S_f = S_h + r_s(E_f - E_h)$

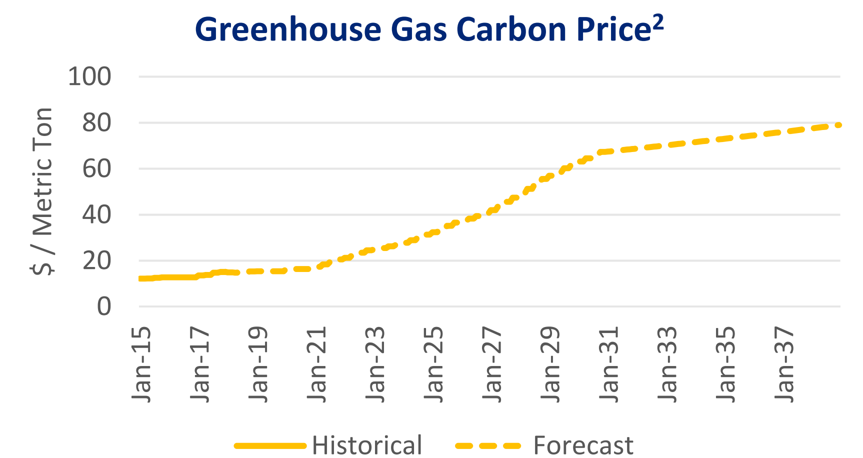
Off Peak:
$S_f = S_h * inflation$</td></tr>
<tr><td>Notes</td><td>• Random selection of historic months to scale, past 3 years</td><td>• Random selection of historic months to scale, past 3 years
• On peak energy prices applied to estimate on-peak reg up</td><td>• Random selection of historic months to scale, past 3 year
• Off peak energy prices applied to estimate off-peak reg down</td><td>• Random selection of historic months to scale, past 3 years
• On peak energy prices applied to estimate on-peak reg up</td></tr>
</table>

Note: Both historical and future natural gas prices are adjusted for GHG. Natural gas and GHG prices are increased by rate of inflation after 2028 and 2030 respectively.
See appendix for all assumptions E=energy, NG=natural gas, RU=reg up, RD=reg down, G=renewable gen., S=spin-res.
Subscript legend: *f* – future, *h* – historical, *p* – peak, *op* – off peak. Other notation: *r* and *s* represent different regression coefficients for the various regressions.

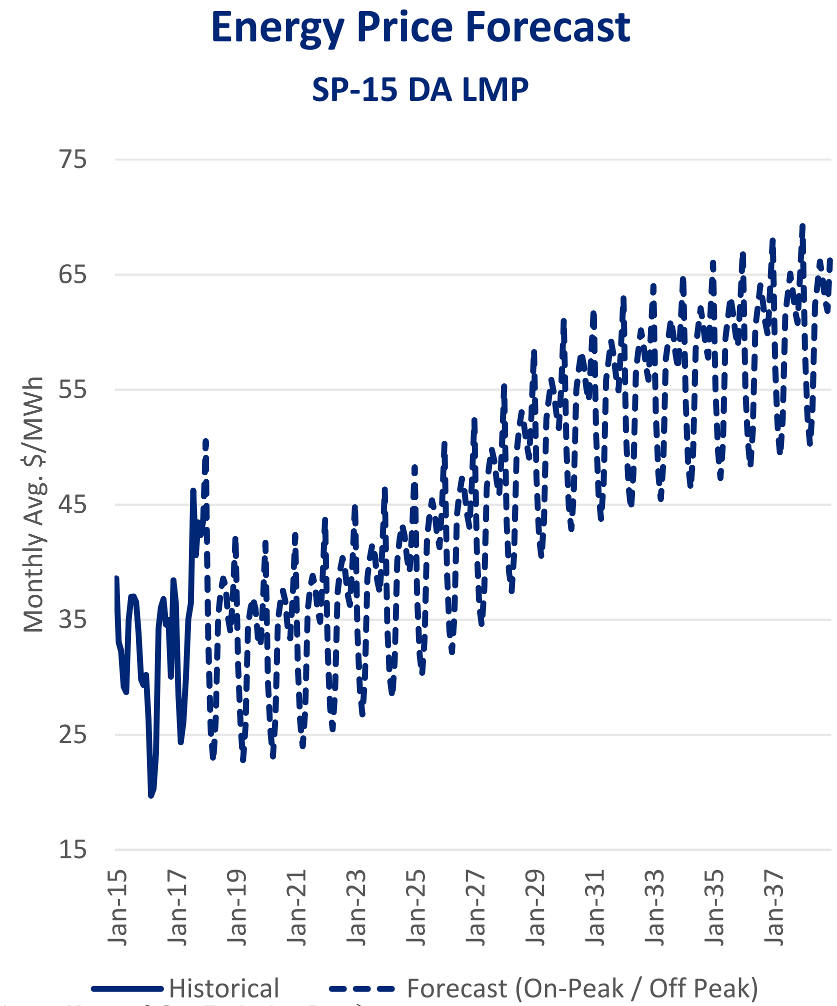
Future hourly (day ahead) energy prices were estimated using forward natural gas contract prices and GHG price forecasts

Intermediate Variable Projections





Energy Price Forecast

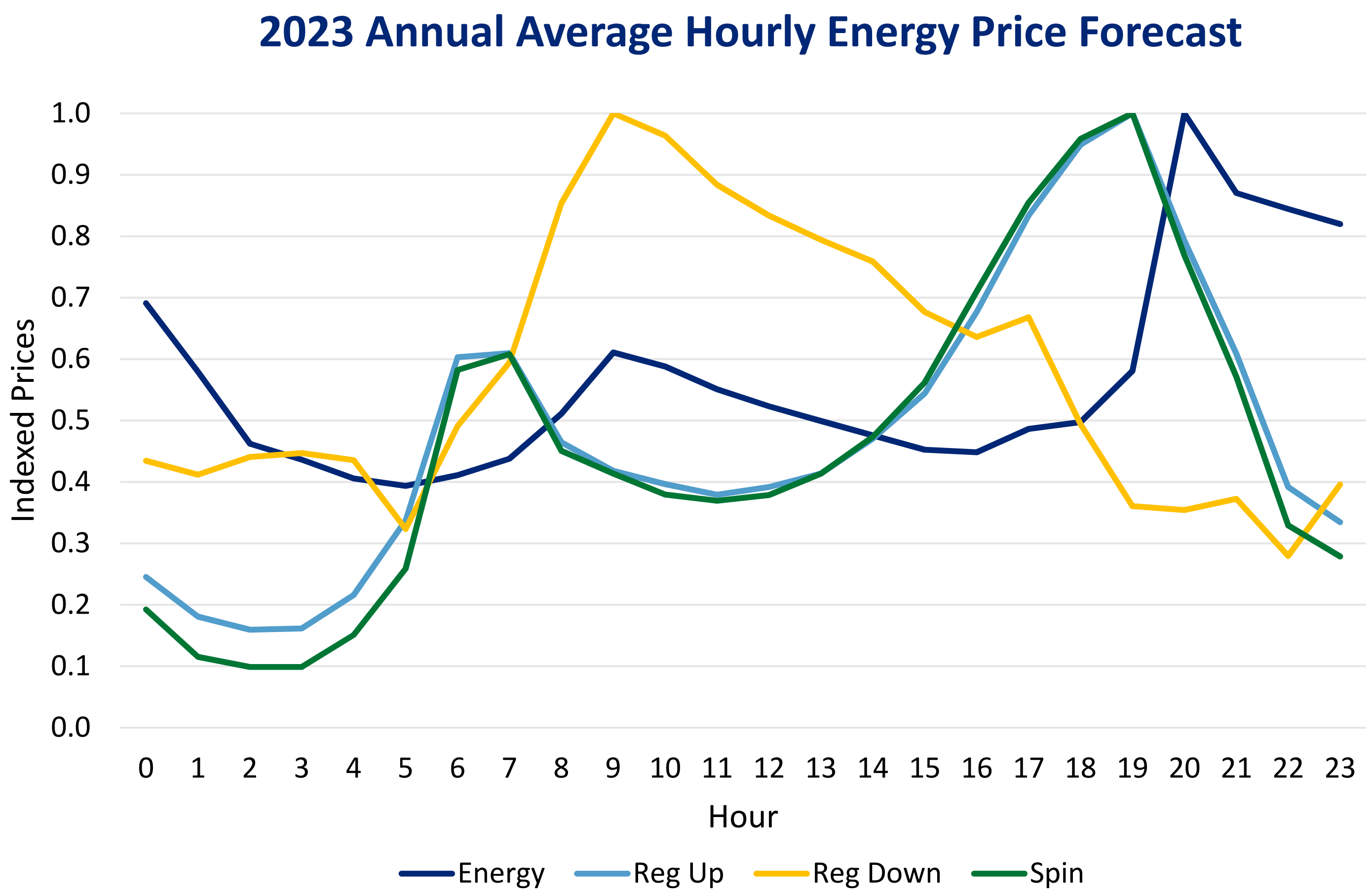


1. Natural gas price adjustment for GHG: $Natural\ Gas_{adj} = Natural\ Gas_{orig} + (Carbon\ Price \times Natural\ Gas\ Emission\ Rate)$
2. Courtesy of ISIC

Natural gas and GHG prices are increased by rate of inflation after 2028 and 2030 respectively. See appendix for all assumptions

Sources: SNL, CAISO, ISIC base GHG forecast, Enovation Partners analysis

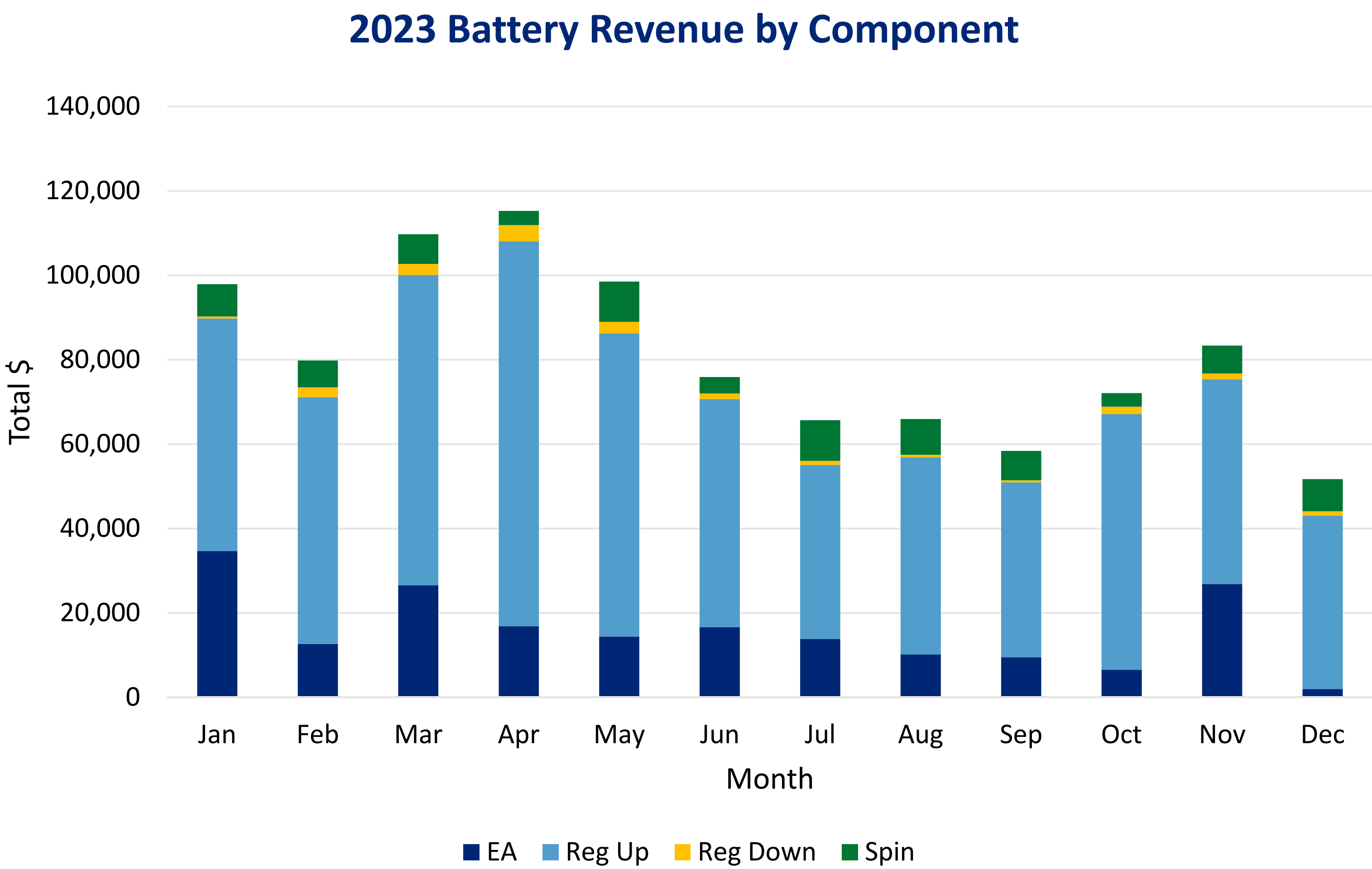
Resulting market prices play an important role in determining charging and discharging decisions



Note: Maximum average hourly price for each stream was set to 1. Average prices in other hours were then indexed off of the price in the max hour. See appendix for actual average hourly prices

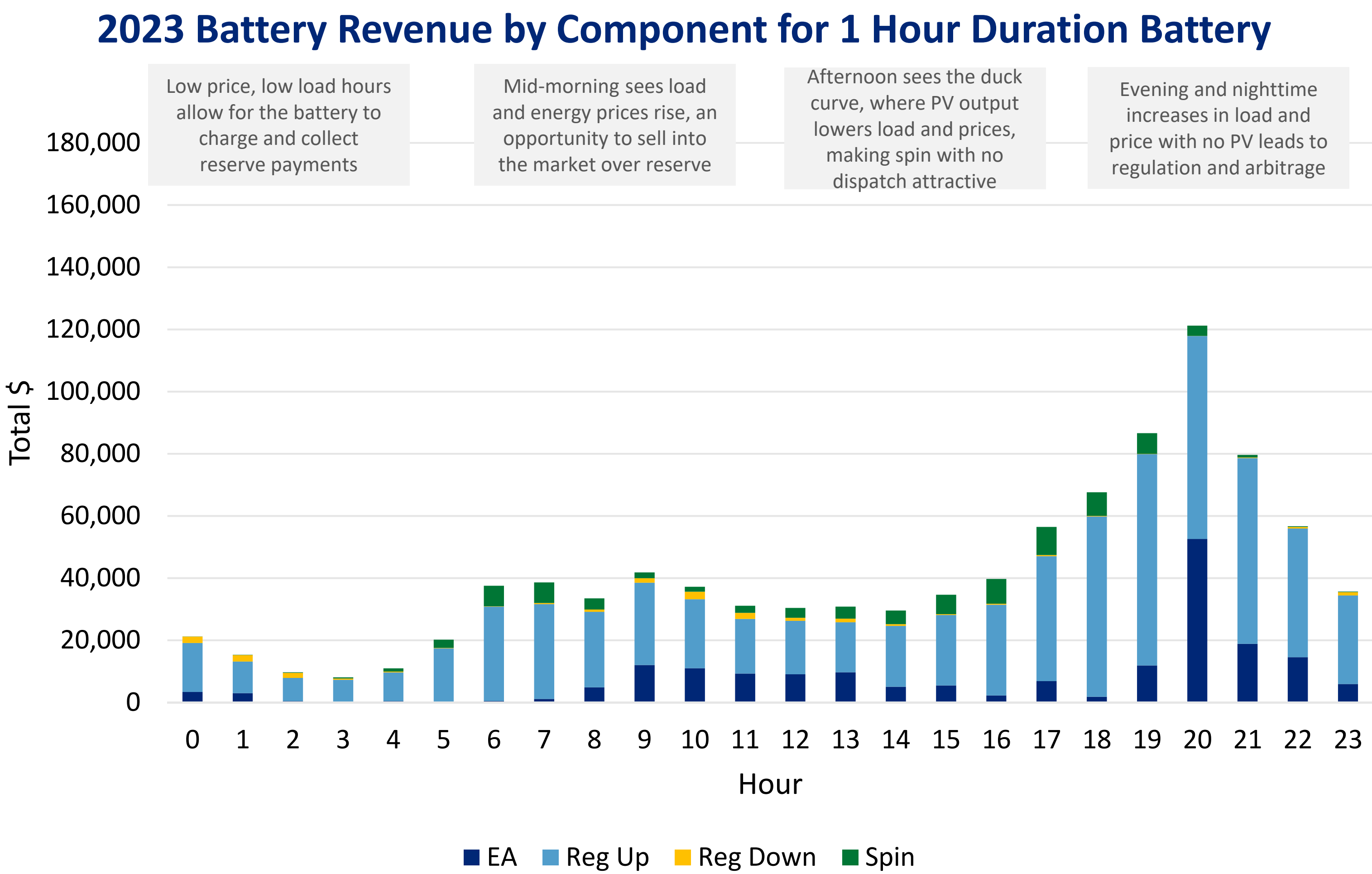
Energy – Real-Time LMP forecast; Reg Up, Reg Down, Spin – Day Ahead CAISO forecast. Reg Up, Reg Down, and Spin only represent the capacity price Additional payments/charges are made for the energy dispatched/received. Other factors, such as battery state of charge and charging cost also play a role in determining charging and discharging decisions.

Almost 90% of revenue comes from participation in energy arbitrage and regulation up



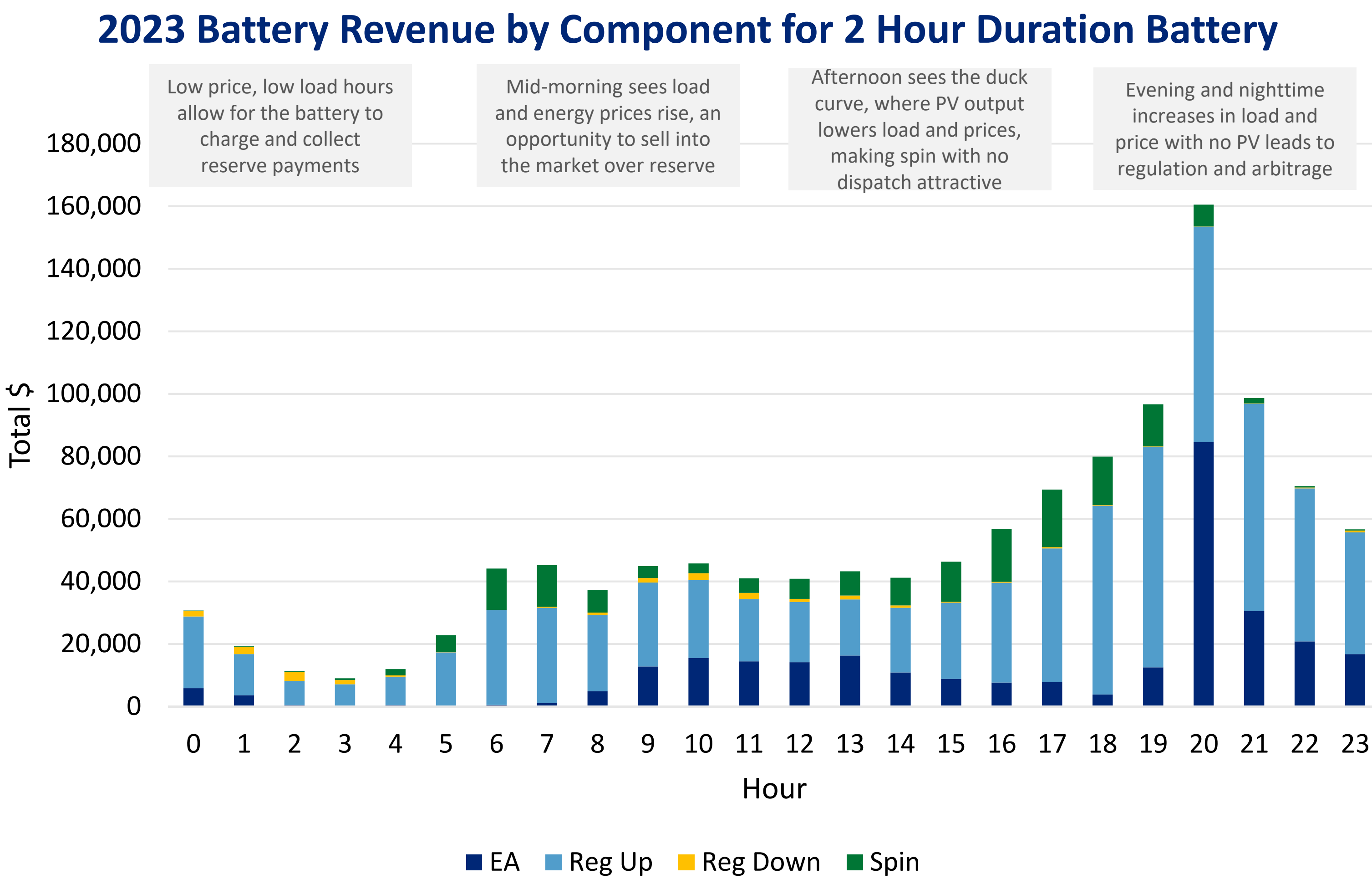
Note: Energy – Real-Time LMP forecast; Reg Up, Reg Down, Spin – Day Ahead CAISO forecast
A reservation in an interval means that the battery was designated by the optimization model to provide that service during that 15-min interval, regardless of whether or not it was called to deliver/take energy

Majority of the revenues earned late afternoon and evening, reflecting "duck curve"



Note: Energy – Real-Time LMP forecast; Reg Up, Reg Down, Spin – Day Ahead CAISO forecast

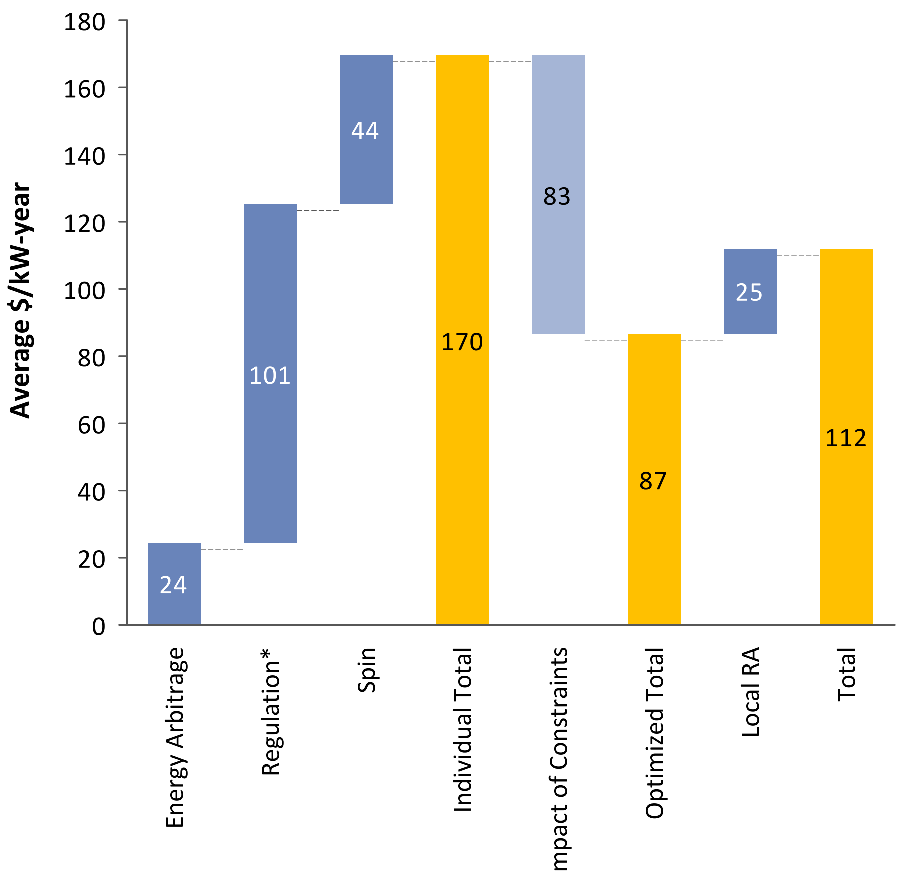
Majority of the revenues earned late afternoon and evening, reflecting "duck curve"



Note: Energy – Real-Time LMP forecast; Reg Up, Reg Down, Spin – Day Ahead CAISO forecast.

Overall, combined revenue is less than the sum of the parts due to coincidence of value between the streams

Average Gross Margin for 10MWh/10MW Project (2018-2038)



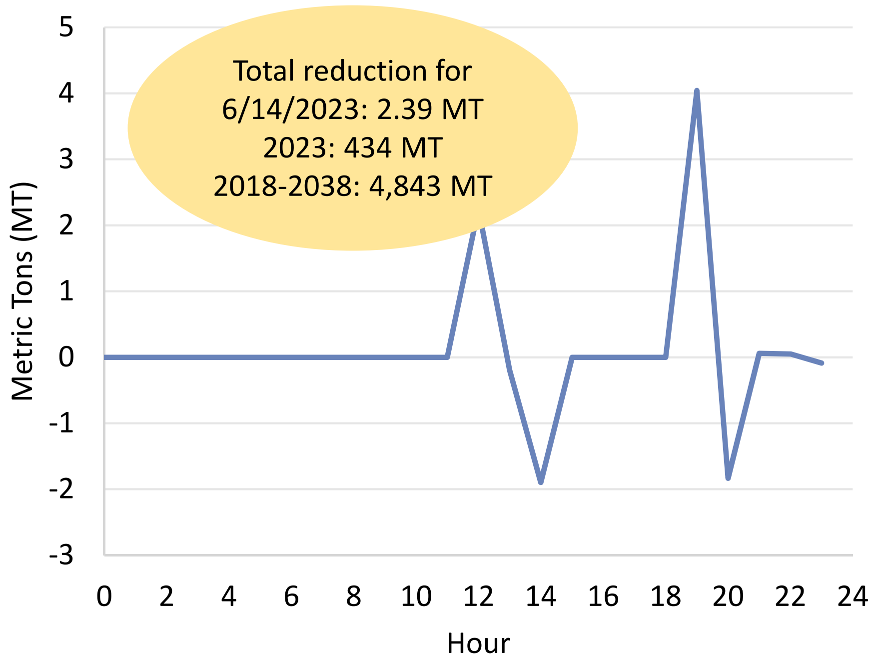
Discussion

- Estimate illustrated here based exclusively on value of wholesale market revenue sources
  - Simulated total assume no simultaneous participation in wholesale revenue streams
- Estimate reflects impact of operational and carbon constraints, relative prices (including GHG) and coincidence between potentially available revenue streams…
- … as well as charging costs, variable O&M, and impact of cycling on system operation and configuration
- As a result of these constraints, practically available revenues are ~50% lower than theoretically available total
- Simulation applies heuristic approach to estimating best available revenue to conservatively reflect operating conditions
  - More robust optimization technique would yield moderately higher estimate of total revenue
- Simulation assumes perfect price and AS foresight

Source: CPUC documents Enovation Partners analysis
Note: * Reg Down cannot exist by itself as it requires another stream to cause discharge of the storage module, so the chart shows non-simultaneous reg-up and reg-down

10 MW/10 MWh system reduces GHG emissions by 4,843 metric tons over its lifetime, mostly during afternoon and evening hours

Reduced GHG Emissions from Battery Operation - 6/14/2023
(Metric Tons)



GHG Reduction Estimate

Method

- Assumes storage will always be displacing a marginal gas units, either a CC or CT
- Calculate an implied heat rate in each 15-min interval to determine how much carbon would be used/saved
- Applies the battery charge/discharge results to calculate total net carbon benefit to the grid

Discussion

- Carbon reduction is achieved when the battery charges in low energy price (low carbon) hours and then discharges in high energy price (high carbon) hours
- When the battery operates in the energy market and uses the energy price as the signal to charge vs. discharge the greatest carbon reduction is achieved
- However, when the battery takes into account other price signals, such as capacity reserve prices, the carbon reduction is reduced

Assumptions for GHG reduction calculation: Hours with non-negative heat rates, gas generators are the marginal unit. Hours with negative heat rates, the market has no cost of carbon. Applied heat rate will be the implied heat rate bounded by 5500 and 11000, the heat rate range of gas generating technologies.

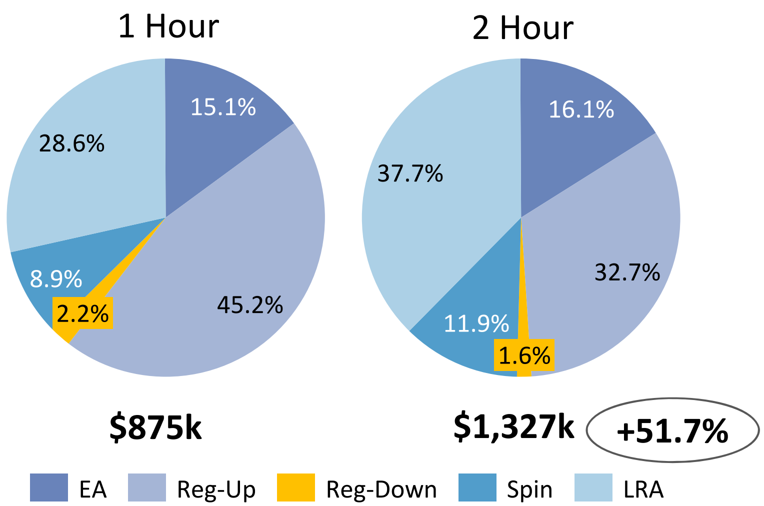
Interpretation of Results

- Reg-up is the most profitable revenue stream for the project, averaging more than $90/kW-year. When operating in the reg-up market the project receives a capacity reserve payment, as well as an energy payment for the energy discharged when called
- Reg-down is the least profitable revenue stream, averaging less than $1/kW-year coming solely from capacity payments. In reg-down, when the project is called, energy is purchased from the grid, which may not be at a desirable price. However, the project does participate in the reg-down market when charging to receive the capacity reserve payment
- Revenue from spinning reserves increases over time, from 5% to 12% of total revenue. It rises because the capacity reserve payment increases, while the charging cost associated with spin is negligible, since it is rarely dispatched
- GHG benefits are lower when the battery operates more in the reserve markets than in the energy market
  - Our estimate of carbon benefits is a function of the heat rate spread, which in turn, is a function of the energy price spread
  - Gross margin from energy arbitrage closely reflects spread in GHG-intensity of different electricity prices (i.e., earn margin by charging from low GHG resources, discharge to displace high GHG resources)
  - Gross margin from participating in regulation and spinning markets does not reflect GHG intensity
- GHG benefits increase when going from a one hour duration (4,843 Metric tons) to a two hour duration (13,786 Metric tons) due to increased participation in the energy market vs. reserve markets[1]
- Total revenues post-2028 level-out as the growth rate of the natural gas and carbon prices slow (by assumption), equipment undergoes degradation, and variable O&M increases

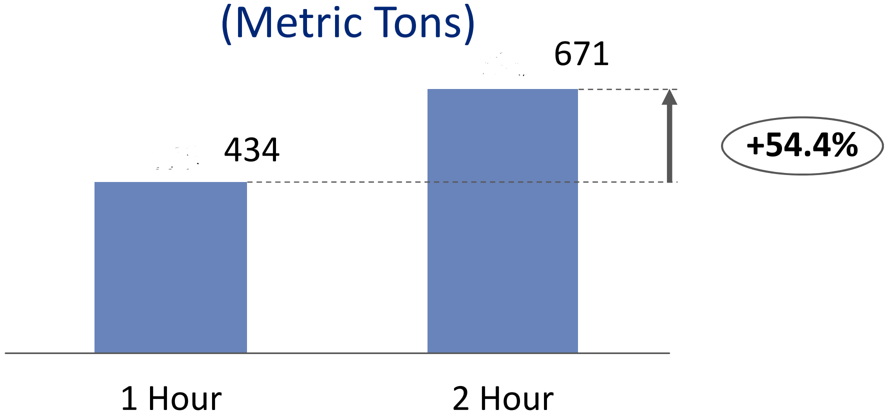
Note: Natural gas prices increase at rate of inflation post-2028. Carbon prices increase at rate of inflation post-2030
1. Reserve revenues are limited by the power rating of the unit, while the energy arbitrage revenues are mainly limited by the energy rating

Increasing the duration of a battery system from one-hour to two-hour has diminishing returns but also increased carbon savings

2023 Battery Gross Margin by Component



2023 GHG Reduction
(Metric Tons)



Discussion

- Transitioning from a 1-hour to a 2-hour duration increases the gross margin by 52%
  - Both the share and magnitude of energy arbitrage and spinning reserve go up at the sake of reg-up
  - Energy arbitrage is available for more hours because of the increase capacity of the storage module
  - Reserve markets are limited by the capacity of the power conversion equipment, so those with high dispatch/reserve ratios are most effected
  - Spin increases in share and magnitude because the optimal strike prices for a 2-hour battery are reduced, opening up more intervals with profitable spin
  - Local resource adequacy is doubled with the fraction of the 4h requirement going from ¼ to ½
- The GHG tonnage impact of increasing the duration to 2-hours is an increase of 54%
  - This increase is due to the increase in energy arbitrage and the transfer of reg-up to spin
  - Energy arbitrage is the best source of GHG savings, displacing energy in high price/heat rate intervals with low price/heat rate intervals
  - Spin requires very little charging and discharging energy (no GHG impact) which removes some of the GHG increasing impacts of reg-up where the price spread is neutral but there are 11% efficiency losses

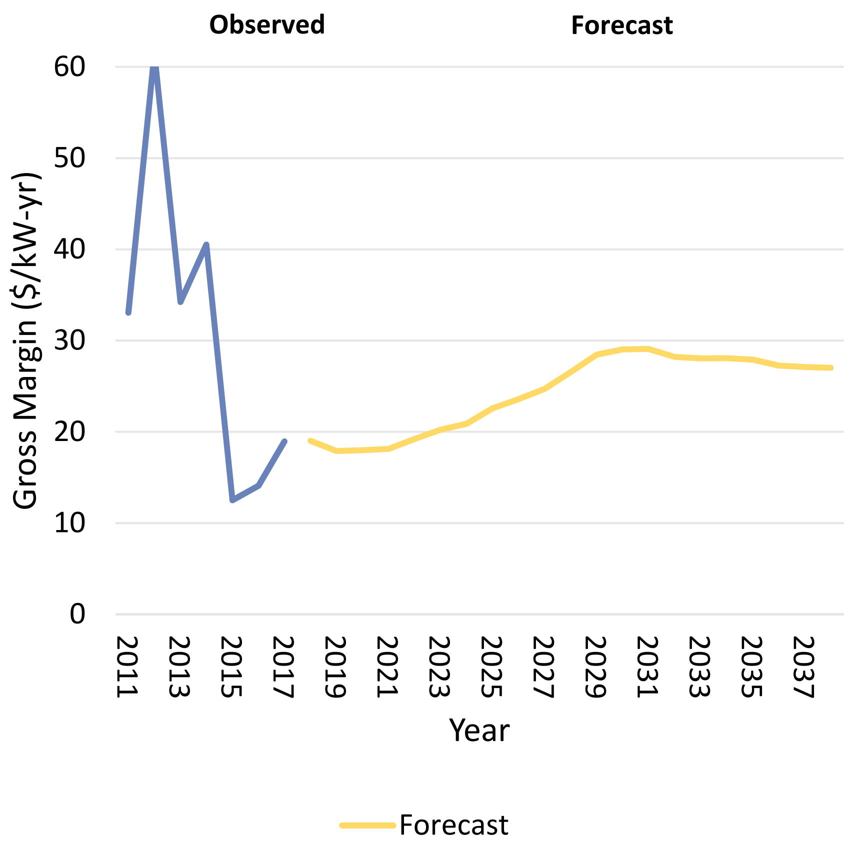
Relatively subtle changes in price forecast assumption could significantly impact revenue and GHG benefits from storage

Assumption	Alternative	Implication
Natural gas-fired generation continues to be the margin unit dispatched during all peak hours	• Increased frequency of renewable generation setting peak and off peak energy prices	• Significantly higher GHG reduction by storage • Higher overall revenue from energy storage • Higher share and value of energy arbitrage and reg down revenues
Negligible impact of energy storage penetration on regulation prices and LCR	• Reduced need and thus price for regulation and LCR due to storage penetration	• Lower overall revenue from energy storage • Higher share and value of energy arbitrage and spinning reserve
Number of energy storage actually called to discharge for regulation and spinning reserve remains constant	• Increased frequency of dispatch required (perhaps due to greater renewable penetration)	• Decreased share of reg up revenues • Increased reg down and energy arbitrage revenues • Higher GHG reduction by storage • Equivocal impact on storage revenue
Hourly shape of the energy supply and ancillaries price curve do not change in the future	• Reducing energy price during solar and wind heavy periods due to more efficient gas turbines setting margin and more volatile prices for regulation markets	• Lower revenue from energy arbitrage and lower associated GHG reduction • Higher share of revenues from regulation

Appendix

Energy Arbitrage

Energy Arbitrage Single Use Case Gross Margin (SDG&E Representative Project – 10MW / 10 MWh)



Overview

	Description
Price setting mechanism	Prices come from the CAISO dispatch and nodal pricing, based on market mechanisms
Drivers of price level and volatility	Fuel prices, price of DER equipment, new technology (e.g. smart inverters for solar), load growth, renewables penetration, transmission growth
Key regulatory uncertainties	Addition and retirement approvals, transmission approvals, treatment of solar net metering, time-of-use rules

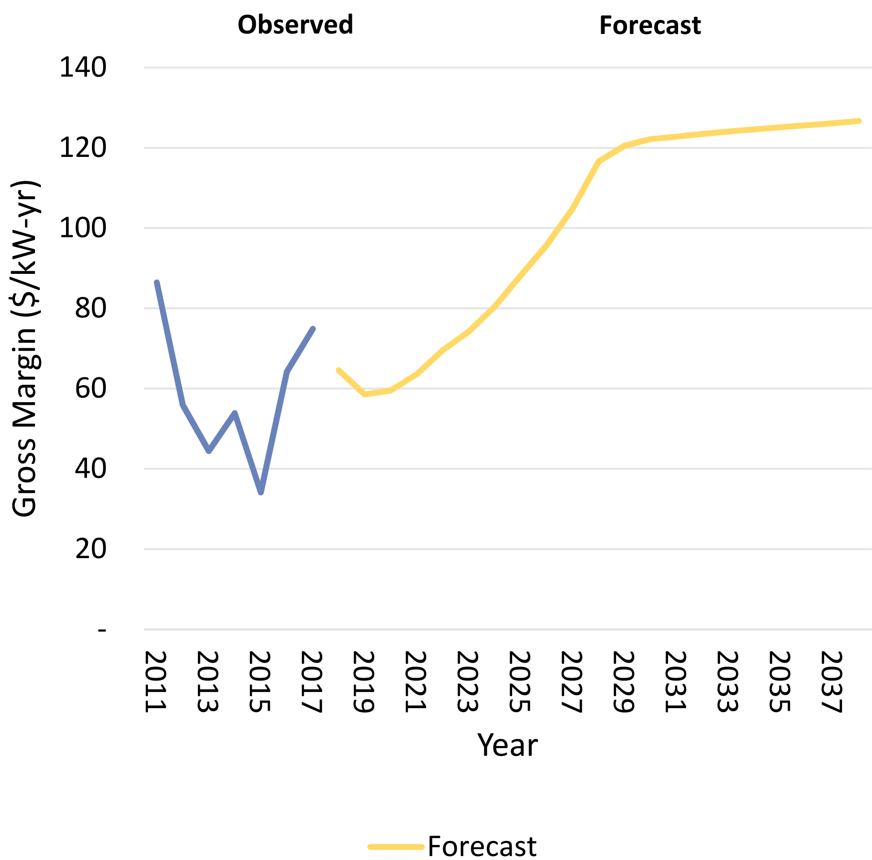
Energy Price Forecast

	Description
Methodology	Energy prices are forecasted using the natural gas future price. Use regression analysis to find historical relationship between gas and energy prices and apply forward
Intuition	A natural gas unit in the marginal unit for most hours in CAISO
Functional Form	On Peak: $E_f = E_h + r_{e_p}(NG_f - NG_h)$ Off Peak: $E_f = E_h + r_{e_{op}}(NG_f - NG_h)$
Key regression statistics	On Peak: r-squared = 0.37, p values ≈ 9.7×10^{-96} Off Peak: r-squared = 0.40, p values ≈ 1.6×10^{-122}

Source: CAISO Annual Reports on Market Issues and Performance, CAISO OASIS; Enovation Partners analysis
Note: Both historical and future natural gas prices are adjusted for GHG. E=energy, NG=natural gas, RU=reg up, RD=reg down, G=renewable gen., S=spin-res.
Subscript legend: f – future, h – historical, p – peak, op – off peak. Other notation: r and s represent different regression coefficients for the various regressions. .

Regulation Up

Regulation Use Case Gross Margin
(SDG&E Representative Project – 10MW / 10 MWh)



Overview

	Description
Price setting mechanism	CAISO calculates Regulation needs based on the projected worst 10 minute ramp rate required, clears market with up bids
Drivers of price level and volatility	Fuel prices, price of DER equipment, new technology (e.g. smart inverters for solar), reservoir levels, load growth, generation plant retirements and additions
Key regulatory uncertainties	BTM participation rules, changes to market structure and rules, DER incentives

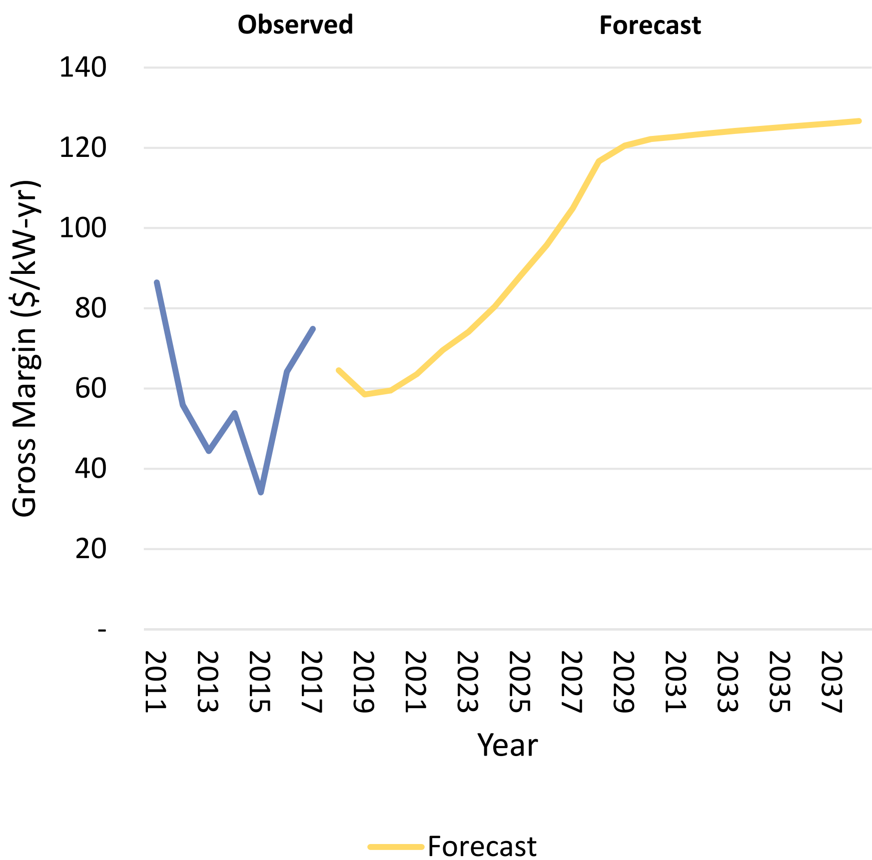
Regulation Up Price Forecast

	Description
Methodology	Reg up prices are forecasted using the energy price forecast for peak hours. Use regression analysis to find historical relationship between reg up and energy prices and apply forward. Off peak hours are scaled by inflation
Intuition	Reg up prices are historically correlated with energy prices in peak hours
Functional Form	On Peak: $RU_f = RU_h + r_{ru}(E_f - E_h)$ Off Peak: $RU_f = RU_h * inflation$
Key regression statistics	On Peak: r-squared = 0.62, p values ≈ 0

Source: CAISO Annual Reports on Market Issues and Performance, CAISO OASIS; Enovation Partners analysis
Note: Both historical and future natural gas prices are adjusted for GHG. E=energy, NG=natural gas, RU=reg up, RD=reg down, G=renewable gen., S=spin-res.
Subscript legend: f – future, h – historical, p – peak, op – off peak. Other notation: r and s represent different regression coefficients for the various regressions.

Regulation Down

Regulation Use Case Gross Margin
(SDG&E Representative Project – 10MW / 10 MWh)



Overview

	Description
Price setting mechanism	CAISO calculates Regulation needs based on the projected worst 10 minute ramp rate required, clears market with up bids
Drivers of price level and volatility	Fuel prices, price of DER equipment, new technology (e.g. smart inverters for solar), reservoir levels, load growth, generation plant retirements and additions
Key regulatory uncertainties	BTM participation rules, changes to market structure and rules, DER incentives

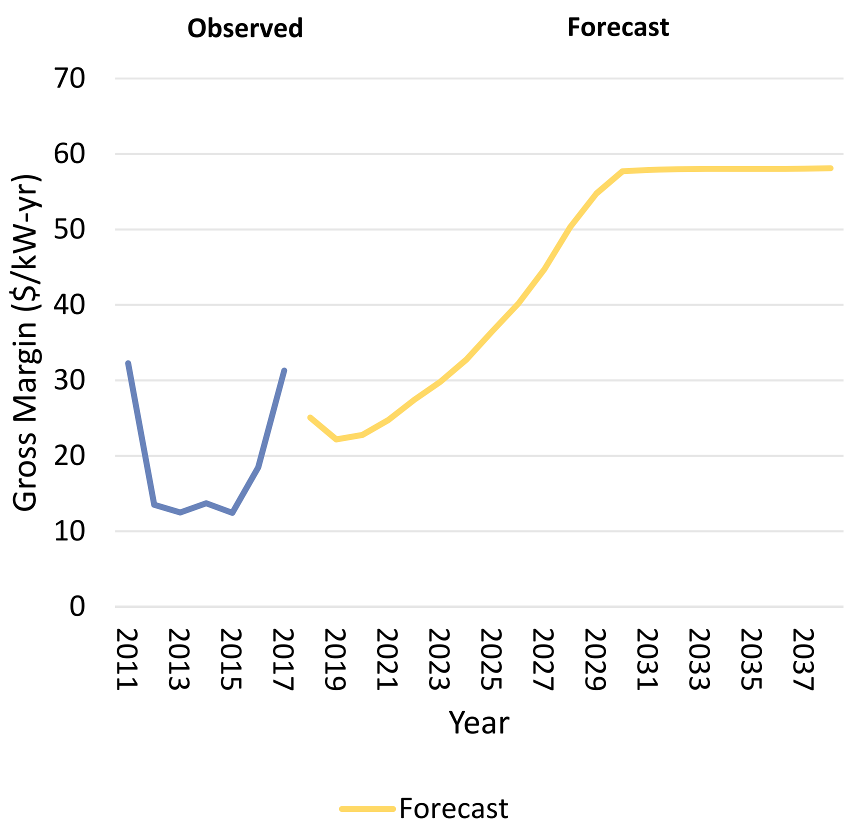
Regulation Down Price Forecast

	Description
Methodology	Reg down prices are forecasted using the energy price forecast and renewable generation for off peak hours. Use regression analysis to find historical relationship between reg down, renewable generation, and energy prices and apply forward. On peak hours are scaled by inflation
Intuition	Reg down prices are historically negatively correlated with energy prices in off peak hours. Increased renewable gen should increase demand for reg down
Functional Form	On Peak: $RD_f = RD_h * inflation$ Off Peak: $RD_f = RD_h + r_{rd}(E_f - E_h) + s_{rd}(G_f - G_h)$
Key regression statistics	Off Peak: r-squared = 0.23, p values ≈ 0 (r_{rd}), 2.7×10^{-123} (s_{rd})

Source: CAISO Annual Reports on Market Issues and Performance, CAISO OASIS; Enovation Partners analysis
Note: Both historical and future natural gas prices are adjusted for GHG. E=energy, NG=natural gas, RU=reg up, RD=reg down, G=renewable gen., S=spin-res.
Subscript legend: f – future, h – historical, p – peak, op – off peak. Other notation: r and s represent different regression coefficients for the various regressions.

Spinning Reserve

Spinning Reserve Single Use Case Gross Margin (SDG&E Representative Project – 10MW / 10 MWh)



Overview

	Description
Price setting mechanism	CAISO sets required hourly reserve (3% of load + 3% of gen/imports) and accepts DA/RT bids to clear the requirement
Drivers of price level and volatility	Fuel prices, price of DER equipment, new technology (e.g. smart inverters for solar), reservoir levels, load growth, change in system load shape, generation plant retirements and additions, demand response participation
Key regulatory uncertainties	Requirement adjustment, time-of-use rules, BTM participation rules, changes to market structure and rules, DER incentives

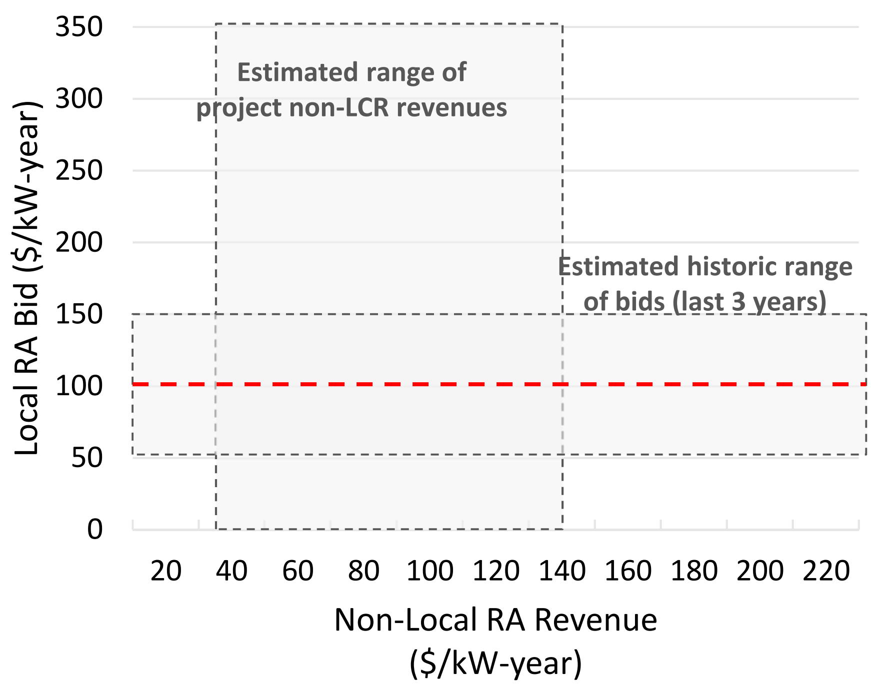
Spinning Reserve Price Forecast

	Description
Methodology	Spin reserve prices are forecasted using the energy price forecast for peak hours. Use regression analysis to find historical relationship between spin reserve and energy prices and apply forward. Off peak hours are scaled by inflation
Intuition	Spin Reserve prices are historically correlated with energy prices in peak hours
Functional Form	On Peak: $S_f = S_h + r_s(E_f - E_h)$ Off Peak: $S_f = S_h * inflation$
Key regression statistics	On Peak: r-squared = 0.66, p values ≈ 0

Source: CAISO Annual Reports on Market Issues and Performance, CAISO OASIS; Enovation Partners analysis
Note: Both historical and future natural gas prices are adjusted for GHG. E=energy, NG=natural gas, RU=reg up, RD=reg down, G=renewable gen., S=spin-res.
Subscript legend: f – future, h – historical, p – peak, op – off peak. Other notation: r and s represent different regression coefficients for the various regressions.

Local Resource Adequacy

Summary of Local Resource Adequacy Estimate



Overview

	Description
Price setting mechanism	Bid submitted to the local utility, in this case SDG&E, to select projects quantitatively and quantitatively to clear mandated requirement
Drivers of price level and volatility	Local resource need, capacity prices, price of DER equipment, new technology (e.g. smart inverters for solar), load growth, generation plant retirements and additions, demand response participation
Key regulatory uncertainties	Administration and collection by SDG&E, time-of-use rules, BTM participation rules, DER incentives

Local Resource Adequacy Estimate

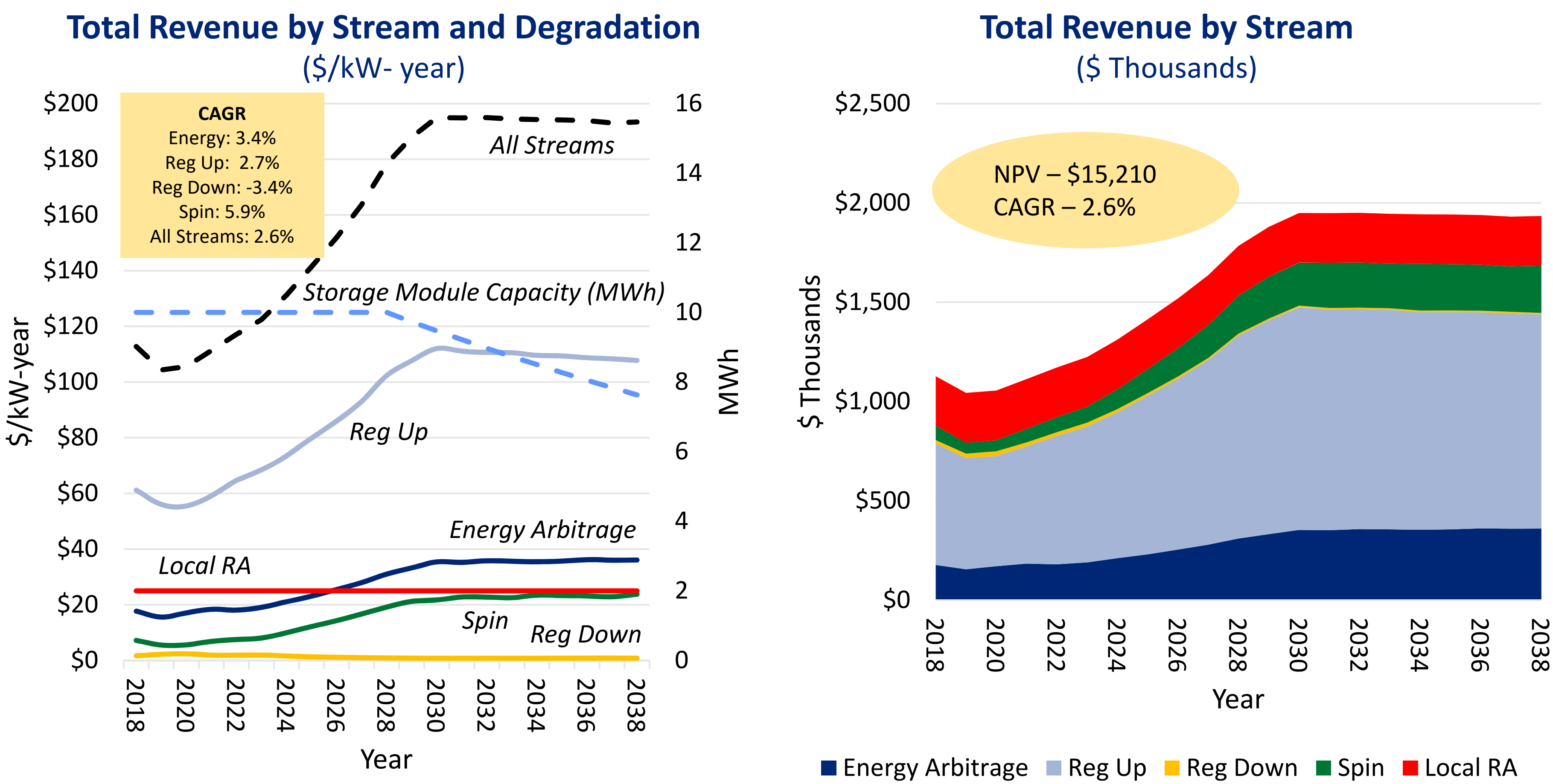
Method
• Estimates for local resource adequacy revenues were gathered from a survey of developers in the southern California region. • Our survey showed that local resource adequacy revenues for battery storage projects were between $50-150/kW-year. • These finding were corroborated by high level numbers published by the CPUC and with a net CONE approach. • Our final revenue calculations use the midpoint of the developer estimates of $100/kW-year.

Source: Enovation Partners Analysis

Enovation Partners

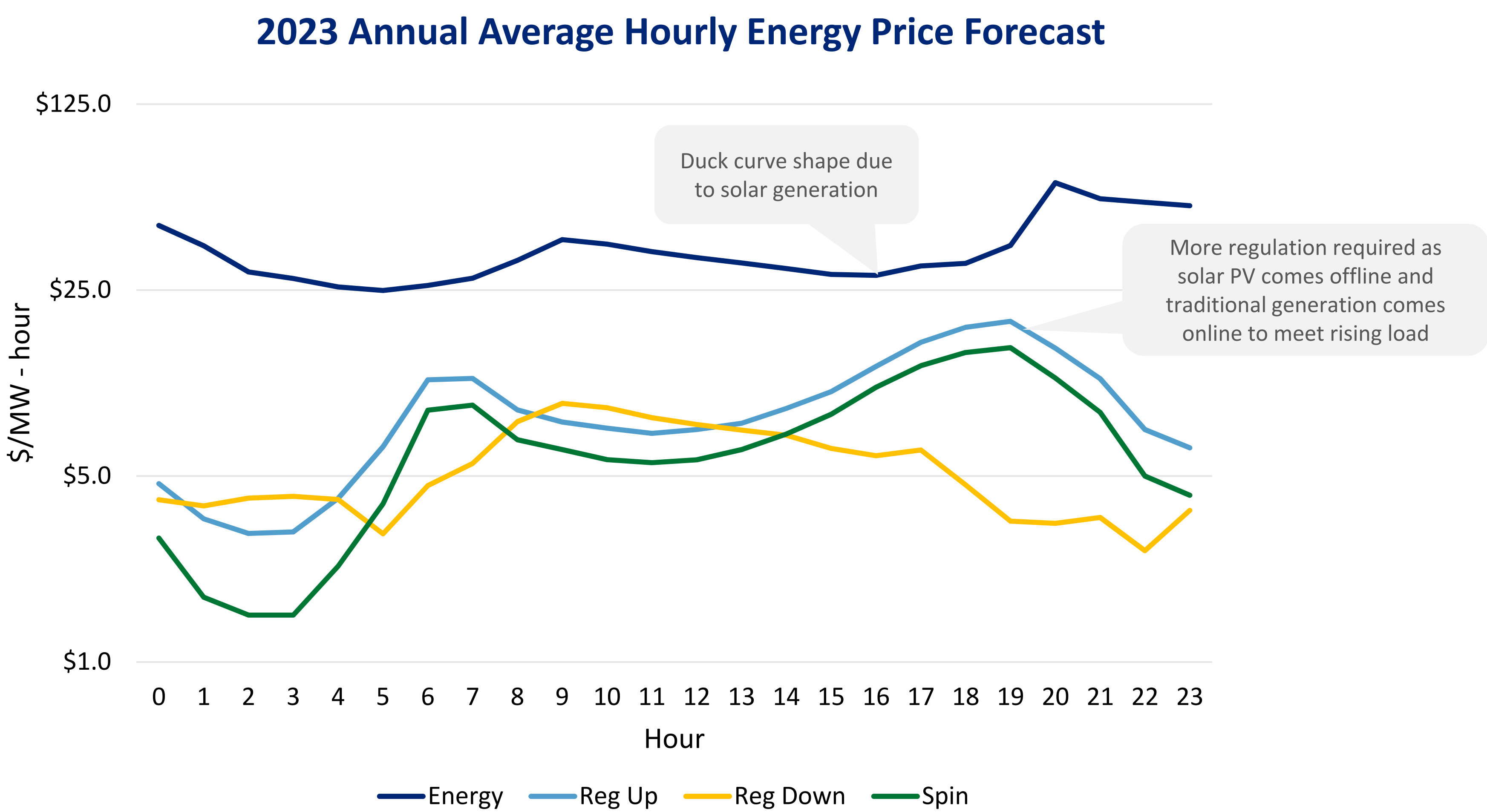
Summary of revenue streams over time

Revenues by Stream and Degradation for Illustrative SDG&E Storage Project (2018 – 2038)



Source: Enovation Partners analysis
Note: These charts show revenue only and do not account for charging costs or VOM. NPV based on 7.5% discount rate. The project can only participate in one revenue stream at a time during each 15-min interval. “All Streams” represents the sum of the individual revenue streams.

Market prices play an important role in determining charging and discharging decisions



Note: Energy – Real-Time LMP forecast; Reg Up, Reg Down, Spin – Day Ahead CAISO forecast. Reg Up, Reg Down, and Spin only represent the capacity price. Additional payments/charges are made for the energy dispatched/received. Other factors, such as battery state of charge and charging cost also play a role in determining charging and discharging decisions.

Assumptions

Category	Inputs	Value	Source
Forecast	Electric Price History	SP-15	SNL
	Gas Price (2018-2028)	SoCal Citygate	SNL
	Gas Price (2028-2038)	Inflation rate scaling prior year's month	EP/SDG&E
	Carbon Price (2018-2030)	ISIC GHG Forecast	ISIC
	Carbon Price (2030-2038)	Inflation scaling previous quarter	EP/SDG&E
	Renewables History	CAISO OASIS Hourly Dispatch History	CAISO OASIS
	Renewables	BNEF Forecast of California Wind and Solar	BNEF Forecast
Optimization	VOM Under Warranty	$5.75.MWh (discharge)	SDG&E
	VOM Escalation Post-Warranty	1.7902%/year	SDG&E
	SM Degradation Under Warranty	0%	EP
	SM Degradation Post-Warranty	2.67%/year	EP
	PCS Degradation Under Warranty	0%	EP
	PCS Degradation Post-Warranty	2%/year	EP
	RTE	89.10%	SDG&E
	RTE Degradation Under and Post-Warranty	0.3%/year	EP
	Deep Cycle Threshold	10%	EP
	Reg Up/Down Dispatch Intervals per Year	26,280 (75% of intervals)	PG&E
	Reg Up/Down Duty Cycle When Called	25%	LCOS
	Spin Dispatch Intervals per Year	200 (0.05% of intervals)	CAISO
	Spin Duty Cycle When Called	100%	EP
	Spin Requirement	2 Hours (if needed)	CAISO
	Maximum Revenue from Spin	20%	EP/SDG&E
GHG	Heat Rate Floor	5500 BTU/kWh	Itron
	Heat Rate Cap	11000 BTU/kWh	Itron
	CC/CT Switching Heat Rate	8000 BTU/kWh	EP
	Emissions Factor for Natural Gas	0.0531 Metric tonCO2/MMBtu	EIA
	Combined Cycle VOM	$3.50/MWh	EIA
	Combustion Turbine VOM	$5.30/MWh	EIA
General	Inflation Rate	2%	EP

Overview of GHG estimation and implications for energy storage project

CPUC-Approved Approach to Estimating GHG Impacts of Energy Storage[1]

Concept

- Estimate GHG content of charged and discharged electricity based on the forecast electricity price.
- Use project gas and GHG prices to estimate GHG content of future electricity prices via estimating heat rate of generation units setting marginal price at each time period
- Critically, the method assumes gas-fired plants set electricity prices in all hours where prices are positive
- Constrain maximum and minimum heat rates to 11,000 and 5,000 BTU/kWh, respectively, and assume negative prices reflect zero GHG
- Intuition; Over time, increasing GHG prices will lead to elimination of highest heat rate generation from supply stack, and will cause more efficient gas units to set marginal prices during lower demand periods

Mathematical Depiction

$GHG\ impact\ of\ storage = Discharge\ GHG\ content\ (displaced) - Charging\ GHG\ content.$ GHG content $estimated\ using\ Implied\ Heat\ Rate$

$$Implied\ Heat\ Rate_h = \frac{RT\ Market\ Priceh - VOMh}{Gas\ Pricem + EFh \times CO_2Price_m} \times 1000$$

for h=hour, m=month

- RT Market Price: SP-15 real-time market price in \$/MWh
- VOM : Gas generation average variable operation and maintenance in \$/MWh
- Gas price: SoCal Citygate price of gas in \$/MMBTU
- EF : Emission factor in Metric ton of CO_2/MMBTU of gas
- CO_2 Price: Market price for CO_2 in \$/Metric ton of CO_2

Implications for Simulated Energy Storage Project

- Over time, both gas price and carbon prices are forecasted to rise more rapidly than electricity prices less VOM
- Mathematically, given formula on the left, the overall effect is decreasing heat rate over time, especially considering the non-linear effects of the heat rate cap and floor
  - The floor on heat rate becomes more relevant over time with the gas+carbon impacts outpacing the electric impacts
  - The cap on heat rate is less and less impactful over time due to trend of falling heat rate
  - Consequently, the delta between charging heat rate and discharging heat rate shrinks
  - This reduction means less carbon savings per storage cycle
- These effects are consistent with economic intuition of the evolution of the power market in a scenario of rising GHG prices
  - Increase in renewables shifts supply curve to the right, reducing heat rate (and thus GHG content) of off peak prices
  - High heat rate gas units become uneconomic and exit far right hand side of supply curve
  - Thus heat rate of both high price (discharging) and low price (charging) generation sources declines over time, and "floor" becomes binding constraint more often…
  - … decreasing GHG reduction impact of energy storage
- Note: If assumption that gas always set the marginal unit were removed, much more GHG reduction could be obtained as storage unit would charge from a zero emission source like wind or solar

[1] The method was developed over 2016-2017 by contractor Itron and discussed at a CPUC workshop in November 2017

Enovation Partners and Cleantech Group

- **Focused on driving innovation to energy and infrastructure sectors**
  - Transition of electricity sector – DER, storage, mobility
  - Natural gas growth and innovation
  - Winner of Consulting Magazine's 2017 "Seven Small Jewels" award
- **Combine industry experience with advanced analytics**
  - Boutique (50 staff in offices in Boston, London, San Francisco, Washington) focused on energy transition
  - Leverage proprietary analytics, data and differentiated market insight
  - Experienced team (former BCG, McKinsey, Deloitte, etc.) with extensive senior industry relationships
- **Acquired Cleantech Group in 2016 to provide corporate, investor communities front-row seat for innovation**
  - 16 years of convening VC/CVCs and cleantech start-ups (annual events in SF, Europe, Chain)
  - I3: Cleantech's online networking platform
  - Proprietary, in-depth market insight and analysis

Enovation Partners has broad experience in energy storage and DER markets and analytics

Selected Projects (2015 to Present)

Client	Issue	Enovation Team Contribution
Lazard Freres	How to compare storage technology costs & use cases?	• Led all analysis for Lazard's annual Levelized Cost of Storage survey (2015 to 2017) • Estimated economic viability of storage across technologies, use case, and markets
>20 large energy clients • **Utilities** • **OEMs** • **Investors** • **Energy retailers**	How big is DER market? Where to participate?	• Modeled economics and adoption of various DER technologies (PV, reciprocating engines, storage) at highly granular level across US, Canada, Australia, Germany • Profiled/developed detailed pro forma economics of contracts and business models
Multiple energy storage developers	How do we compare to competitors? How to differentiate?	• Assessed potential for thermal and other non-Li-ion chemistries • Conducted large scale customer research – buying criteria, process • Leveraged competitive assessment and benchmarking to inform market strategy, M&A, financial and organizational plan
US Independent Power Producer	How to compete in a changing demand response market?	• Developed a 5-yr. growth strategy leveraging improved customer engagement. • Evaluated revenue streams in ISONE and NY and requirements to operate • Plan achieved 3X EBITDA growth ($50M+ p.a.) in less than 3 years
Leading IPP	Potential for hybrid storage at fossil plants	• Forecasted PJM and MISO energy, capacity, ancillary services • Assessed costs, optimal configuration of adding storage to large fleet • Analyzed project economics based on optimized storage operation
Edison Electric Institute	When/where will DER threaten utilities?	• Utilized proprietary analytics offering to evaluate DER attractiveness by zip code • Developed sensitivities on when behind the meter resources would be in the money for residential and commercial customers.
Multiple US utilities	How will DER impact IOU? Which business models best harness DER?	• Load forecast, financial impact, regulatory strategy, stakeholder plan • Designed range of options for multiple US utilities to incorporate DER and other advanced energy technologies into business model for future utility operations • Developed pro forma financials, regulatory, and M&A strategy to support plan