CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

## FINAL PROJECT REPORT

# Eos Energy Storage: Utility Demonstration of Non-Flammable, Aqueous-Zinc Battery Storage

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# PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov

# ABSTRACT

Partnered with the California Energy Commission (CEC), Eos Energy Storage (Eos) was awarded grant "EPC-18-023" to implement and demonstrate their Gen 2.3 Battery Energy Storage System in a commercial application. This installation consisted of (1) singular Eos Gen 2.3 Energy Block$^{TM}$ rated for 125kW / 500kWh at a 4-hour energy discharge system. The system was installed and became commercially operational at the end of 2021.

This project showcased Eos' technology as an alternative to battery storage systems, such as lithium-ion. The technology uses a zinc aqueous electrolyte manufactured and designed for a long-term duration and non-flammable energy storage system. This technology is the first zinc aqueous electrolyte battery to be used commercially and is a stepping stone in the industry to provide longer-term energy.

This grant provided by the CEC allowed Eos to install its technology and gather data through different testing procedures. Eos then gathered, analyzed, and used this data to help advance its technology for itself and its stakeholders.

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**Keywords:** California Energy Commission, long duration energy storage, zinc aqueous electrolyte, non-flammable

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# Executive Summary

This project demonstrated the Eos' Generation 2.3 battery storage system, which utilizes zinc aqueous electrolyte technology. Eos has been able to install this technology in a real-world application to showcase its functionality and resiliency as a long-duration battery energy storage technology, while also highlighting its safety benefits.

## Background

California has been a leader in supporting the clean energy revolution including renewables; solar, wind, battery energy storage, and electric vehicles. The Senate Bill (SB) 100 Joint Agency Report indicates that California will need a total of 50 gigawatts (GW) or more of energy storage, including 4 GW of long-duration storage, in order to meet its 2045 goal of reliably supplying end-use customers with electric retail sales that are 100% renewable and carbon-free.

Eos Energy Storage (Eos) is a battery energy storage manufacturing company founded in 2008. Historically a research and development company, Eos has continued to build on their technology for the last 15 years, striving to deliver an alternative approach for battery energy storage in a predominantly lithium-ion (li-ion) market.

Currently, the majority of energy storage deployed in California is li-ion technology and these battery energy storage products are designed for short-duration energy storage (~2 hours of deployed energy). However, as the environment continues to evolve and with California's need for grid resiliency, there is a growing need for longer periods of energy to be delivered. Eos' technology is one of the only battery energy storage systems that can provide for such a demand over a longer period of time, ranging between 4 – 12 hours of delivered energy.

## Project Purpose and Approach

The purpose of this project, in partnership with the California Energy Commission (CEC), is to test the Eos Gen 2.3 battery storage system in a real-world application and to highlight the technological advances in the battery, such as its energy density, in comparison to the Gen 2.0 battery storage system. Eos planned to test a multitude of different use-cases, or test scenarios, that are most experienced with the electrical grid; including, but not limited to, peak shaving to help reduce overall demand on the grid during times of high consumption/demand, 4 – 12 hours of long-duration energy storage deployed, and demand responses.

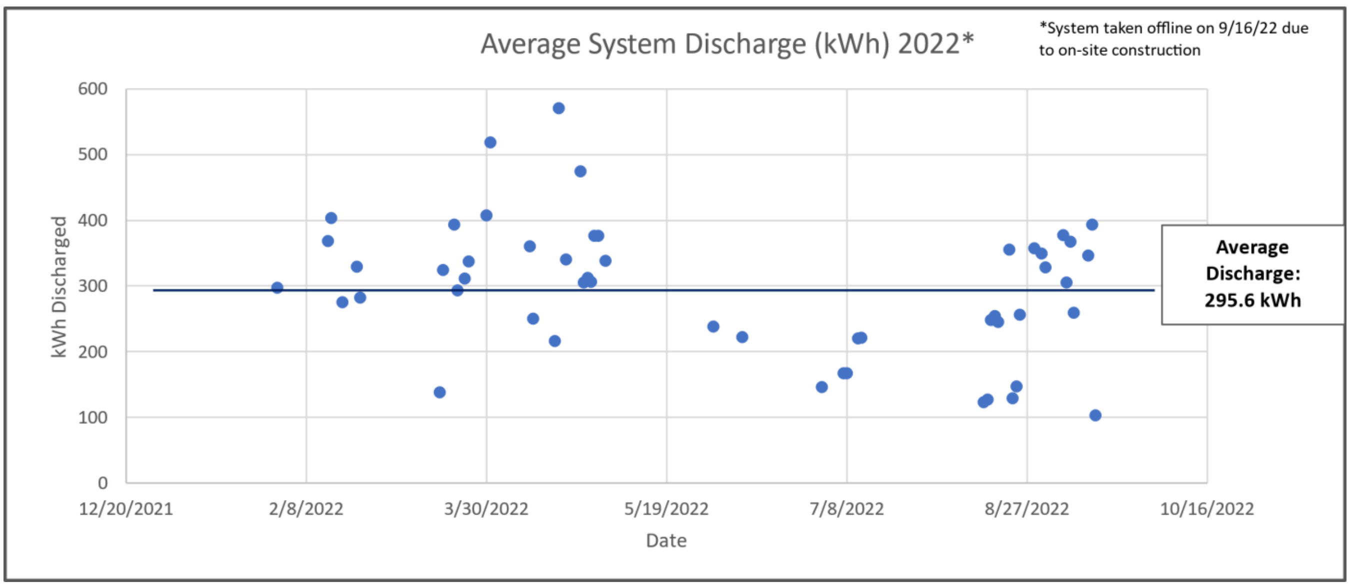
This project showcased Eos Generation 2.3 Energy Storage battery technology as an alternative approach to more standard battery storage systems, such as li-ion, which has risks of thermal runaway. Eos' technology is comprised of a zinc aqueous electrolyte and due to its inherent chemistry, this electrolyte is non-flammable; allowing the system to be installed without any need of fire suppression or HVAC equipment. The battery system is manufactured and designed for a long-term duration and non-flammable energy storage system. The Eos battery system is the first of its kind to be used commercially and is a stepping stone in the industry to provide longer-term energy.

Eos tested the storage system and functionality of the Energy Block™ outside of the research and development lab, providing clean energy to local stakeholders and helping to create a more resilient electrical grid. The Eos' Generation 2.3 125 kilowatts (kW)/500 kilowatt hours (kWh) battery storage system was installed at the Pala Del Norte site in San Diego, California, during the summer of 2021 and operational by the end of the 2021.

## Key Results

As part of the project, Eos' technology successfully provided a battery energy storage system capable of discharging clean energy to local stakeholders during the test cycling and periods of peak demand from the electrical grid. Figure ES-1 highlights the total energy the system discharged throughout 2022.

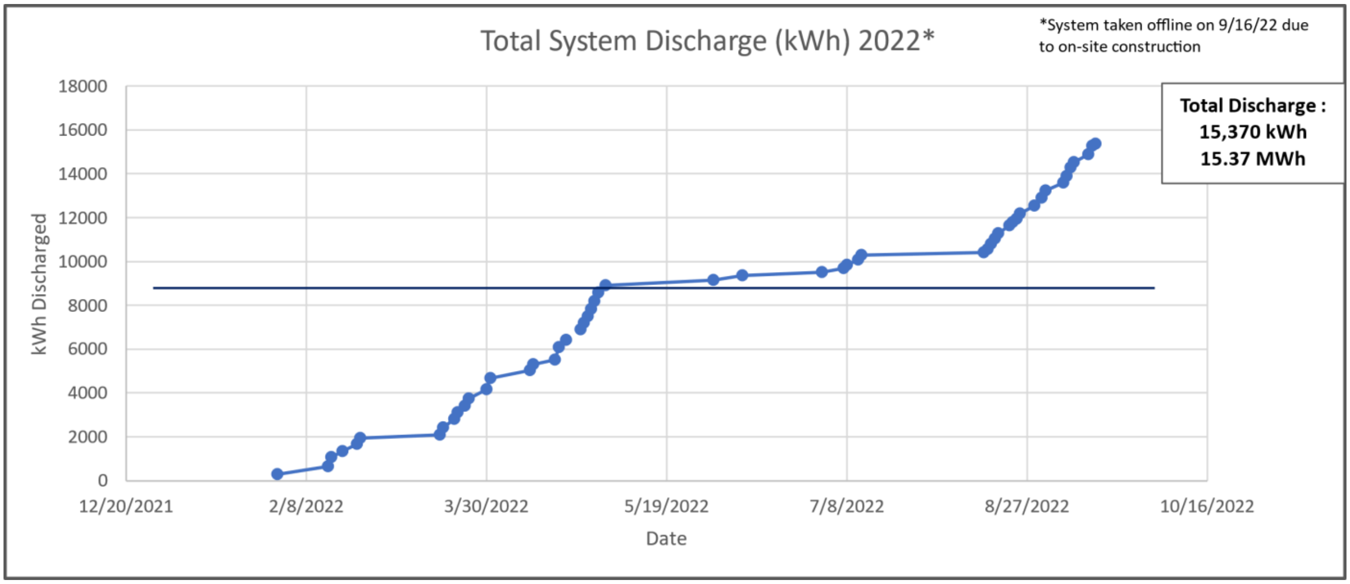
**Figure ES-1: Eos Energy Block™ Average Energy Discharge 2022**




Source: Eos Energy Storage

Eos' Energy Block™ installed at the Pala Del Norte site had an average energy discharge of 295.6kWh during 2022. As shown in Figure ES-2 the Eos' Energy Block™ installed at the Pala Del Norte site had a total energy discharge of 15,370 kWh, or 15.37 megawatt hours (MWh), during 2022.

**Figure ES-2: Eos Energy Block$^{TM}$ Total Energy Discharge 2022**




Source: Eos Energy Storage

Although the system was taken offline on September 16, 2022, the total energy discharged by this system that can be extrapolated would be closer to 20,000 kWh – 21,000 kWh, or 2 MWh – 2.1 MWh. That is enough electricity to offset the demands of 2 or 3 households in the San Diego area for an entire year; an area where household average yearly energy consumption is about 8,832 kWh.

Eos was also able to better understand system functionality during a variety of different circumstances. Each cycle performed during this project was unique since the parameters will never be identical to each other, such as temperature, charge duration, discharge duration, etc. With the data collected, Eos analyzed functionality of the Energy Block$^{TM}$ for optimal use-cases and how to advance its technology.

## Knowledge Transfer and Next Steps

The team published the projects' findings to the industry leaders, technical advisory committee, and board members for feedback and recommendations helping Eos to advance and improve the results of this project and future projects and technology. The project team presented preliminary project findings to relevant stakeholders such as the U.S. Department of Energy (DOE) and the CEC staff and commissioners. The design and implementation of Eos Energy System's first commercial grid-scale battery storage system prototype successfully demonstrated the early-stage use by the industry and the customer technologies. While past California programs have had success with various battery storage systems, this project has piloted Eos Energy System's technology and presented the opportunity of growth and expansion for the renewable energy industry. In addition, showcasing a successful use of the Eos technology without the need for a fire suppression system has allowed Eos to move forward with other pilot projects that will be installed in an indoor setting; an industry leading effort that, by any other battery energy storage system, has not been feasible previously. This crucial steppingstone can help support stakeholders locally, nationally, and internationally.

# CHAPTER 1: Introduction

## 1.1 Energy Storage Market Opportunity

Eos develops and supplies innovative, low-cost energy storage solutions for the electric utility and commercial and residential industries. Energy storage is primed as a high growth market, with multiple applications and value streams within the energy sector.

### 1.1.1 Problem Statement

At the most fundamental level, energy storage – like storage in any other supply chain – fulfills a very basic function: it decouples supply from demand. For energy storage, it allows energy to be generated on one schedule and consumed on another. The basic principle that supply and demand must be decoupled governs the design of every major supply chain, except for electricity. For example, storage allows any oil refinery to produce products according to a smooth production schedule (made possible by storage of crude oil, intermediate products, and finished products) while the sales of gasoline, diesel and other products can fluctuate day to day and place to place. Storage works to facilitate the efficiency of other supply chains because it is cheaper to store products than it is to produce them on site the moment they are required by a customer. It is also easier to satisfy a customer's requirement quickly from a product in storage than it is to have the customer wait until you have a chance to produce and deliver it to them. Most supply chains find a careful balance between the efficiency of manufacturing and distribution with the ability to quickly gratify a customer's expectations.

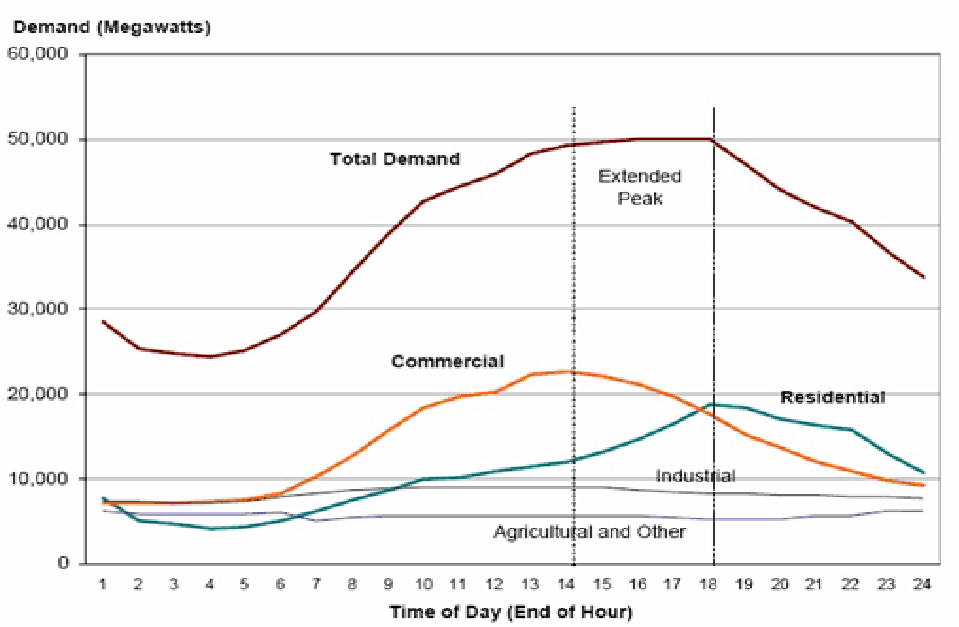
Every major commodity in the world – oil, gas, coal, grain, manufactured goods, textiles – has storage to enhance the efficiency of the supply chain. The only exception is electricity; the electricity grid is run by instantaneously matching supply and demand. Except for a small (in comparison to the total market) amount of pumped hydro1, there is very little energy storage in the electric grid. This is not the fault in the design of the electricity supply chain, but because energy storage is expensive. In many cases, it has been cheaper to discard surplus electricity available at off-peak and produce new electricity at the time of highest demand (peak).

As shown in Figure 1, a high aggregate demand develops during the middle of the day and only about half as much demand occurs during the night. As demand increases during peak times, increasingly expensive and polluting power generation resources are operated to meet that increase in demand, while many inexpensive and clean forms of energy generation (such as power from wind, which often peaks at night) are underused during off-peak periods due to insufficient demand. The relative absence of energy storage on the grid requires that the

1 Pumped hydro is a large-scale form of energy storage where excess power is used to pump water into an upper reservoir; and that water is released from the upper reservoir and run through a turbine before discharge into a lower reservoir whenever power is needed. Pumped hydro is an economically viable form of energy storage, but one that requires unique and rare geologic conditions.

entire electrical infrastructure be built to meet the peak demand during the peak hour of the peak day of the peak year, even though a large portion of that infrastructure is underused much of the time. In fact, the U.S. Department of Energy estimates that 25 percent of distribution and 10 percent of generation and transmission assets in the U.S., representing hundreds of billions of dollars of investment, are used less than 400 hours (roughly 2½ weeks) per year2.

**Figure 1: Example of Average Daily Demand for Electricity**




Source: Eos Energy Storage

### 1.1.2 Applications for Energy Storage

Energy storage could facilitate the decoupling of supply and demand on the grid, allowing the energy generated from less expensive or cleaner off-peak resources or both to be stored until needed during peak hours. Using an effective and efficient energy storage system would reduce peak power requirements and the associated infrastructure, allowing the grid to run more efficiently and at a lower cost.

Furthermore, as renewable energy from variable sources becomes an increasingly large part of the generation profile, the California electricity grid in most regions is becoming increasingly unstable. Indeed, the primary sources of renewable energy—wind and solar—are variable and intermittent; that is, they only work when the wind blows or the sun shines. As shown in Figures 2 and 3, these fluctuations in output ironically require increasing amounts of ramp-able

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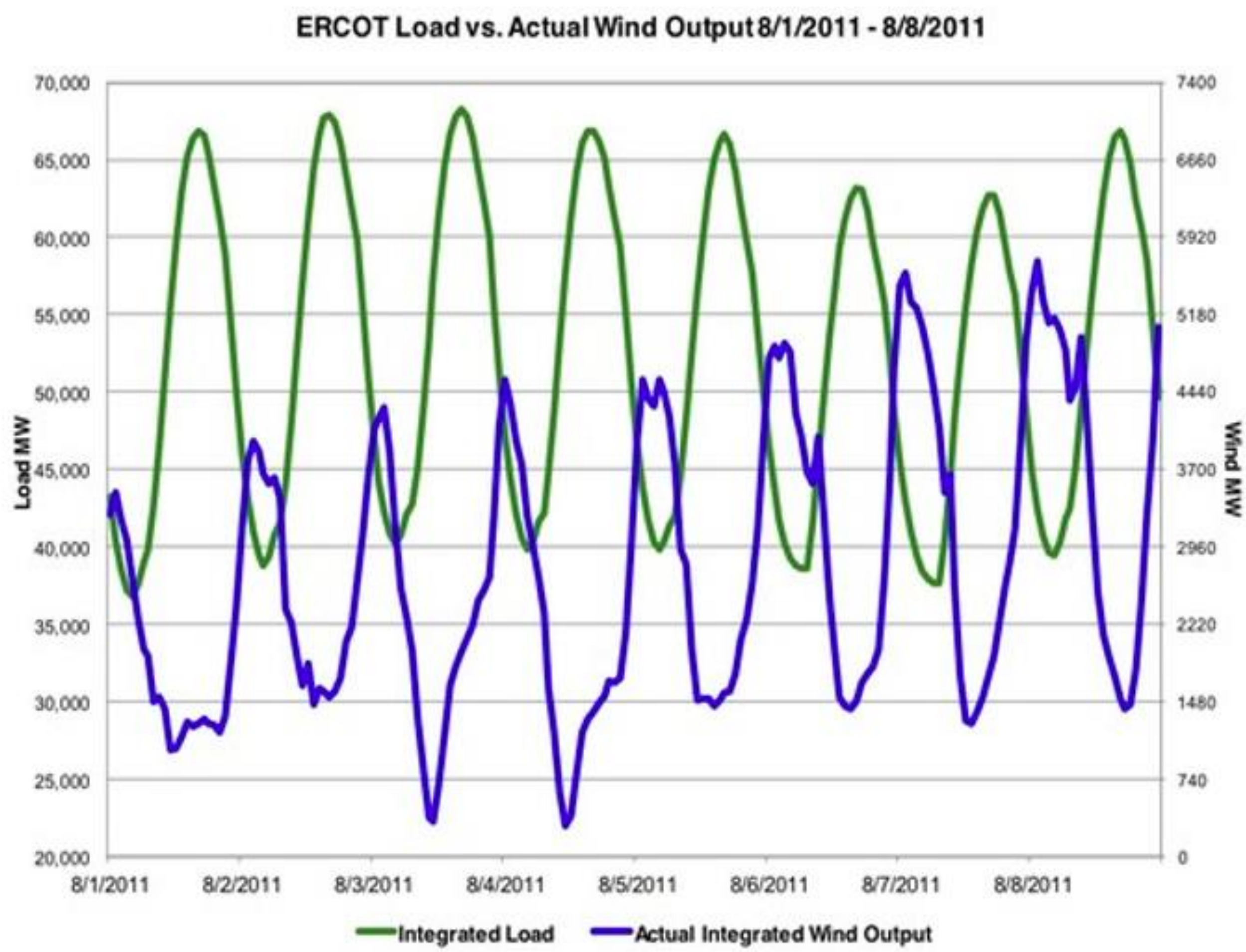
2 The Smart Grid: An Introduction, U.S. Department of Energy, by Litos Strategic Communication under contract No. DE-AC26-04NT41817, Subtask 560.01.04.

traditional power plants – precisely what renewable energy is intended to replace – just to keep the electricity supply stable and reliable.

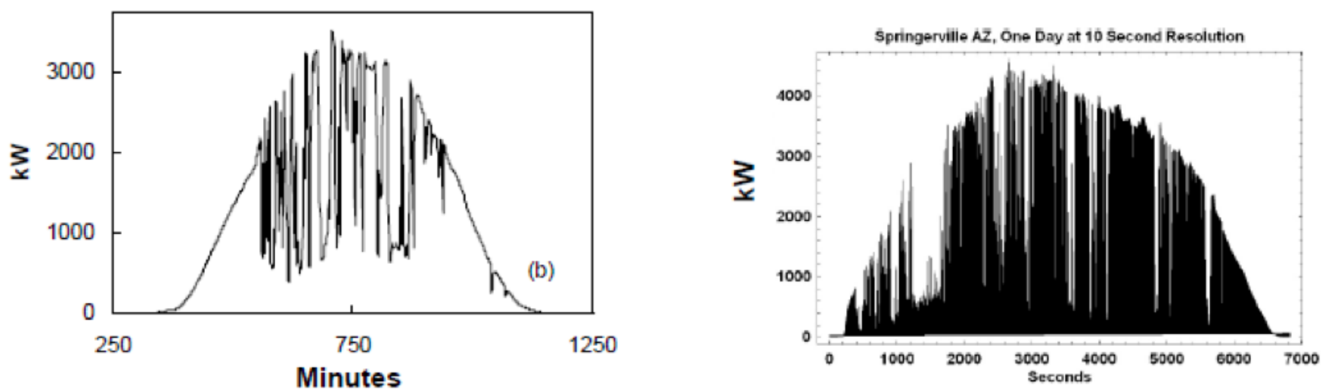
**Figure 1: Integrated Load vs. Actual Integrated Wind Output in ERCOT[3]**




Source: Eos Energy Storage

3 *The Wind-Energy Myth*, Robert Bryce, National Review Online, August 12, 2011.

**Figure 2: Typical Pattern of Solar Output**



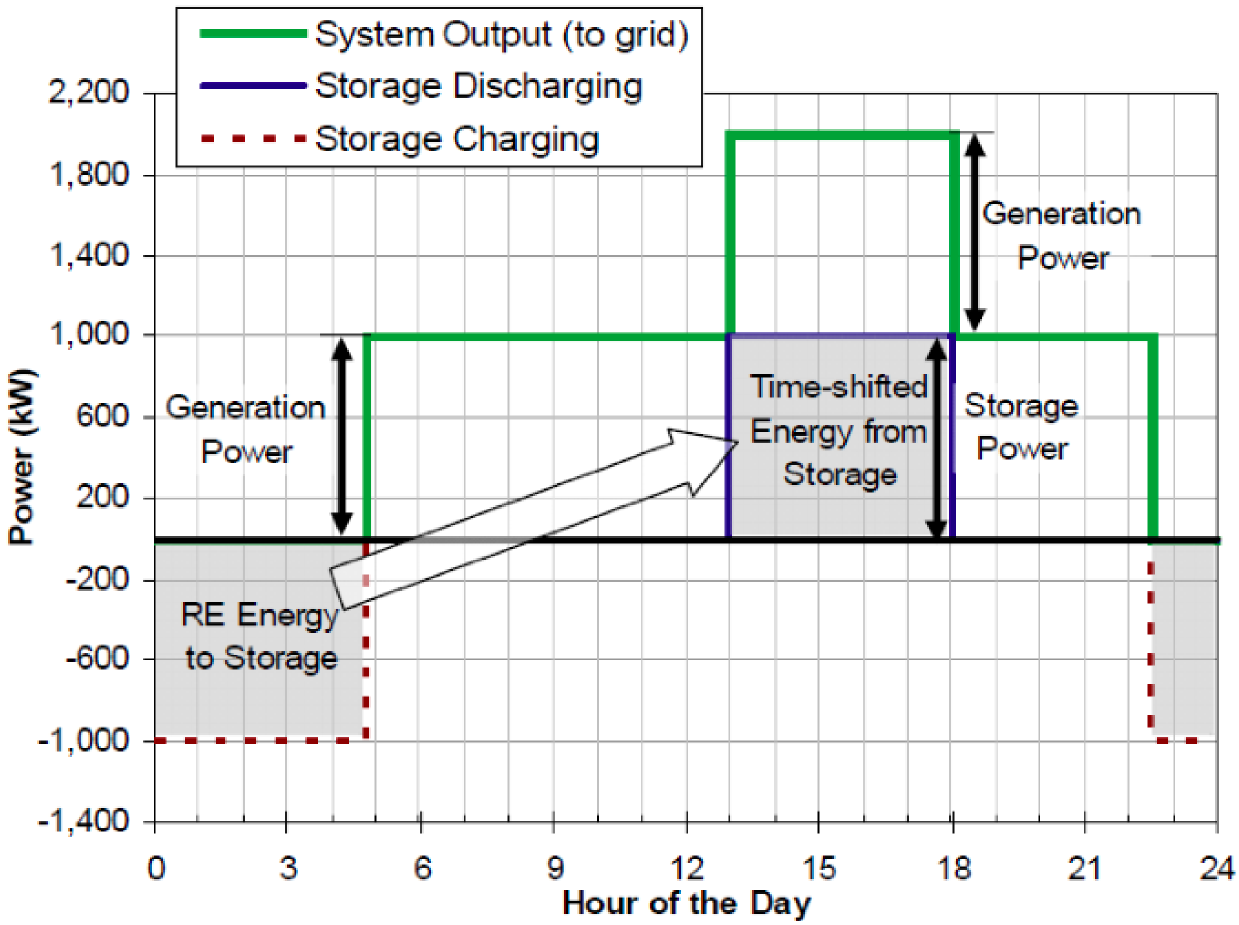

**The spikes are due to changing cloud cover*4***

Source: Eos Energy Storage

As shown in Figure 4, energy storage is the key to solving this problem because batteries can smooth and firm the delivery of solar power and shift the power from wind turbines – which in many regions tend to produce power during the night when it is not needed – to the peak hours of the day.

4 Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits, Electric Power Research Institute, December 2010.

**Figure 3: Simplified Example of Time Shifting Using Energy Storage*5***




Source: Eos Energy Storage

Energy storage is the key to reducing strain on the electricity grid, especially in urban and other highly populated areas where new transmission and distribution lines can be prohibitively expensive, take years to build, and are in many cases logistically and technically impractical. Storing energy in batteries within load centers (for example where there are dense offices, stores, factories, residences) at night when energy is cheap, and the transmission lines are underused can reduce the strain on the energy infrastructure and better use the generating, transmission and distribution assets. Recognizing the compelling and multi-faceted value proposition for energy storage, Eos has identified eight critical areas where its battery storage systems can add value to the operation and efficiency of the electricity grid, beginning with the sources of generation, running through the transmission and distribution infrastructure, and ending with the load centers and consumers, as shown in Table 1.

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5 Sandia National Laboratories, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, February 2010.

**Table 1: Targeted Energy Storage Application Descriptions and Value Streams**[6]


| Application | Description | Value Streams |
|---|---|---|
| **1. Grid Congestion Solution** | Battery used for peak shaving in specific locations where infrastructure constraints create need for transmission and/or distribution upgrades and market congestion is highly volatile | 1. Deferral of necessary T&D upgrades<br>2. Capacity payments (location specific)<br>3. Energy arbitrage |
| **2. Grid Regulation and Balancing** | Battery participates in competitive ancillary service markets for provision of frequency regulation or other ancillary services (spinning reserves, black start, etc.) | 1. Capacity payment for provision of frequency regulation or other ancillary services in wholesale markets<br>2. Capacity payments (peak reliability)<br>3. Real time energy revenues from charge/discharge (if applicable) after ISO dispatch could be profit, loss, or held neutral |
| **3. Generator Operational Efficiency Enhancement** | Co-location of battery assets with fossil fuel powered generation to enhance operational efficiencies | 1. Lower fixed and variable O&M<br>2. Extended life of generation asset<br>3. Black start/alternate power source and critical equipment back-up<br>4. Enhanced energy/ancillary services and capacity value |
| **4. Peak Generation Replacement + Real Estate Development** | Development of battery assets to replace ageing or uneconomic peaking generation. Interconnection would leverage existing T&D infrastructure. | 1. Real estate development value<br>2. Capacity payments (location specific)<br>3. Energy arbitrage in wholesale markets<br>4. Emission/pollution credits (if applicable) |

6 *Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits*, Electric Power Research Institute, December 2010.

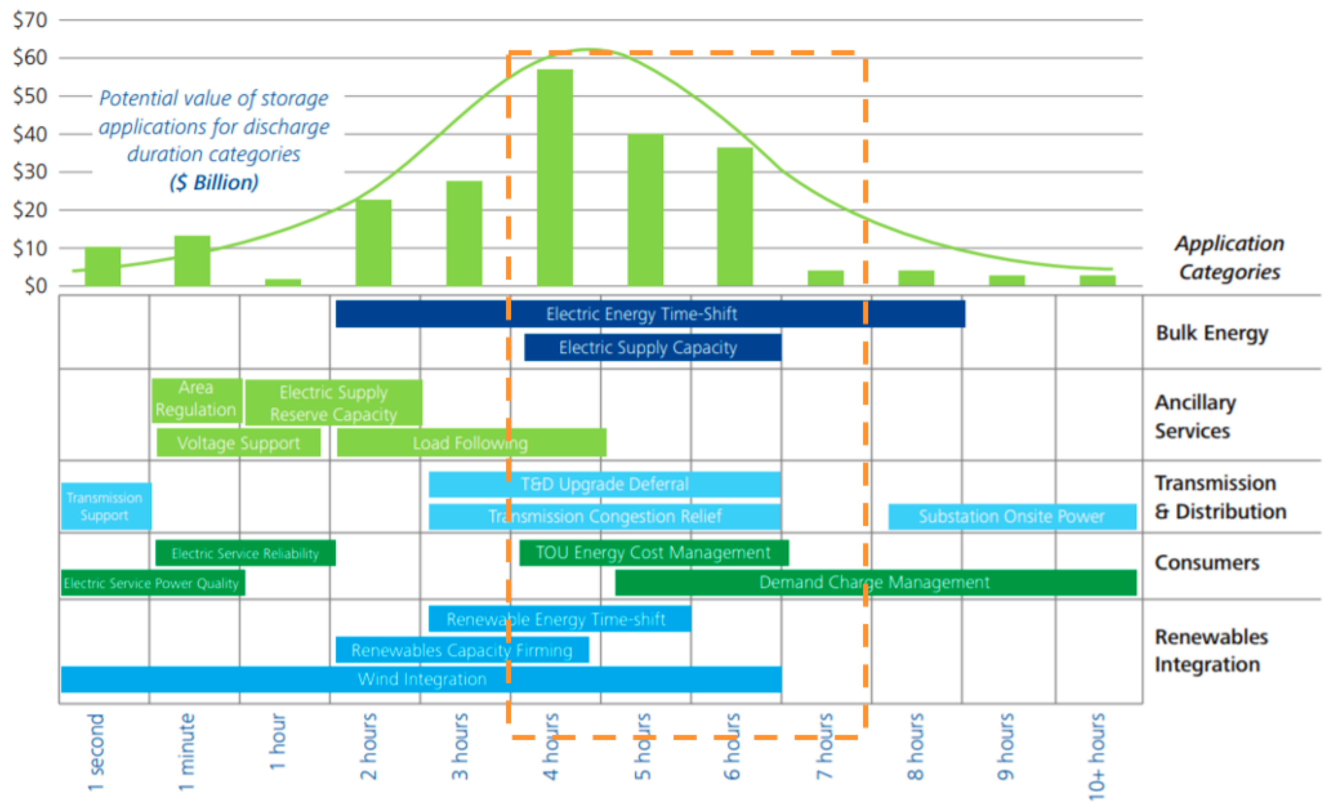
| | | |
|---|---|---|
| **5. Wind Generation Enhancement** | Co-location of battery assets on wind farms to store off-peak intermittent wind energy production and provide firmed on-peak energy at higher prices | 1. Increased revenues from off-peak to on-peak energy shifting<br>2. Avoided cost of curtailment<br>3. Improved capacity payments (i.e., wind as baseload generation)<br>4. Transmission upgrade deferral (depending on battery location) |
| **6. Grid Solar Photovoltaic (PV) Integration** | Installation of battery assets at or near the site of solar PV generation for energy smoothing/shaping to avoid necessary infrastructure upgrades | 1. Avoided cost of transmission or distribution system upgrade required for PV installation<br>2. Increased capacity and energy value (for utility/offtake) |
| **7. Behind-the-Meter Energy Management** | Installation of battery assets behind the customer meter to reduce end-user costs and participate in demand side management (DSM) programs | 1. Energy arbitrage (retail rates, or energy markets)<br>2. Demand charge reduction<br>3. DSM program payment(s)<br>4. Reliability & Power Quality |
| **8. Microgrids** | Deployment of batteries in conjunction with on-site generation and smart grid technologies to provide islanding capabilities and create a self-sufficient microgrid as needed | 1. Energy access, security, and reliability<br>2. Reduced energy consumption costs (when not in islanding mode) |

Source: Eos Energy Storage

### 1.1.3 Product Application Fit

Of the multiple use cases addressed, it is important to note the difference between power and energy applications. For these applications, some require technologies to provide bursts of power quickly, while others require energy delivered over an extended period. While the need for storage spans the value chain and includes multiple timescales, many grid-related applications cluster near the multi-hour discharge requirement. The variety of energy storage applications can be seen in Figure 5.

**Figure 4: Energy Storage Applications and Value per Discharge Duration**[7]




Source: Eos Energy Storage

Of the various energy storage applications, industry analysts expect applications with 3–6-hour discharge capacities to represent 75 percent of total value creation and generate the most value for utilities. Some of the use cases with the highest growth potential include solar and storage pairings for shifting and balancing, deferred production through peak shaving, transmission and distribution investment deferral, and locational capacity, as well as behind the meter demand management.8

Industry analysts suggest that the market for energy storage could be tremendous, although there is significant variation in the timing of the market growth due to differing cost assumptions. As shown in Figure 6, Bloomberg new Energy Finance predicts that the global battery energy storage market will reach $55 billion by the end of 2024.9

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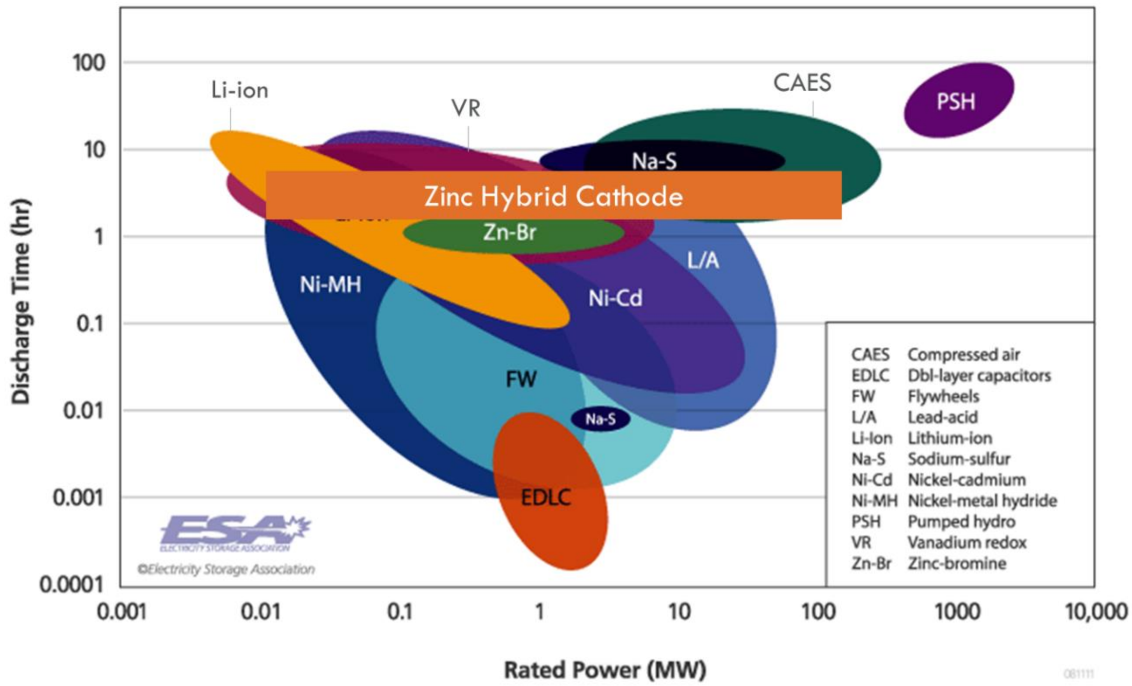
7 Energy Storage: Tracking the Technologies that will Transform the Power Sector, Deloitte. Published 2015.

8 Energy Storage: Tracking the Technologies that will Transform the Power Sector, Deloitte. Published 2015.

9 Bloomberg New Energy Finance. Global Energy Storage Forecast 2016-2024. Aug 16

**Figure 5: Power vs Energy Performance Characteristics of Common Energy Storage Technologies**



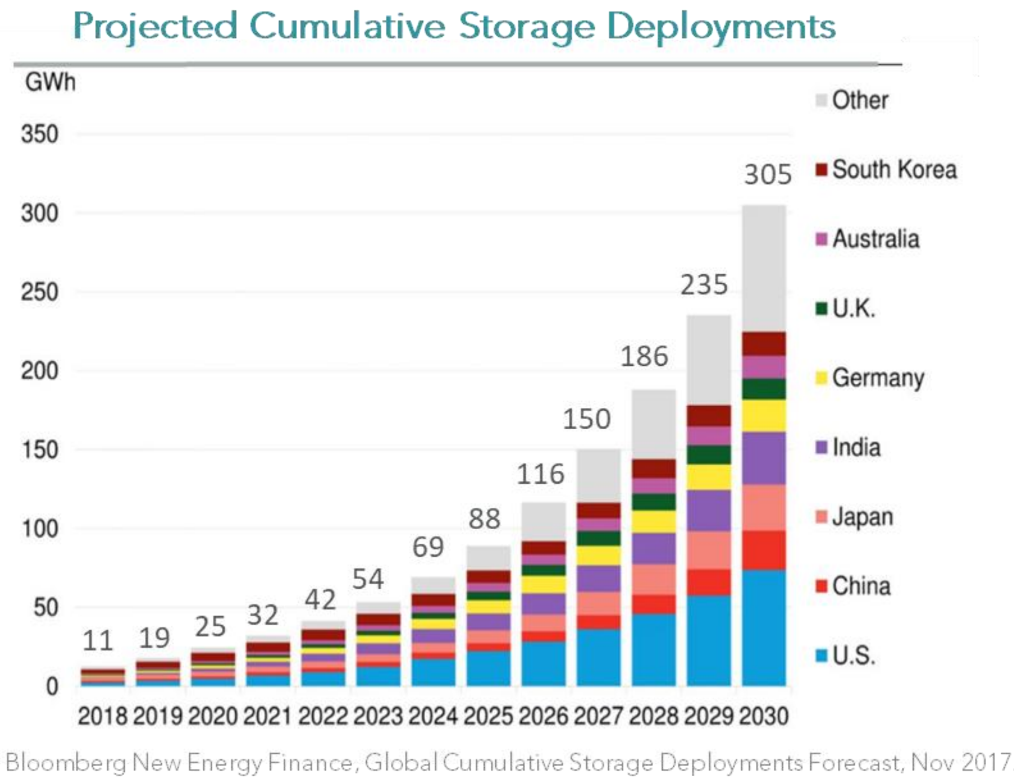

Source: Electricity Storage Association

No one single technology can address both power and energy applications. Some technologies are more suited for long duration, while others are suited for short discharge times. Each technology fills a niche of rated power vs discharge within a range. The Eos battery performance characteristics and discharge rate can compete with various technologies due to the wide spectrum of performance.

## 1.2. Growth of Energy Storage Industry

A congruence of technology advancement, cost reduction, and supportive policy are now paving the way for robust growth in the grid-connected energy storage market. Low-cost battery technologies, namely Eos' Znyth technology, are beginning to compete head on with incumbent peaking generation in capacity markets. The potential market size for peak shaving opportunity corresponds to the cost of the installed battery solution (relative to gas combustion turbines) and the incremental demand for new capacity resources. As such, the global energy storage market is primed for massive growth across all geographies; as shown in Figure 7.

**Figure 6: Global Energy Storage Market Forecast by Geography***10*




Source: Bloomberg New Energy Finance

Information Handling Services (IHS) reports that at a prevailing capital price of $300-500/kWh, energy storage is competitive with new gas fired combustion turbines in some areas, opening a market opportunity for 2.6 GW of storage in the U.S. At a capital cost below $300/kWh, energy storage becomes competitive in densely populated cities where it is difficult to site new thermal generation units, thus expanding the market opportunity for energy storage from 2.6 GW to 42 GW in the U.S. Further reducing the capital cost to below $200/kWh makes energy storage competitive with conventional generation in almost all locations, opening 85 GW of storage opportunity in the U.S.[11] The global market is estimated to be five times the size of the U.S. market.[12] Figure 8 summarizes the total market opportunity for batteries as a capacity resource in North America depending on the installed cost of the energy storage solution.

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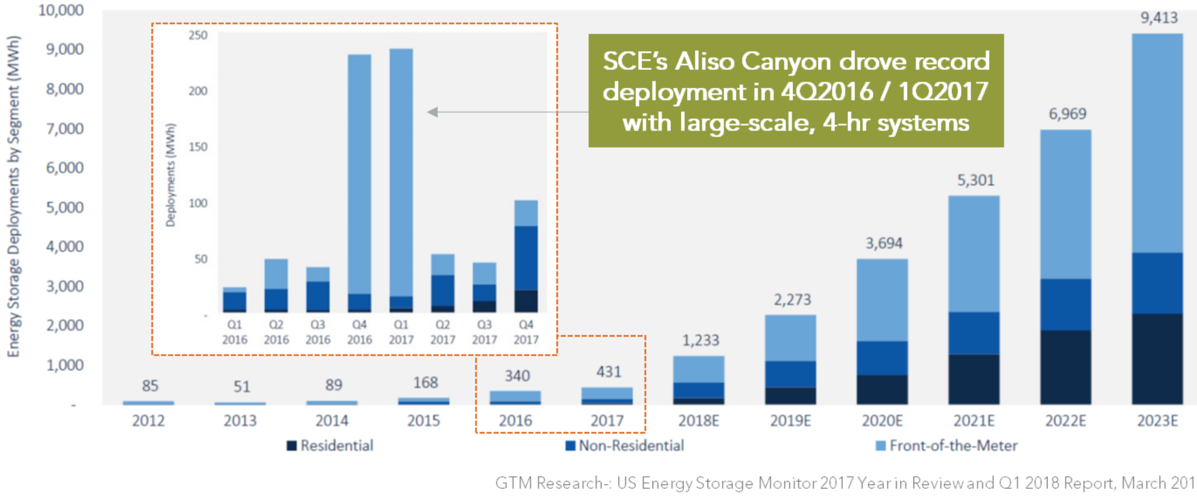
10 Bloomberg New Energy Finance. Global Energy Storage Forecast 2016-2024. Aug 16

11 *IHS Market Estimates, IHS. Published August 2014.*

12 *Energy Storage Technologies in Utility Markets Worldwide*, SBI Research, August 2010.

**Figure 7: Projected US Energy Storage Market**




Source: GTM Research

## 1.3 Energy Storage in California

California has been the epicenter of the energy storage market in the United States. Energy storage has seen strong support from the state on a regulatory basis along with grass roots support from the California communities. Today, there are calls from commercial and industrial consumers, helping to drive the incorporation of energy storage into California's energy market. The state overall is seeing the greatest push for energy storage integration and has the support and market incentives to drive the technology's market adoption.

As the power generation mix is changing within the country, it is at a greater scale and faster pace within the state of California. Where gas has become the marginal unit in today's power markets, California has taken initiative to start pushing gas resources out of the market to be fully replaced by clean renewable energy as seen with Senate Bill 100 (De León, Chapter 312, Statutes of 2018); the 2017 Aliso Canyon disaster being a prime example of why California would push for the change. The major issues with pushing a fast transition to go fully renewable is the intermittent supply the system receives from renewable power resources.

Energy storage can play a major role in filling the supply gaps and smooth the generation profile across the state. As the costs continue to come down for batteries as a whole, Eos' Znyth battery technology has the added advantage of solely using earth abundant resources in its chemical makeup. Eos' manufacturing capabilities still see opportunity for exponentially reducing costs through gained economies of scale, where li-ion batteries have already flattened out. Li-Ion batteries fight with demand from the rapid growth in electric vehicles, which are making a scarce resource even less obtainable, along with the major humanitarian risk li-ion sees in its upstream supply chain (the Democratic Republic of the Congo grew to roughly 70 percent of the worlds cobalt resource from 65 percent in 2018).[13] Eos' zinc-hybrid battery chemistry does not face current or foreseeable setbacks of any similar nature. As

13 *The Latest Storage Symposium Download: Prospects from Upstream-to-Downstream*. Bank of America Merrill Lynch. January 2019.

California and its constituents take pride in promoting the growth of the clean energy movement, they are also the perfect market to help set the standard in "clean" batteries that also have sustainable production like Eos' Znyth battery.

California originally established its Renewables Portfolio Standard (RPS) enacted in legislation in 2002. Subsequent amendments have resulted in requirements for electric utilities to have 50 percent of their retail sales derived from renewable sources by 2030. Interim targets are listed:

20 percent of retail sales by December 31, 2013

25 percent of retail sales by December 31, 2016

33 percent of retail sales by December 31, 2020

44 percent of retail sales by December 31, 2024

52 percent of retail sales by December 31, 2027

60 percent of retail sales by December 31, 2030

In 2013, AB 327 (Perea, Chapter 611, Statutes of 2013) was enacted allowing the California Public Utilities Commission (CPUC) to set requirements greater than those stated above. These early progressions into fortifying a strong green base paved the way for future legislation to further focus on technologies to support clean energy growth.

Legislation was enacted in September 2010 to support adopting requirements for utilities to procure energy storage systems in AB 2514 (Skinner, Chapter 469, Statutes of 2010). By October 2013, the CPUC adopted formal requirements for the three investor-owned utilities (Pacific Gas & Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company) to adopt procurement targets totaling 1,325 MW of energy storage by 2020.

With these bills enacted, the California legislature and market could dive deeper into building a strong energy storage plan for the state. AB 2868 (Gatto, Chapter 681, Statutes of 2016 was eventually enacted in 2016, ordering the additional procurement of 500 MW of behind-the-meter energy storage, helping to push the residential side of the equation to adopt the technology as well. The state also uses its self-generating incentive program (SGIP) to spur private installations of energy storage where it has earmarked $448 million in incentives with

$391 million for large-scale storage projects 10 kW or greater and $57 million for residential projects at 10 kW or less.[14]

The advanced progression of the energy storage market through policy and demonstrations in California has setup the state to act as the home of US energy storage standards. For these reasons, Eos believes California is the best market to showcase its technology and demonstrate how it can further help the energy storage movement reduce cost and improve efficiency for non-lithium storage technologies.

14 California PUC finalizes new 500 MW BTM battery storage mandate. Utility Dive. May 2017.

# CHAPTER 2: Project Approach

## 2.1 Technology Overview

The core of the Eos Energy Block™ is the Znyth (zinc hybrid cathode) battery technology, which employs a unique zinc-halide oxidation/reduction cycle to generate output current and to recharge. Eos' simple battery design includes three key components: bipolar electrodes (current collector and carbon cathode substrate), injection-molded plastic frames and an aqueous, near-neutral electrolyte. These materials are packaged in a sealed, flooded, bipolar battery design. There are no tanks, plumbing or electrolyte outside the battery case, no flow channels, or high-pressure seals. There is no membrane to foul or damage. Eos' Znyth technology is built on 21 patents and patent applications with over 600 claims covering cell configuration and architecture, cathode design and materials, electrolyte and electrolyte additives, battery management systems, and low-cost manufacturing processes. The Eos Zynth™ Battery is shown in Figure 9.

**Figure 8: Eos Zynth™ Battery Schematic**

Source: Eos Energy Storage

The Eos Znyth battery was chemically inspired by large-scale acid zinc plating baths, which produce uniformly smooth and bright zinc plating at massive production scales. These zinc electroplating operations use dimensionally stable titanium electrodes catalyzed with precious metals that are known to last at least 25 years. The key step in commercializing Eos' product was to invent titanium-based, dimensionally stable electrodes that didn't require precious metal catalysts.

In 2008, Eos developed and patented a proprietary conductive material that was inexpensive and durable enough to substitute for precious metal oxides on its titanium electrodes. These coated titanium current collectors maintain a stable resistance over years of operation, virtually eliminating another mode of battery degradation. The mechanical toughness, corrosion resistance and chemical stability of coated titanium current collectors allow for greater flexibility in the selection and combining of electrochemical reactions for energy storage.

As shown in Figure 10, the battery stores electrical energy through zinc deposition, similarly to industrial zinc electrowinning or a simple zinc plating bath. Aqueous electrolyte is held within the individual cells of the battery creating a pool that provides dynamic separation of the electrodes. Eos' current collectors consist of thinly rolled and formed metal with a proprietary ceramic coating which creates a conductive, non-corrosive anode surface upon which zinc is plated and dissolved during oxidation/reduction reactions. Eos' hybrid cathode reaction (illustrated above) produces solid and aqueous complexes contained within the electrode assembly when charged. Upon discharging, those complexes return to their free-flowing state within the electrolyte.

**Figure 9: Simplified Schematic of Eos Zinc Hybrid Cathode (Znyth) Technology**

**Zinc Halide Redox**


Source: Eos Energy Storage

The bipolar design of the electrode simplifies internal battery connections to reduce internal resistance and improve round-trip efficiency. Moreover, Eos' novel chemistry and design eliminate the need for a traditional membrane separator, cutting out significant cost and a common source of battery failure. During charge and discharge, ions move through the electrolyte to their respective electrode to donate or accept electrons, creating a current flow through the bipolar stack.

### 2.1.1 Advantages in Design

#### 2.1.1.1 Safe, Abundant Materials

Znyth batteries are made from only five non-toxic, nonvolatile materials that are inexpensive and plentiful – zinc, titanium, carbon, non-flammable plastic and salt water (aqueous electrolyte). Titanium and carbon are two of the most common elements on the planet (comprising 0.66 percent and 0.18 percent of the Earth's crust respectively), while zinc ranks 24th, at 0.004 percent. By comparison, lithium comprises a mere 0.0007 percent, nearly one sixth of zinc.

All the materials in the Znyth battery except the plastic are commonly found in the human body; indeed, zinc is an essential mineral necessary for good health. Titanium dioxide is found in many sunscreens and lipsticks.

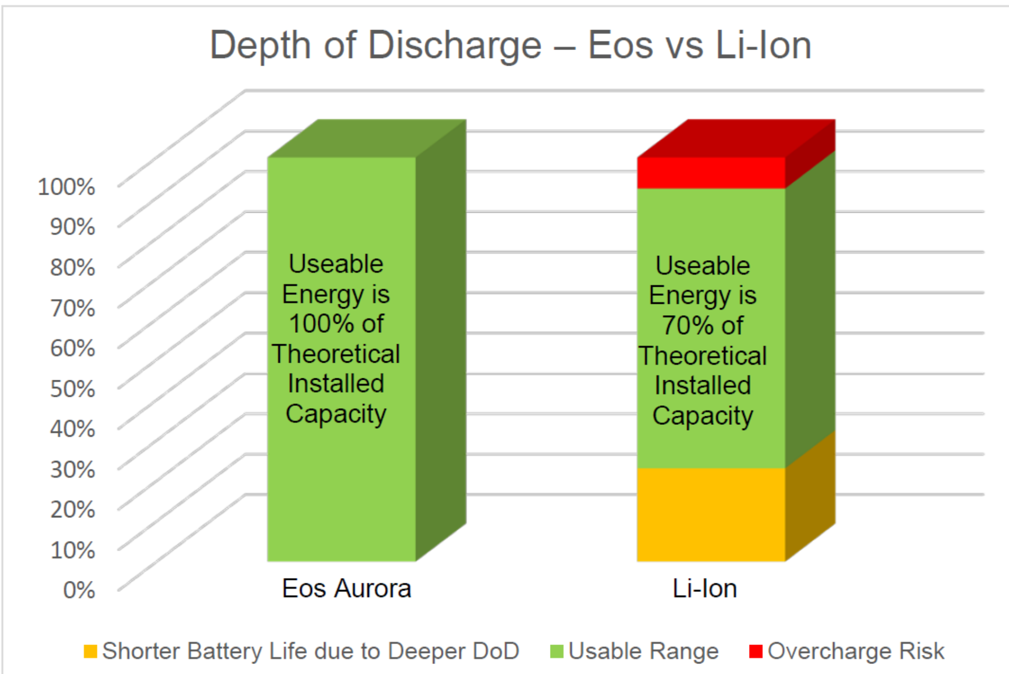
Eos' aqueous electrolyte is composed of water and a proprietary blend of halides, additives and buffering agents that enhance zinc solubility and plating. Eos' proprietary electrolyte formula eliminates dendrite and densification issues that inevitably plague virtually all other rechargeable zinc batteries. The electrolyte is non-hazardous when it is first manufactured and returns to that state when the batteries are fully discharged. The non-hazardous chemical classification simplifies shipping, storage, installation and end-of-life disposal and recycling. Eos' electrolyte formulation is non-dendritic and does not absorb $CO_2$, eliminating carbonate clogging issues. When fully charged, the electrolyte is mildly acidic (below pH 2) so any spills may be neutralized with baking soda or any commercially available acid spill kits.

Znyth technology is a zinc-based chemistry that includes an aqueous electrolyte that is non-flammable with no flashpoint and is encased in Underwriters Laboratories (UL) UL94-V0 flame retardant strengthened plastic. The battery is sealed, static, and tolerant to temperature extremes (-20C to 50C) and abusive conditions. Znyth batteries are manufactured fully discharged and ship as non-hazardous goods with a near-zero voltage, drastically simplifying the shipping and installation process.

### 2.1.1.2 Depth of Discharge

A battery's allowable depth of discharge (DoD) directly correlates to the percent of usable energy available within the battery relative to its nameplate ratings. The life span of lead-acid, li-ion and many other types of batteries depends heavily upon the number of charge/discharge cycles they undergo and the DoD for each cycle. Typically, the higher the DoD per cycle, the shorter the life span as measured by the number of cycles the battery can withstand while still providing acceptable performance to the customer. Although specific batteries can vary widely, it is a general characteristic of li-ion systems that the usable energy capacity is less than 100 percent of the theoretical capacity, with the standard being around 70 percent (although some li-ion companies claim 100 percent use). In addition, li-ion batteries become unstable if they are fully discharged and can result in damage to the cell. This can be seen in Figure 11.

**Figure 10: Comparison of Depth of Discharge Between Eos and Li-Ion**




Source: Eos Energy Storage

In contrast, Eos Znyth batteries allow for 100 percent DoD, with no restrictions affecting battery life span or performance. With a full 4 hours of discharge capability, Eos batteries are designed for a 100% DoD daily duty cycle. Compared to Eos, most li-ion batteries will require greater up-front capital investment to accommodate an extra 30% of theoretical battery capacity that will never be used.

#### 2.1.1.3 Flammability

Eos' Znyth technology features a non-flammable aqueous electrolyte that can operate safely across a much wider voltage and temperature range than li-ion, with almost zero risk of catastrophic failure. Even under the most adverse thermal runaway conditions, such as a short or battery management failure, the realistic worst-case scenario involves battery cells leaking electrolyte into their housing.

Li-ions shuttle through an inherently flammable liquid electrolyte from one electrode to the other when the battery is being charged. If these batteries are overcharged or if there's an internal or external short circuit, thermal runaway can cause the batteries to spontaneously combust. In an energy generation installation, a fire can easily set off a catastrophic chain of destruction. Preventing thermal runaway in li-ion batteries requires complex and sophisticated battery management, fault-free HVAC systems, and reliable fire suppression.

#### 2.1.1.4 Over-Charge and Short-Circuit Resiliency

To test the over-charge and short-circuit resiliency, Eos Znyth batteries were over-charged at maximum charge rate to twice the rated amp hour (Ah) capacity, then monitored for thermal runaway. Even under these conditions the battery did not emit smoke, fire, electrolyte leakage, or any high temperature excursion. If fact, even though the battery is not required to operate after the UL 2596 test, the Eos battery preserved almost all its operational performance after the test was completed.

To determine the maximum sustained short-circuit current of the battery, the terminals of a fully charged battery were connected to a remote-actuated contactor with an in-line current shunt, which was then connected to a data-logger. A thermal forward-looking infrared (FLIR) camera recorded surface temperature uniformity. The contactor was closed, creating a direct short-circuit path between the terminals, and the resulting current was recorded. The short circuit was maintained until the measured current was stable at a decayed value.

This example test assembly proved to yield a maximum current of <350 Amps and 70°C (specifications highlighted in Figure 13). The only cooling was from natural convection in a 20°C laboratory. This testing also confirmed that if the fuses and circuit breaker were to fail within the Eos Energy Block™ system, the cable assembly would not catch fire. No electrolyte or hazardous materials were ejected or vented from the pressure relief valves during the test. The benign behavior of the batteries under short circuit were confirmed with similar tests conducted on site at UL.

#### 2.1.1.5 Toxicity

Due to the adverse effects of exposure to lithium, the manufacturing, storage, shipment, installation, removal, and disposal of li-ion batteries is highly regulated to prevent accidental discharge that could lead to lithium toxicity. Large-scale use of li-ion batteries raises concerns about containment in the event of unexpected exposure (such as auto accidents, electrical fires, spillage.)

Eos' electrolyte is non-hazardous in the as-manufactured state and returns to that state whenever the batteries are fully discharged. The electrolyte is corrosive when fully charged due to an acidic pH level (<pH 2) and could contain modest concentrations of hypo-halite species. In the unlikely event of an electrolyte spill, baking soda and a normal spill kit can be used, accompanied by applicable personal protective equipment (PPE), to neutralize and clean-up discharged electrolyte.

#### 2.1.1.6 Off-Gassing

Off-gassing occurs when batteries are overcharged, which can result in electrolyte gases being released from the cells. For li-ion systems, hydrogen off-gassing protection is highly prioritized due to its volatility, so sensors are used to detect its presence in parts per billion. Sensors also typically detect dimethyl and diethyl carbonates, hydrocarbons, and volatile organic compounds.

During abuse testing of the Znyth battery, the hydrogen generation was negligible (~ 6 microliters per minute), so hydrogen monitoring is not required. The Eos enclosure also features a chimney effect convection cooling design that will automatically dissipate the small amount of hydrogen that could be outgassed. In addition, stacked enclosures can be fitted with a forced-air ventilation system if the natural convection air flow is deemed insufficient for venting purposes.

#### 2.1.1.7 Sustainability

Eos' Znyth battery is 100 percent fully recyclable at the end of its life. Applying a "cradle-to-cradle" philosophy to minimize waste across the entire product lifecycle, Eos incorporates a simple, six-part battery design for easy disassembly into environmentally friendly base materials. All major components of the battery have high salvage value and are fully recyclable. The Znyth aqueous electrolyte is composed of water and salts (halides) that can be separated via evaporation and recycled. The inherently safe, non-toxic, and non-volatile battery design minimizes risk in transportation and installation. Eos batteries also eliminate the need for parasitic energy consumption directed to HVAC in most cases, as required by most li-ion systems.

### 2.1.2 Eos Energy Block™ System Overview

The Eos Energy Block™ direct current (DC) battery system is designed specifically to meet the requirements of the grid-scale energy storage market. With 4-12 hours of continuous discharge capability, immediate response time, and modular construction, the Eos Energy Block™ DC battery system can be scaled and configured to reduce cost and maximize profitability in utility, commercial, and industrial markets. Each Eos Energy Block™ DC battery system includes DC batteries packaged into a system including an outdoor-rated enclosure, Battery Management System, and wiring connections. The Eos Energy Block™ DC battery system is optimized for 100 percent depth of discharge, every day throughout its lifetime and has flexible application to meet site-specific conditions.

The specifications in Table 2 describes the Eos Gen 2.3 Zynth™ Battery.

**Table 2: Table of Eos Zynth™ Battery Product Specifications**

| Characteristic | Units | Parameter |
|---|---|---|
| Nominal Voltage | $V_{DC}$ | 64 |
| Charging Voltage @ 833 W | $V_{DC}$ | 75 |
| Voltage Range | $V_{DC}$ | 48 to 82 |
| Rated Power | kW | 0.833 |
| Maximum Rated Energy | kWh | 3.5 |
| Rated Energy @ Nominal Power | kWh | 3.2 |
| State-of-Charge Range | % | 0 – 100 |
| Nominal Discharge Capacity | Ah | 51.8 |
| Nominal Charge Capacity | Ah | 59 |
| Nominal Discharge Current | $A_{DC}$ | 13 |
| Nominal Charge Current | $A_{DC}$ | 10 |
| Maximum Current | $A_{DC}$ | 18 |
| Short Circuit Current (pk) | $A_{DC}$ | 425 |
| Short Circuit Time Constant (L/R) | | < 5ms |
| Peak Round Trip DC Efficiency | % | 78 |
| Self-Discharge (@ 25-35 °C) | % | 1% / hr @ 100% SOC |
| Certifications | | UL 1973, UL 9540A |
| Optimum Operating Temperature | °C | 10 to 45 |
| Full Operating Temperature (Ambient) | °C | -20 to 55 |
| Dimensions (H x W x D) | in (mm) | 15.2 x 16.9 x 23.0<br>(386 x 428 x 585) |
| Weight | lbs (kg) | 215 (98) |

Source: Eos Energy Storage

The following specification describes the Eos Energy Block™ Battery System, specifically a 150 kW/500 kWh system. Tables 3, 4, and 5 highlight the specifications characteristics of the Energy Block™.

**Table 11: Table of Eos Energy Block™ Product Specifications**

| Energy Block System Specification | Unit | Value |
|---|---|---|
| Nominal System Power | kW | 120 |
| Maximum Power during Discharge | kW | 120 |
| Maximum Power during Charge | kW | 150 |
| Maximum Delivered Energy | kWh | 500 |
| Delivered Energy @ Nominal Power | kWh | 460 |
| SOC Operating Range | % | 0 - 100 |
| Average Discharge Voltage | $V_{DC}$ | 768 |
| Nominal Charge Voltage | $V_{DC}$ | 907 |
| Minimum Operating Voltage | $V_{DC}$ | 600 |
| Maximum Operating Voltage | $V_{DC}$ | 980 |
| Nominal System Current Discharge | $A_{DC}$ | 156 |
| Nominal System Current Charge | $A_{DC}$ | 132 |
| Maximum Charge Current @ 900 VDC | $A_{DC}$ | 167 |
| Maximum Discharge Current @ 600 VDC | $A_{DC}$ | 200 |
| Peak Round Trip DC Energy Efficiency | % | 78 |
| Response Time | ms | < 5 |
| Storage/Initial Start Voltage | $V_{DC}$ | 0 |
| Self-Discharge (@ 25-35 °C) | % | 1% / hr @ 100% SOC |
| Communication | | Modbus TCP/IP |
| Balance Process | | Active |
| SOC Accuracy | % | < 10% |

Source: Eos Energy Storage

**Table 4: Eos Energy Block™ Physical Characteristics**

| Specification | Unit | Value |
|---|---|---|
| Eos Energy Block, Footprint (L x D x H) | ft<br>(m) | 20 x 8 x 9.5<br>(6.1 x 2.4 x 2.9) |
| Eos Energy Block Weight | lbs (kg) | 45,525 (20,650) |

Source: Eos Energy Storage

**Table 5: System Environmental Characteristics**

| Environmental Specification | Unit | Value |
|---|---|---|
| Nominal Operating Ambient Temperature Range | °C (°F) | 10 to 45 (50 to 113) |
| Full Operating Ambient Temperature Range | °C (°F) | -20 to 50 (-4 to 131) |
| Storage Temperature | °C (°F) | -20 to 70 (-4 to 158) |
| Ambient Relative Humidity | % | 5 to 95 (non-condensing) |
| Energy Block Enclosure Rating | | NEMA 3R \| IP54 |
| Maximum Operating Altitude | ft (m) | 3280 (1000) |
| Thermal Management | | Forced Ambient Air |
| Seismic Rating | | Zone 3 |
| Acoustic Noise Level | dBA | < 75 at 1 m |

Source: Eos Energy Storage

### 2.1.3 Battery Management System Overview

The BMS monitors the battery strings through various sensors. The BMS includes low-level safety control of the battery by both disconnecting an Energy Stack™ in the event of an abnormal condition and providing warning, or alarm, statuses to external systems. In addition, the system includes automated sequences to connect parallel strings and to bring the system to rest mode. The BMS behaves as a slave on the Modbus TCP network and will transmit pertinent battery data to external controls. The BMS stores operational battery data, which may be downloaded later. Characteristics of the BMS are highlighted in Table 6.

**Table 612: BMS Characteristics**

| Specification | Unit | Value |
|---|---|---|
| Communications External | | SunSpec Compliant Modbus TCP/IP |
| Modbus Termination | | RJ45 |
| BMS Power Alternating Current (AC) | Volts-AC (VAC) | 120 or 240 |
| Enclosure Rating | | NEMA 4 |

Source: Eos Energy Storage

The main component of the BMS is the BMS Controller, the main interface to external systems. The BMS controller is a master controller that collects data from string level BMS controllers which aggregate the data being provided by the Zynth™ battery modules – inclusive of voltage, temperature, current, state of charge, etc. An example, simplified BMS single-line diagram (SLD) is shown in Figure 12.

**Figure 12: BMS Simplified One-Line Diagram**

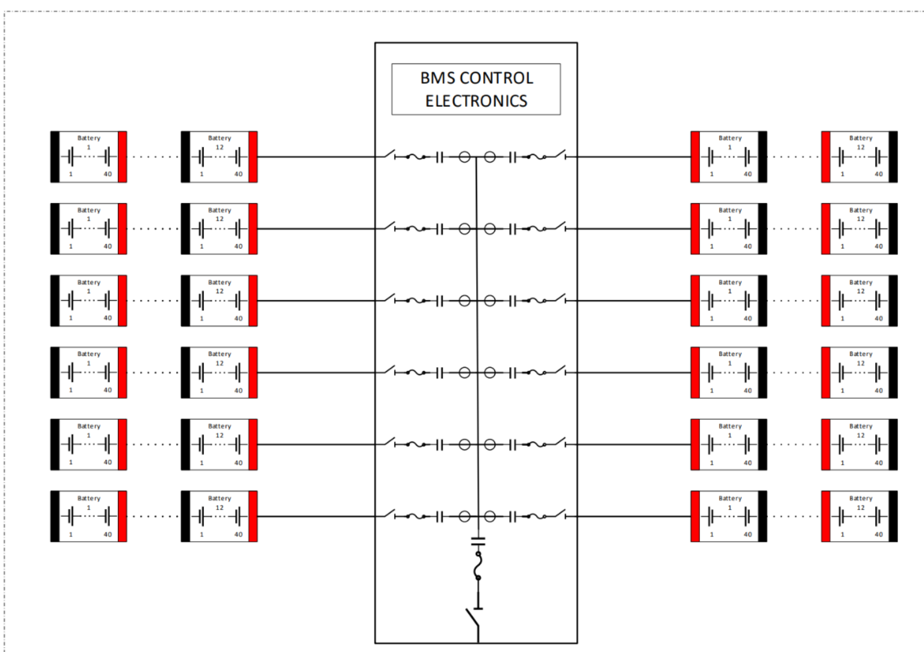



Figure 1: Simplified One-Line Diagram for Eos Energy Block

Source: Eos Energy Storage

### 2.1.4 Thermal Management Overview

The Eos Gen 2.3 Energy Block™ system contains ventilation fans and side airways. The ventilation fans are utilized to maintain adequate airflow through the Energy Block™. Ventilation fans are shipped loose[15], directly to the customer, and installed in the field.

Due to the electrolyte chemistry of the Eos Zynth™ battery module, there is no need for additional HVAC or cooling systems required. As a zinc-aqueous based solution, there is no risk of thermal runaway or need for fire suppression.

[15] Covers/caps are installed prior to shipment of all Energy Blocks™ to ensure a seal from the outside environment

# CHAPTER 3: Results

## 3.1 Partnership Overview

### 3.1.1 SDG&E

The San Diego Gas and Electric company (SDG&E) is an Investor-owned utility. SDG&E owns the facility in which the Eos BESS was installed and also is the interconnected utility.

### 3.1.2 CEC

The California Energy Commission is the primary energy policy and planning agency for California. This project was funded by a CEC provided grant (EPC-18-023)

### 3.1.3 Indie Energy

Indie Energy is an Energy Management System (EMS) provider and integrator. Indie Energy provided the EMS, the main overall system site controller, for this grant.

## 3.2 Project Scope

### 3.2.1 Characterization Testing

The first group of procedures are the functional performance tests that determine energy storage system performance in comparison to the supplier’s advertised specifications. These procedures are intended to be energy system technology indifferent and not used to rate or rank the various technologies against each other. Rather, they provide valuable information to utilities and other interested parties as to what performance and functional capabilities a particular technology can provide and how well with respect to the manufacturer’s claims.

The following Energy Storage System Capacity or Available Discharge/Charge Energy at Rated Power test procedure, highlighted in section 3.2.2, is one in a series of detailed procedures developed by the Electric Power Research Institute (EPRI) in concert with the Performance Working Group of the Energy Storage Integration Council. The combined set of procedures make-up the EPRI Utility User’s Guide for the performance testing of energy storage systems. The objective is to provide specific, detailed test procedures that are reproducible so that utilities and other test laboratories can easily use them for the performance evaluation of energy storage systems.

### 3.2.2 Functional Performance Testing

The Eos Energy Storage Gen 2.3 energy storage system were tested for functional capability using the procedures listed below. As a representative example of the rigor of these procedures, the Draft Round Trip Efficiency procedure has been included.

EPRI Utility Energy Storage Users Guide, Functional Performance Test Procedures 1-8:

1. Round Trip Efficiency
2. Available Discharge Energy at Rated Power (Capacity)
3. Charge Duration
4. Rated Continuous Discharge Power
5. Rated Continuous Charge Power
6. Rated Continuous Reactive Power
7. Auxiliary Load Determination
8. Response Time, Rise Time (Ramp Rate), Settling Time to Steady State Operation

## 3.3 Manufacturing and Installation

The Eos Gen 2.3 batteries were manufactured on site within Eos' state of the art facility in Turtle Creek, Pennsylvania. These batteries were created through automated processes, as well as by hand, along an assembly line. Figures 13, 14, and 15 highlight portions of the manufacturing process assembly line at the Turtle Creek facility.

**Figure 13: Battery Cores on an Assembly Line**

Source: Eos Energy Storage

**Figure 14: Automated Welding Equipment**

Source: Eos Energy Storage

**Figure 15: Semi-automated Cell Gluing Station Equipment**

Source: Eos Energy Storage

Quality assurance and testing were conducted between assembly stages to ensure product consistency – shown in Figure 16.

**Figure 16: Battery Quality Assurance and Testing Process**

Source: Eos Energy Storage

## 3.4 Instrumentation and Testing Set Up

Instrumentation was installed to measure the energy storage system performance for various tests. The system parameters measured included, but were not restricted to, power (W), current (I), voltage (V), power factor (pf), frequency (Hz) and total harmonic distortion (THD, percent). Additionally, ambient temperature (°C), was also monitored. Power meters for measuring AC were installed at three locations; the output line of the isolation transformer, or point of common coupling, the input line to the 400-kW load bank, and the output line from the panel board. Additional power meters were installed between the isolation transformer and power conversion system and on the DC conductors between the battery and the power conversion system. All instrumentation had current calibration records and were subjected to calibration verification during the test. All instrumentation used were required to meet the criteria for measurement accuracy and logging rate.

### 3.4.1 Measurement Accuracy and Logging Rate

#### 3.4.1.1 Voltage, (V)

Voltage measurements were performed using potential transducers (PTs) selected for the appropriate voltage characteristics (AC or DC) and operating range and coupled with a suitable power monitor with a minimum sampling rate of at least 128 samples per 60 Hz cycle. System accuracy shall be within ±3 percent of indication with voltage measurements reported as root mean square (RMS) values.

#### 3.4.1.2 Current, (I)

Current measurement was performed using current transducers (CTs) selected for the appropriate operating range and coupled with a suitable power monitor with a minimum sampling rate of at least 128 samples per 60 Hz cycle. System accuracy shall be within ±3 percent of indication with current measurements reported as RMS values.

#### 3.4.1.3 Power Factor, (pf)

Power factor measurement was performed using the PTs and CTs noted above in conjunction with a suitable power monitor with a minimum sampling rate of at least 128 samples per 60 Hz cycle. System accuracy shall be within ±0.02 of indication with pf measurements reported as true pf.

#### 3.4.1.4 Power, (W)

Power measurement was performed using a suitable power monitor with a minimum sampling rate of at least 128 samples per 60 Hz cycle. System accuracy shall be within ±3 percent of indication.

#### 3.4.1.5 Energy, (E)

Energy measurement was performed using a suitable power monitor with power over time integration capability and a minimum sampling rate of at least 128 samples per 60 Hz cycle. System accuracy shall be within ±3 percent of indication.

#### 3.4.1.6 Ambient Temperature, ($T_A$)

Ambient temperature measurement was performed using resistance temperature detectors (RTDs) selected for the appropriate operating range and coupled with a suitable transmitter. System accuracy shall be within ±0.5 °C.

## 3.5 Commissioning

### 3.5.1 Commissioning Site Safety and Health

Health and safety risks were identified and evaluated by SDG&E and Eos Energy Storage. During the creation of the commissioning plan and testing program, all aspects of the work, including site risks, were evaluated to minimize or eliminate exposure to those risks to complete the test program in a safe manner. The following sub-sections are specific areas that were reviewed for satisfactory adherence.

#### 3.5.1.1 Administrative Controls

A pre-job safety plan with job hazard assessment was completed by SDG&E prior to delivery and set-up of the energy storage system. The Site Safety Orientation was completed by all Eos employees and sub-contractors prior to beginning work at the facility. Daily Safety Tailboards were mandatory to review the work for the day and to discuss all safety requirements for each job. All Safety Tailboards were documented.

### 3.5.1.2 Electrical Safety

Clearance procedures, underground/overhead utilities, confined spaces, high voltage clearances, hazardous materials, were issues that needed to be considered when performing this project. Each worker had to take the precautions necessary to protect all persons (employees of Eos Energy Storage, SDG&E, and third parties, including members of the public), and property (of Eos Energy Storage, SDG&E, and third parties) from exposure to these risks. At a minimum, Eos Energy employees and their sub-contractors complied with all federal, state, local, and any other regulations that apply to the work.

SDG&E notified Eos Energy Storage and their sub-contractors of any specific electrical safety requirements, such as arc flash boundaries, PPE required including flame retardant clothing and others that must be adhered to while working onsite.

The inverter enabling grid connection of the Eos Energy Storage Energy Block™ energy storage system was certified UL-1741 compliant. Should power on the grid circuit be lost for any reason, the energy storage system would trip offline and remain in the off status until power to the grid is restored. For safety reasons, once grid power is restored the energy storage system would not be allowed to restart automatically but is required to have operator intervention to restart grid connected charge and discharge activities.

### 3.5.1.3 Chemical and Environmental Hazards

All SDG&E employees, Eos Energy Storage employees, and third parties have a right to know what chemicals they have possible exposure to. The ATS Chemical Hygiene Officer was notified regarding the types and quantities of chemicals in use through provided Safety Data Sheets. In addition to the chemicals themselves, Eos Energy Storage provided safety information on potential breakdown products in the event of a spill or fire in the energy storage system container.

The Eos Energy Storage Energy Block™ energy storage system was designed for secondary containment to contain all chemicals that may be released. ATS site environmental requirements do not allow for the release of any chemicals, particularly down the storm drains. Additional spill containment kits were required to ensure no environmental release occurs.

#### 3.5.1.4 Fire Suppression and Notification

The Eos Energy Storage Energy Block$^{TM}$ energy storage system included a fire detection system within the system container. The fire detection system was certified to be fully functional by an appropriate certifying body, such as the local fire department. Fire sensors such as smoke or flame detectors must provide local alarm both audial and visual as an early warning to employees and the public. SDG&E worked with Eos Energy Storage and the local fire department regarding appropriate first response measures to take in case of fire.

#### 3.5.1.5 Emergency Shutdown

Emergency Shutdown Devices (ESD) was installed at two locations outside the fenced boundary of the test yard. These ESD buttons were able to shut down the energy storage system operation and disconnect the energy storage system from the grid. The ESD's were placed in a location that was easily accessible, well-marked and identifiable. The test team was trained in their use.

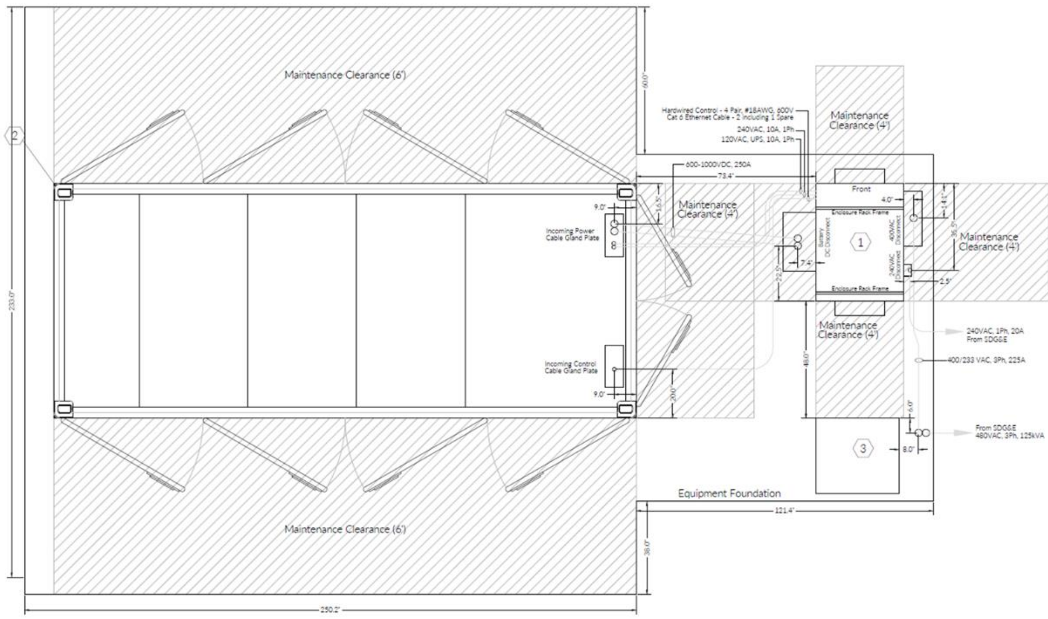
## 3.6 Installation

The Eos Energy Storage Energy Block$^{TM}$ energy storage system arrived as a fully integrated unit. The 150 kW/500 kWh energy storage system was paired with a LS Energy Inverter providing DC to AC power conversion, an Eaton Transformer providing the necessary step-up point of interconnection voltage and an Indie Energy Energy Management System providing intelligent control for the operation of the entire system.

### 3.6.1 Test System Layout

Shown in Figure 17 is the overall Energy Storage System layout at the Pala Del Norte facility. The main system components consist of (1) Eos Energy Block$^{TM}$, (1) LS Energy Inverter, (1) Eaton Transformer, and (1) Indie EMS system installed and tied into the SDG&E facility.

**Figure 1713: The Eos Energy Storage System Sited at Pala Del Norte's Facility**

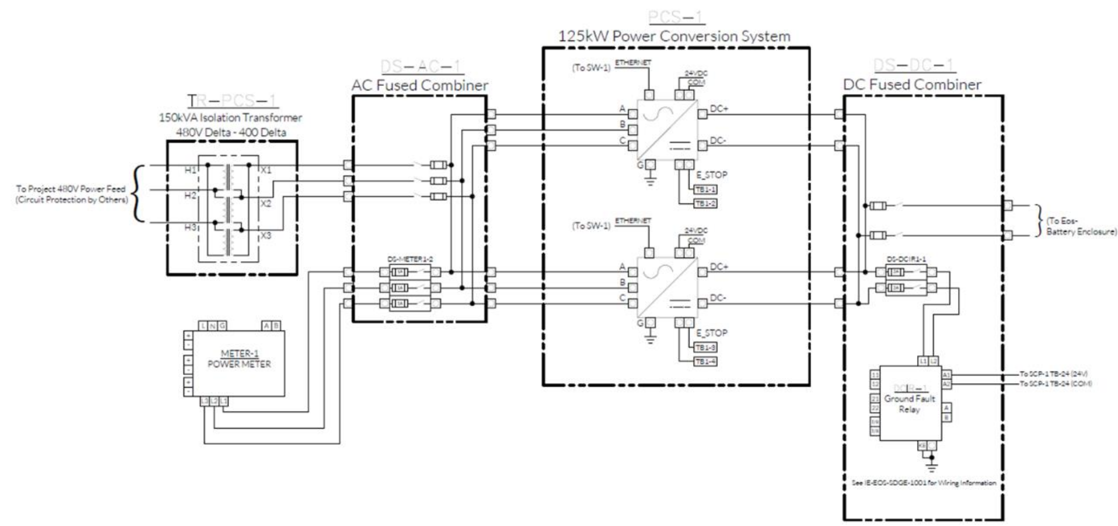



Source: Eos Energy Storage

## 3.6.2 Test System Installation and Interconnection

Shown in Figure 18 is the single line diagram of this circuit with all necessary electric equipment needed for this test. The energy storage system was directly connected to a 150 kilo-volt-amperes (kVA) isolation transformer set-up in the Y/Δ configuration. Power was transferred to and from the energy storage system operating at nominal 480 VAC.

**Figure 18: Single Line Diagram of the Eos Energy Storage System Grid Interconnection**




Source: Eos Energy Storage

### 3.6.3 Communication

Communication with the Energy Block™ energy storage system was facilitated by direct cable connection from the local cable provider. CAT 6 Ethernet cable was routed from the control room to the energy storage system, providing the link up to the cable provider. A wireless modem was used to provide access to archived test result data and real time monitoring of the energy storage device condition. Thus, alarm indication and system status could be monitored remotely through this system. However, no operational control was permitted over this communication system due to SDG&E policy of not allowing external entities remote operation capability of assets located on facilities.

### 3.6.4 Installation Analysis – Previous Projects

In 2017 and 2018, with support from the Energy Commission from PON-13-302, Eos prototyped its Gen1 battery (Technology Readiness Level (TRL) 6) and delivered a 75 kW AC-integrated system for testing with SDG&E at the company's San Ramon Technology Center (SRTC) in California. The project represents first time the technology was used in a grid-connected application and resulted in extremely valuable learnings relating to battery mechanical design to improve reliability, system design to support serviceability, improvement of battery management system controls and functionality, development of manufacturing processes to improve quality control and throughput, and development of partners and capability for system deployment and maintenance. Figure 19 includes photos of key milestones in the project from system integration at First Priority Green Fleet's facility in Stockton to installation and commissioning of the system at SDG&E's SRTC. The system was operated by SDG&E under a prescribed test program with DC system efficiency recorded at 59-78 percent depending on use case and operating conditions.

**Figure 19: Integration, Installation, and Commissioning of the 75kW AC-integrated System for Testing With SDG&E at the San Ramon Technology Center**

Source: Eos Energy Storage

In late 2018 to early 2019, Eos incorporated many of the lessons learned from its Gen1 deployment to create a more robust offering for the marketplace. Enhancements of the Gen2 product (TRL 7) include:

- Mechanical redesign of the battery module to replace gaskets (or O-rings) used to seal the battery with an industrial, heat-activated glue.
- In-house development of the BMS to offer battery-level monitoring as opposed to string-level monitoring.
- Transition from bespoke system design to an industrial cabinet/enclosure with racking that allows for easy battery replacement and full access to all electrical components.

At this time, Eos had prototyped three Gen2 Beta systems and was in the process of adapting this design to serve behind-the-meter commercial/industrial applications in partnership with the University of California San Diego through a second contract with the CEC awarded under PON-13-203. These projects are shown in Figure 20.

**Figure 20: Project Installations in Locations Outside California**

**Left to right: (1) testing Eos' first Gen2 system at its HQ in Edison, NJ, (2) 120kWh pilot system deployed in India, (3) 1MWh system at the PSE&G microgrid in New Jersey.**

Source: Eos Energy Storage

## 3.7 Project Test Plan & Results

### 3.7.1 Project Testing Overview

After a successful commissioning phase of the Eos Gen 2.3 system installed for this project, the system was proposed to undergo a variety of tests to demonstrate overall system capability. The ultimate goal of this project and this testing was to demonstrate the advancement of the Eos technology, from previous generations to the current Gen 2.3 Energy Block: specifically on increased performance level of greater energy density and therefore throughput. The measure of success in achieving the goal of the project is comparing average energy discharged from the system against the defined system specifications.

### 3.7.2 System Test Plan

Appendix A highlights the proposed test plan and system use cases provided by Eos for the EPC-018-23 project.

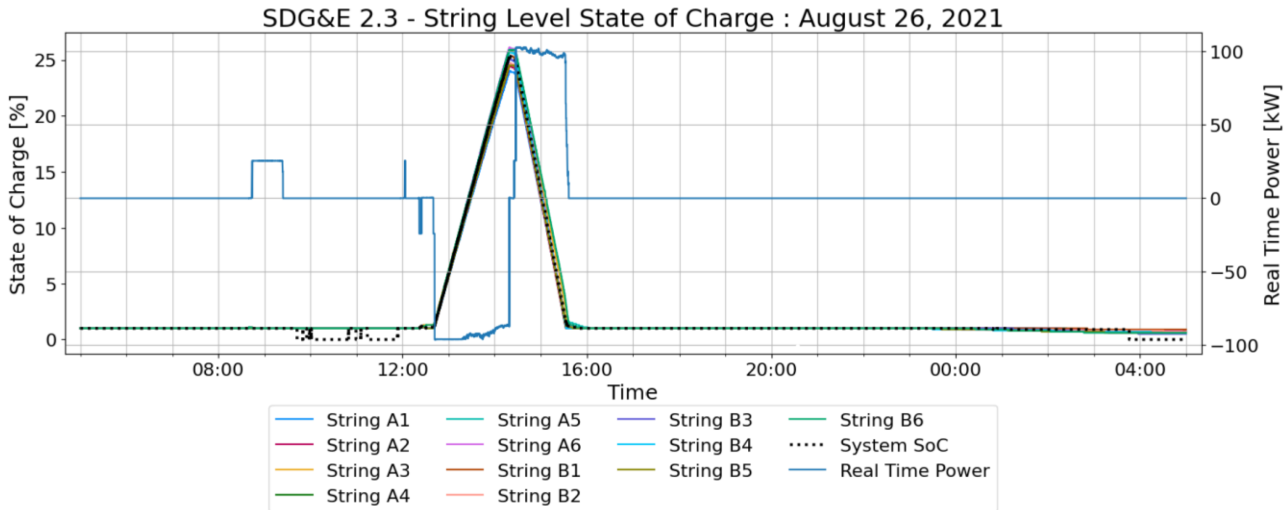
### 3.7.3 Project Results

Over the multiple years of this project, the Eos BESS installed at the Pala Del Norte site underwent a variety of operational charge and discharge cycles. Eos was able to collect data through a cloud based network and analyze it to understand system performance based on varying parameters. The following selection of data sets are a few examples of what Eos collected, given the large data population that was gathered.

#### 3.7.3.1 Example: August 26, 2021

As seen in Figures 21 and 22, the Eos Energy Block™ underwent a 25 percent charge cycle on August 26, 2021. After analyzing the data, it was found that this cycle produced 70.81kWh over a ~2-hour discharge and had an overall cycle efficiency of 49.75 percent.

**Figure 21: String Level State of Charge – August 26, 2021**




Source: Eos Energy Storage

**Figure 22: Eos Energy Block™ Performance Summary – August 26, 2021**

SDG&E 2.3 - Energy Block Performance Summary

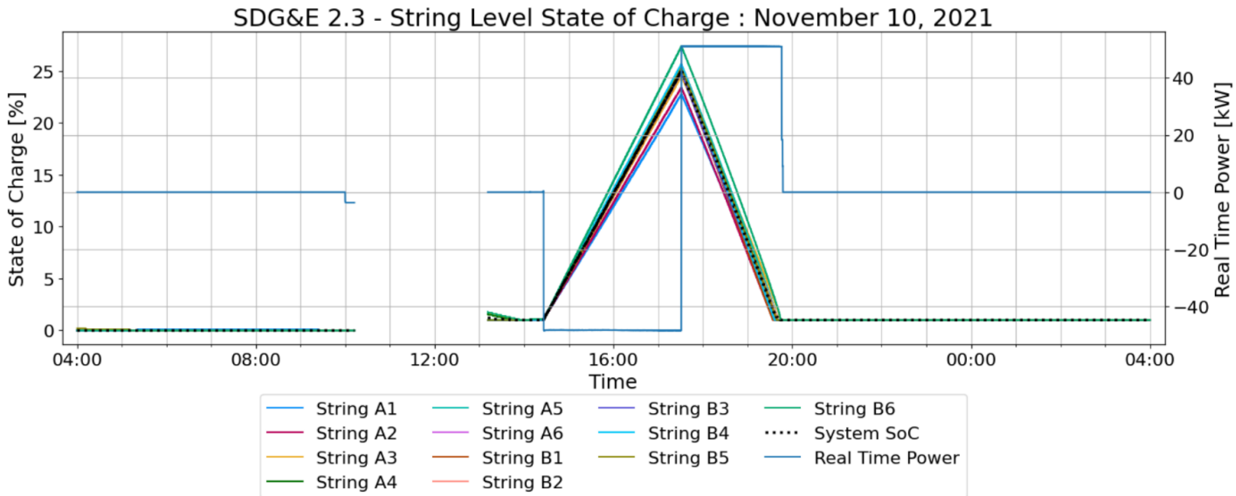
| | | | |
|---|---|---|---|
| Cycle start | 2021-08-26 04:00:00 | Total discharge energy | 70.81 kWh |
| Cycle end | 2021-08-27 04:00:00 | Total charge energy | 142.34 kWh |
| Charge duration (h:m:s) | 1:34:13 | Max. state of charge | 25.30 % |
| Discharge duration (h:m:s) | 2:02:22 | Energy efficiency | 49.75 % |
| String charge power limit | 10.00 kW | Coulombic efficiency | 58.64 % |
| String discharge power limit | 10.00 kW | Min. temperature | 24.10 °C |
| Avg. discharge power | 34.72 kW | Max. temperature | 38.20 °C |
| Avg. charge power | 90.65 kW | Avg. temperature | 31.85 °C |

Source: Eos Energy Storage

### 3.7.3.2 Example: November 10, 2021

As seen in Figures 23 and 24, the Eos Energy Block™ underwent a 25 percent charge cycle on August 26, 2021. After analyzing the data, it was found that this cycle produced 70.81kWh over a ~2-hour discharge and had an overall cycle efficiency of 76.94 percent.

## Figure 23: String Level State of Charge – November 10, 2021




Source: Eos Energy Storage

## Figure 24: Eos Energy Block™ Performance Summary – November 10, 2021

SDG&E 2.3 - Energy Block Performance Summary

| | | | |
|---|---|---|---|
| Cycle start | 2021-11-10 04:00:00 | Total discharge energy | 114.65 kWh |
| Cycle end | 2021-11-11 04:00:00 | Total charge energy | 149.02 kWh |
| Charge duration (h:m:s) | 3:07:40 | Max. state of charge | 25.00 % |
| Discharge duration (h:m:s) | 2:16:09 | Energy efficiency | 76.94 % |
| String charge power limit | 10.00 kW | Coulombic efficiency | 89.42 % |
| String discharge power limit | 10.00 kW | Min. temperature | 0.20 °C |
| Avg. discharge power | 50.53 kW | Max. temperature | 51.40 °C |
| Avg. charge power | 47.64 kW | Avg. temperature | 21.61 °C |

Source: Eos Energy Storage

Comparing the data from August 26, 2021 and November 10, 2021, it is apparent that the cycles experienced a charge to a ~25 percent State of Charge. It is also clear that the efficiencies of 49.75 percent and 76.94 percent, respectively, are drastically different from one another despite having a similar discharge duration of ~2-hours. There are a number of differences in the variables such as the discharge power, discharge energy, charge power, charge duration, and temperature, however the main takeaway that Eos wants to highlight is centered around the charge power and charge duration.

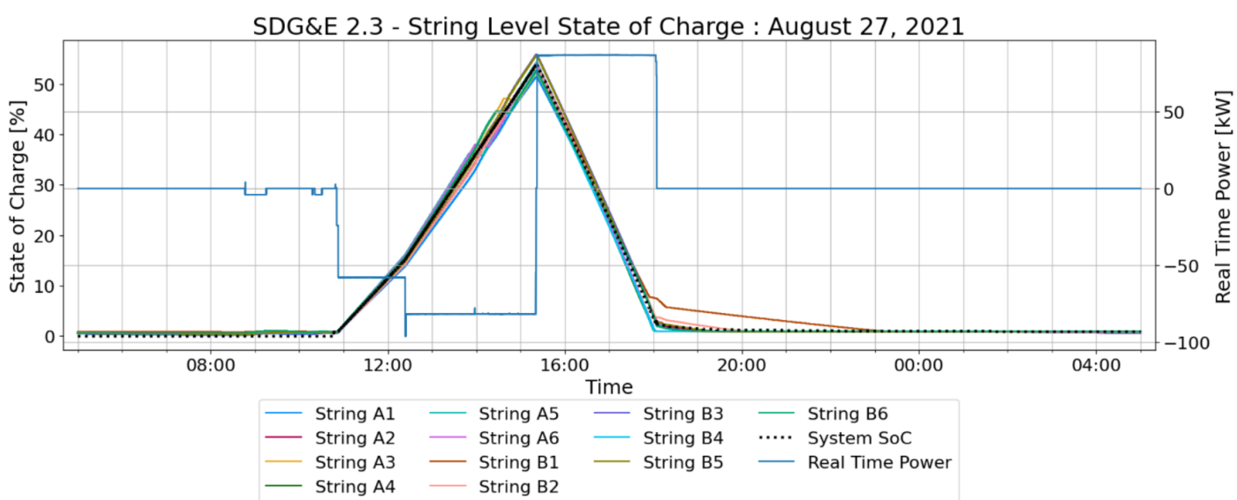
According to this sample data set, there is a correlation between energy efficiency, or Round

Trip Efficiency, and both charge power and charge duration. The correlation is such that the Eos Energy Block™ will result in a higher Round Trip Efficiency, and therefore higher discharge energy, when the system is charged with a lower charge power limit, or charge duration. In other words, a slower rate of charge applied to the Eos Energy Block™ will lead to a larger energy throughput. The correlation being showcased between the data sets on August 26, 2021 and November 10, 2021 support Eos' research and development due diligence prior to commercial operation and testing as part of this grant, EPC-18-023.

### 3.7.3.3 Example: August 27, 2021

As seen in Figures 25 and 26, the Eos Energy Block™ underwent a 50 percent charge cycle on August 27, 2021. After analyzing the data, it was found that this cycle produced 227.31kWh over a ~2.5-hour discharge and had an overall cycle efficiency of 68.25 percent.

**Figure 25: String Level State of Charge – August 27, 2021**




Source: Eos Energy Storage

**Figure 26: Eos Energy Block™ Performance Summary – August 27, 2021**

SDG&E 2.3 - Energy Block Performance Summary

| | |
|---|---|
| Cycle start | 2021-08-27 04:00:00 |
| Cycle end | 2021-08-28 04:00:00 |
| Charge duration (h:m:s) | 5:09:05 |
| Discharge duration (h:m:s) | 2:37:08 |
| String charge power limit | 10.00 kW |
| String discharge power limit | 10.00 kW |
| Avg. discharge power | 86.80 kW |
| Avg. charge power | 64.65 kW |

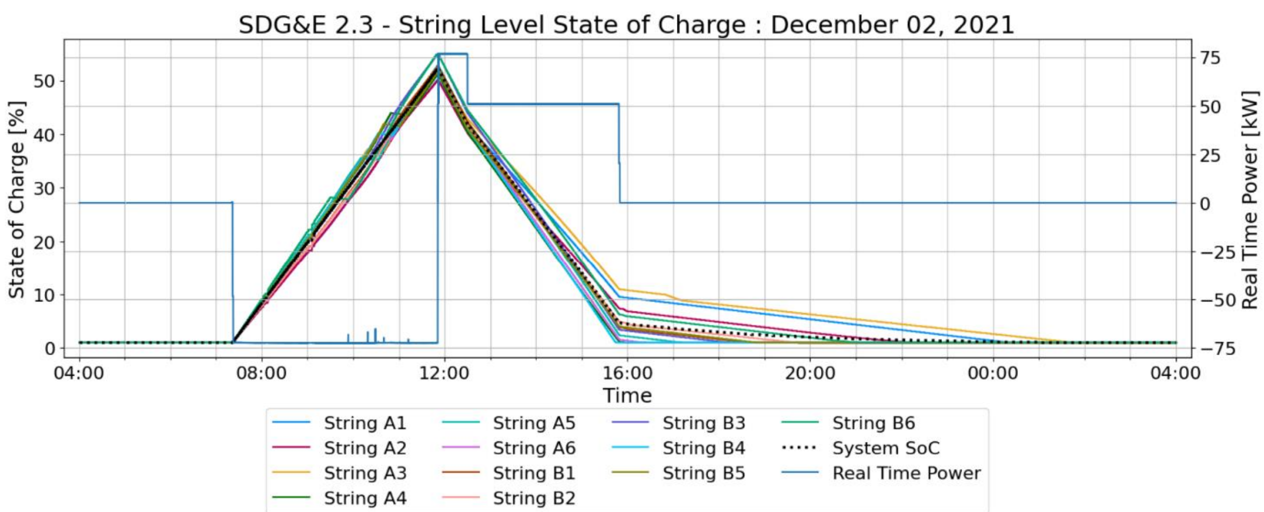
| | |
|---|---|
| Total discharge energy | 227.31 kWh |
| Total charge energy | 333.05 kWh |
| Max. state of charge | 53.80 % |
| Energy efficiency | 68.25 % |
| Coulombic efficiency | 78.18 % |
| Min. temperature | 21.20 °C |
| Max. temperature | 51.40 °C |
| Avg. temperature | 33.06 °C |

Source: Eos Energy Storage

### 3.7.3.4 Example: December 02, 2021

As seen in Figures 27 and 28, the Eos Energy Block™ underwent a 50 percent charge cycle on August 27, 2021. After analyzing the data, it was found that this cycle produced 218.37kWh over a ~4-hour discharge and had an overall cycle efficiency of 70.35 percent.

**Figure 27: String Level State of Charge – December 02, 2021**




Source: Eos Energy Storage

### Figure 28: Eos Energy Block™ Performance Summary – December 02, 2021

SDG&E 2.3 - Energy Block Performance Summary

| | | | |
|---|---|---|---|
| Cycle start | 2021-12-02 04:00:00 | Total discharge energy | 218.37 kWh |
| Cycle end | 2021-12-03 04:00:00 | Total charge energy | 310.39 kWh |
| Charge duration (h:m:s) | 4:17:14 | Max. state of charge | 52.20 % |
| Discharge duration (h:m:s) | 3:58:34 | Energy efficiency | 70.35 % |
| String charge power limit | 10.00 kW | Coulombic efficiency | 81.83 % |
| String discharge power limit | 10.00 kW | Min. temperature | 10.80 °C |
| Avg. discharge power | 54.92 kW | Max. temperature | 28.50 °C |
| Avg. charge power | 72.40 kW | Avg. temperature | 22.15 °C |

Source: Eos Energy Storage

Comparing the data from August 27, 2021 and December 02, 2021 shown in Figures 25/26 and Figures 27/28, respectively, it is apparent that the cycles experienced a charge to a ~50 percent State of Charge. It is also clear that the efficiencies of 68.25 percent and 70.35 percent, respectively, are are only marginally different from one another. There are a number of differences in the variables such as the discharge power, discharge energy, charge power, charge duration, and temperature, however the main takeaway that Eos wants to highlight is centered around the total discharge energy and energy efficiency.

According to this sample data set, the notion that having a more balanced charge duration and discharge duration, over a longer period of time, will result in a higher total discharge energy and energy efficiency, or Round Trip Efficiency. The two cycles being previously dipicted show states of charge that are within a few percentiles of each other and ultimately the same for total discharge energy.

It is important to note that there is slight ambiguity in the data collected for August 27, 2021. It is evident that the charge cycle began at a much lower rate of charge power, about 53kW, between the timestamps of about 11:00am – 12:30pm before the charge power increased closer to about 75kW for the remaining hours of the charge cycle. This difference in charge power is the reason for the charge duration being drastically longer than the cycle's discharge duration. The critical components to take away from this cycle on August 27, 2021 are total discharge energy and energy efficiency, or Round Trip Efficiency.

The main takeaway, is that having a balanced charge duration and discharge duration applied to the Eos Energy Block™ will lead to a greater energy efficiency and energy throughput. The correlation being showcased between the data sets on August 27, 2021 and December 2, 2021 support Eos' research and development due diligence prior to commercial operation and testing as part of this grant.

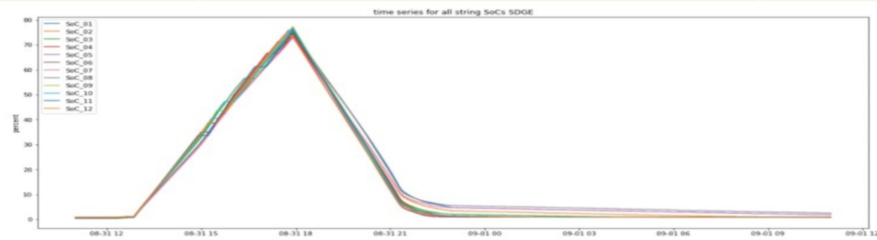
### 3.7.3.5 Example: August 31, 2022

As seen in Figure 29, the Eos Energy Block™ underwent a 75 percent charge cycle on August 31, 2022. After analyzing the data, it was found that this cycle produced 349kWh over a ~5-hour discharge and had an overall cycle efficiency of 73 percent. It is evident that there was a balanced charge and discharge duration as they both are nearly identical, resulting in a 73% overall energy efficiency; within the expected tolerance range for the Eos Energy Block™ as highlighted in the specification sheet.

**Figure 29: Example 75 Percent SOC Performance Summary – August 31, 2022**

**Example Energy Block Performance Summary (75% SOC)**

| | | | |
|---|---|---|---|
| Date | 8/31/22 | Energy Efficiency | 73% |
| Total Charge Energy | 479 kWh | Charge Duration (hh:mm:ss) | 05:01:00 |
| Total Discharge Energy | 349 kWh | Discharge Duration (hh:mm:ss) | 05:03:00 |
| Max State of Charge | 75% | Avg Charge Power | 94.7kW |

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Source: Eos Energy Storage

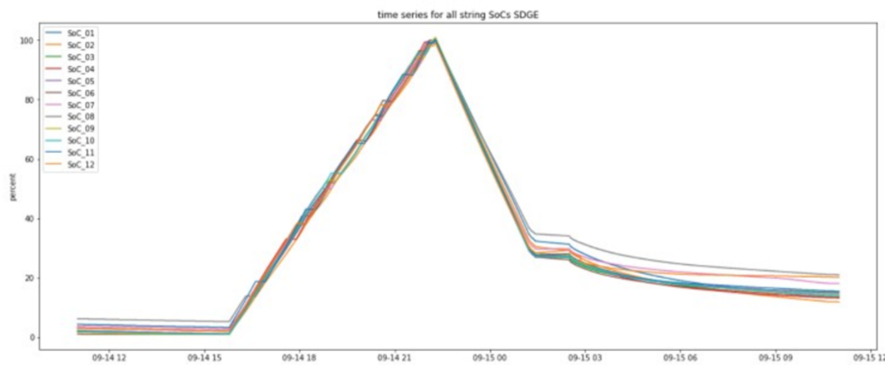
### 3.7.3.6 Example: September 14, 2022

As seen in Figure 30, the Eos Energy Block™ underwent a 100 percent charge cycle on September 14, 2022. After analyzing the data, it was found that this cycle produced 393kWh over a ~12.5-hour discharge and had an overall cycle efficiency of 62 percent; an energy efficiency below the expected 75 percent Round Trip Efficiency. Looking closer at the data, it is evident that the Eos Energy Block™ entered it's secondary discharge around 35 percent State of Charge which is atypical. During a secondary discharge, the overall power limit, or discharge power, is reduced or limited and therefore causes the BESS to deploy energy at a lower power rate for a longer period of time. As a result for an early secondary discharge, it is clear that the Eos Energy Block™ was not able to fully discharge nearly 20 percent of its overall capacity therefore resulting in a lower overall energy efficiency and therefore overall total discharge energy. This concept was taken back to Eos' research and development team to investigate to help resolve similar issues in the future.

**Figure 30: Example 100 Percent SOC Performance Summary – September 14, 2022**

## Example Energy Block Performance Summary (100% SOC)

| | | | |
|---|---|---|---|
| Date | 9/14/22 | Energy Efficiency | 62% |
| Total Charge Energy | 638 kWh | Charge Duration (hh:mm:ss) | 06:26:00 |
| Total Discharge Energy | 393 kWh | Discharge Duration (hh:mm:ss) | 12:32:00 |
| Max State of Charge | 100% | Avg Charge Power | 98.3kW |

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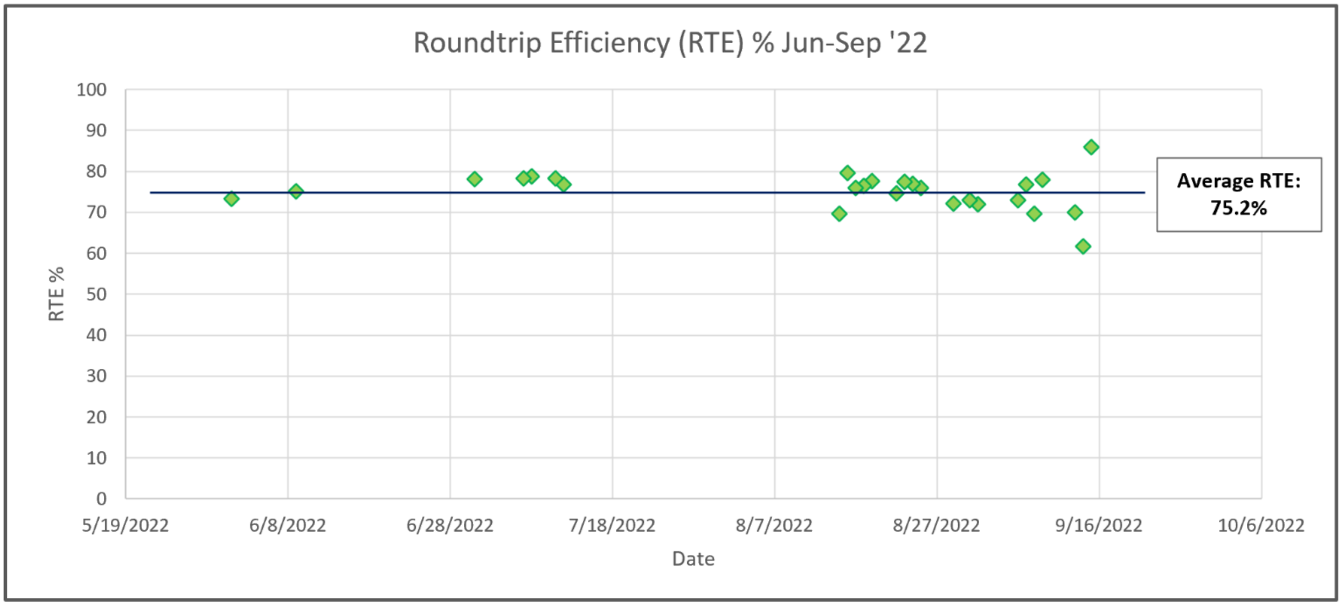
Source: Eos Energy Storage

Figures 31 and 32 represent a large data set of operational cycles throughout the months of June and September of 2022. Each of the data points represents a full cycle, but each cycle consisted of a varying parameters such as State of Charge, charge power, charge duration, discharge power, discharge duration, and temperatures.

The Round Trip Efficiencies for each of the cycles can be seen in green diamonds as part of Figure 36. As shown through the data, there is a range of Round-Trip Efficiencies; approximately 62 percent - 87 percent. Out of the 27 data points, or cycles, depicted, the Average Round Trip Efficiency was found to be 75.2 percent - within the tolerances expected as part of the Eos Energy Block™ specification sheet.

**Figure 31: Roundtrip Efficiency Data Set – June-September 2022**

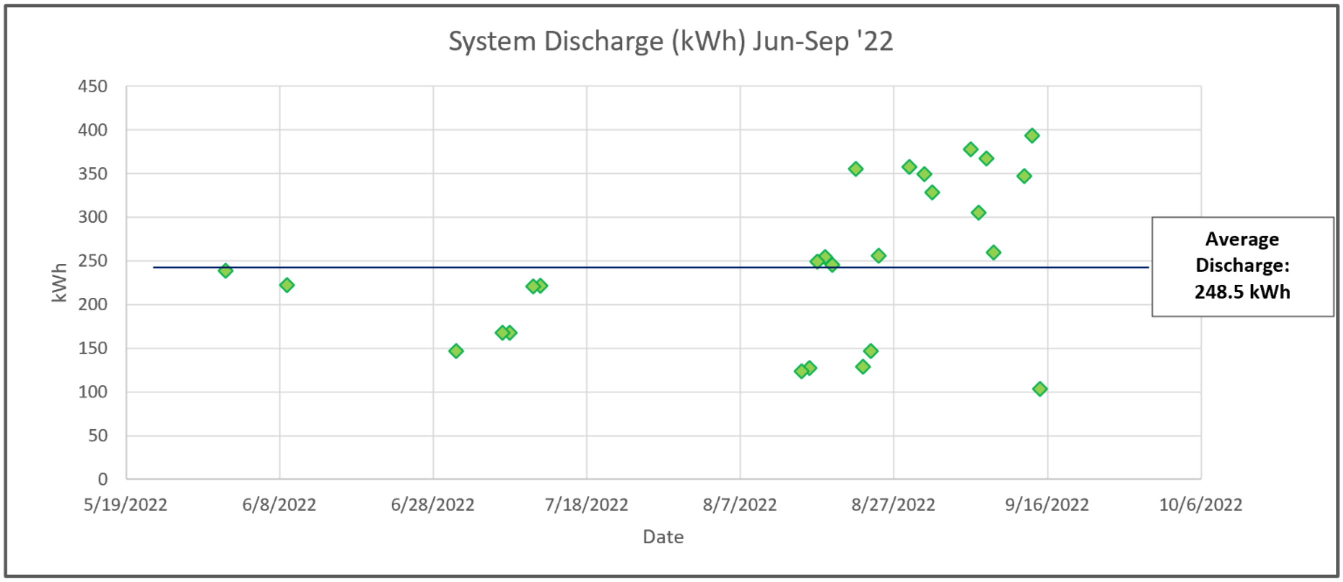



Source: Eos Energy Storage

The System Discharge Energy, in kWh, for each of the cycles can be seen in green diamonds as part of Figure 32. These data points directly corrleate to those in Figure 31.

As shown through the data, there is a range of total System Discharge; approximately 105kWh – 400kWh. Out of the 27 data points, or cycles, depicted, the Average System Discharge, in kWh, was found to be 248.5kWh. Due to the variation in State of Charge values associated with each data point, or cycle, it is expected that the average System Discharge does not match that of the Eos Energy Block™ specification sheet maximum – however, the total discharge energy does align the expected outputs for the range of different State of Charge.

**Figure 32: System Discharge Data Set – June-September 2022**




Source: Eos Energy Storage

### 3.7.4 Project Barriers/Challenges

Prior to deploying the Eos Energy Block™ to the Pala Del Norte site as part of EPC-18-023, Eos was solely a research and development entity. In this stage of new technology development, simulations are the only way to test a large variation of parameters and even during this stage, it's almost impossible to foresee every scenario a product will face. Being able to deploy the Eos Energy Block™ in a commercial setting and gathering data for further analysis granted Eos the opportunity to analyze system functionality under real-life applications and scenarios. This opportunity of data collection and analysis shed light on barriers and challenges the technology faced during this grant project and ultimately gave Eos a path forward on how to further develop its technology. Some of the barriers and challenges faced are highlighted:

1. Time of secondary discharge
    a. This challenge was seen in Example 3.7.3.5. During this 100 percent State of Charge cycle, it was found that the Eos Energy Block™ experienced a secondary discharge, a preventative state in which the discharge power limit is decreased to release additional power from the BESS mitigating the risk of demanding too high of power should the individual string State of Charges vary a certain percentage of each other, earlier during the discharge cycle than anticipated. This challenge is something that will cause the Eos Energy Block™ to not follow its designed discharge curve and therefore limit both the amount of overall discharge energy and Round-Trip Efficiency of the cycle. Eos has taken this data set and will use it to better understand system functionality for future product development.

2. Construction at SDG&E – Pala Del Norte Site
    a. This barrier and challenge were experienced during the time period of mid-September 2022 through end of July 2023. The facility began construction activity on site as part of another project initiative, outside of this project. In effect, the transformer installed under this project was required to be disconnected and moved due to the risk of having construction workers and equipment too close to an energized system. As a result, the Eos Energy Block™ was taken offline during this period of time and was unable to operate to continue collecting data. This has affected the overall amount of data available for analysis with this project, but Eos has been able to analyze the data collected and gather important information to move forward on development and product improvement.
3. Cell Modem out of service
    a. This challenge was experienced during the construction occurring at the SDG&E Pala Del Norte site. Upon SDG&E personnel disconnecting the transformer on site due their construction efforts, Eos' equipment remained unenergized and therefore could not remotely access the equipment. Upon reconnection of the transformer, Eos' field service technicians performed an on-site inspection as well as communications test. The communications test resulted in discovering the cell modem that was installed on site, a device that provides internet access for data to be collected, was out of service. This unforeseen challenge caused slight delay in Eos' ability to reestablish connection to the system and continue operation.
4. Fire suppression system
    a. Although this barrier is not directly applicable to EPC-18-023, it is important to highlight that Eos has experienced barriers around the need for fire safety and fire suppression. As an alternative technological approach to BESS, such as li-ion, Eos' Energy Block™ is comprised of a proprietary zinc-aqueous electrolyte. Due to its chemical makeup of being an aqueous solution, Eos' technology does not face the same challenges of thermal runaway or risk of fires. With the installation of this system without any means of fire suppression at the Pala Del Norte site, it is one step forward for Eos to highlighting the safety around its technology. This project has given Eos the ability to slowly remove the barrier around fire suppression and thermal runaway within a BESS.

# CHAPTER 4: Conclusion

The grant, provided by the CEC to Eos allowed for the opportunity to use an alternative approach to battery energy storage systems to California. Over the more than 2 years in operation, the Eos Generation 2.3 Energy Block™ produced power and energy to be dispatched to local stakeholders. While in operation and benefiting local stakeholders, Eos was able to collect and analyze performance data from the installed system. The data collected and the challenges and barriers faced during this project are crucial for Eos to help drive further advancement in their technology and therefore drive further advancement in benefits for stakeholders, not only in the state of California, but across the globe.

While Eos is not the only entity providing alternative solutions to battery energy storage systems, it provides a unique approach with the proprietary zinc-aqueous electrolyte. This is a crucial step forward in the renewable energy market and why the opportunity to showcase this technology, as part of EPC-18-023, is so important. To date, most battery energy storage systems have been comprised of li-ion and more geared towards providing grid resiliency through power generation. Li-ion technology is crucial for providing sources of power during peak demand as well as in backup power or black start scenarios. In addition, the current legislation is centered around incentivizing discharge power in the form of $ per kW – an incentive primarily benefiting technologies such as li-ion. However, there is an inherent risk with using li-ion technology, specifically around its volatility with thermal runaway and potential fire or explosion. This concept is a major concern as more unfortunate thermal events have occurred throughout the country, and world.

The importance of Eos' technology being used at Pala Del Norte stems from the concepts listed above, power resiliency and thermal runaway.

The current energy market has been focused on providing power to the grid in an effort to sustain resiliency whereas Eos' Energy Block™ is better suited to providing longer duration energy to stakeholders. Looking at the data as a result from this project, there is correlation on how the Eos technology performs over a longer period of time. Under correct conditions, the Eos Energy Block™ has been proven to provide energy over a longer period of time (4+ hours) and at a higher efficiency, thus resulting in a higher value of discharge energy. This is crucial to understand both for Eos and its stakeholders.

As the renewable energy market continues to grow and advance, so will its needs and desires. As alluded to previously, the current market provides incentives for the amount of power being distributed from a battery energy storage system rather than the amount of energy being distributed – specifically $ per kWh. For Eos to maintain a resilient grid, power distribution will need to continue to reach long-term energy sustainability, with a growing need for technologies like Eos' Energy Block™ to provide such energy.

In addition, with Eos' proprietary zinc-aqueous electrolyte, the technology does not face the same inherent risk of thermal runaway due to its chemical makeup of being an aqueous, or water based, solution. This concept is also critical to understand when thinking about the future of the electrical grid. Although Eos' technology is not well suited for power resiliency, as seen in the lower efficiencies with data points containing sub-2-hour discharge durations, it still provides a concept similar to resiliency due to the notion of being non-flammable. This concept also opens doors for providing battery energy storage systems, using Eos' technology, within an indoor application or setting – a feat not yet achievable by any other battery energy storage system technologies.

Looking forward, Eos' vision is large and plans to continue its advancement in the battery energy storage system space. As the market continues to shift in the direction of providing longer term energy storage, Eos will be able to highlight the system installed at the Pala Del Norte site, along with many others expected to achieve commercial operation dates soon, with the hope of providing the Eos Energy Block™ solution, or future iterations, to a larger audience. There is also legislation and policies being worked on to help incentivize energy production as opposed to power production. This concept will greatly benefit Eos and its customers/stakeholders as it will provide incentives to developers to seek out long-term energy storage system manufacturers, like Eos, to install on their future project sites. With the help of this CEC grant, Eos has been able to lead the industry in alternative technologies for Battery Energy Storage Systems when compared to li-ion. Eos' state of the art manufacturing facility located in Turtle Creek, Pennsylvania is prepared for the volume of product expected and Eos is in progress of expanding its production facility to other locations in an effort to follow the ever-growing demand.

As Eos looks forward into the future, it does not forget the past. The support provided by the CEC, and other prior grants, has given Eos the opportunity to validate its technology within a commercial application as well as gather crucial data sets to help drive development of future products. Eos is grateful for the collaboration with the CEC, SDG&E, local stakeholders, and all others associated with this grant and is excited for the future of battery energy storage systems.

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# Project Deliverables

Project Deliverables may be accessed upon request. Project Deliverables include:

Task 2 System Engineering & Design:

- System Engineering and Design Memo

Task 3 Battery Manufacturing:

- DC Battery System Assembly Memo

Task 4 AC System Integration & UL Certification:

- AC/DC System Integration Summary Memo
- UL Certification Presentation

Task 5 Develop Data Monitoring & Analytics:

- Use Case Characterization Presentation

Task 6 Shipping, Installation, Commissioning:

- Installation And Commissioning Task Memo
- TAC Summary Memo #1
- CPR Report #1

Task 7 Testing, Operating, Monitoring & Verification:

- Test Plan
- System Performance Presentation
- TAC Summary Memo #2
- CPR Report #2

Task 8 Evaluation of Project Benefits:

- Kick-Off Meeting Benefits Questionnaire
- Mid-Term Benefits Questionnaire
- Final Meeting Benefits Questionnaire

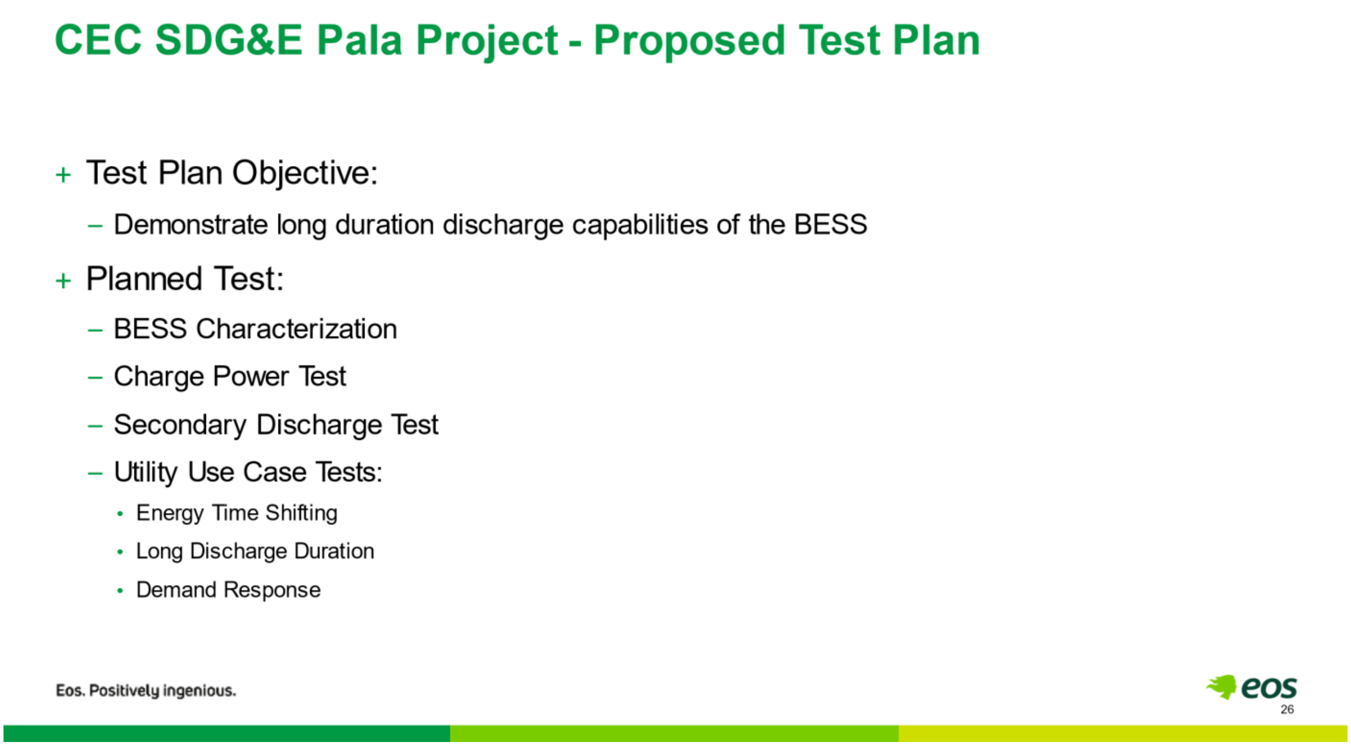
Task 9 Technology/Knowledge Transfer Activities:

- Initial Fact Sheet (Draft and Final)
- Final Project Fact Sheet (Draft and Final)
- Presentation Materials (Draft and Final)
- High Quality Digital Photographs
- Technology/Knowledge Transfer Plan (Draft and Final)
- Technology/Knowledge Transfer Report (Draft and Final)

# APPENDIX A: Test Plan and Use Cases

Figures A-1 – A-7 depict the test plan and use cases used for this project.

**Figure A-1: Proposed Test Plan - Overview**




Source: Eos Energy Storage

**Figure A-2: Test Plan - BESS Characterization**

## Test Plan – BESS Characterization

The BESS will be charged and discharged from the minimum state of charge to target state of charge, at constant discharge and charge power.

| Test # | Charge Power (kw) | Discharge Power (kw) | SoC Target |
|---|---|---|---|
| 1 | 108 | 108 | 25% |
| 2 | 108 | 108 | 30% |
| 3 | 108 | 108 | 40% |
| 4 | 108 | 108 | 50% |
| 5 | 108 | 108 | 60% |
| 6 | 108 | 108 | 70% |
| 7 | 108 | 108 | 75% |

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Source: Eos Energy Storage

**Figure A-3: Test Plan – Charge Power Tests**

## Test Plan – Charge Power Tests

The BESS will be charged and discharged from 0% SoC to target state of charge, at increments of charge power and constant discharge power.

| Test # | Charge Power (kw) | Discharge Power (kw) | SoC Target |
|---|---|---|---|
| 8 | 150 | 108 | 50% |
| 9 | 120 | 108 | 50% |
| 10 | 90 | 108 | 50% |
| 11 | 60 | 108 | 50% |
| 12 | 150 | 108 | 60% |
| 13 | 120 | 108 | 60% |
| 14 | 90 | 108 | 60% |
| 17 | 60 | 108 | 75% |
| 18 | 150 | 108 | 75% |
| 19 | 120 | 108 | 75% |
| 20 | 90 | 108 | 75% |
| 21 | 60 | 108 | 75% |

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Source: Eos Energy Storage

**Figure A-4: Test Plan – Secondary Discharge Tests**

## Test Plan – Secondary Discharge Tests

The BESS will be charged and discharged from the minimum state of charge to target state of charge. The batteries will then undergo a secondary discharge at a lower discharge power.

| Test # | Charge Rate (kw) | Discharge Rate (kw) | SoC Target | Secondary Discharge Rate (kw) |
|---|---|---|---|---|
| 22 | 108 | 108 | 25% | 10 |
| 23 | 108 | 108 | 30% | 10 |
| 24 | 108 | 108 | 60% | 10 |
| 25 | 108 | 108 | 50% | 10 |
| 26 | 108 | 108 | 60% | 10 |
| 27 | 108 | 108 | 70% | 10 |
| 28 | 108 | 108 | 75% | 10 |

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Source: Eos Energy Storage

**Figure A-5: Test Plan – Energy Time Shifting**

## Use-Case – Energy Time Shifting

The test comprises of a charge window and a discharge window with a floating window in between. During the charge window, constant power will be applied to bring the BESS to the targetSoC. During the floating window, the operation and internal support loads for the BESS included but limited to, ventilation system will be maintained. The BESS will be tested with discharge window of 8 to 4 hour test windows.

| Test # | Charge Power (kw) | Charge SoC | Floating Window | Discharge Duration | Discharge Power (kw) TBD |
|---|---|---|---|---|---|
| 29 | 108 | 75% | 2 hours | 8 Hours | |
| 30 | 108 | 75% | 2 hours | 6 hours | |
| 31 | 108 | 75% | 2 hours | 4 hours | |
| 34 | 108 | 75% | 4 hours | 8 Hours | |
| 36 | 108 | 75% | 4 hours | 6 hours | |
| 38 | 108 | 75% | 4 hours | 4 hours | |

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Source: Eos Energy Storage

**Figure A-6: Use-Case – Long Discharge Duration**

## Use-Case – Long Discharge Duration

+ The following procedures will test the discharge duration capabilities of the BESS. The BESS will be charged to target SoC and discharged over specified discharge duration.

| Test # | Charge Power (kw) | Charge SoC | Discharge Duration | Discharge Power (kw) (TBD) |
|---|---|---|---|---|
| 35 | 108 | 50% | 8 hours | |
| 36 | 108 | 50% | 10 hours | |
| 37 | 108 | 50% | 12 hours | |
| 38 | 108 | 50% | 16 hours | |
| 39 | 108 | 75% | 8 hours | |
| 40 | 108 | 75% | 10 hours | |
| 41 | 108 | 75% | 12 hours | |
| 42 | 108 | 75% | 16 hours | |

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Source: Eos Energy Storage

**Figure A-7: Use-Case – Demand Response**

## Use-Case – Demand Response

+ The following procedures will test the ability of BESS to be charged and discharged at varying periods of time throughout a day to simulate demand response.

| Test # | Charge Power (kw) | Target SoC | Discharge Power (kw) | Discharge Frequency | Discharge Duration |
|---|---|---|---|---|---|
| 43 | 108 | 75% | 108 | Every hour | 30 minutes |
| 44 | 108 | 75% | 108 | Every hour | 20 minutes |
| 45 | 108 | 75% | 108 | Every hour | 10 minutes |
| 46 | 108 | 75% | 108 | Every 30 minutes | 20 minutes |
| 47 | 108 | 75% | 108 | Every 30 minutes | 15 minutes |
| 48 | 108 | 75% | 108 | Every 30 minutes | 10 minutes |

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Source: Eos Energy Storage