AGENDA ITEM
Public Utilities Commission
City and County of San Francisco

DEPARTMENT	Power Enterprise	AGENDA NO.	**11i**
		MEETING DATE	September 23, 2014

Approve Report: Consent Calendar
Project Managers: Michael Hyams/Whitney Ramos

<u>Approve SFPUC Energy Storage Report as required by Public Utilities Code section 2836(b):</u>

Summary of Proposed Commission Action:	**Approve** the recommendations of the San Francisco Public Utilities Commission (SFPUC) report entitled "Analysis and Recommendations Regarding Energy Storage Procurement Policy Pursuant to Assembly Bill (AB) 2514" (Energy Storage Report). The Energy Storage Report concludes that: 1) it is not cost-effective for the SFPUC to procure energy storage to meet its electricity needs at this time, however, staff should continue to evaluate energy storage as a procurement option and should treat it equally against other energy technologies and resources; 2) the General Manager should report back to the Commission at least annually regarding the further evaluation of electric storage technology and its potential for meeting the SFPUC's energy procurement needs; and 3) the SFPUC should identify opportunities to develop a pilot energy storage system in San Francisco. Under the requirements of Assembly Bill (AB) 2514 (*Stats. 2010, Ch. 469)* the Commission is required by October 1, 2014 to "determine appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems to be achieved by December 31, 2016, and December 31, 2020." (Public Utilities Code Section 2836(b)).
Background:	Both the price of electric energy and the amount of energy needed to meet customer demand can vary significantly over time. The principle of energy storage is the same as that of a rechargeable electric battery,[1] namely the ability to absorb energy, store it for a period of time with minimal loss, and then release the energy for consumptive purposes at a later time. When integrated into the bulk

[1] Batteries are only one of the technologies capable of storing energy. Energy storage systems are defined in AB2514 as "commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy" using "either mechanical, chemical or thermal processes" (Public Utilities Code Section 2835(a)).

APPROVAL: ______________________

COMMISSION SECRETARY Donna Hood

	electric system, energy storage can provide flexibility that facilitates the real-time balance between electricity supply and demand. For example it can allow for energy to be stored during times when either prices or demand is low, and then make this energy available when prices or demand is high. Electric storage can improve reliability by minimizing fluctuations in the electric system, and also can allow for renewable energy (such as solar) to be stored during the day, and then used when needed. In 2010, the California Legislature enacted Assembly Bill (AB) 2514, signed by the Governor (*Stats. 2010, Ch. 469).* AB2514 directed California's electric utilities to examine if the use of electric storage would be cost-effective for their operations and if so, to adopt targets for acquiring electric storage. AB2514 specifically requires that by October 1, 2014 "the governing board of each local publicly owned electric utility shall determine appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems to be achieved by December 31, 2016, and December 31, 2020." In response to this legislative requirement, SFPUC staff examined the potential to utilize cost-effective electric storage as part of the SFPUC's electric operations and have summarized their findings and conclusions in the attached report; "Analysis and Recommendations Regarding Energy Storage Procurement Policy Pursuant to Assembly Bill (AB) 2514." Although it does not qualify as an "energy storage" system under AB2514, the ability to flexibly dispatch SFPUC's existing Hetch Hetchy system to meet electric demand (subject to the requirements of the City's "water first" policy), already provides the SFPUC with many of the benefits that electric storage provides. The report concludes that the SFPUC has no near-term need for energy storage services apart from the potential use of energy storage to fulfill Local Resource Adequacy Capacity requirements, which is not a cost-effective use at this time. The report also concluded that there may be benefits to pursuing a pilot energy storage project to better understand the potential benefits of energy storage as well as the issues associated with their development and operation. This approach is consistent with the goals of San Francisco's 2011 Updated Electricity Resource Plan (as adopted by the Commission in Resolution 11-0035 and the Board of Supervisors in Resolution 349-11) to develop San Francisco as a "green test bed" for new energy technologies and to encourage the use of electric storage "as an alternative to the existing use of diesel and natural-gas powered back-up generation." As the cost and technology of electric storage continues to evolve,

	and as the SFPUC's operations change over time, electric storage may become a cost-effective component of the SFPUC's electric energy portfolio. SFPUC staff will continue to evaluate the benefits of electric storage and will report back to the Commission as necessary. AB2514 requires the Commission to re-evaluate its adopted storage targets on or before October 1, 2017.
Result of Inaction:	Local publicly-owned electric utilities are required under Public Utilities Code Section 2836(b) to determine prior to October 1, 2014 "appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems to be achieved by December 31, 2016, and December 31, 2020."
Recommendation:	SFPUC staff recommends that the Commission adopt the attached resolution.
Attachments:	1. SFPUC Resolution 2. SFPUC Report: "Analysis and Recommendations Regarding Energy Storage Procurement Policy Pursuant to Assembly Bill (AB) 2514." 3. Attachments A& B to the Report.

PUBLIC UTILITIES COMMISSION

City and County of San Francisco

RESOLUTION NO. ____________________

WHEREAS, The California Legislature, in enacting Assembly Bill (AB)2514 (*Stats. 2010, Ch. 469)* found that expanding the use of energy storage systems could assist California in optimizing the operation of the electric grid, integrating increased amounts of renewable energy (such as solar and wind) resources, help California meet its greenhouse gas reduction goals emissions and potentially reduce costs to ratepayers by avoiding or deferring the need for new fossil-fueled power plants and electric transmission and distribution system upgrades; and

WHEREAS, Energy storage systems are defined in AB2514 as “commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy” using “either mechanical, chemical or thermal processes” (Public Utilities Code Section 2835(a)); and

WHEREAS, AB2514 requires that by October 1, 2014 “the governing board of each local publicly owned electric utility shall determine appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems to be achieved by December 31, 2016, and December 31, 2020”; and

WHEREAS, In response to this legislative requirement, SFPUC staff examined the potential to utilize cost-effective electric storage as part of the SFPUC’s electric operations and have summarized their findings and conclusions in the attached report entitled “Analysis and Recommendations Regarding Energy Storage Procurement Policy Pursuant to Assembly Bill (AB) 2514” (SFPUC Energy Storage Report); and

WHEREAS, The SFPUC Energy Storage Report concluded that the SFPUC has no near-term need for energy storage services apart from the potential use of energy storage to fulfill Local Resource Adequacy Capacity requirements which is not cost-effective at this time; and

WHEREAS, The SFPUC Energy Storage Report concluded that there may be benefits to pursuing a pilot energy storage project to better understand the costs and potential benefits of energy storage as well as the issues associated with their development and operation; and

WHEREAS, Development of a pilot storage program is consistent with the goals of San Francisco’s 2011 Updated Electricity Resource Plan (as adopted by the Commission in Resolution 11-0035 and the Board of Supervisors in Resolution 349-11) to develop San Francisco as a “green test bed” for new energy technologies and to encourage the use of electric storage “as an alternative to the existing use of diesel and natural-gas powered back-up generation;” and

WHEREAS, SFPUC staff will continue to evaluate the benefits of electric storage and will report back to the Commission both as necessary and in time for the Commission to reevaluate (as required by AB2514) its adopted storage targets on or before October 1, 2017; now, therefore, be it

RESOLVED, That the Commission approves the recommendations contained in the SFPUC Energy Storage Report (attached to this Resolution); and be it

FURTHER RESOLVED, That the Commission concludes that it is not cost-effective for the SFPUC to adopt an electric storage procurement target at this time; and be it

FURTHER RESOLVED, That the SFPUC should continue to evaluate energy storage as a procurement option and should treat it equally against other energy technologies and resources for purposes of fulfilling the SFPUC's on-going procurement needs; and be it

FURTHER RESOLVED, That the Commission directs the General Manager to: 1) identify opportunities to develop a pilot energy storage system at a high-value site in San Francisco consistent with the guidelines contained in the SFPUC Energy Storage Report; and 2) report back to the Commission annually regarding further evaluation of electric storage technology and its potential for meeting the SFPUC's energy procurement needs.

I hereby certify that the foregoing resolution was adopted by the Public Utilities Commission at its meeting of September 23, 2014.

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Secretary, Public Utilities Commission

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MEMORANDUM

DATE: September 3, 2014

TO: The Commission

THROUGH: Barbara Hale, Assistant General Manager, Power

FROM: Michael Hyams, Acting Manager, Regulatory and Legislative Affairs
Whitney Ramos, Regulatory and Legislative Affairs

SUBJECT: Analysis and Recommendations Regarding an Energy Storage Procurement Policy Pursuant to Assembly Bill (AB) 2514 (2010)

I. Summary of Findings and Recommendations

Assembly Bill (AB) 2514 requires the governing board of each local publicly owned utility (POU) to evaluate the cost-effectiveness of energy storage and determine whether it should adopt appropriate targets for the procurement of viable and cost-effective energy storage systems by 2016 and 2020.

The central function of energy storage technologies is to absorb energy, store it for a period of time with minimal loss, and then release the energy for consumptive purposes at a later time. When integrated into the bulk electric system, energy storage can provide flexibility that facilitates the real-time balance between electricity supply and demand.[1]

SFPUC staff analyzed energy storage technologies and the services they may provide against near-term SFPUC electricity procurement needs. Staff found that while the SFPUC could utilize energy storage systems, as defined in AB 2514, to meet its Local Resource Adequacy (RA) Capacity requirements, energy storage is not cost-effective for these purposes at this time. Due to the lack of cost-effective and viable energy storage options for these purposes today, staff makes the following recommendations:

- The SFPUC should not adopt an energy storage procurement target at this time; however, Power Enterprise staff should continue to evaluate energy storage as a procurement option and should treat it equally against other energy technologies and resources for purposes of fulfilling the SFPUC's on-going procurement needs;

- Staff should monitor the energy storage market and report to the General Manager annually on the state of the market and the viability of energy storage as resource for the SFPUC; this information should be used to inform the SFPUC's consideration of future energy storage procurement targets;

[1] For purposes of compliance with AB 2514, hydroelectric generating resources similar to the existing make-up of the Hetch Hetchy system do not qualify. See more on qualifying energy storage below.

- Staff should conduct additional research on the value of energy storage for SFPUC customer energy management, particularly the use of energy storage as an alternative to conventional back-up generation; and

- Staff should investigate opportunities to develop an energy storage pilot project in San Francisco at a high value site to demonstrate the potential benefits of storage and improve familiarity and experience with new technologies.

II. Background

AB 2514 requires all POUs to determine whether to adopt procurement targets for energy storage. Public Utilities Code Section 2836(b) requires the governing board of each POU to "initiate a process to determine appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems to be achieved by December 31, 2016, and December 31, 2020."[2] The POU must make the determination to adopt or not to adopt procurement targets by October 1, 2014 and must reevaluate its determination every three years thereafter. AB 2514 expressly requires any procurement targets to be technologically viable and cost-effective, but does not define cost-effectiveness. Additionally, "the governing board may consider a variety of possible policies to encourage the cost-effective deployment of energy storage systems including refinement of existing procurement methods to properly value energy storage systems."

Energy storage, as envisioned by AB 2514, is intended to help optimize the operation of the grid, integrate renewables, and help California meet its GHG reduction goals. Energy storage includes a wide range of technologies that, depending on their configuration and other circumstances, can provide a number of different energy system services.

This staff report reviews energy storage technologies and the services these technologies may provide to the SFPUC. Consistent with AB 2514, the report analyzes the cost-effectiveness of energy storage as a means to address near-term SFPUC procurement requirements. The report concludes with recommendations for addressing the AB 2514 requirements and for building SFPUC knowledge and experience with energy storage.

III. The Definition of Energy Storage System under AB 2514

An energy storage system is defined under PUC Section 2835(a) to mean a "commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy." Energy storage systems must use either mechanical, chemical or thermal processes to (1) store energy that was generated at one time for use at another time; (2) store energy that was generated from renewable resources for use at a later time; or (3) store energy generated from mechanical processes that would otherwise be wasted for delivery at a later time. Energy storage systems may also store thermal energy for direct use for heating or cooling at a later time if it avoids the need to use electricity at that later time.[3]

AB 2514 also requires qualifying energy storage systems to do one of the following:

1. Reduce greenhouse gas emissions;
2. Reduce demand for peak electrical generation;

[2] AB 2514 added Chapter 7.7 and Sections 2835-2839 to the California Public Utilities Code
[3] Public Utilities Code 2835(a)

3. Defer or substitute for an investment in generation, transmission, or distribution assets; or
4. Improve reliable operation of the electrical transmission or distribution grid;

Finally, qualifying energy storage systems may either be centralized (large-scale) or distributed (small-scale); owned by a POU, its customer, a third party or any combination thereof; and procured by ownership or by contract to use the energy, capacity, or ancillary services of the energy storage system.

IV. Overview of Energy Storage Technology Types, Applications and Costs

The central function of energy storage technologies is to absorb energy, store it for a period of time (second, minutes, hours) with minimal loss, and then release the energy for consumptive purposes at a later time. When integrated into the bulk electric system, energy storage can provide flexibility and ancillary services that facilitates the real-time balance between electricity supply and demand.

Typically this real-time balance is achieved by keeping power plants in reserve and on standby to ensure there is sufficient supply at all times. Grid operators adjust the output of fast-responding and dispatchable resources, such as hydropower and natural gas fired combustion turbines, to keep the system in energy balance and to maintain appropriate system frequency and voltage levels. These are often called "ancillary services." Grid operators require utilities to either provide their proportionate share of these ancillary services to the grid or to purchase them from third parties. Energy storage systems can also serve this role. The California ISO, the grid operator for most of California, is currently evaluating how storage technologies can provide these services and be paid for them.

There is a large and diverse array of energy storage technologies that are at various stages of commercialization. Battery storage, which encompasses a number of emerging and mature technologies, Pumped Storage Hydroelectric, Compressed Air Energy Storage, Thermal Energy Storage and Flywheels are a number of energy storage technology types that can be evaluated for potential application. These technologies, their varying characteristics and resulting best uses are summarized below.

Battery Storage: This category covers a wide range of electro-chemical devices that convert electrical energy into chemical energy for storage. There are three categories of batteries including conventional (lead-acid and lithium-ion), high temperature (sodium-sulfur and sodium-nickel-chloride) and flow batteries (vandadium redox and zinc-bromine). Best uses of batteries include local, quick discharging (often in milliseconds), and small to medium-scale applications (kilowatts to tens of megawatts). The modularity of battery systems means that they can be conveniently sited and easily adjusted to the appropriate scale of the required use. Primary limitations include high costs and comparatively short lifespans; however, the battery storage industry continues to make advances in these areas.

Pumped Storage Hydroelectric: Pumped hydro is the world's most mature and abundant form of electric energy storage.[4] Pumped hydro systems use low-cost off-peak electricity to pump water from a lower reservoir into an upper reservoir for storage (gravitational potential energy). When the stored energy is needed, the water is released and passed through a turbine used to generate electricity. Pumped hydro is best used for large scale storage that has the ability to

[4] There is approximately 22,000 MW of installed pumped hydro in the United States and 127,000 MW worldwide.

both store and discharge energy over long periods of time. Challenges associated with the development of pumped hydro include a lack of suitable sites and environmental impact due to the technology's large footprint, high initial capital costs (hundreds of millions of dollars), a long-lead time to construct, and an uncertain and costly permitting process.

Compressed Air Energy Storage (CAES): CAES technology is a relatively mature form of energy storage with some new applications under development. CAES uses low-cost off-peak electricity to compress air inside an air-tight vessel (underground caverns or above ground pipes or bladders). The energy contained in the compressed air is then converted back to electricity by reheating and mixing the cool pressurized air with fuel, which is then passed through an expansion turbine where the fuel (natural gas, hydrogen, gasified biomass and oil) is combusted to drive an electric generator. There are two primary types of CAES systems – bulk and small. Bulk systems typically use subterranean compressed air storage and can be hundreds of megawatts in capacity. Small systems are typically above ground, on the order of 10-20 MW in capacity, and use pipes, bladders and other man-made vessels to store compressed air. Primary challenges associated with CAES development include locational constraints (particularly for large-scale subterranean systems), high capital costs for large systems, fuel use and emissions for combustion, and high lifecycle energy costs for small above-ground systems.

Thermal Energy Storage (TES): TES is a technology that stores thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and for power generation. TES systems can be either centralized (providing bulk or wholesale services) or distributed (providing services to end use customers). Centralized applications can be used in district heating or cooling systems, large industrial plants, combined heat and power plants, or in renewable power plants (Concentrating Solar Plants). The most common TES systems are decentralized and used by customers in buildings and industrial processes to shift energy use from one period to another. These TES systems use off-peak electric power to heat or cool a medium (often water) which is then stored in an insulated tank for later use. Both centralized and decentralized TES systems can reduce energy demand at peak times. TES requires a large cooling load to be cost-effective, as well as a large space to store the cooled or heated medium, both of which can limit opportunities to implement this technology.[5]

Flywheel Energy Storage (FES): FES systems convert electricity to rotational kinetic energy in the form of the momentum of a spinning mass. The spinning mass, or rotor, rests on bearings that facilitate its rotation. FES systems charge using electricity to power a motor-generator, which spins a shaft connected to the rotor to store energy. To discharge energy, the kinetic energy in the rotor is used to power a motor-generator to produce electricity. Although some FES systems are able to provide up to an hour of stored energy, they are generally considered short discharge duration technologies. FES systems are capable of instantaneous response time, which makes them a good choice for uninterruptible power supply, grid ancillary services (voltage and frequency support) and power quality applications. The primary challenges with Flywheel deployment are system size limitations, relatively low energy density, and the need to charge/discharge power quickly due to high frictional losses.

Tables 1 and 2 below summarize and compare the characteristics of different energy system types, including typical scale, best applications, technology development stage, and project lifetimes and cost ranges.

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[5] For more information on TES see IEA-ETASAP and IRENA, *Thermal Energy Storage Technology Brief*, January 2013, at: http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf

Table 1: Energy Storage Characteristics by Technology Category

	Batteries	Pumped Hydro	CAES	TES	Flywheel
Process Category	Chemical	Mechanical	Mechanical	Thermal	Mechanical
Scale	Small to Medium	Large	Medium to Large	Small to Medium	Small to Medium
Typical Storage Capacity (kW or MW)	Low: 5 kW High: 50 MW	Low: 100 MW High: 1,000 MW	Low: 10 MW High: 300 MW	Low: 1 kW High: tens of MW	Low: 10 kW High: 20 MW
Best Applications	Varies (See Table 2)	Bulk Energy Services (time-shift & arbitrage); Ancillary Services	Bulk Energy Services (time-shift & arbitrage); Ancillary Services	Bulk Energy Services (time-shift) and Customer Energy Management	Short-Discharge Ancillary Services/Power Quality and Uninterruptible Power Supply
Stage of Development	Varies (See Table 2)	Mature	Some Commercial and Some Demonstration	Commercial	Demonstration
Efficiency (Charge-to-Discharge)	75-95%	75-85%	75-80%	70-80%	85-87%
Lifetime	Varies (See Table 2)	60 years	20 years	15-20 year	15 years
Total Plant Cost ($ per kW) [6]	$1,100 to $10,000	$1,500 to $4,300	$1,000 to $2,200	$3,400 to $4,500	$1,900 to $2,200
Total Plant Cost Range (Small to Large, $)[7]	Small: $25,000 Large: $400,000,000	Small: $700,000,000 Large: $3.7 billion	Small: $100,000,000 Large: $200,000,000	Small (customer-sited): $5,000 Large (solar thermal storage): $112,500,000	Small: $2,000,000 Large: $44,000,000

Sources: Department of Energy/Electric Power Research Institute (DOE/EPRI), *2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories, 2013; and Purdue University, State Utility Forecasting Group, *Utility Scale Energy Storage Systems – Benefits, Applications and Technologies*, June 2013; and International Energy Agency (IEA)-Energy Technology Assistance Programme (ETSAP) and International Renewable Energy Agency (IRENA), *Thermal Energy Storage Technology Brief*, January 2013

Due to the large number of types of batteries, diversity of applications and costs, more detail for this group of energy storage technologies is provided below in Table 2.

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[6] Total plant cost is calculated by dividing the total costs to install and operate a plant (including battery or part replacement if applicable, fixed O&M costs over the plant's life, etc.) by the plant capacity and rated energy per cycle.

[7] Total Plant Cost Range figures represent the high and low cost estimates to develop an energy storage system covering the typical storage capacity ranges included in the table. Source: DOE/EPRI (2013)

Table 2: Summary of Selected Battery Technology Performance and Cost

	Advanced Lead Acid	**Lithium-ion**	**Sodium Sulfur (NaS)**	**Sodium Nickel Chloride**	**Vanadium Redox**	**Zinc-Bromine**
Type	Conventional	Conventional	High Temp	High Temp	Flow	Flow
Stage of Development	Commercial	Commercial	Commercial	Commercial	Demo	Demo
System Size Range	5 kW to 100 MW	25 kW to 10 MW	1 MW to 50 MW	25 kW to 50 MW	200 kW to 50 MW	5 kW to 100 MW
Hours of Energy Storage[8]	0.25 to 8	0.25 to 5	6 to 7.2	2 to 5	3 to 5	1 to 5
Depth of Discharge[9]	25% to 80%	60% to 100%	80%	80% to 85%	100%	100%
Roundtrip Efficiency[10]	85% to 90%	80% to 95%	75%	85%	68-75%	60% to 65%
Lifetime	2,000 to 4,500 cycles (15 years)	2,000 to 4,500 cycles (10-15 years)	2,500 to 4,500 cycles (10-15 years)	Up to 3,000 cycles (10-15 years)	>10,000 cycles, (10-15 years)	2,000 to 10,000 (10-15 years)
Total Plant Cost ($/kW)	$1,200 to $8,000	$1,100 to $6,600	$3,000 to $4,000	$1,800 to $5,700	$3,000 to $5,200	$1,500 to $10,000
Total Plant Cost ($/kWh)[11]	$350 to $4,000	$1,000 to $4,000	$445 to $550	$565 to $1,700	$750 to $1,500	$290 to $3,500
Best Applications	Short-Discharge Ancillary Services/Power Quality and Uninterruptible Power Supply (UPS)	Ancillary Services and Customer Energy management (UPS)	Distribution support, Bulk Energy Services (renewable integration) and UPS	Ancillary Services and Bulk Energy Services (renewable integration)	Bulk Energy Services; Ancillary Services; and Transmission and Distribution Support	Bulk Energy Services; Ancillary Services; and Transmission and Distribution Support

Sources: Department of Energy/Electric Power Research Institute (DOE/EPRI), *2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories, 2013; and Purdue University, State Utility Forecasting Group, *Utility Scale Energy Storage Systems – Benefits, Applications and Technologies*, June 2013

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[8] Hours of energy storage optimal for a system depends on its use. For example, if the system is intended to provide regulation services or frequency/voltage support, short energy discharge durations may be best.

[9] Depth of discharge is defined as the portion of energy discharged from a storage system relative to the amount extractable stored energy.

[10] Roundtrip efficiency is defined as the ratio of the output of an electricity storage system to the input required to restore it to the initial state of charge under specified conditions.

[11] The Total Plant Costs per kWh represents the total fixed cost associated with installing and operating a plant (including battery or part replacement if applicable, fixed O&M costs over the plant's life, etc.) divided by the plant's rated energy for a single cycle. It does not include variable costs such as the cost to charge or store the energy. These figures are another way of presenting the plant-related costs of an energy storage system and do not reflect the average cost of energy from a given energy storage system, which must be assessed on a case-by-case basis.

V. Assessment of SFPUC Energy Storage Need

The first step in determining whether the SFPUC should set a procurement target for energy storage systems is to determine whether there is a SFPUC energy procurement need in the near or mid-term that storage could fulfill. The next step is to determine whether energy storage would be the most cost-effective means of reliably fulfilling that procurement need. Here, "cost-effective" means that the benefits (either avoided costs or direct revenues) outweigh the costs (to build, operate, maintain or procure energy storage services from a third party), or that there is no alternative non-storage resource that could provide the same service at a lower cost or with less technical, operational and financial risk.

The electricity system services that energy storage can provide are described below. These services are then assessed against SFPUC energy procurement needs and whether SFPUC investment in energy storage systems would be a cost-effective means of addressing those needs.[12]

A. Existing SFPUC Power Supply System and Resources

The benefits of storage must be evaluated against the existing SFPUC power system and its energy services needs to meet its customers' service requirements. The SFPUC's Hetch Hetchy system consists of four hydroelectric power plants with a combined peak capacity of 385 MW.

Under average hydrological conditions, the system produces 1,550,000 MWh per year. San Francisco's annual peak demand is approximately 140 MW which remains fairly constant through the year. Total electric usage by the SFPUC's retail customers in 2013 was 1,000,000 MWh.

The Hetch Hetchy system is operated under the City's "Water First" policy. After meeting those requirements, the amount of water flowing through the system (and hence the amount of electric generation) can be adjusted throughout the day. Typically, the resulting "Water First" generation profile, remaining operating flexibility in the system, and supplemental purchases (when needed) allow for the amount of energy generated to meet or exceed the SFPUC's electric demand and for the SFPUC to meet its ancillary services requirements.

The amount of Hetch Hetchy generation varies seasonally. During spring run-off, the SFPUC is usually generating and selling generation that is excess to its retail needs and its wholesale obligations to the Modesto and Turlock Irrigation Districts. During the fall and winter, Hetch Hetchy generation may not always be sufficient to meet retail demand, requiring the SFPUC to purchase supplemental supplies to meet its retail demand.

The SFPUC's power supply portfolio also includes generation from 7.7 MW of solar energy located within San Francisco, 3.1 MW of biomass energy associated with the operation of the SFPUC's Southeast and Oceanside waste-water treatment plants, and supplies purchased from the Western Area Power Administration to serve Treasure Island.

[12] This exercise is intended to be a first screen as to the cost-effectiveness of energy storage services for purposes of compliance with AB 2514. It uses the most current publicly available data, from authoritative sources, such as the US Department of Energy. This analysis is not intended to substitute for an actual procurement to address a specific SFPUC power procurement need, which could be satisfied by a number of different resource types, including but not limited to energy storage.

B. Energy Storage Services[13]

The primary benefit of energy storage technologies is to provide greater flexibility to power producers, electric grid operators and end user customers by allowing energy produced in one period to be used in another period. By storing energy for use at a later time, energy storage systems can also provide back-up power, improving end user electric service reliability.

The services a given energy storage technology can provide depend on the technology's performance characteristics. Some energy storage technologies are able to ramp quickly but do not store large amounts of energy. Such storage technologies (e.g., flywheels and some batteries) are effective at managing short-term imbalances in supply and demand, system frequency issues, and short-term disruptions in power supply. Other energy storage technologies may not ramp quickly but are capable of storing and releasing large amounts of energy over a longer period of time (e.g., pumped hydro and some battery technologies). These can be good for a number of functionally similar activities including load-leveling, peak load shifting, firming and shaping of variable renewable resources and energy market arbitrage (taking advantage of price spreads).

Energy storage services can be bundled into the following four categories, covering each part of the electricity supply chain and end use consumption.

<u>*Bulk Energy and Capacity Services*</u>: energy storage can be used to purchase (or generate) and store energy during periods when prices are low so that it can be used when prices are high (arbitrage). Similarly, energy storage can be used to time-shift variable renewable energy production (e.g., solar or wind energy) by storing excess energy for use at a later time when demand is greater or the renewable resource unavailable. Finally, energy storage can be used to defer or reduce the need to buy or build new generating capacity and in California may be used by a load serving entity (LSE) to meet its Resource Adequacy (RA) requirements (e.g., System, Local and/or Flexible RA capacity).

<u>*Grid Support or Ancillary Services*</u>: the electricity grid requires a number of support services, called ancillary services, which help maintain power quality and reliability, improve system efficiency and promote smooth and coordinated operation of grid components. Examples include regulation of system voltage and frequency, spinning and non-spinning reserves and black start (helping the grid re-power after an outage).

<u>*Transmission and Distribution Services*</u>: energy storage can provide transmission and distribution utilities with a means to regulate power quality, reduce congestion on lines or transformers and defer infrastructure upgrades. To ensure system stability and maintain power quality, transmission and distribution lines must be operated within specific voltage and frequency ranges. Strategic citing and sizing of energy storage can help balance fluctuations in voltage and frequency by absorbing and injecting power into transmission and distribution lines. Additionally, just as energy storage can delay or defer the need to build new generating capacity, it can also reduce congestion on the transmission and distribution system and reduce or defer the need to build new transmission and distribution infrastructure.

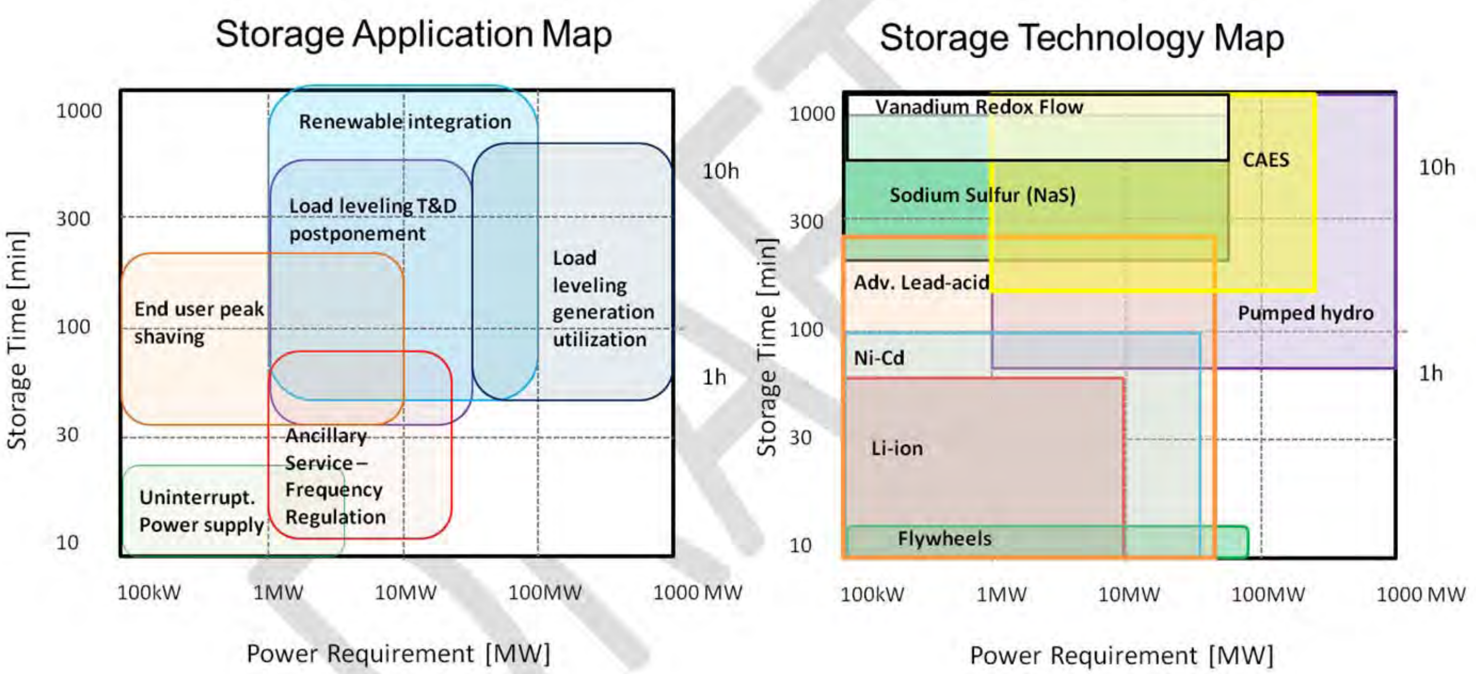
<u>*Customer Energy Management Services*</u>: energy storage sited at an end use customer's location ("behind the meter") can provide a number of services including improving electric service reliability by providing uninterrupted power supply during a black out; improving end user

[13] The energy storage services analyzed in this report are the same services presented and analyzed in the DOE/EPRI 2013 Electricity Storage Handbook

power quality; time-shifting energy consumption to avoid peak energy rates; and demand charge management. Customers on time-of-use rates can avoid peak period pricing by charging their storage device during off-peak periods when prices are low and discharging it during peak periods when prices are high. Commercial customers that pay demand charges ($/kW) can use energy storage in a similar fashion to flatten or shave their peak demand.

The types of services or applications a given energy storage system may provide depend on the characteristics of the technology in terms of energy storage capacity, discharge duration and rated power. Figure 1 illustrates the types of applications energy storage systems may provide as a function of their storage time and power requirements. The Storage Application Map may be compared against the Storage Technology Map to see which technologies have features that are best suited for a particular application.

Figure 1: Energy Storage Application and Technology Maps



Source: SFPUC reproduced from Purdue University, State Utility Forecasting Group, *Utility Scale Energy Storage Systems – Benefits, Applications and Technologies*, June 2013

Each of the energy storage service categories described above with their associated sub-services are evaluated against the SFPUC's near-term procurement needs below.

C. SFPUC Energy Procurement Needs and Energy Storage Services

SFPUC staff evaluated the types of services energy storage systems can provide against the SFPUC's current procurement needs. The results of this evaluation are summarized in Table 3 below.

The only near-term SFPUC procurement need that could be addressed by a qualifying energy storage system is the provision of Local RA Capacity that the SFPUC could use to satisfy its California Independent System Operator (CAISO) Reliability Requirements. However, without additional avoided cost or revenue stream benefits, SFPUC ownership of an energy storage system is not cost-effective at this time.

Table 3: SFPUC Energy Storage Need Evaluation

Energy Storage Service	Service Description	Fulfills SFPUC Procurement Need?
Bulk Energy Service		
Energy Time-Shift or Arbitrage	Energy time-shift/arbitrage involves purchasing or generating electricity during periods when prices are low and storing that energy to be used or sold at a later time when prices are high. Storage can also time-shift or balance energy production by storing excess energy, which might otherwise be curtailed for use at a later time (e.g., from renewable sources such as wind or solar).	*Not At This Time* The SFPUC does not have an intra-day balancing need at this time as its generation supply is more than adequate to cover hourly loads. The ability to control water flows (and hence electric generation) from the Hetch Hetchy system (subject to meeting the requirements of the City's "water first" policy) already provides the SFPUC with sufficient flexibility to adjust electric output over the course of a day to better match electric demand. Additionally, considering the uncertainty in future differentials in intra-day prices, it would be purely speculative to invest in/commit to energy storage for this purpose.
Resource Adequacy Capacity	Energy storage could be used to defer or reduce the need to buy or build new central station generating capacity. Storage can be used to satisfy CAISO Resource Adequacy requirements (i.e., System, Local and Flexible).	*Energy Storage Could Satisfy Local Capacity Requirements* The Hetch Hetchy system has sufficient capacity for San Francisco to meet its System-wide and Flexible Capacity obligations. However, since this resource is neither located within the Greater Bay Area nor currently within any of the Local Capacity Requirement (LCR) zones established by the CAISO, the SFPUC might need additional local capacity. SFPUC could count energy storage capacity that meets LCR operating criteria and that is located in a CAISO designated Local Capacity Area toward its Local RA obligations.
Wholesale Ancillary Services		
Regulation Services	Regulation resources reconcile momentary differences caused by fluctuations in energy production and demand. Regulation helps maintain the proper grid frequency and ensure that the control area (e.g., CAISO) is compliant with reliability standards.	*Not At This Time* The SFPUC currently has no need for any of these ancillary services as it either self-provides using the Hetch Hetchy system or acquires these services through the CAISO. In the future, depending on the system location and technology type, an SFPUC-owned energy storage system might be able to provide ancillary services to the CAISO and get paid for those services. The CAISO is currently working on addressing interconnection procedures for energy storage systems participating in its markets.
Spinning/Non-spinning Reserves	Operation of the electric grid requires reserve capacity that can be called upon when some portion of the normal electric supply becomes unavailable or if there is large demand forecast error.	
Voltage Support	Grid operators must maintain system voltage within specified limits to ensure system stability. This requires the management of reactance, which is typically done using power plants to generate reactive power. Strategically sited energy storage can also provide system voltage support.	
Black Start Support	If suitably located, energy storage can be used to energize transmission and distribution lines and provide station power to help bring power plants on-	

Energy Storage Service	Service Description	Fulfills SFPUC Procurement Need?
	line after a black-out.	
Transmission Infrastructure Services		
Transmission Upgrade Deferral	The delay or avoidance of otherwise required utility transmission capacity (expansion) investments can be achieved through strategic siting and sizing of energy storage.	*Not at This Time* The SFPUC's transmission system is not facing capacity constraints, but as new needs arise, we will evaluate storage options alongside other available technologies. The CAISO is still developing policies and procedures for considering energy storage as an alternative to transmission investment.
Transmission Congestion Relief	Transmission congestion occurs when the flow limit of a transmission line reaches its capacity, increasing the cost of energy on the congested side of the transmission line (where the demand is). Storage can be used to alleviate transmission constraints and avoid congestion-related costs and charges if it is located on the congested side of the transmission line. Energy is stored when there is no congestion (when demand is low) and discharged during peak periods to reduce congestion.	*Not at This Time* Beginning July 2015, with the expiration of the City's Existing Transmission Contract rights, the SFPUC will face an estimated increase of \$100,000 to \$200,000/year (\$0.15 per MWh) in unhedged transmission congestion costs. The SFPUC plans to mitigate this exposure by participating in the CAISO's Congestion Revenue Rights allocation process. Energy storage may also help the SFPUC further mitigate its transmission congestion costs. However, the expected congestion exposure is not significant and any benefits energy storage may provide in this regard are estimated to be minor.
Distribution Infrastructure Services		
Distribution Upgrade Deferral	The delay or avoidance of an otherwise required investment to maintain adequate distribution capacity. Energy storage can defer the need to replace or expand the capacity of an existing transformer and/or reconductor existing lines with heavier wire.	*Not at This Time* SFPUC does not have a distribution capacity investment that could be deferred or a distribution voltage issue that could be addressed with a storage application at this time, but as new needs arise, staff will evaluate storage options along side other available technologies.
Distribution Voltage Support	Like the transmission system, utilities must regulate voltage on distribution lines within specified limits. Properly sited energy storage can help regulate voltage on distribution systems as well.	
Customer Energy Management		
Power Reliability	Energy storage can provide customers with uninterrupted power supply during a black out.	*Not at This Time* SFPUC rate schedules, which include demand charges (\$/kW) and time-of-use rates (\$/kWh) for medium and large commercial customers, provide a price signal that allows these customers to evaluate the potential benefits energy storage may provide. However, while customer use of energy storage to avoid or reduce their demand or peak energy charges will provide bill reduction benefits to the customer, it will result in lost revenue to the SFPUC. In some cases, there may be off-setting avoided costs to the SFPUC in the form of reduced transmission and distribution charges or purchased power costs, but those reductions will be case specific. Many of the SFPUC's customers provide critical public services such as police, fire, hospital, airport, and
Retail Electric Energy Time-Shift	Customers on time-of-use rates can avoid peak period energy prices by charging energy storage system during off-peak periods and discharging during peak periods. This is similar to the energy time-shift noted above, except at the retail level.	
Demand Charge Management	Medium and large commercial customers with energy storage can reduce or avoid maximum demand charges by charging their energy storage system during off-peak periods and discharging their energy storage	

Energy Storage Service	Service Description	Fulfills SFPUC Procurement Need?
	during peak, high demand charge periods, typically between 12:00 p.m. and 5:00 p.m.	water/waste-water operations. Almost all of the facilities providing this service currently have emergency back-up generation (natural gas or diesel) which might be candidates for electric storage. SFPUC policy to promote customer-side energy storage would benefit from further research to better understand the value of energy storage applications on the SFPUC customer's side of the meter. Staff believes that Customer Energy Management services could be an excellent area for demonstrating new energy storage technologies, particularly small or medium scale battery storage.
Power Quality	Energy storage can help protect customer loads against poor power quality events, including voltage variations, frequency variations, lower power factor, harmonics, and momentary service interruptions.	

D. Cost-Effectiveness Findings and Recommendations

At this time staff does not recommend the SFPUC set a procurement target for energy storage. However, staff will continue to evaluate energy storage as a procurement option and should treat it equally against other energy technologies and resources for purposes of fulfilling the SFPUC's on-going procurement needs.

Staff recommends a number of additional steps below to improve SFPUC knowledge of the energy storage market and technologies, including regular reports to the General Manager on the state of the energy storage market and the pursuit of an energy storage pilot project in San Francisco.

1. *Energy storage is not currently a cost-effective means of fulfilling the SFPUC's Local RA Capacity requirements.*

The only near-term SFPUC procurement need that could be fulfilled by an energy storage system(s) is the provision of Local RA Capacity. LSEs in the CAISO balancing authority area are required to procure an amount of RA capacity sufficient to meet their monthly peak load forecast plus a reserve margin and report their RA capacity on an annual and monthly basis.[14] The capacity LSEs procure must be capable of delivering energy to the CAISO system and a subset must be located in certain local areas the CAISO has identified as transmission constrained. The SFPUC is required to procure its Local RA Capacity from within Local Capacity Areas in Pacific Gas and Electric's transmission service area.[15]

While the Hetch Hetchy system provides more than enough System RA Capacity[16] needed to fulfill the SFPUC's needs it does not currently qualify as a Local RA capacity resource in any

[14] The SFPUC adopted a reserve margin of 15% in its Interim Resource Adequacy Plan.
[15] The Local Capacity Areas in PG&E's transmission service area include the Greater Bay Area, Greater Fresno, Stockton, Sierra, North Coast/North Bay and Humboldt. For additional information on CAISO Local Area Capacity requirements see the CAISO's Reliability Requirements Business Practice Manual, available at: http://bpmcm.caiso.com/Pages/BPMLibrary.aspx
[16] System RA Capacity is capacity that the CAISO determines can deliver energy anywhere in its system. Unlike Local RA Capacity, System RA Capacity does not have to be located in or "deliverable" to one of the CAISO Local Capacity Areas.

of the CAISO's Local Capacity Areas.[17] As a result, the SFPUC must procure additional capacity or it must pay the CAISO to do so if the CAISO determines there is a system shortfall. If sited in one of the CAISO's Local Capacity Areas, an energy storage system or multiple systems could provide qualifying capacity that might count toward the SFPUC's Local RA requirements.

Staff research and publicly available market data indicates that Local RA Capacity is available at prices ranging between $30 and $40/kW-year.[18] Using the energy storage cost data presented in Section IV above and in Attachment A, the comparable annual capacity cost of an energy storage system ranges, depending on the technology type, between $100/kW-year and $300/kW-year, or three to ten times the cost of Local RA Capacity available from existing resources in the market today.

Based on these prices, it would not be cost-effective for the SFPUC to procure energy storage to satisfy its Local RA requirements. However, the costs presented in Section IV represent the total plant cost to develop a new energy storage system. While it may not be cost-effective for the SFPUC to develop an energy storage system for Local RA purposes alone, it is possible that a third party owned energy storage system could offer its RA capacity to the SFPUC at prices that are competitive with other resources, particularly if the energy storage owner can take advantage of multiple revenues streams from the other services the storage system provides. However, the market for energy and capacity sales by energy storage providers is in a gestational period and there is insufficient information to determine that energy storage procurement targets based solely on third party sales are either cost-effective or technological viable.

Recommendation: SFPUC staff does not recommend establishing an energy storage procurement target for Local RA purposes at this time. Instead, staff recommends that the SFPUC continue to evaluate all options for procuring Local RA Capacity, including energy storage. To the extent energy storage capacity prices are competitive with other resources, energy storage should be considered a viable option for satisfying the SFPUC's Local RA obligations.

2. *The SFPUC has no near-term need for energy storage as a means of intra-day time-shifting of energy supplies to meet demand; additionally, energy storage is not an effective means of providing seasonal time-shifting of supply.*

The SFPUC does not have an intra-day energy balancing need as its Hetch Hetchy hydroelectric system fully satisfies its load-serving requirements. While the SFPUC does make market energy purchases during certain times of the year, typically in the fall, this seasonal energy supply need is more cost-effectively addressed through energy market purchases than the development of an energy storage system.

Like other hydroelectric systems in California, the Hetch Hetchy system produces more electricity than it needs during the spring run-off when the SFPUC must make additional water deliveries to its regional water customers to manage snow melt water flows. As a result, the

[17] The Hetch Hetchy system is expected to provide sufficient Flexible RA capacity to meet the SFPUC's needs, which begin in 2015.
[18] For example, see the CPUC's 2012 Resource Adequacy Report, p. 28, at: http://www.cpuc.ca.gov/NR/rdonlyres/94E0D083-C122-4C43-A2D2-B122D7D48DDD/0/2012RAReportFinal.pdf

SFPUC makes additional spring sales of energy. Although the SFPUC is exposed to intra-year seasonal price differentials, the revenue the SFPUC earns selling excess energy during the spring months offsets – either in whole or in part – any purchases it must make in the fall months, when Hetch Hetchy system may generate less than the SFPUC needs to satisfy its hourly load requirement. Additionally, energy storage technologies are not currently capable of providing time-shifting of production across seasons. Such time shifts would require very long-duration storage capabilities with high energy densities and extremely low capacity utilization, resulting in an exceedingly high energy cost for storage.

Recent cost data indicates that most energy storage technologies require significant intra-day price spreads that are not available in the energy market today, or require significant capital investment (e.g., pumped hydro). Table 3 below compares forecasted average peak and off-peak energy price forecasts for 2014-2019 in Northern California[19] against the calculated break-even price spreads for some of the energy storage technologies discussed in this report. The break-even price is the difference between what an electric storage operator would pay to buy energy during off-peak hours, and what he/she would need to sell it for during on-peak hours in order to recover the costs of their investment.[20] The low price represents the smallest average spread between on-peak and off-peak prices and the high price indicates the largest spread. Based on these numbers, one can quickly conclude that energy storage technologies currently require price spreads that are significantly higher than forecasted average price spreads in Northern California over the next five years.

Table 4: Peak/Off-Price Price Forecast and Break-even Buy-sell Spread for Energy Storage Technologies

	Low ($/MWh)	High ($/MWh)
Peak/Off-Peak Price Spread (2014-2019)	$7.75	$20.75
Required Energy Storage Break-even Price Spreads		
	Low ($/MWh)	**High ($/MWh)**
Pumped Hydro	$46.70	$124.21
CAES	$41.77	$133.85
Li-ion	$475.18	$1,611.62
Adv. Lead-Acid	$484.09	$1,034.45
Vandium Redox (Flow)	$267.67	$402.59
NaS	$338.13	$377.91

Sources: TFS Energy Futures, LLC (2014); DOE/EPRI (2013); Purdue University (2013); and Schalk Cloete (2014), http://theenergycollective.com/schalk-cloete/421716/seeking-consensus-internalized-costs-energy-storage-batteries

Recommendation: Staff should monitor the energy storage market and report to the General Manager annually on the state of the market and the viability of energy storage as bulk energy resource for the SFPUC; this information should be used to inform the SFPUC's consideration of future energy storage procurement targets.

[19] Based on prices at NP-15, a centralized trading hub used by the CAISO to determine regional energy prices.

[20] The price spreads presented for energy storage technologies represent the buy/sell spread required for a given storage investment to break-even, assuming the project cost ranges and performance data presented in this report for energy storage configured to provide Bulk Energy Services. See Attachment B for data supporting the energy storage technology price spread calculations.

3. *SFPUC rate schedules already provide price signals to end-use customers allowing them to evaluate the potential savings energy storage may provide.*

SFPUC rate schedules for medium and large commercial customers include demand charges ($/kW) and time-of-use energy rates ($/kWh), which provide a price signal that encourages customers to reduce their energy usage during the times of the day when energy prices are highest. These rate structures already allow these customers to evaluate the potential bill reduction benefits energy storage may provide. However, customer use of energy storage to avoid or reduce their demand or peak energy charges does not provide a benefit to the SFPUC because the SFPUC's generation is adequate to meet hourly load. This will result in lost revenue to the SFPUC. In some cases, there may be off-setting avoided costs to the SFPUC in the form of reduced transmission and distribution charges and purchased power costs during peak periods, but those avoided costs will be case specific and need to be assessed on a case-by-case basis.

As noted above, an additional benefit of an energy storage system is that it could provide power to customers during a utility outage. This may be of particular value to certain critical municipal loads, particularly in the event of a natural disaster that causes an extended outage. The 2011 update to the San Francisco Electric Resource Plan (ERP), identified the deployment of energy storage in City-owned buildings and facilities as a potential alternative to the use of back-up diesel and natural gas generation. The ERP observed that electric batteries in particular could replace back-up generators and might even be networked to provide bulk energy services to the grid including local ancillary services and peak load reduction when not needed to provide back-up energy.

As the 2011 Updated ERP noted, the ability to network energy storage devices and bundle the devices to provide coordinated bulk energy services to the grid is still being developed and tested in the market. Moreover, the rules under which electric energy storage may participate in and get paid for providing energy and ancillary services to the wholesale market are also being worked out at the Federal Energy Regulatory Commission. The CAISO and the California Energy Commission are beginning a process to develop an Energy Storage Roadmap to address some these very issues.[21] Further, as discussed above, these options are not currently cost-effective for the SFPUC.

SFPUC policy on customer-side energy storage would benefit from further research to better understand the value of energy storage applications on the SFPUC customer's side of the meter. Staff believes that Customer Energy Management services could be an excellent area for demonstrating new energy storage technologies, particularly small or medium scale battery storage.

Recommendation: Staff should conduct additional research on the value of energy storage for SFPUC customer energy management, particularly the value of energy storage in managing customer demand charges and as an alternative to conventional back-up generation. This research should include an assessment of the feasibility of aggregating customer-sited energy storage to facilitate use of the energy storage for other purposes, such as grid regulation and peak-load reduction.

[21] See CAISO Energy Storage Roadmap website at: http://www.caiso.com/informed/Pages/CleanGrid/EnergyStorageRoadmap.aspx

4. *An energy storage pilot project at a high value site in San Francisco could allow the SFPUC to showcase an emerging technology while developing staff knowledge regarding the costs and benefits of energy storage systems.*

Energy storage is still an emerging technology with a number of potential applications that remain largely untested or for which there are limited examples. Additionally, the cost of energy storage technologies varies widely and is dependent on a number of variables. Piloting a project in San Francisco at a high value site would allow staff to better understand the potential benefits of energy storage systems as well as the issues associated with their development and operation.

This approach would be consistent with the recommendations of the 2011 Updated ERP to develop San Francisco as a "green test bed" for new energy technologies and, as noted above, to encourage the use of electric storage as an alternative to the existing use of diesel and natural-gas powered back-up generation.

As the cost and technology of electric storage continues to evolve and as the SFPUC operations change over time, electric storage may become a cost-effective component of the SFPUC's electric portfolio. This may be particularly true if the SFPUC is able to take advantage of multiple benefits from storage and promote projects at high value sites, particularly sites with critical loads and/or that provide vital services to the local community. At such locations, storage may be combined with solar or other on-site renewable energy supplies to provide energy services for an extended period during an emergency.

Recommendation: Staff should investigate opportunities to develop an energy storage pilot project in San Francisco at a high value site to demonstrate the potential benefits of storage and improve staff familiarity and experience with new technologies.

ATTACHMENTS

Attachment A: Energy Storage Technology Performance and Cost

Attachment B-1 through B-6: Break-even Buy-sell Spread Calculation Information for Energy Storage Technologies

Attachment A: Electric Energy Storage Technology Performance and Cost

August 2014

Technology Option	Best Service Types	Maturity	Power (MW) Low End	Power (MW) High End	Duration (hrs)	Depth of Discharge	% Efficiency (total cycles)	Plant Cost ($/kW) (Low)	Plant Cost ($/kW) (High)	Olant Cost ($/kWh)	Total Plant Cost ($) Low/Low	Total Plant Cost ($) High/High
Pumped Hydro (small)	①②③	Mature	280	530	6 to 16	100%	80%	2,500	4,300	420-430	$ 700,000,000	$ 2,279,000,000
Pumped Hydro (large)			900	1400			(>13,000)	1,500	2,700	250-270	$ 1,350,000,000	$ 3,780,000,000
Compressed Air Energy Storage (CAES) (underground)	①②③	Commercial	50	400	8 to 20	N/A	70-90%	960	1,900	60-125	$ 60,000,000	$ 320,000,000
CAES (aboveground)		Demo	10	50	5		(>10,000)	1,950	4,500	390-430	$ 19,500,000	$ 225,000,000
Flywheel	①③	Demo	1	20	0.25	100%	85% (>100,000)	1,950	2,200	7,800-8,800	$ 1,950,000	$ 44,000,000
Advanced Lead-acid	①②③	Commercial	20	100	4 to 6	25% to 85%	75-90%	1,700	5,800	350-1,080	$ 87,000,000	$ 433,000,000
	③	Demo	1	100	0.25 to 1		(2,200-4,500)	1,200	2,500	2,400-4,700	$ 1,200,000	$ 180,000,000
	④⑤	Demo	1	100	1 to 10			2,500	5,900	500-2,500	$ 2,500,000	$ 400,000,000
	⑥⑦	Demo	0.005	1	2 to 10			2,500	8,000	2,770-3,800	$ 31,000	$ 8,000,000
Lithium-ion (Li-ion)	③	Demo	1	3	0.25 to 1.25	60% to 100%	80-90% (4,500)	1,100	2,500	1,400-4,000	$ 1,100,000	$ 4,100,000
	④⑤	Demo	1	10	1 to 5			1,300	5,300	1,000-2,100	$ 2,100,000	$ 53,000,000
	⑥⑦	Demo	0.025	0.5	1 to 4			3,000	6,600	1,000-3,400	$ 92,000	$ 1,500,000
Sodium-sulfur (NaS)	①②③④⑤	Commercial	1	50	6 to 7.2	80%	75% (4,500)	3,000	4,000	445-550	$ 3,500,000	$ 300,000,000
Sodium-nickel-chloride	①②	Demo	10	50	5	80% to 85%	85-90%	2,800	5,300	565-1050	$ 56,000,000	$ 230,000,000
	③④⑤	Demo	1	1	2 to 5			1,800	5,700	920-1150	$ 1,800,000	$ 5,700,000
	⑥⑦	Demo	0.025	0.5	2 to 4			2,350	5,000	1,200-1,650	$ 131,000	$ 2,900,000
Vanadium Redox (Flow)	①②③④⑤	Demo	0.2	50	3 to 5	100%	65-70% (>10,000)	3,000	5,200	750-1,500	$ 1,000,000	$ 190,000,000
Zinc-bromine (Zn/Br)	①②	Demo	50	100	5	100%	60-65%	1,500	1,750	290-350	$ 75,000,000	$ 175,000,000
	③	Demo	1	1	1		(>10,000)	1,500	1,750	1,500-1,750	$ 1,500,000	$ 1,750,000
	④⑤	Demo	1	10	2 to 5			1,700	3,000	360-1,500	$ 1,700,000	$ 30,000,000
	⑥⑦	Demo	0.005	1	2 to 5			2,300	10,000	450-3,500	$ 25,000	$ 2,300,000
Zinc-air (Zn/air)	①②③	R&D	50	50	6	100%	75% (>10,000)	1,440	1,700	240-340	$ 72,000,000	$ 85,000,000
	④⑤⑥⑦	R&D	1	1			75% (4,500)	1,750	1,900	310-350	$ 1,750,000	$ 1,900,000
Sensible Thermal Energy Storage (TES)	①②⑦	Commercial	0.001	100	10 to 50	N/A	50%-90%	3,400	4,500	70-450	$ 5,000	$ 112,500,000

Service Type Key	
Bulk Energy Service - Time-Shift, Arbitrage, Renewable Integration	①
Bulk Energy Service - Resource Adequacy Capacity	②
Wholesale Ancillary Services	③
Transmission Infrastructure Services	④
Distribution Infrastructure Services	⑤
Customer Energy Management - Reliability and Power Quality	⑥
Customer Energy Management - Time-Shift and Demand Charge Management	⑦

Sources

-US DOE/EPRI, *2013 Electricity Storage Handbook in Collaboration with NRECA* , Sandia National Laboratories, July 2013

-Purdue University, State Utility Forecasting Group, *Utility Scale Energy Storage Systems - Benefits, Applications and Technologies* , June 2013

-IEA-ETSAP and IRENA, *Thermal Energy Storage Technology Brief* , January 2013

Definitions

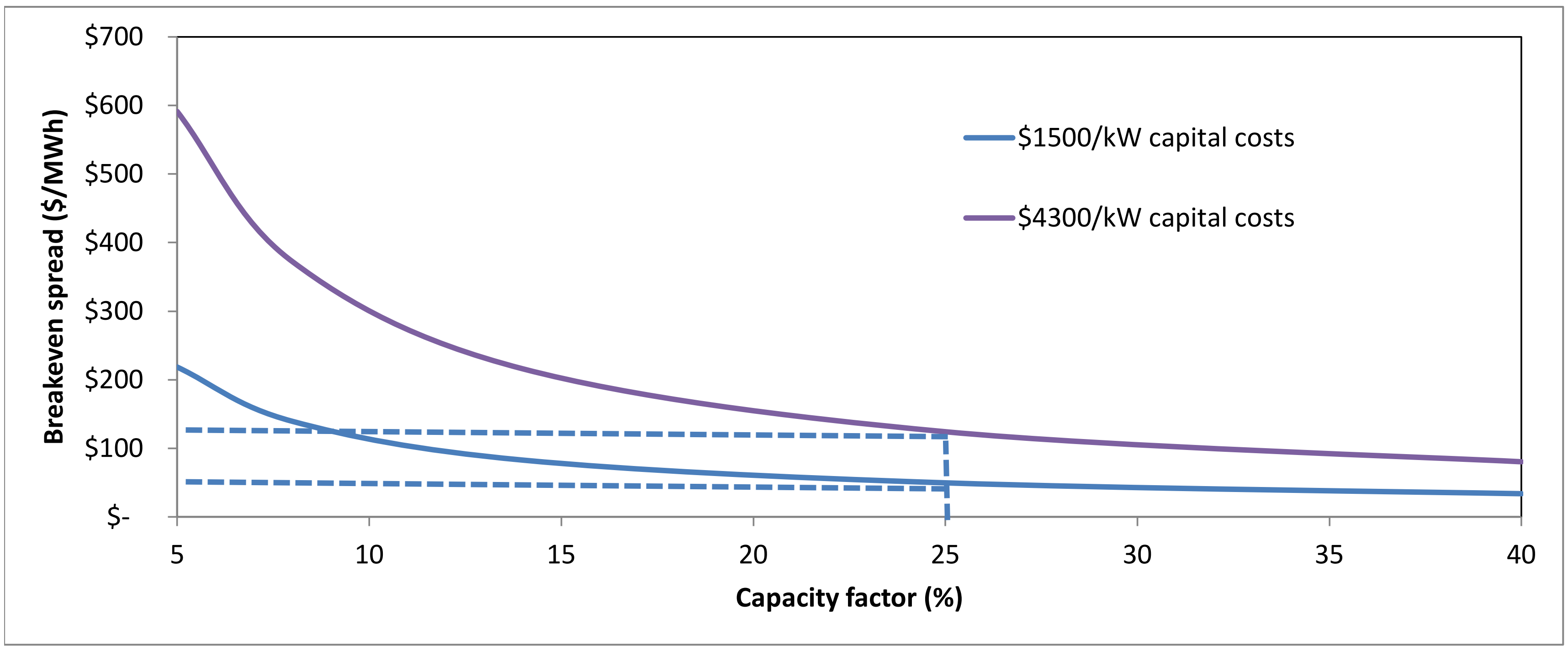
Duration:	The hours of available energy storage
Depth of Discharge:	The portion of eneryg discharged from a storage system relative to the amount of extractable stored energy
% Efficiency (total cycles):	The ratio of the energy output of an energy storage system to the input required to restore it to the initial state of charge (the rated number of charge/discharge cycles over a system's lifetime)
Plant Cost ($ per kW):	The total fixed costs associated with installing and operating a plant divided by the plant's rated capacity
Plant Cost ($ per kWh):	The total fixed costs associated with installing and operating a plant divided by the plant's rated energy for a single cycle
Total Plant Cost:	The total estimated fixed costs associated with installing and operating a plant for the project size ranges identified

Attachment B-1: Pumped Hydro

Capacity factor (%)	$1500/kW capital costs	$4300/kW capital costs
5	$ 218	$ 591
8	$ 139	$ 372
14	$ 83	$ 216
25	$ 50	$ 124
40	$ 34	$ 80

Assumptions

Lifetime	40	years
O&M	5	$/kW.yr
efficiency	0.8	
buying price	30	$/MWh
Discount rate	5	%

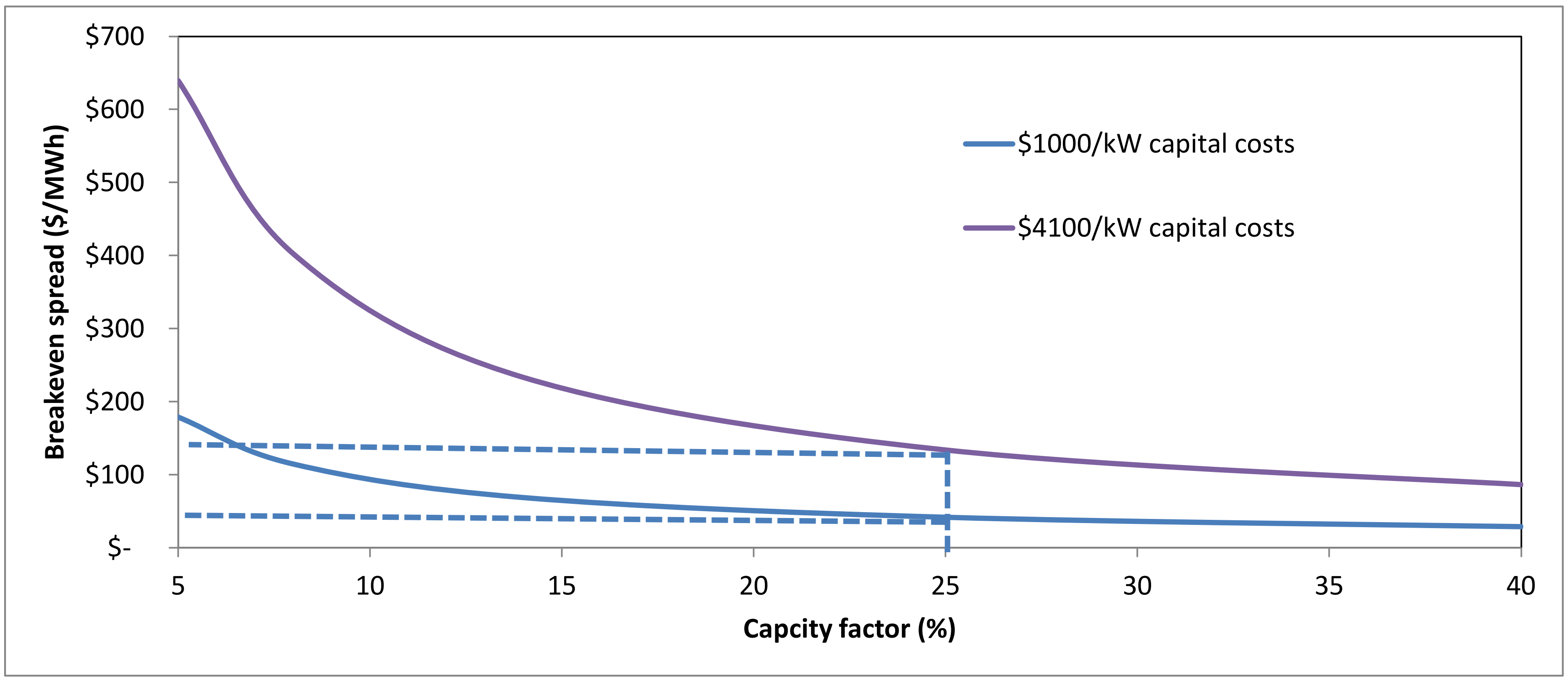


Attachment B-2: CAES

Capacity factor (%)	$1000/kW capital costs	$4100/kW capital costs
5	$ 179	$ 639
8	$ 115	$ 402
14	$ 69	$ 233
25	$ 42	$ 134
40	$ 29	$ 86

Assumptions

Lifetime	30	years
O&M	10	$/kW-yr
efficiency	0.8	
buying price	30	$/MWh
Discount rate	5	%

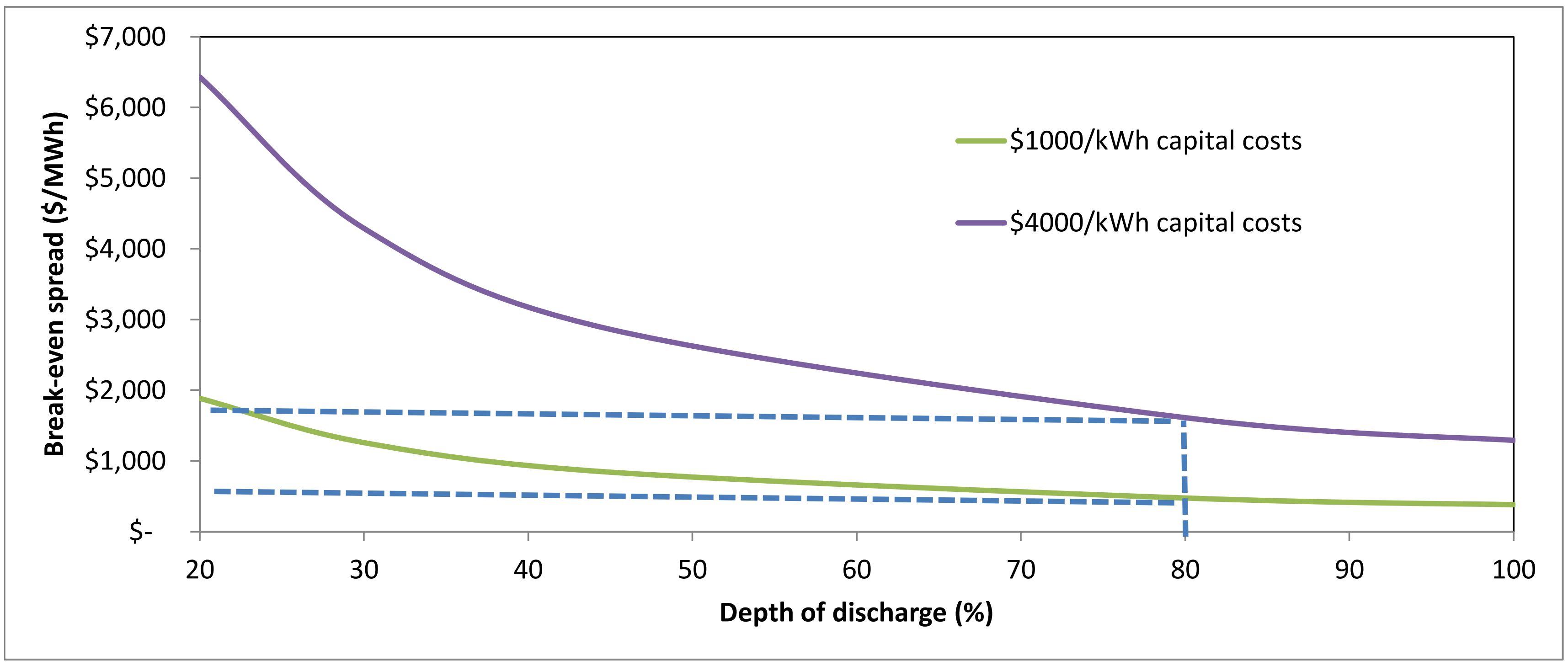


Attachment B-3: Lithium Ion

Depth of discharge (%)	$1000/kWh capital costs	$4000/kWh capital costs
20	$ 1,885	$ 6,431
30	$ 1,258	$ 4,289
45	$ 841	$ 2,861
80	$ 475	$ 1,612
100	$ 381	$ 1,290

Assumptions

Lifetime	4500	cycles
BOP & PCS	150	$/kWh
O&M	10	$/kWh.yr
efficiency	0.85	
buying price	30	$/MWh
Discount rate	5	%
Charge per day	1	

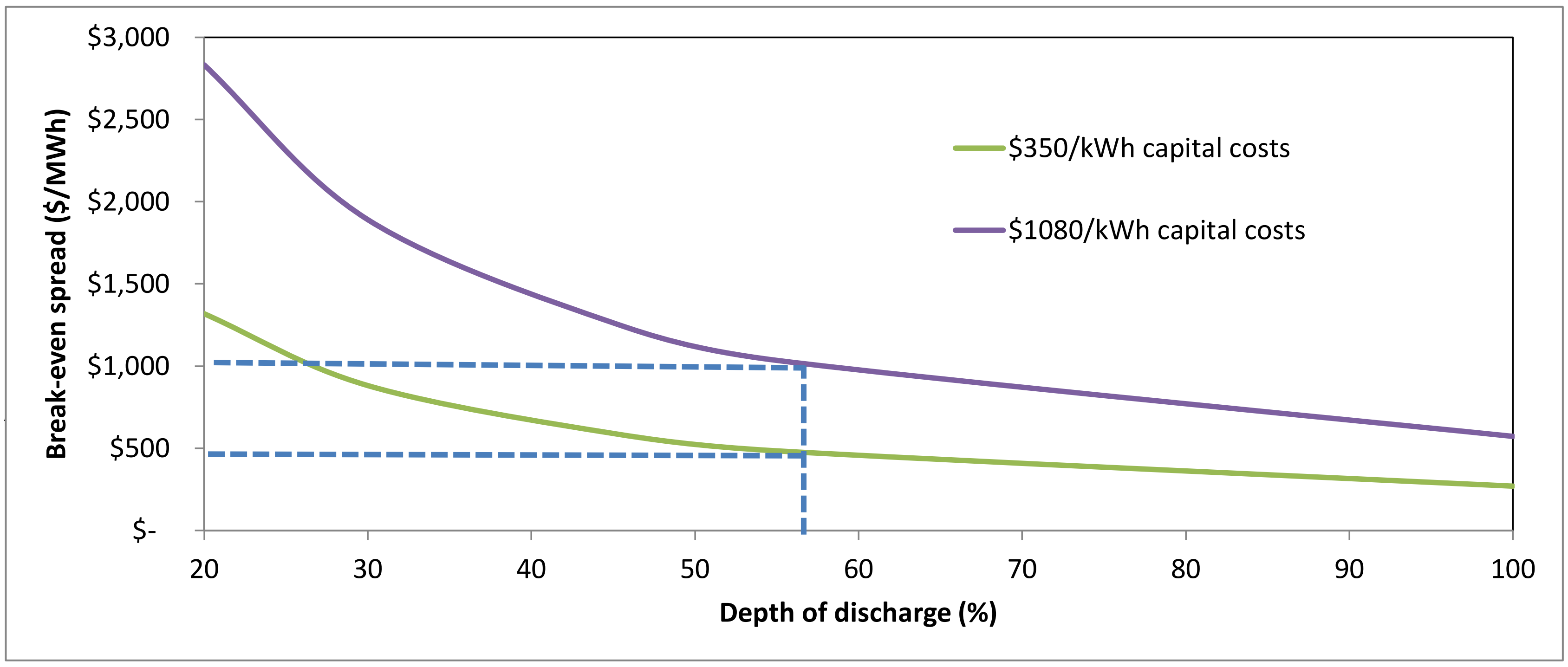


Attachment B-4: Advanced Lead-acid

Depth of discharge (%)	$350/kWh capital costs	$1080/kWh capital costs
20	$ 1,318	$ 2,832
30	$ 881	$ 1,890
45	$ 590	$ 1,263
55	$ 484	$ 1,034
100	$ 270	$ 572

Assumptions

Lifetime	3000	cycles
BOP & PCS	150	$/kWh
O&M	20	$/kWh.yr
efficiency	0.8	
buying price	30	$/MWh
Discount rate	5	%
Charge per day	1	

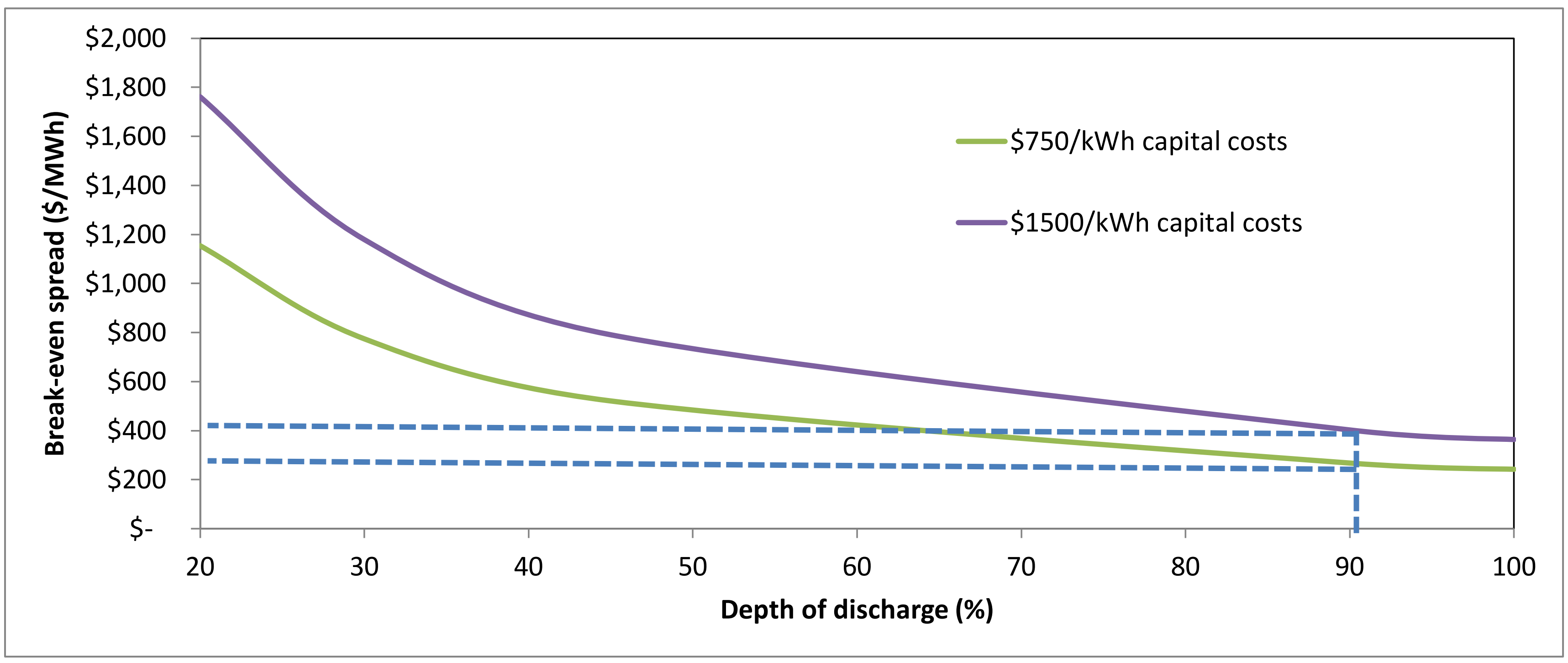


Attachment B-5: Vandium Redox (Flow)

Depth of discharge (%)	$750/kWh capital costs		$1500/kWh capital costs	
20	$	1,154	$	1,761
30	$	774	$	1,179
45	$	521	$	791
90	$	268	$	403
100	$	242	$	364

Assumptions

Lifetime	14000	cycles
BOP & PCS	150	$/kWh
O&M	30	$/kWh.yr
efficiency	0.675	
buying price	30	$/MWh
Discount rate	5	%
Charge per day	1	



Attachment B-6: NaS

Depth of discharge (%)	$445/kWh capital costs	$550/kWh capital costs
20	$ 1,323	$ 1,482
30	$ 885	$ 991
45	$ 593	$ 664
80	$ 338	$ 378
100	$ 273	$ 304

Assumptions

Lifetime	4500	cycles
BOP & PCS	150	$/kWh
O&M	30	$/kWh.yr
efficiency	0.75	
buying price	30	$/MWh
Discount rate	5	%
Charge per day	1