# An Economic Assessment of Portland General Electric's Salem Smart Power Center Energy Storage System

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***Abstract-* This paper presents an assessment of the economic potential of a 5 MW/1.25 MWh Energy Storage System (ESS) installed at the Salem Smart Power Center, a smart-grid technology demonstration facility owned and operated by Portland General Electric in Salem, Oregon. The ESS and the grid conditions in which it operates were modeled using Pacific Northwest National Laboratory's Battery Storage Evaluation Tool to explore tradeoffs between services and to develop optimal control strategies. The analysis resulted in a number of lessons that provide crucial insights into the practical application of ESS.**

***Keywords-* Energy storage, energy storage valuation, valuation methodology, PGE, PNNL, Salem Smart Power Center**

## I. Introduction

The proper assessment of potential economic benefits of energy storage systems (ESS) is essential for utilities interested in installing new ESS or investing in the expansion of ESS service capabilities. With an adequate analysis of economic benefits, an ESS project developer would be better equipped to understand how a given ESS would perform against a set of economic opportunities, as well as whether modifications are necessary in design parameters and control strategies to improve returns on investment (ROIs).

The industry values learnings achieved by analyzing deployed systems, as they provide practical and useful lessons. Particularly at this growing phase of the ESS industry when utilities are expanding investment in ESS technologies, learnings achieved from an existing system are particularly valuable. This was the motivation for this paper, which presents the outcome and lessons from an economic benefit assessment of a utility-scale 5 MW/1.25 MWh ESS installed at Portland General Electric's (PGE's) Salem Smart Power Center (SSPC) in Salem, Oregon.

## II. The Salem Smart Power Center ESS

The SSPC project, a test and demonstration facility near PGE's Oxford substation in Salem, Oregon, was developed at a cost of around $20M. It was jointly funded by the U.S. Department of Energy (DOE) and PGE, with its principal technology partners EnerDel, Eaton, and Alstom. The facility contains a 5 MW/1.25 MWh lithium ion ESS composed of 20 EnerDel-manufactured SP90-590 modular energy storage racks organized into 5 blocks, with each block containing 4 racks [1]. Each of the racks consist of 18 small drawer-type units, each containing 4 battery modules for a total of 1,440 modules in the system. Each battery module contains 12 series-connected lithium ion cells, which lead to a total of 48 series-connected cells in a drawer unit. Fig. 1 shows the organization of the cells, modules, and racks in a battery block. The system contains 20 inverter banks organized into 5 blocks. Grid interconnection is through the 12-kV side of PGE's Oxford substation.

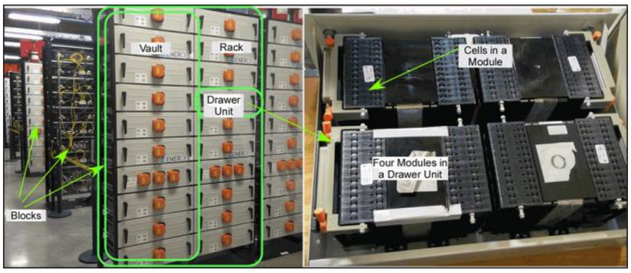



Fig. 1. Salem Smart Power Center ESS.

## III. ESS VALUATION METHODOLOGIES AND COST ESTIMATES

Valuation methodologies and assumptions play an important role in the estimated benefits. Brief descriptions of valuation methodologies, data, and assumptions used for estimation of SSPC use case benefits are provided below. A use case is an application or services offered by an energy storage system (ESS) that provides value to the grid.

### *A. Energy Arbitrage*

Arbitrage is the practice of taking advantage of differences between two market prices. The economic reward is the price differential between buying and selling electrical energy, minus the cost of round-trip efficiency (RTE) losses during the full charging/discharging cycle. The battery system we studied could provide up to approximately 1.25 MWh of energy to bid into the wholesale energy market. Hourly Mid-Columbia Energy Price Index data were obtained from Powerdex for the 2011-2016 time period. Prices during those 6 years ranged from a high of over $220/MWh to a low of $-3.14.

### *B. Western Energy Imbalance Market*

PGE will be joining the Western Energy Imbalance Market (EIM) operated by the California Independent System Operator (CAISO) in 2017 and could use the SSPC as an asset while participating in the EIM. This use case functions very similarly to arbitrage inasmuch as it offers PGE an opportunity to participate in the wholesale pricing of energy. To evaluate the benefit of using the SSPC in the EIM, Pacific Northwest National Laboratory (PNNL) acquired 5- and 15-minute data for the PacifiCorp West load aggregation point nearest the PGE service territory (ELAP_PACW_APND). The data were obtained from the CAISO OASIS system for 2015 to 2016.

### *C. Demand-Response Benefit*

PGE offers a number of demand-response programs in which the SSPC ESS could participate to obtain economic benefits of up to $100/kW-year. In one case, we modeled the benefits using the assumption that PGE can predict demand response events at least 1 hour in advance; in the alternative case, we assumed the ESS must be held at full power awaiting a call between 2 and 6 p.m. during certain months when demand-response events may occur. With a total energy capacity of 1.25 MWh and 300 kWh reserved for primary frequency reserve, 950 kWh remain for demand response. With a 3-hour target window, total demand-response capacity is limited to 317 kW. In 2016, there were eight relevant demand response events ranging from 1 to 3 hours in duration, covering a total of 19 hours.

### *D. Regulation Up/Down*

SSPC, with its ± 5 MW of ESS power capacity, could provide regulation services to the grid. To estimate SSPC regulation up/down benefits, we obtained the regulation prices from a Northwest Power Pool (NWPP) previous PNNL project's production cost analysis [2]. The amount of regulation services possible each hour is limited by both the power and energy capacities of the SSPC. Such constraints have been modeled in the optimal scheduling process.

### *E. Primary Frequency Response*

The SSPC is part of PGE's operational plan for responding to Western Electricity Coordinating Council (WECC)-wide frequency-response events. The SSPC control strategy is designed to generate a 300-kWh response. Based on the set points (high and low) established by a frequency-regulation screen, the SSPC responded 181 times over 13 months, for an average of 13.9 times per month. During roughly 10 months in 2016, PGE registered 18 frequency response events requiring SSPC responses, for an average of 1.8 events per month. Of these events, the SSPC responded 15 times. Thus, the screen governing the SSPC response successfully responded to a frequency-response event 83.3 percent of the time, but triggered nearly eight times as many responses as were required by NERC.

Benefit estimation is performed by taking the weighted average of two recent purchases of primary frequency response services. CAISO recently purchased primary frequency response capabilities from Seattle City Light (SCL) and the Bonneville Power Administration (BPA). The SCL contract transfers 15 MW of frequency regulation to SCL at a contract price of $1.22M, or $81/kW-year [3]. The BPA contract transfers 50 MW/0.1 HZ of frequency regulation to BPA at a contract price of $2.22M, or $44.40 per kW-year [4]. The weighted average of these two values ($52.8/kW-year) was used in the base case, while the SCL value was used as an alternative measure.

We calculated base-case benefits assuming that the frequency-response events cannot be predicted, and therefore, 300 kWh of energy must be held in reserve at all times. We considered an alternative case in which we assumed the events *can* be predicted, thus eliminating the need to hold energy in reserve.

### *F. Spin/Non-Spin Reserve*

The SSPC ESS has the capacity to provide both spinning and non-spinning reserve to balance load and generation during contingencies. To estimate the value of these services, spin and non-spin reserve prices were obtained from the NWPP production cost analysis performed at PNNL [2]. In addition to power capacity limits, these services are also constrained by energy capacity due to the requirement to provide energy at the required power for at least an hour.

*G. Volt/VAR and Conservation Voltage Reduction*

The Volt Ampere Reactive (VAR) capacity of the SSPC ESS inverter provides local VAR supply and conservation voltage reduction (CVR) benefits. Providing VAR locally from ESS inverters relieves the system of the burden of transmitting VARs from the upstream network. This reduction in burden could be considered a release of the upstream system capacity, which can be monetized based on the utility's cost of capacity. Synching VAR by the ESS inverter can reduce operating voltage and reduce energy consumption that could translate into an economic benefit in terms of the prevailing electricity price.

To estimate the benefit of local VAR support, a model alternating current (AC) system upstream of the PGE Oxford substation was considered in order to achieve a reduction in its VAR supply burden by an amount equal to the VAR supplied by SSPC inverters. This reduction in VAR would then be translated into an equivalent active power capacity using AC system capability curves defined by the relationship among active, reactive, and apparent power capacities, and monetized using PGE's $120/kW-year capacity price [5]. CVR benefit was estimated by monetizing the reductions in hourly active power flow from the Oxford substation using 2016 Mid-Columbia electricity prices. Tests were conducted at the Oxford substation by regulator tapping and inverter control to determine the CVR factor (0.86) for benefit assessment.

*H. Valuation Modeling Approach*

PNNL's Battery Storage Evaluation Tool (BSET) was used to perform an hourly look-ahead optimization to determine the ESS power schedules with tradeoffs among different services while taking all operational limits into consideration. We then used the simulation to determine the actual battery operation and estimate the co-optimized value of the modeled services. The detailed modeling and formulation of this method can be found in Wu et al. (2015) [6]. As services are provided, the revenue or value derived from the service is logged, as is the time the ESS is engaged in providing each service. The formulation includes energy costs incurred during charging and RTE losses. We assessed the economic benefit for both individual services and bundle services.

*I. Estimating ESS Costs and Revenue Requirements*

The SSPC was originally conceived as a research and development (R&D) project that would advance PGE's capacity around integration of ESS, smart-grid technologies, and micro-grid resources. Due to the R&D nature of the project and the nascent stage of development of grid-scale lithium ion batteries, system costs reached $20.4M. Considering learning and reductions in battery and component costs, PGE estimates that the SSPC today would cost roughly $10.1M.

PNNL has also considered alternative cost scenarios based on data presented in Lahiri (2017) [7]. These costs are based on deals being monitored by DNV GL[1] and reported in Lahiri (2017), and are stratified somewhat differently from those presented by PGE. PNNL took the mid-point of values presented in Lahiri (2017), applied them to a 20-year battery installation, and estimated the present-value costs of the existing SSPC at $5.4M if built today [7]. Costs were also estimated for 5 MW of power capacity with 5, 10, 15, and 20 MWh of energy capacity at $8.1, $11.8, $15.4, and $19.0M, respectively.

For energy storage to be cost competitive, its benefits must not only exceed its costs, but also all associated revenue requirements, including taxes, debt, and returns to investors. A detailed pro forma for the ESS was prepared to estimate revenue requirements. Major parameters used in the pro forma are presented in Table I.

Based on the combination of costs and assumptions outlined, we determined revenue requirements that accounted for full system costs, including all taxes, debt, and returns to investors and present them in Table II.

TABLE I.
FINANCIAL ANALYSIS PARAMETERS

| Parameter | Assumptions |
|---|---|
| Analysis Time Horizon | 20 years |
| Battery Operating Lifetime | 10 years |
| Federal Income Tax Rate | 35% |
| State and Local Income Tax Rate | 7.69% |
| After-Tax Weighted Cost of Capital | 6.32% |
| Long-Term Rate of Inflation | 2.25% |
| Property Tax Rate | 1.4% |
| Discount Rate | 6.32% |

TABLE II.
ESS REVENUE REQUIREMENTS

| Scenario | Revenue Requirements (Millions) |
|---|---|
| PGE Actual Expenditures | $28.4 |
| PGE Estimate if SSPC Built Today | 14.6 |
| Lahiri 2017 for 5 MW/1.25 MWh ESS | 7.9 |
| Lahiri 2017 for 5 MW/5 MWh ESS | 11.5 |
| Lahiri 2017 for 5 MW/10 MWh ESS | 16.4 |
| Lahiri 2017 for 5 MW/15 MWh ESS | 21.3 |
| Lahiri 2017 for 5 MW/20 MWh ESS | 26.1 |

## IV. ECONOMIC BENEFITS

An analysis of SSPC historical operation, costs and benefit scenarios suggests that this asset is currently underutilized. With it only using 1.9% of available hours in a month exclusively for primary frequency response, a good deal of value remains unrealized. Though the SSPC

[1] https://www.dnvgl.com/

as originally designed and built is not currently generating positive ROIs, the analysis below demonstrates that if the system were built today at current prices and at an optimally scaled size, benefits would exceed revenue requirements.

*A. SSPC Benefits and Revenue Requirements*

The first step in estimating the benefits associated with SSPC operation was to evaluate the benefits of each service individually. Table III and Fig. 2 present the results of these individual assessments. The results demonstrate that if the battery were used exclusively for each service, the value of these services could exceed $7.5M in present-value (PV) terms over 20 years. However, the capacity of the ESS to generate value is constrained by its operating characteristics and its ability to provide energy when needed for each application. That is, some services are in conflict and cannot be provided simultaneously.

There is competition for the energy in the SSPC, on both an intertemporal and an application basis. Knowledge of the battery's characteristics and the landscape of economic opportunities matters in terms of optimizing value. To resolve these conflicts, the research team employed BSET. When the model co-optimizes the benefits under the base case, limiting the value to what is technically achievable by the SSPC, economic value declines to $5.9M over a 20-year period in PV terms. Note that in the individual assessments, charging costs are embedded in each value. In the co-optimized case, they are reported separately.

The base case scenario, for which the values are reported in Table III and presented in Fig. 2, employs the following assumptions:

- Arbitrage is run for 2016 using Mid-Columbia and EIM prices, with 300 kWh of energy set aside for primary frequency-response events.
- 317 kW of demand response is provided and the events can be predicted.
- 5 MW of primary frequency response, with 300 kWh of energy set aside at all times for primary frequency response events.
- All ancillary services co-optimized with 300 kWh of energy set aside for primary frequency-response events.
- After all other service-based commitments have been met, the remaining capacity of the SSPC is used to provide Volt-VAR and CVR support, as needed.

The achievable value available to the base case, when co-optimized, is reduced significantly because the energy-to-power ratio of the SSPC is low at 0.25, and roughly one-fourth of its energy must be held in reserve for primary frequency-response at all times. The energy must be held in reserve because primary frequency-response events cannot be predicted. The lack of available energy limits the ability of the SSPC to generate value in more energy-intensive applications such as the ancillary services (e.g., regulation up/down, spin and non-spin reserves).

TABLE III.
INDIVIDUAL VS. CO-OPTIMIZED BENEFITS

| Service | Individual | Co-Optimized |
|---|---|---|
| Charging Costs | | $(449,115) |
| Arbitrage (Mid-Columbia) | $75,590 | $746,299 |
| EIM | $373,778 | |
| Demand Response | $540,259 | $428,155 |
| Regulation Up | $727,250 | $374,609 |
| Regulation Down | $908,795 | $656,706 |
| Primary Frequency Response | $2,971,424 | $3,568,826 |
| Spin Reserve | $831,079 | $100,622 |
| Non-Spin Reserve | $720,221 | $46,124 |
| Volt-VAR/CVR | $393,619 | $393,619 |
| Total | $7,542,017 | $5,865,846 |

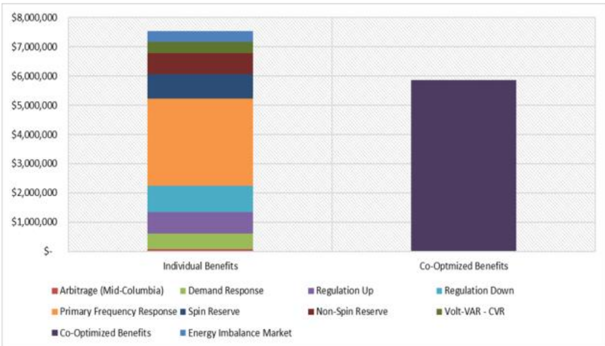



Fig. 2. Individual benefits estimates by use case versus co-optimized benefits.

SSPC benefits for the base case ($5.9M) fall far short of the revenue requirements for the SSPC as originally designed and built ($28.4M) (Fig. 3). It is important to understand, however, that the SSPC was developed as an R&D facility to advance PGE's and the region's understanding of smart-grid technologies, energy storage, distributed energy, and micro-grid systems.

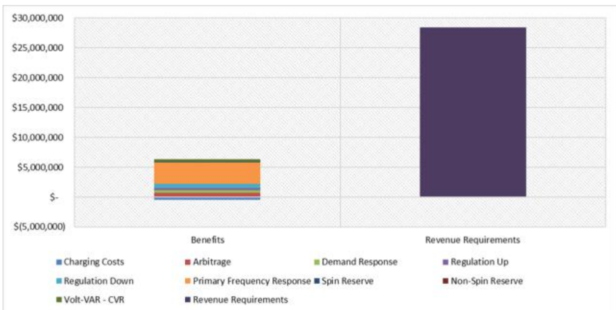



Fig. 3. Base-case benefits and revenue requirements for SSPC.

Table IV and Fig. 4 present the results of a scenario that evaluates costs based on current prices, estimated using Lahiri (2017) [7]. The primary benefit is the one currently being realized by PGE—primary frequency response—which PNNL values at $3.6M over 20 years. However, all other use cases or services yielded an additional $2.3M in currently unrealized benefits over 20 years. Of those services, arbitrage when also bidding into the Western EIM held the most revenue potential at $0.7M, followed by regulation down ($0.7M), demand response ($0.4M), and Volt-VAR/CVR ($0.4M).

TABLE IV
CO-OPTIMIZED 20-YEAR BENEFITS VS. REVENUE REQUIREMENTS (BASE CASE-LAHIRI 2017 COSTS)

| Service | Individual | Revenue Requirements |
|---|---|---|
| Charging Costs | $(449,115) | |
| Arbitrage (Mid-Columbia) | $746,299 | |
| EIM | | |
| Demand Response | $428,155 | |
| Regulation Up | $374,609 | |
| Regulation Down | $656,706 | |
| Primary Frequency Response | $3,568,826 | |
| Spin Reserve | $100,622 | |
| Non-Spin Reserve | $46,124 | |
| Volt-VAR / CVR | $393,619 | |
| Total | $5,865,846 | $7,893,775 |

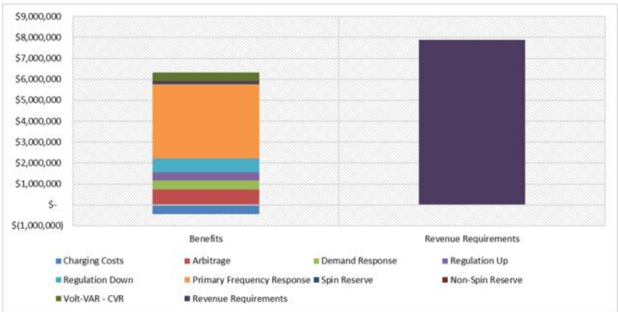



Fig. 4. Benefits and revenue requirements, using current-day pricing, for a 5 MW/1.25 MWh ESS.

The SSPC was originally meant to be operated as a component of a larger micro-grid system, with attention placed on engineering rather than economic goals. Thus, the SSPC holds a small energy capacity (1.25 MWh) in relation to its power capacity (5 MW). With an energy-to-power ratio of only 0.25, it is not well suited to engage in most energy-intensive applications such as arbitrage or ancillary services. Thus, PNNL studied scenarios with energy-to-power ratios closer to industry standards (1.0–4.0).

While expanding the energy capacity increases the costs of the ESS, many system components are defined based on power capacities. Thus, doubling the energy capacity does not double the price. By expanding the energy capacity of the ESS, demand response and the more energy-intensive applications (e.g., arbitrage and ancillary services) generate much more value. By upsizing the energy storage capacity to 5 MWh and 10 MWh, the additional value allows the benefits ($13.3M and $20.3M, respectively) to exceed the system's revenue requirements ($11.5M and $16.4M, respectively). The value would be much higher yet if the ESS were sited in a manner that generated locational benefits associated with outage mitigation or distribution deferral.

## *B. Application Hours and Values*

Though nine value streams are available, the SSPC, when operated in an optimal manner, would remain idle roughly 22 percent of the time. When not idle, it would be most often engaged in arbitrage (1,265 hours), followed by regulation up (1,025 hours) and spin reserve (655 hours). Fig. 5 presents the number of hours the ESS would be engaged in the provision of each service annually. Primary frequency response and demand response provide tremendous value despite the small number of hours engaged each year—17 and 19, respectively. While the SSPC would be optimally engaged in arbitrage and ancillary services 78 percent of the time, those services only generate 27 percent of the total value.

## *C. Participation in the Western EIM*

Two scenarios were considered for bidding the battery energy storage system (BESS) into the Western EIM. One scenario assumed PGE would bid the SSPC into either the EIM or the Mid-Columbia market on an hourly basis to charge the ESS at the lowest price and discharge at the highest price between the two markets. Using EIM data from the PacifiCorp West load aggregation point, doing so would have generated a value of $27,674 in 2016. An alternative scenario was also run in which PGE would bid the SSPC into the EIM on an hourly basis but it would be dispatched by CAISO, subject to 5-minute real-time market (RTM) prices. This scenario takes advantage of ESS flexibility in providing energy more rapidly throughout each hour. This scenario generated a benefit of $152,619 annually, or $2.1M in PV terms, over 20 years. EIM benefits expand to $214,109 annually, or $2.9M in PV terms, over 20 years if the ESS energy capacity expands to 5 MWh.

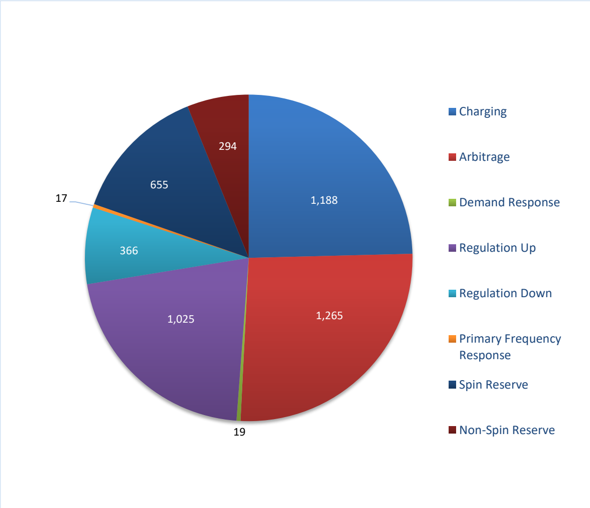


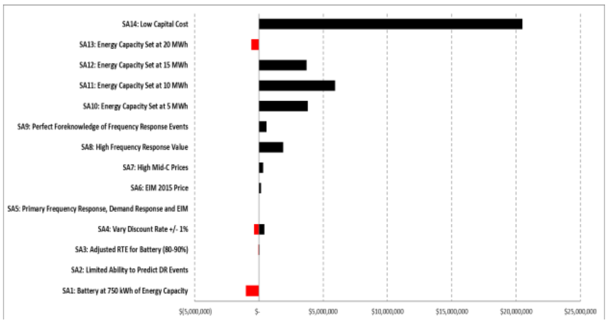

Fig. 5. Hours per service per year.

*D. Alternative Scenarios and Sensitivity Analysis*

To explore the sensitivity of the results to varying a number of key assumptions, we conducted a series of sensitivity analyses. Fig. 6 shows the various scenarios and their impacts measured in comparison to the base case. Parameters varied for sensitivity analysis include battery capacity, RTE, predictability of a particular event (e.g., frequency response), and price of electricity and ancillary services. Results suggest that changes in the energy capacity and use of current-day prices would profoundly impact the ESS economic benefit.

As shown in Fig. 6, most sensitivity analyses result in benefit improvements, suggesting that the base case was somewhat conservative. The most negative impact is revealed in SA1, when the battery capacity is limited to 750 kWh by setting strict state-of-charge range (20-80 percent) limits. On the positive side, using the higher value for primary frequency response tied to the CAISO contract with SCL would increase benefits by $1.9M over 20 years. Perfect foreknowledge of frequency response events would free up 300 kWh of energy capacity for other applications, resulting in an increase of nearly $600,000 in total benefits. Most other cases (e.g., adjusted RTE, modified discount rate, alternative price years) had a negligible impact on economic returns.

Fig. 7 presents the ROI ratios (defined as PV benefits divided by PV revenue requirements) for the sensitivity analysis cases. Cells shaded red have ROI ratios under 0.5, cells shaded yellow have ROI ratios between 0.5 and 1.0, and cells shaded green represent scenarios with ROI ratios exceeding 1.0. When PGE cost estimates are used in the denominator of the ROI calculations, all fall short of 1.0, meaning that benefits fall short of revenue requirements. With current-day prices [7], the base case ROI ratio is 0.79 and several scenarios generate positive net benefits. When the energy capacity is scaled up to, 10, and 15 MWh, ROI ratios reach 1.15, 1.24, and 1.08, respectively. With 20 MWh, ROI falls below unity. This finding suggests that an energy capacity of 5 to 10 MWh would be optimal in terms of maximizing returns based on the landscape of economic opportunities present. However, increasing the energy capacity of SSPC over a certain limit could have a detrimental impact on the ROI.




| | Low-End | High-End |
|---|---|---|
| SA1: Battery at 750 kWh of Energy Capacity | $ (1,007,444) | |
| SA2: Limited Ability to Predict DR Events | $ (23,928) | |
| SA3: Adjusted RTE for Battery (80-90%) | $ (37,997) | $ 53,224 |
| SA4: Vary Discount Rate +/- 1% | $ (375,709) | $ 428,565 |
| SA5: Primary Frequency Response, Demand Response and EIM | | $ (9,345) |
| SA6: EIM 2015 Price | | $ 164,738 |
| SA7: High Mid-C Prices | | $ 334,211 |
| SA8: High Frequency Response Value | | $ 1,901,296 |
| SA9: Perfect Foreknowledge of Frequency Response Events | | $ 589,890 |
| SA10: Energy Capacity Set at 5 MWh | | $ 3,805,708 |
| SA11: Energy Capacity Set at 10 MWh | | $ 5,921,969 |
| SA12: Energy Capacity Set at 15 MWh | | $ 3,702,353 |
| SA13: Energy Capacity Set at 20 MWh | | $ (584,804) |
| SA14: Low Capital Cost | | $ 20,494,044 |

Fig. 6. Sensitivity analysis results.

| | Base Case | Batt-750 kW of Capacity | Demand Response Alternative Constraint | Batt-80% RTE | Batt-90% RTE | Primary Requency Response, Demand Response and EIM | EIM 2015 Price |
|---|---|---|---|---|---|---|---|
| PGE Actuals | 0.21 | 0.17 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 |
| PGE Today | 0.40 | 0.33 | 0.40 | 0.40 | 0.41 | 0.40 | 0.41 |
| Lahiri 2017 Basis | 0.74 | 0.62 | 0.74 | 0.74 | 0.75 | 0.74 | 0.76 |
| Lahiri 2017 Basis - 5 MW | | | | | | | |
| Lahiri 2017 Basis - 10 MW | | | | | | | |
| Lahiri 2017 Basis - 15 MW | | | | | | | |
| Lahiri 2017 Basis - 20 MW | | | | | | | |

| | High Mid-C Prices | Perfect Foreknowledge of Frequency Response Event | High Frequency Response | Batt-5 MWh | Batt-10 MWh | Batt-15 MWh | Batt-20 MWh |
|---|---|---|---|---|---|---|---|
| PGE Actuals | 0.22 | 0.23 | 0.27 | | | | |
| PGE Today | 0.42 | 0.44 | 0.53 | | | | |
| Lahiri 2017 Basis | 0.79 | 0.82 | 0.98 | | | | |
| Lahiri 2017 Basis - 5 MW | | | | 1.15 | | | |
| Lahiri 2017 Basis - 10 MW | | | | | 1.24 | | |
| Lahiri 2017 Basis - 15 MW | | | | | | 1.08 | |
| Lahiri 2017 Basis - 20 MW | | | | | | | 0.90 |

Fig. 7. ROI for alternative scenarios.

PNNL evaluated the impact of adjusting the energy-to-power ratio of the SSPC upward, from 0.25 (1.25 MWh) to 4.0 (20 MWh). With an energy to power ratio less than approximately 0.5, we observed that the cost is higher than total benefits, thus the ROI is less than 1, as shown in Fig. 8. As the ratio increases, benefits increase at a higher rate than the costs; therefore, ROI continues to increase until the energy-to-power ratio reaches a value of 2. Once the ratio surpasses 2, benefits increase at a lower rate than costs, causing the ROI ratio to decrease. At an energy-to-power ratio of approximately 3.5, costs surpass benefits, bringing the ROI ratio below 1.0.

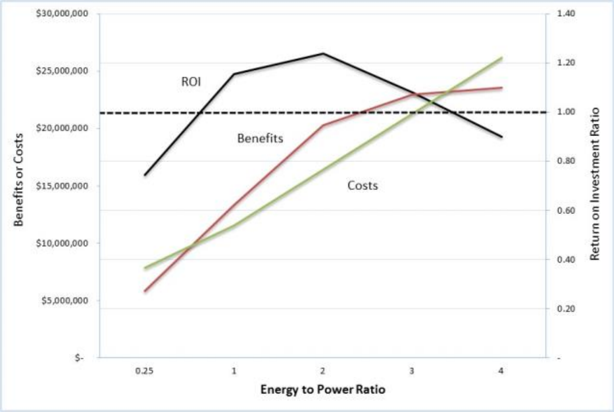



Fig. 8. Impacts of energy-to-power ratio on costs, benefits, and ROI.

## V. Conclusion

This assessment examined the financial feasibility of the SSPC by monetizing the values derived from nine services it could provide to PGE and the customers it serves. The ESS and the grid conditions under which it operates were modeled using PNNL's in-house optimization tool, BSET, to explore tradeoffs between services and develop optimal control strategies. The analysis resulted in a number of lessons that provide crucial insights into the practical application of ESS, including:

- The SSPC, which was originally conceived as a research and test facility and built with the prevailing maturity technology level, was built at a cost ($20.4M) that exceeds current-day prices ($5.4M) for a similarly designed and built 5 MW/1.25 MWh system.
- In terms of economic operation, the SSPC is currently underutilized, deployed only for primary frequency response. PNNL modeling indicates that optimal operation of the ESS could generate an additional value of $2.3M over 20 years. It should also be noted that while primary frequency response is the highest benefit application, it requires a response from the SSPC only 17 hours each year. While optimally engaged, the ESS could provide arbitrage and ancillary services 78 percent of the time, but those services currently generate only 27 percent of the total value.
- Participation in Western EIM represents an interesting opportunity for PGE, with a potential to generate $2.1M value in PV terms over 20 years in the 5-minute RTM.
- With an energy-to-power ratio of only 0.25, the SSPC is not well suited to engage in most energy-intensive applications, such as arbitrage or ancillary services. By upsizing the storage capacity to 5 MWh or 10 MWh, the additional value allows the benefits ($13.3M and 20.3M, respectively) to exceed the system's revenue requirements ($11.5M and $16.4M, respectively). For the SSPC, ROI ratios exceeded 1.0 when the energy-to-power ratio fell between 0.5 and 3.5, and peaked at an energy-to-power ratio of 2.0.

This report represents the output of the first of a two-phase effort. Phase II will involve the development of enhanced control strategies to assist PGE in realizing the benefits of energy storage in real time.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