AB 2514 Energy Storage Systems Evaluation

September 9, 2014

PASADENA
Water&Power

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

This report is written in response to the requirements of California Assembly Bill 2514 regarding Energy Storage Systems. The law requires that California utilities evaluate the potential to procure viable and cost-effect energy storage systems and that the governing bodies of local publicly owned utilities (the Pasadena City Council, in the case of Pasadena Water and Power, or “PWP”) set appropriate procurement targets, if any, by October 1, 2014 for energy storage systems to be procured by December 31, 2016 and December 31, 2021.

The law defines energy storage systems, but does not define *cost effective*. There is rather broad consensus through-out the industry that one indicator of cost-effectiveness is a benefit-to-cost ratio greater than or equal to one. More debatable is the question of whether an energy storage system must fill a need in order to be cost-effective. The California Public Utilities Commission (“CPUC”), in establishing initial procurement targets for the state’s Investor-Owned Utilities (“IOUs”), Electricity Service Providers (“ESPs”) and Customer Choice Aggregators (“CCAs”), found that AB2514 is silent on any requirement to conduct or apply a system need determination as a basis for storage procurement targets. The CPUC found that prior precedent supports the setting of storage procurement targets without a system needs determination, and that it was reasonable for it to set procurement targets to encourage the development and deployment of new energy storage technologies. However, in the longer term, the CPUC will consider adjusting procurement target for energy storage to reflect need determinations within its Long Term Procurement Plan proceeding and as part of its regular evaluation of energy storage procurement targets and policies.

Most publicly-owned utilities do not find it reasonable to set procurement targets in the absence of need, and are concerned that doing so will lead to higher costs for their customers. For this reason, PWP has added to its definition of “cost effective” the qualifier that, in addition to having a benefit-to cost ratio greater than or equal to one, *an energy storage system must fill an existing or anticipated unmet need*. This is consistent with prudent risk management principals practiced by PWP.

This report provides summary descriptions of several leading forms of energy storage technology and the most common applications or uses for them in the electric utility industry, borrowed heavily from the research and writings of other industry leaders. Energy storage can be connected at the transmission, distribution or customer level. The table at the end of Section 4, from a SCPPA Energy Storage Working Group report, maps out some of the primary technologies and their applications.

Section 5 summarizes the procurement targets established by the CPUC for the state’s IOUs, ESPs, and CCAs. It also summarizes some early reports submitted by a few of the local publicly-owned utilities. Most of the publicly-owned utilities are finding that viable energy storage systems are not cost effective for them at this point in time.

1.1 CONCLUSIONS

There are relatively few viable, cost-effective, integrated, utility scale energy storage systems available today. Those that make the most sense (e.g., pumped hydro and CAES) tend to be very large in scale and dependent on geologic site conditions.

PWP already has at its disposal cost-effective means of achieving most of the functions provided by energy storage systems. For example, conservation and demand response can provide energy time-shift, congestion relief and upgrade deferrals. Existing generation and the market can provide ancillary services such as regulation, reserves, voltage support and reliability services. Time-of-use rates can provide energy time-shift and demand charge management.

As a CAISO participant, with sufficient generation to meet its reliability requirements, PWP does not presently have a “need” for the identified bulk energy, ancillary service, or transmission infrastructure services provided by energy storage systems. If there is a need for these services by the CAISO, market prices do not adequately reflect it. As a consequence, it does not appear that PWP customers would benefit from, nor recover the costs of, energy storage systems procured by PWP to provide these services today. Without a need and a sufficient revenue stream, even viable energy storage systems cannot be cost-effective.

PWP has not identified specific distribution upgrades that could cost-effectively be deferred through the use of energy storage systems. If, at some point in the future, certain radial feeders experience voltage fluctuations or other power quality issues as a result of a high penetration of local solar installations, electric vehicle charging, or other distribution network transformation, energy storage systems on the distribution network or for customer energy management services may begin to make sense from a reliability perspective, although cost-effectiveness may still be difficult to demonstrate. PWP will continue to monitor the situation and will advise the City Council of any recommendations during periodic updates.

The City Council need not set specific procurement targets for PWP to procure or encourage cost-effective deployment of energy storage systems as needs arise, these systems mature and their costs decrease. Through its regular annual updates of its procurement plan, PWP will advise the City

Council of any changes in its forecast needs and the least cost/best fit means of satisfying those needs. Furthermore, at least every three years, PWP will reevaluate the issue of energy storage system procurement targets and policies and make recommendations to the City Council pursuant to AB2514.

1.2 RECOMMENDATIONS

1.2.1 PROCUREMENT TARGETS

PWP does not recommend at this time that the City Council establish any specific energy storage system procurement targets to be achieved by December 31, 2016, or December 31, 2021, since no cost-effective, viable energy storage systems have been identified by PWP.

1.2.2 ONGOING EVALUATION

PWP staff will continue to look for appropriate opportunities to encourage cost-effective deployment of energy storage systems as it executes its Integrated Resource Plan, and procures future renewable and conventional energy. PWP staff will continue to work with the Southern California Public Power Authority ("SCPPA") to evaluate various energy storage technologies through solicitation of proposals for energy storage systems as standalone offers as well as in conjunction with renewable and conventional energy projects.

PWP will reevaluate the issue of energy storage system procurement targets and policies and make recommendations to the City Council at least once every three years.

1.2.3 CEC REPORTING

PWP will report to the California Energy Commission (CEC) regarding energy storage system procurement targets and policies adopted by the City Council.

If the City Council adopts any energy storage system procurement targets or policies to encourage the cost effective deployment of energy storage systems, then by January 1, 2017, PWP will submit a report to the CEC demonstrating that it has complied with the energy storage system procurement targets, if any, and policies adopted by the City Council. Such report, with confidential information redacted, will be made available to the public by being published by the CEC and/or PWP on their respective websites.

By January 1, 2022, PWP will submit a report to the CEC demonstrating that it complied with any energy storage system procurement targets and policies adopted by the City Council. The report, with confidential information redacted, will be made available to the public by the CEC and/or PWP on their respective websites.

2.0 ASSEMBLY BILL 2514

2.1 SUMMARY

California Assembly Bill 2514 (2010, Skinner. Energy Storage Systems.) ("AB 2514") requires that publicly-owned utilities begin evaluating the potential to procure viable and cost-effective energy storage systems by March 1, 2012, and that their governing boards, such as the Pasadena City Council, set appropriate procurement targets, if any, by October 1, 2014 for energy storage systems to be procured by December 31, 2016 and December 31, 2021. The City Council may also consider a variety of possible policies to encourage the cost-effective deployment of energy storage systems, including refinement of existing PWP procurement methods to properly value energy storage systems. The City Council must reevaluate the policies and procurement targets, if any, at least once every three years. The Pasadena City Council, PWP's governing board, directed PWP to begin the evaluation process as part of the Integrated Resource Plan Update adopted by the City Council on March 5, 2012.

The law imposed a similar requirement on the California Public Utilities Commission to open a proceeding to determine appropriate targets, if any, for other load-serving entities in the state, including investor-owned utilities and energy service providers, to procure viable and cost-effective energy storage systems to be achieved by December 31, 2015 and December 31, 2020, and to adopt the procurement targets, if determined to be appropriate, by October 1, 2013 (one year earlier than the targets for publicly-owned utilities).

2.2 PURPOSE OF LEGISLATION

The legislative policy embodied in AB 2514 was enacted to expand the use of energy storage systems to:

(a) Assist in integrating increased amounts of renewable energy resources into the electrical transmission and distribution grid in a manner that minimizes emissions of greenhouse gases;

(b) Optimize the use of the significant additional amounts of variable, intermittent, and off-peak electrical generation from wind and solar energy that will be entering the California power mix on an accelerated basis;

(c) Reduce costs to ratepayers by avoiding or deferring the need for new fossil fuel-powered peaking power plants and avoiding or deferring distribution and transmission system upgrades and expansion of the grid;

(d) Reduce the use of electricity generated from fossil fuels to meet peak load requirements on days with high electricity demand and potentially avoid or reduce the use of electricity generated by high carbon-emitting electrical generating facilities during those high electricity demand periods, which could have substantial co-benefits from reduced emissions of criteria pollutants ;

(e) Provide the ancillary services otherwise provided by fossil-fueled generating facilities to reduce emissions of carbon dioxide and criteria pollutants.

2.3 DEFINITION OF ENERGY STORAGE SYSTEM

According to AB 2514, the term "energy storage system" means commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy.

An "energy storage system" may be either centralized or distributed. It may be either owned by a load-serving entity or local publicly owned electric utility, a customer of a load-serving entity or local publicly owned electric utility, a third party, or jointly owned by two or more of the above.

An "energy storage system" must be *cost effective* and:

- Reduce emissions of greenhouse gases,
- Reduce demand for peak electrical generation,
- Defer or substitute for an investment in generation, transmission, or distribution assets, or
- Improve the reliable operation of the electrical transmission or distribution grid.

An "energy storage system" must do one or more of the following:

(A) Use mechanical, chemical, or thermal processes to store energy that was generated at one time for use at a later time.

(B) Store thermal energy for direct use for heating or cooling at a later time in a manner that avoids the need to use electricity at that later time.

(C) Use mechanical, chemical, or thermal processes to store energy generated from renewable resources for use at a later time.

(D) Use mechanical, chemical, or thermal processes to store energy generated from mechanical processes that would otherwise be wasted for delivery at a later time.

AB 2514 doesn’t define cost effective. The following is the definition PWP has used in its analysis. At a minimum:

a. The product or service must fill an existing or anticipated unmet need, and
b. Must have a benefit-to-cost[1] ratio ≥ 1, and
c. The benefits must accrue proportionately to the parties that pay the costs[2].

To be cost effective, the energy storage product or service generally must be less expensive (or more effective) than alternative means of providing the same product or service, especially if existing equipment (such as the local natural gas-fired plant) is already available.

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[1] Benefit-to-cost ratio is defined as the net present value (NPV) of all direct, quantifiable benefits divided by the NPV of the direct, quantifiable costs of a defined energy storage system providing specific grid (or distribution/customer) services over its lifetime.

[2] For example, if it is determined that an energy storage system installed in Pasadena could provide hundreds of millions of dollars of net benefits to the CAISO system (of which PWP load is only about 1%), but there is no way for PWP customers to recover the remaining cost of the energy storage system from the other 99% of CAISO customers if PWP were to install it, then by this definition, it would not be cost effective for PWP, even if the benefit-to-cost ratio were >1 for the CAISO.

3.0 TYPICAL ENERGY STORAGE TECHNOLOGIES[3]

3.1 TECHNOLOGY SUMMARY TABLE

The following table summarizes the major energy storage system technologies, their primary applications, what is currently known about them, and challenges with each.

Technology	Primary Application	What we know currently	Challenges
CAES	• Energy management • Backup and seasonal reserves • Renewable integration	• Better ramp rates than gas turbine plants • Established technology in operation since the 1970's	• Geographically limited • Lower efficiency due to roundtrip conversion • Slower response time than flywheels or batteries • Environmental impact
Pumped Hydro	• Energy management • Backup and seasonal reserves • Regulation service also available through variable speed pumps	• Developed and mature technology • Very high ramp rate • Currently most cost effective form of storage	• Geographically limited • Plant site • Environmental impacts • High overall project cost
Fly wheels	• Load leveling • Frequency regulation • Peak shaving and off peak storage • Transient stability	• Modular technology • Proven growth potential to utility scale • Long cycle life • High peak power without overheating concerns • Rapid response • High round trip	• Rotor tensile strength limitations • Limited energy storage time due to high frictional losses
Advanced Lead- Acid	• Load leveling and regulation • Grid stabilization	• Mature battery technology • Low cost • High recycled content • Good battery life •	• Limited depth of discharge • Low energy density • Large footprint • Electrode corrosion limits useful life
NaS	• Power quality • Congestion relief • Renewable source integration	• High energy density • Long discharge cycles • Fast response • Long life • Good scaling potential	• Operating Temperature required between 250° and 300° C • Liquid containment issues (corrosion and brittle glass seals)

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[3] *Excerpts from Chapter 2 of DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*

Technology	Primary Application	What we know currently	Challenges
Li-ion	• Power quality • Frequency regulation	• High energy densities • Good cycle life • High charge/discharge efficiency and	• High production cost - scalability • Extremely sensitive to over temperature, overcharge internal pressure buildup
Flow Batteries	• Ramping • Peak Shaving • Time Shifting • Frequency regulation • Power quality •	• Ability to perform high number of discharge cycles • Lower charge/discharge efficiencies • Very long life	• Developing technology, not mature for commercial scale development • Complicated design • Lower energy density
SMES	• Power quality • Frequency regulation	• Highest round-trip efficiency from discharge	• Low energy density • Material and manufacturing cost
Electrochemical Capacitors	• Power quality • Frequency regulation	• Very long life • Highly reversible and fast discharge	• Currently cost prohibitive
Thermochemical Energy Storage	• Load leveling and regulation • Grid stabilization	• Extremely high energy densities	• Currently cost prohibitive

3.2 COMPRESSED AIR ENERGY STORAGE ("CAES")

CAES systems use off-peak electricity to compress air and store it in a reservoir, either an underground cavern or aboveground pipes or vessels. When electricity is needed, the compressed air is heated, expanded, and directed through an expander or conventional turbine-generator to produce electricity.

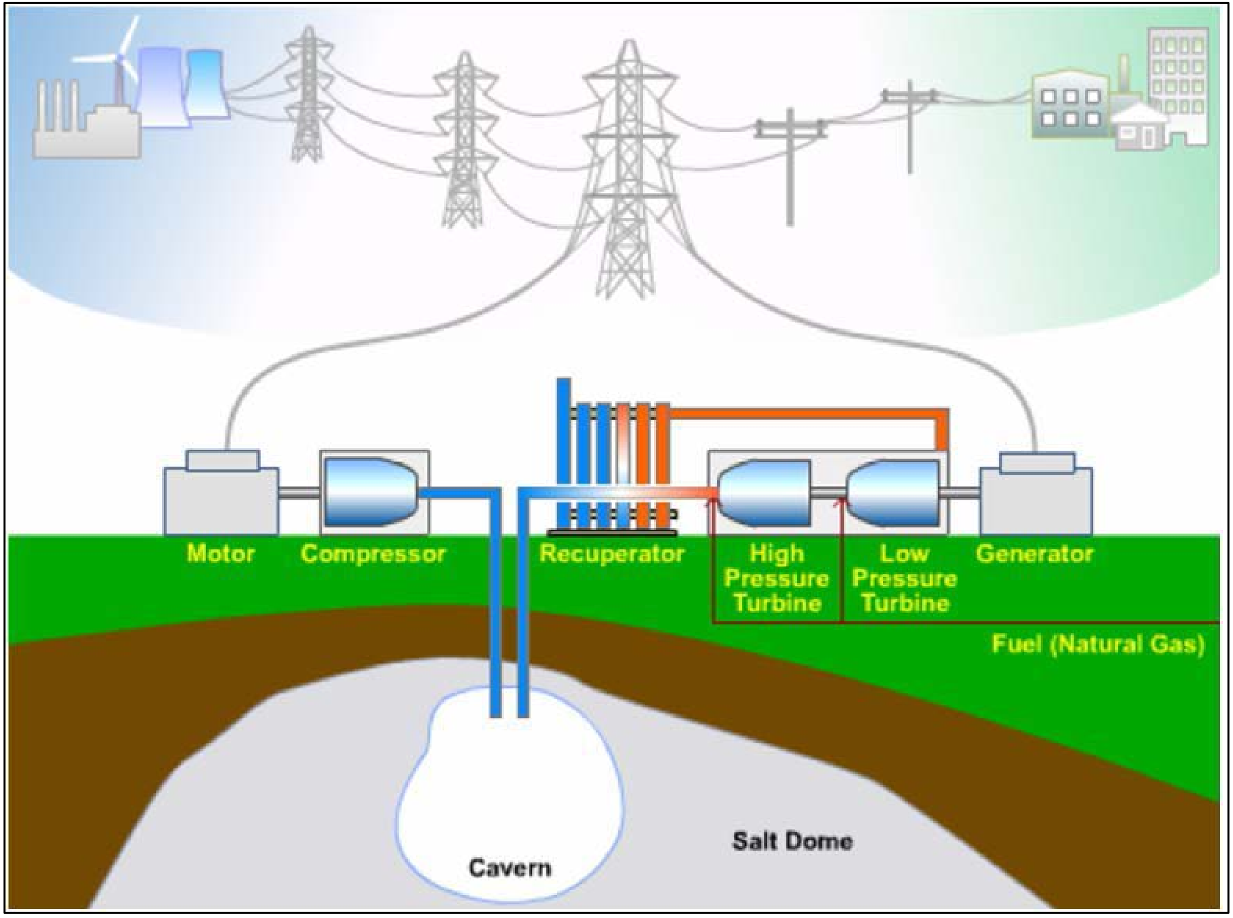
CAES is the only commercial bulk energy storage plant available today, other than pumped hydro. There are two operating first-generation systems: one in Germany and one in Alabama.

CAES plants employing aboveground air storage would typically be smaller than plants with underground storage, with capacities on the order of 3 to 50 MW and discharge times of 2 to 6 hours. Aboveground CAES plants are easier to site but more expensive to build (on a $/kW basis) than CAES plants using underground air storage systems, primarily due to the incremental additional cost associated with aboveground storage.

Underground CAES storage systems are most cost-effective with storage capacities up to 400 MW and discharge times of 8 to 26 hours. Siting such plants involves finding and verifying the air storage integrity of a geologic formation appropriate for CAES in a given utility's service territory.

One of the largest natural salt formations in the United States happens to be located adjacent to the 1,800 MW Intermountain Power Project, from which PWP purchases coal-fired generation. A 1,200 MW CAES project has been proposed there to take advantage of wind energy delivered from Wyoming via the proposed Zephyr transmission project. The City of Burbank has lead efforts to get transmission studies focused on the feasibility and potential benefits of the development. PWP and other SCPPA members are following the project with interest.

Figure 3.2
Schematic of Compressed Air Energy Storage Plant with Underground Compressed Air Storage



3.3 PUMPED HYDRO STORAGE

Pumped hydroelectric energy storage is a large, mature, and commercial utility-scale technology currently used at many locations in the United States and around the world. Pumped hydro typically employs off-peak electricity to pump water from a reservoir up to another reservoir at a higher elevation. When electricity is needed, water is released from the upper reservoir through a hydroelectric turbine into the lower reservoir to generate electricity. Figure 3.3A shows a cutaway view of a typical pumped hydro plant.

Figure 3.3A - Cutaway Diagram of a Typical Pumped Hydro Plant

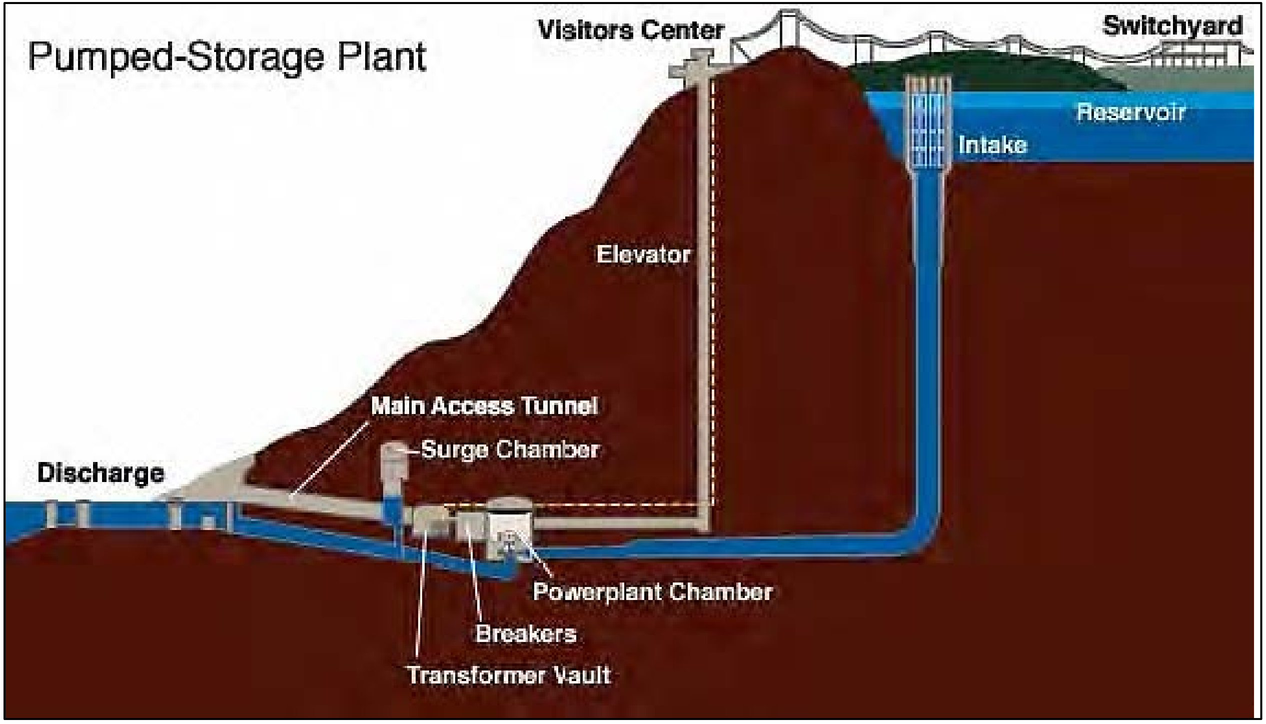
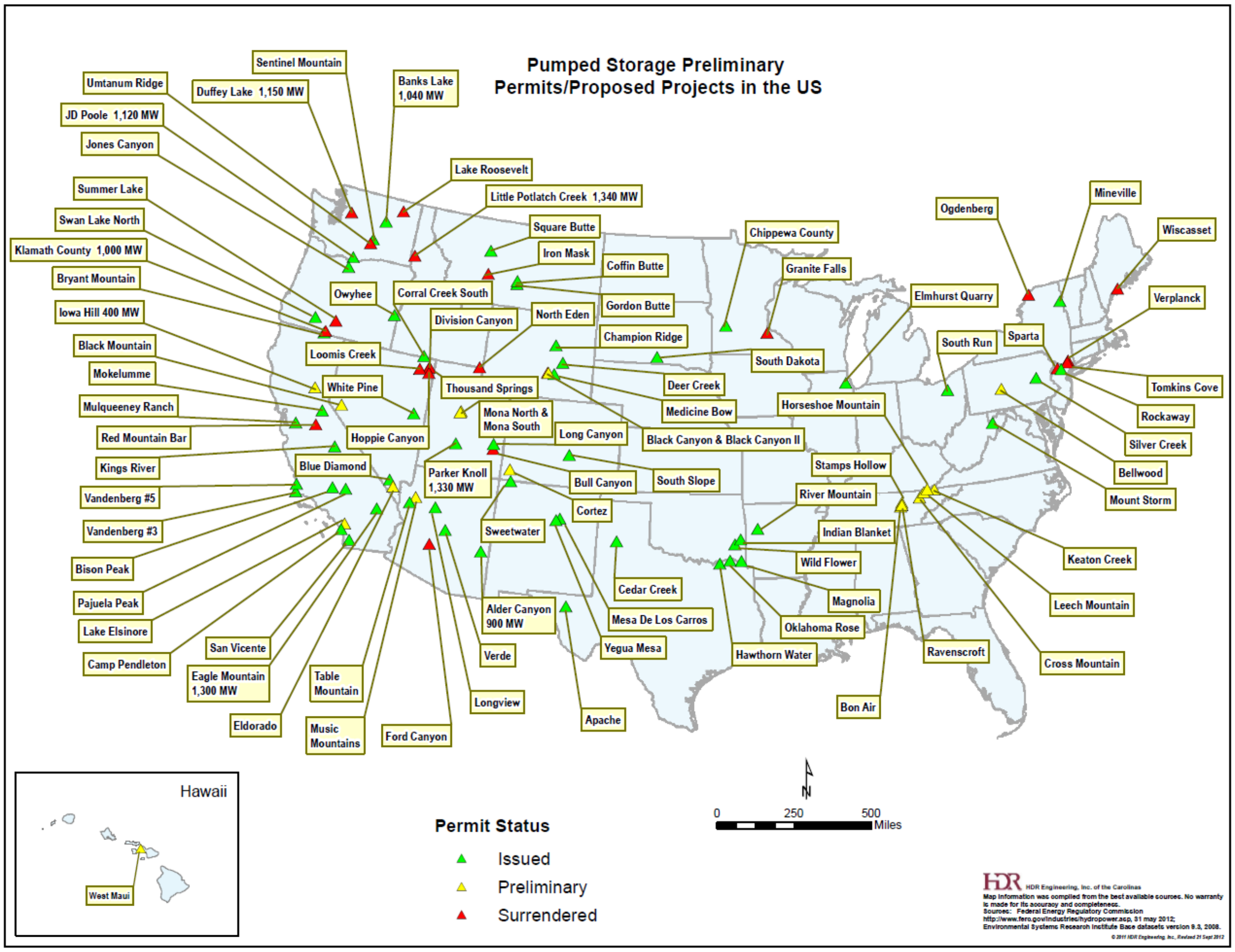


Figure 3.3B – Pumped Storage Preliminary Permits/Proposed Projects in the US



HDR Engineering, Inc. of the Carolinas
Map information was compiled from the best available sources. No warranty is made for its accuracy and completeness.
Sources: Federal Energy Regulatory Commission http://www.ferc.gov/industries/hydropower.asp, 31 may 2012; Environmental Systems Research Institute Base datasets version 9.3, 2008.
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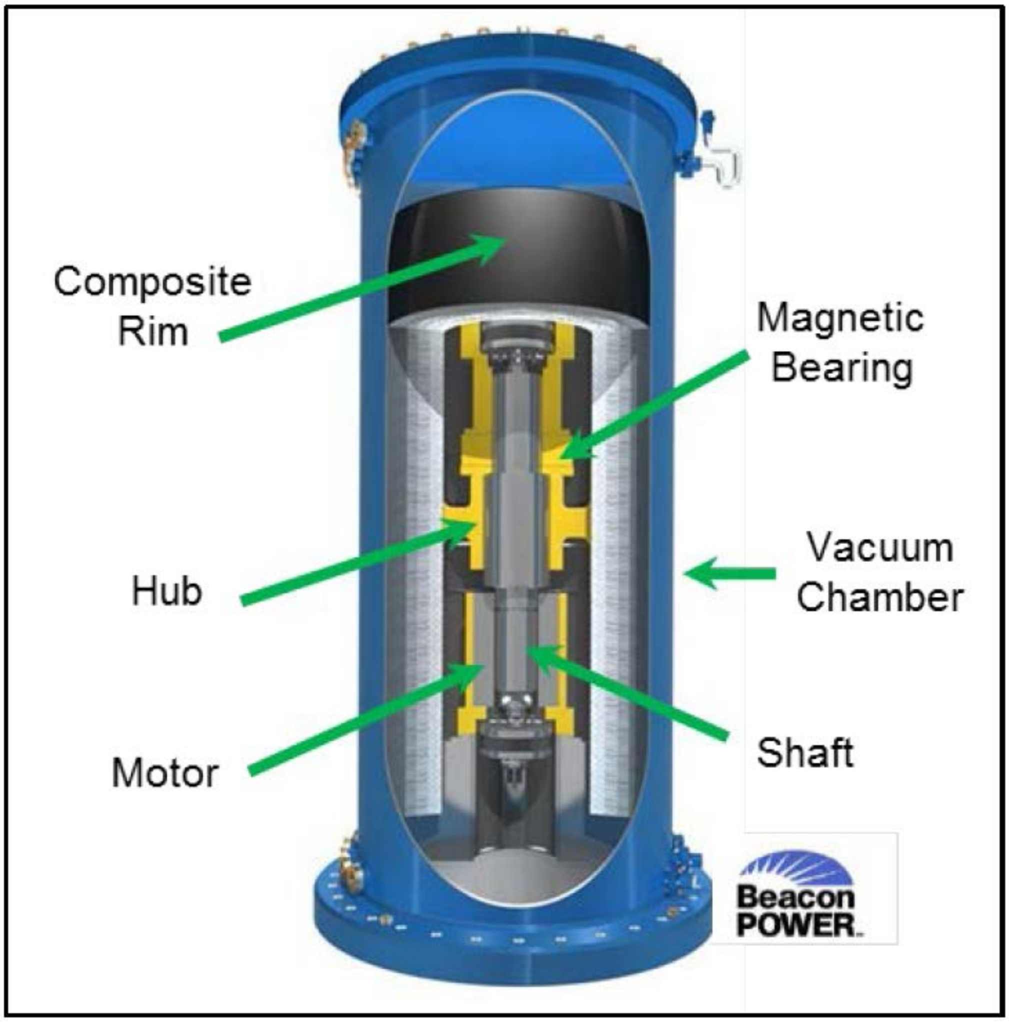
3.4 FLYWHEELS

Flywheels store energy in the form of the angular momentum of a spinning mass, called a rotor. The work done to spin the mass is stored in the form of kinetic energy. A flywheel system transfers kinetic energy into AC power through the use of controls and power conversion systems.

Most modern flywheel systems have some type of containment for safety and performance-enhancement purposes. This containment is usually a thick steel vessel surrounding the rotor, motor-generator, and other rotational components of the flywheel. If the wheel fractures while spinning, the containment vessel would stop or slow parts and fragments, preventing injury to bystanders and damage to surrounding equipment. Containment systems are also used to enhance the performance of the flywheel. The containment vessel is often placed under vacuum or filled with a low-friction gas such as helium to reduce the effect of friction on the rotor.

Figure 3.4
Integrated Flywheel System Package Cutaway Diagram
(Courtesy Beacon Power)



3.5 ADVANCED LEAD-ACID BATTERIES

Lead-acid batteries are the oldest form of rechargeable battery technology. Originally invented in the mid-1800s, they are widely used to power engine starters in cars, boats, planes, etc. All lead-acid designs share the same basic chemistry. The positive electrode is composed of lead-dioxide, PbO2, while the negative electrode is composed of metallic lead, Pb. The active material in both electrodes is highly porous to maximize surface area. The electrolyte is a sulfuric acid solution, usually around 37% sulfuric acid by weight when the battery is fully charged.

Lead-acid energy storage technologies are divided into two types: lead-acid carbon technologies and advanced lead-acid technologies. Lead-acid carbon technologies use a fundamentally different approach to lead-acid batteries through the inclusion of carbon, in one form or another, both to improve the power characteristics of the battery and to mitigate the effects of partial states of charge. Certain advanced lead-acid batteries are conventional valve-regulated lead-acid (VRLA) batteries with technologies that address the shortcomings of previous lead-acid products through incremental changes in the technology.[4] Other advanced lead-acid battery systems incorporate solid electrolyte-electrode configurations, while others incorporate capacitor technology as part of anode electrode design.

Laboratory carbon technology prototypes have undergone deep-discharge testing and withstood more than 1600 cycles before failure. In comparison, most lead-acid batteries designed for deep discharges deliver 300 to 500 cycles. Application-specific prototypes may offer several performance advantages over conventional lead-acid batteries, including:

- Significantly faster recharge rates,
- Significantly longer cycle lives in deep discharge applications, and
- Minimal required maintenance.

Some advanced lead batteries have supercapacitor-like features that give them fast response, similar to flywheels or Li-ion batteries. Advanced lead-acid systems from a number of companies are currently in early field trial demonstrations.

Disposal of lead-acid batteries is an important part of the life cycle. The environmental and safety hazards associated with lead require a number of regulations concerning the handling and disposal of lead-acid batteries. Lead-acid batteries are among the most recycled products in the world. Old batteries are accepted by lead-acid manufacturers for recycling. Batteries are separated into their component parts. The lead plates and grids are smelted to purify the lead for use in new batteries. Acid electrolyte is neutralized, scrubbed to remove dissolved lead, and released into the environment. Other component parts such as plastic and metal casings are also recycled.

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[4] "*Energy Storage and Distributed Generation Technology Assessment: Assessment of Lead-Acid-Carbon, Advanced Lead-Acid, and Zinc-Air Batteries for Stationary Application*", EPRI, EPRI ID 1017811, EPRI, Palo Alto, CA, December 2009.

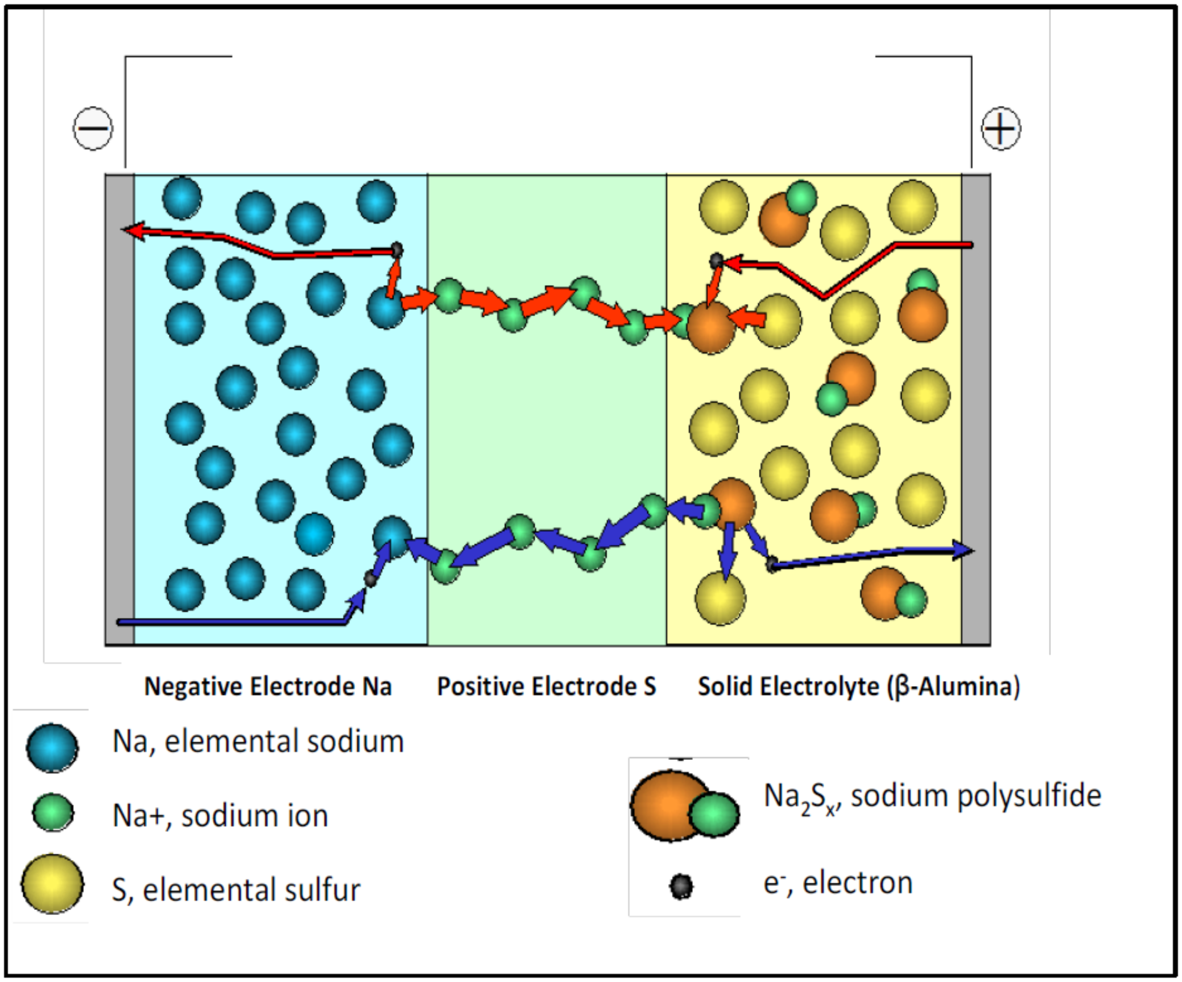
Figure 3.5
1.5-MW/1-MWh Advanced Lead-acid Dry Cell Systems by Xtreme Power in a Maui Wind Farm

3.6 SODIUM SULFUR BATTERIES (NaS)

Sodium-sulfur (NaS) batteries are a commercial energy storage technology finding applications in electric utility distribution grid support, wind power integration, and high-value grid services. NaS battery technology holds potential for use in grid services because of its long discharge period (approximately 6 hours). Like many other storage technologies, it is capable of prompt, precise response to such grid needs as mitigation of power quality events and response to Automatic Generation Control (AGC) signals for area regulation.

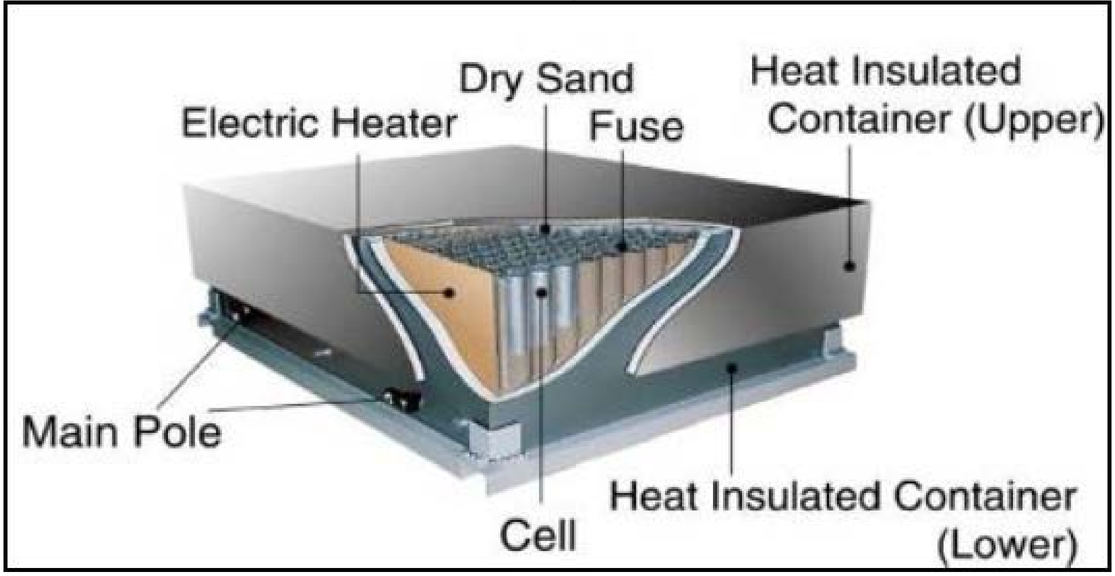
The NaS batteries use hazardous materials including metallic sodium, which is combustible if exposed to water. Therefore, construction of NaS batteries includes airtight, double-walled stainless-steel enclosures that contain the series-parallel arrays of NaS cells. Each cell is hermetically sealed and surrounded with sand both to anchor the cells and to mitigate fire, as shown in Figure 3.6B. Other safety features include fused electrical isolation and a battery management system that monitors cell block voltages and temperature. The sodium, sulfur, beta-alumina ceramic electrolyte, and sulfur polysulfide components of the battery are disposed of by routine industrial processes or recycled at the end of the NaS battery life. NaS batteries can be installed at power generating facilities, substations, and at renewable energy power generation facilities where they are charged during off peak hours and discharged when needed. Battery modules contain cells, a heating element, and dry sand.

Figure 3.6A - Chemical Structure of a Sodium-sulfur Cell



Standard units typically used in energy storage contain five 50-kW NaS modules that include a control unit, heater, heater controller, and voltage and current measurement sensors. Multiple, parallel standard units are used to create multi-megawatt systems.

Figure 3.6B
Sodium-sulfur Battery Module Components



3.7 LITHIUM-ION BATTERIES

In the past two years, Li-ion battery technology has emerged as the fasted growing platform for stationary storage applications. Already commercial and mature for consumer electronic applications, Li-ion is being positioned as the leading technology platform for plug-in hybrid electric vehicles (PHEVs) and all-electric vehicles, which will use larger-format cells and packs with capacities of 15 to 20 kWh for PHEVs and up to 50 kWh for all-electric vehicles.

The most common types of liquid Li-ion cells are cylindrical and prismatic cell. They are found in notebook computers and other portable power applications. Another approach, prismatic polymer Li-ion technology, is generally only used for small portable applications such as cellular phones and MP3 players. Rechargeable Li-ion batteries are commonly found in consumer electronic products, which make up most of the worldwide production volume of 10 to 12 GWh per year.

Compared to the long history of lead-acid batteries, Li-ion technology is relatively new. There are many different Li-ion chemistries, each with specific power-versus-energy characteristics. Large-format prismatic cells are currently the subject of intense R&D, scale-up, and durability evaluation for near-term use in hybrid EVs, but are still only available in very limited quantities as auto equipment manufacturers gear up production of PHEVs.[5]

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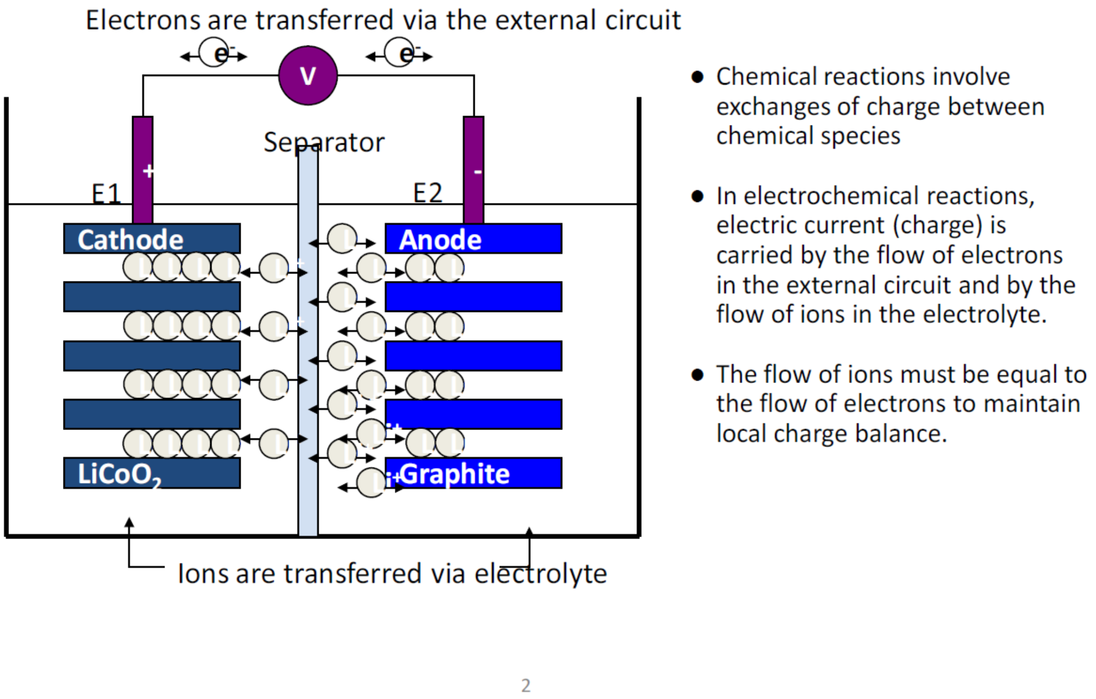
[5] *Electric Energy Storage Technology Options: A White Paper Primer on Applications, Costs and Benefits*, PI: Dan Rastler, EPRI ID 1020676, EPRI, Palo Alto, CA, September 2010.

A Li-ion battery cell contains two reactive materials capable of undergoing an electron transfer chemical reaction. To undergo the reaction, the materials must contact each other electrically, either directly or through a wire, and must be capable of exchanging charged ions to maintain overall charge neutrality as electrons are transferred. A battery cell is designed to keep the materials from directly contacting each other and to connect each material to an electrical terminal isolated from the other material's terminal. These terminals are the cell's external contacts (see Figure 3.7).

Figure 3.7 – Principles of a Li-ion Battery



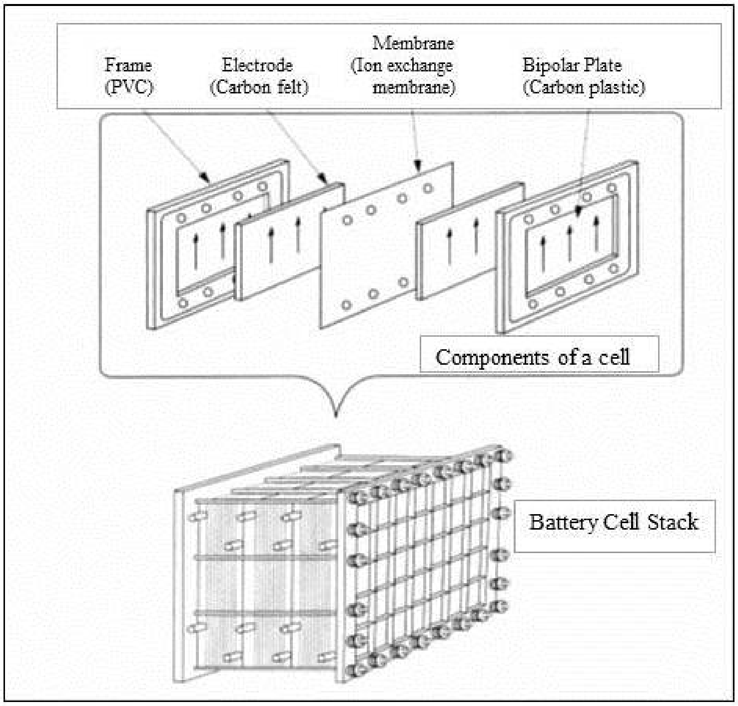
- Chemical reactions involve exchanges of charge between chemical species
- In electrochemical reactions, electric current (charge) is carried by the flow of electrons in the external circuit and by the flow of ions in the electrolyte.
- The flow of ions must be equal to the flow of electrons to maintain local charge balance.

3.8 FLOW BATTERIES - VANADIUM REDOX

In *flow batteries*, one or both active materials is in solution in the electrolyte at all times. Vanadium reduction and oxidation (redox) batteries are one type of *flow batteries*. In this case, the vanadium ions remain in an aqueous acidic solution throughout the entire process. The vanadium redox flow battery is a flow battery based on redox reactions of different ionic forms of vanadium. During battery charge, V3+ ions are converted to V2+ ions at the negative electrode through the acceptance of electrons. Meanwhile, at the positive electrode, V4+ ions are converted to V5+ ions through the release of electrons. Both of these reactions absorb the electrical energy put into the system and store it chemically. During discharge, the reactions run in the opposite direction, resulting in the release of the chemical energy as electrical energy.

In construction, the half-cells are separated by a proton exchange membrane that allows the flow of ionic charge to complete the electrical circuit. Both the negative and positive electrolytes (sometimes called the anolyte and catholyte, respectively) are composed of vanadium and sulfuric acid mixture at approximately the same acidity as that found in a lead-acid battery. The electrolytes are stored in external tanks and pumped as needed to the cells (see Figure 3.8.1A).

Figure 3.8.1A – Construction of a Vanadium Redox Cell Stack
(Courtesy Sumitomo Electric Industries)



Vanadium redox flow batteries have an important advantage among flow batteries: the two electrolytes are identical when fully discharged. This makes shipment and storage simple and inexpensive and greatly simplifies electrolyte management during operation.

Vanadium redox systems are capable of stepping from zero output to full output within a few milliseconds, if the stacks are already primed with reactants. In fact, the limiting factor for beginning battery discharge is more commonly the controls and communications equipment. For short-duration discharges for voltage support, the electrolyte contained in the stacks can respond without the pumps running at all. The cell stack can produce three times the rated power output provided the state of charge is between 50% and 80%.

The physical scale of vanadium redox systems tends to be large due to the large volumes of electrolyte required when sized for utility-scale (megawatt-hour) projects. Unlike many other battery technologies, cycle life of vanadium redox systems is not dependent on depth of discharge. Systems are rated at 10,000 cycles, although some accelerated testing performed by Sumitomo Electric Industries, Ltd., produced a battery system with one 20-kW stack for cycle testing that continued for more than 13,000 cycles over about two years.

When decommissioning a vanadium redox system, the solid ion exchange cell membranes may be highly acidic or alkaline and therefore toxic. They should be disposed of in the same manner as any corrosive material. If possible, the liquid electrolyte is recycled. If disposed of, the vanadium is extracted from the electrolyte before further processing of the liquid. Research is ongoing to determine the exact environmental risk factors for vanadium.

Figure 3.8.1B[6] illustrates the schematic of a vanadium redox flow battery.

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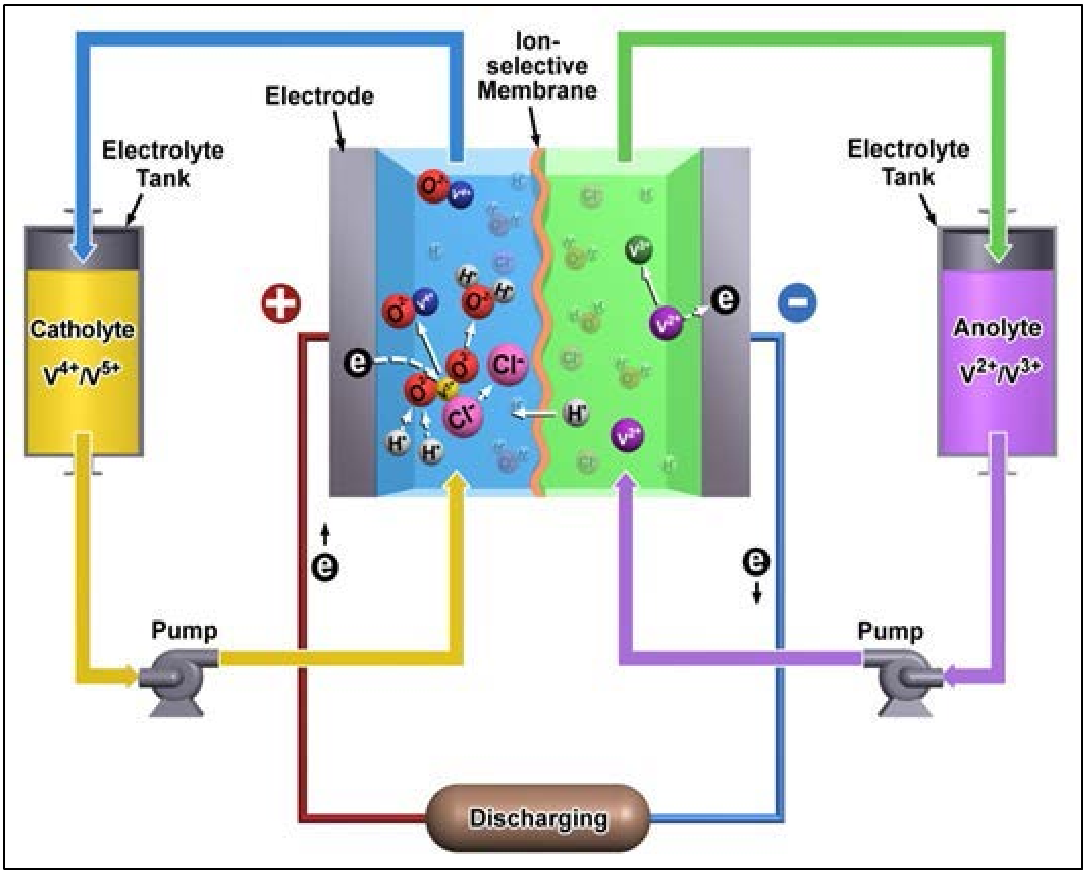
[6] *VRB Energy Storage for Voltage Stabilization: Testing and Evaluation of the PacifiCorp Vanadium Redox Battery Energy Storage System at Castle Valley, Utah*, PI: Harash Kamath – EPRI PEAC Corporation, EPRI ID 1008434, EPRI, Palo Alto, CA, March 2005.

Figure 3.8.1B – Principles of the Vanadium Redox Battery
(Courtesy of the Pacific Northwest National Laboratory)



3.9 THERMAL ENERGY STORAGE[7]

Thermal energy storage refers to storage systems that store heat or cooling (in the form of chilled or frozen water) to displace electrical air conditioning load during peak periods. In the case of California, ice thermal storage is particularly relevant. Most firms in this space offer large-scale systems for commercial businesses such as airports, convention centers, or large hotels. Small, modular systems have also been developed for single-building applications such as office buildings.

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[7] *SMUD Energy Storage AB 2514 Report*, 8/29/2014 (Sacramento Municipal Utility District)

4.0 TYPICAL ENERGY STORAGE APPLICATIONS/USES[8]

4.1 ENERGY STORAGE FUNCTION OVERVIEW

The DOE's Electricity Storage Handbook[9] identifies 18 services or functional uses that are available from various electricity storage devices that can be broken down into 5 groups (presented with no order of importance or preference):

1) Bulk Energy Services
2) Ancillary Services
3) Transmission Infrastructure Services
4) Distribution Infrastructure Services
5) Customer Energy Management Services

Based on this broad range, electricity storage can possibly provide services to all levels of grid operations.

4.2 BULK ENERGY SERVICES

There are 2 primary bulk energy services that can be provided with energy storage systems: 1) time-shift of electric energy consumption; and 2) electric supply capacity.

1) Electric energy time-shift allows utilities to purchase inexpensive electricity and store it for use or sale at a later time when system marginal cost or market prices are higher (i.e., arbitrage). Time shift can also be achieved when excess generation from wind or solar that might otherwise be curtailed is stored for use at a later, high load period. These time shifts can be very short (hourly), but also of longer duration (diurnal swings and seasonal differences).

2) Energy storage can be used to defer and/or reduce the need to build new generation facilities or purchase capacity in the wholesale market to meet system requirements. The use or applicability of storage as supply capacity is very utility-specific and dependent on load/resource balance, climate, and economics.

Pumped hydro, compressed air and thermal energy storage technologies have traditionally been deployed to meet such system needs.

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[8] "*Energy Storage Technology Abstract*," Southern California Public Power Authority Energy Storage Working Group, February 2014, Bryan Cope, SCPPA Director of Program Development – Principal Author

[9] "*DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*," Sandia Report SAND2013-5131, Unlimited Release - July 2013

4.3 ANCILLARY SERVICES

Ancillary services represent grid support functions that are available from energy storage. The descriptions and examples presented below are very general in nature and not intended to represent the full complexity of electric utility operations.

These services include:

1) Regulation – or the managing of interchange flows between control areas to closely match scheduled flows with the load variations in each balancing authority. Regulation and response is needed to maintain grid frequency and for operators to comply with specific North American Reliability Council (NERC) standards. Battery storage technologies are particularly well-suited for regulation support because of relatively fast response times and ramp rates.

2) Spinning, Non-Spinning, and Supplemental Reserves – are required for grid stability and represent capacity that can be called on when other electric supply resources become unavailable unexpectedly. Spinning reserves include generating capacity that is on-line but unloaded from the system and typically needs to be available and synchronized within 10 minutes. Frequency-responsive spinning reserves need to be available in 10 seconds. Non-spinning reserve is generating capacity that may be off-line but can be brought on-line within 10 minutes. Supplemental Reserves are resources that can serve load within 1 hour of system disturbance. Many energy storage technologies can be well-suited to serve any or all of these reserve capacity roles. Ideally, the use of storage to serve as a spinning reserve resource can allow utilities to reduce or eliminate the use of fossil fuel-fired power plants as a spinning reserve resource. In such a scenario, the thermal resource can be held as a non-spinning resource to “take-over” the reserve role initially provided by the storage system.

3) Voltage Support – is the system operators’ requirement to maintain voltages within specified limits. The nominal time needed for voltage support is assumed to be 30 minutes. This is typically done with specific power plants that are used to generate reactive power (VAR) to offset fluctuating load and reactance in the grid. The power conversion systems (PCS) of many, if not all, electricity storage systems on the market are capable of operating at a non-unity power factor and “absorb” or “provide” reactive power or volt-ampere reactive (VARs). Battery and flywheel technologies are generally seen as very good alternatives to typical resources used to provide voltage support.

4) Black Start – is the ability for a resource to provide an active reserve of power to energize transmission or distribution lines or provide station power to bring power plants back on-line after a catastrophic failure or outage. Storage can

provide such start-up power if the storage system is suitably sized and there is a clear transmission path from the storage system to the power plant.

5) Load Following and Ramping Support for Renewables – Electricity storage is ideally suited for and is already being used in balancing the variability of wind and solar photovoltaic (PV) systems' generation and/or large load swings on utility systems. Normally, generation is used for load following. However, there are operational considerations (e.g., ramp rates, efficiency degradation, emissions) that can make the use of thermal resources for load following challenging. Since most electricity storage systems can operate at "partial load" with modest or nominal performance penalties or efficiency loss and they can respond (ramp up – or down) very quickly (as compared to most generation) – storage is a very good fit for load following services.

4.4 TRANSMISSION SYSTEM SERVICES

Storage may be useful in three key areas of transmission system support: 1) transmission system upgrade deferral, 2) transmission congestion relief, as well as 3) damping support.

1) Deferral or elimination of large capital investments to upgrade a transmission line that is at or near its fully loaded capacity can probably be achieved with a relatively small investment in energy storage downstream from the overloaded transmission node. In addition, assuming the storage system reduces the loading on existing equipment, one result of the energy storage system could be to improve or increase the life of the existing transmission equipment, including transformers and cables.

2) Transmission congestion relief might be achieved by placing storage systems at locations downstream of the congested area(s) on the transmission system, with energy stored during low load periods and discharged during high load periods when the transmission line is congested. This could provide high value for many utilities and customers as congestion costs may be reduced or eliminated.

3) Storage systems that have sub-second response times can increase the load-carrying capacity of a transmission system by improving the system's dynamic stability and providing active real and/or reactive power modulation at sub-synchronous resonance frequencies.

4.5 DISTRIBUTION SYSTEM SERVICES

Storage can defer the need for distribution system upgrades (and associated voltage support), similar to effects on transmission systems. Distribution systems are typically designed for 15- to 20-year planning horizons. As systems evolve and grow, upgrades are made to serve load requirements and meet the needs of customers. With the changing utility industry including the deployment of distributed generation resources and electric vehicles, utilities' distribution systems are experiencing significant changes that were not anticipated when they were designed. However, energy storage systems that are located in circuits and on feeders that are impacted or near full-load capacity can defer or eliminate the need for large capital investments to upgrade the system in that specific region. Similar to the transmission system discussion above, and assuming that the storage system reduces loading on existing equipment, the energy storage system could improve or increase the life of the existing distribution equipment, including transformers and cables.

4.6 CUSTOMER ENERGY MANAGEMENT SERVICES

Energy storage can be valuable to utilities, as well as directly to customers. It is important for utilities to understand the relative value of site-specific storage applications for customers to ensure that the cost and benefits of energy storage additions are shared equitably among all participants. Below are some of the key areas in which customers can derive value from energy storage technology.

1) Power Quality – protect customer on-site loads that are downstream of the storage against voltage or frequency fluctuations, low power factor, harmonics, and short (partial to full second) interruptions in service;
2) Power Reliability – protect from total loss of power from utility;
3) Retail Energy Time Shift – take advantage of time of day/real-time pricing (arbitrage);
4) Demand Charge Management – shift demand at their facility to avoid peak period demand charges.

Beyond these 4 items, there is an additional benefit or value to customers from energy that is not addressed in the Handbook, as it relates to the use of thermal energy storage. Specifically, the application of thermal energy storage systems to shift peak demand of large-scale, chiller-based air conditioning systems and/or small-scale, refrigerant-based systems can provide customers who employ these technologies with improved cooling capacity from their system and an associated, increased level of comfort for occupants.

Each of the services or functions listed above can be provided by the correct energy storage system(s). Each service also presents a specific value proposition for each utility. Some services may not be needed at all while one (or more) may be useful to a particular electric system's operations. Similarly, and importantly, energy storage can possibly provide great value for customers. For those who may choose to employ location-specific storage applications and take advantage of arbitrage or cost-saving opportunities or improve power quality/reliability – the impact will be direct. However, the development and addition of cost-effective energy storage anywhere on the local electric system will provide value for all of the customers/owners of each Publicly Owned Utility. These storage systems will improve a utility's operating efficiencies and maintain or reduce costs which will directly flow through to customers as the utility is able to continue to provide low-cost and highly reliable electric service. Determining the need for such services and understanding the value of those services for all participants as we continue to evaluate the changing energy storage market will be important for utilities and potential participating customers.

4.7 STACKED SERVICES—USE CASE COMBINATIONS

Electricity storage can be used for any of the services listed above, but it is rare for a single service to generate sufficient revenue to justify its investment. However, the flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams and becomes economically viable. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis.

In the California Public Utility Commission's (CPUC's) energy storage proceeding R1012007, a series of electricity storage use cases was considered and studied by multiple stakeholders. CPUC divided the use cases into three general categories based on the location of the storage as shown in Table 4.7. When connected to the grid at the transmission level, energy storage can provide grid-related service to ancillary markets under the control of ISOs while bidding into the energy market. Energy storage can also act as a peaker to provide system capacity. When placed on the distribution circuits, energy storage can help solve local substation-specific problems (mitigating voltage problems, deferring investment upgrades, etc.) while providing ancillary services to the grid. On the customer side of the meter, energy storage system can shave the customer's peak load and reduce the electricity bill while improving power quality and reliability. Detailed documents about the CPUC-defined electricity storage use cases can be found on the CPUC website.[10]

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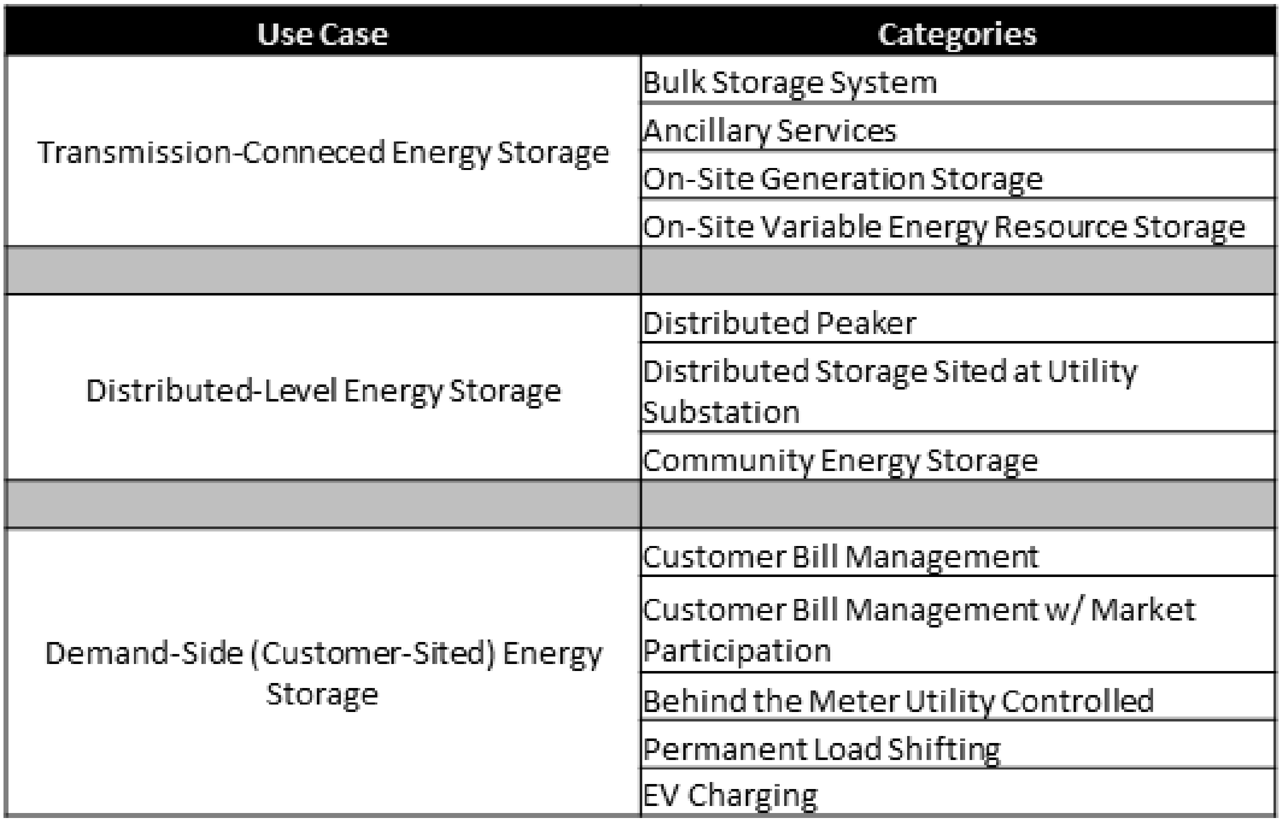
[10] http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm, last accessed March 15, 2013.

Table 4.7. Illustration of California Public Utility Commission Use Cases
(Source: EPRI presentation in CPUC Storage OIR Workshop, March 25, 2013[11]*)*



Use Case	Categories
Transmission-Conneced Energy Storage	Bulk Storage System
	Ancillary Services
	On-Site Generation Storage
	On-Site Variable Energy Resource Storage
Distributed-Level Energy Storage	Distributed Peaker
	Distributed Storage Sited at Utility Substation
	Community Energy Storage
Demand-Side (Customer-Sited) Energy Storage	Customer Bill Management
	Customer Bill Management w/ Market Participation
	Behind the Meter Utility Controlled
	Permanent Load Shifting
	EV Charging

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[11] http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm, last accessed March 15, 2013.

4.8 SCPPA SUMMARY OF TECHNOLOGIES/APPLICATIONS

				TRANSMISSION													DISTRIBUTION						BEHIND THE METER				
Technology	**Primary Application**	**What We Currently Know**	**Challenges**	Frequency Regulation	Peak Shifting and Firming	Ramping	Renewable Integratioin	Black Start	Load Shaving	Power Quality	Deferring Transmission Upgrade	Congestion Mitigation	Regulation, Load Following	Transient Stability, Improve Short-Duration Performance	Backup and Seasonal Reserves	Spinning and Non-Spinning Reserves	Power Quality	Deferring Distribution Infrastructure Upgrade	Peak Shifting Downsteam of Distribution System	Intermittent Distributed Generation Integration	Micro-Grid Formation	Transportable Outage Mitigation	Time-of-Use rate Optimization	Intermittent Distributed Generation Integration	Micro-Grid Formation	Power Quality	Backup Power During Outages
Compressed Air Energy Storage	• Energy management • Backup and seasonal reserves • Renewable integration	• Better ramp rates than gas turbine plants • Established technology in operation since the 1970's	• Geographically limited • Lower efficiency due to roundtrip conversion • Slower response time than flywheels or batteries • Environmental impact				●	●			●				●	●							○				
Pumped Hydro Energy Storage	• Energy management • Backup and seasonal reserves • Regulation service also available through variable speed pumps	• Developed and mature technology • Very high ramp rate • Currently most cost effective form of storage	• Geographically limited • Plant site • Environmental impacts • High overall project cost					●			●		●		●	●							○				
Flywheel Energy Storage	• Load leveling • Frequency regulation • Peak shaving and off peak storage • Transient stability	• Modular technology • Proven growth potential to utility scale • Long cycle life • High peak power without overheating concerns • Rapid response • High round trip energy efficiency	• Rotor tensile strength limitations • Limited energy storage time due to high frictional losses	●	●				●				●	●												●	●
Advanced Lead-Acid Batteries	• Load leveling and regulation • Grid stabilization	• Mature battery technology • Low cost • High recycled content • Good battery life	• Limited depth of discharge • Low energy density • Large footprint • Electrode corrosion limits useful life		●			●	●		●		●					●	●	●	●	●	●	●	●	●	●
Sodium-Sulfur (NaS) Batteries	• Power quality • Congestion relief • Renewable source integration	• High energy density • Long discharge cycles • Fast response • Long life • Good scaling potential	• Operating temperature required between 250º and 300º C • Liqiud containment issues (corrosion and brittle glass seals)		●		●	●		●	●	●					●	●	●	●	●	●	●	●	●	●	●
Lithium-Ion Batteries	• Power quality • Frequency regulation	• High energy density • Good cycle life • High charge/discharge efficiency	• High production cost - scalability • Extremely sensitive to over temperature, overcharge and internal pressure buildup • Intolerance to deep discharges	●	●				●	●	●						●	●	●	●	●	●	●	●	●	●	●
Flow Batteries	• Ramping • Peak shaving • Time shifting • Frequency regulation • Power quality	• Ability to perform high number of dischange cycles • Lower charge/discharge efficiencies • Very long life	• Developing technology, not mature for commercial scale development • Complicated design • Lower energy density	●	●	●			●	●	●						●	●	●	●	●	●	●	●	●	●	●
Superconducting Magnetic Energy Storage (SMES)	• Power quality • Frequency regulation	• Highest round-trip efficiency from discharge	• Low energy density • Material and manufacturing cost prohibitive	●																							
Electrochemical Capacitors	• Power quality • Frequency regulation	• Very long life • High reversible and fast discharge	• Currently cost prohibitive	●					●																		
Thermochemical Energy Storage/ Thermal Energy Storage/ Generation Storage	• Load leveling and regulation • Grid stabilization	• Extremely high energy density	• Currently cost prohibitive		●								●						●				●				

Reference: SANDIA Report, DOE/ EPRI 2013 Electric Storage Handbook in Collaboration with NRECA, Grid Energy Storage U.S. Department of Energy December 2013

5.0 ENERGY STORAGE PROCUREMENT TARGETS OF OTHERS

5.1 CPUC JURISDICTIONAL ENTITIES

5.1.1 CPUC ENERGY STORAGE ORDER INSTITUTING RULEMAKING[12]

In October 2013, the California Public Utilities Commission ("CPUC") issued Decision 13-10-040 adopting an energy storage procurement framework and design program in its Rulemaking establishing procurement targets for viable and cost-effective energy storage systems for its jurisdictional entities, which include investor-owned utilities, Electric Service Providers ("ESPs"), and Customer Choice Aggregators ("CCAs") in the state of California (excluding local publicly-owned utilities such as PWP).

The CPUC established a procurement target of 1,325 MW across the three investor-owned utilities, Pacific Gas & Electric ("PG&E"), Southern California Edison ("SCE"), and San Diego Gas & Electric ("SDG&E") within three specific grid domains: transmission-connected, distribution-connected, and customer-side applications. The energy storage is to be installed and operational no later than the end of 2024. The decision concluded that IOU ownership of 100% in transmission and distribution-connected storage was premature until it was determined what narrow applications are best suited for utility ownership versus third-party ownership, and limited utility ownership of storage systems to 50% across grid domains, evaluated on a case-by-case basis consistent with the CPUC's Long-Term Procurement Proceeding.

The CPUC established targets for ESPs and CCAs to purchase energy storage projects equal to 1% of their 2020 annual peak load by 2020, with installation and operation of the projects required by the end of 2024.

The decision acknowledged that the utilities have a number of energy storage projects either installed or under contract. It further acknowledged that pumped storage projects offer similar benefits as all of the emerging storage technologies, but the majority of pumped storage projects are each sized at 500 MW or greater. A single pumped storage project could account for the entire procurement target within a utility territory, and

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[12] California Public Utilities Commission ("CPUC") Order Instituting Rulemaking 10-12-007 Pursuant to Assembly Bill 2514 to Consider Adoption of Procurement Targets for Viable and Cost-Effective Targets for Energy Storage Systems, Decision 13-10-040, issued October 17, 2013

would dwarf smaller, emerging technologies, inhibiting the fulfillment of market transformation goals. The decision excluded pumped storage projects larger than 50 MW from participating in the IOU's Energy Storage program, but stated that pumped storage projects larger than 50 MW should be evaluated by utilities in their generation solicitations for new capacity in other proceedings.

The CPUC found that AB2514 is silent on any requirement to conduct or apply a system need determination as a basis for storage procurement targets. The CPUC found that it is reasonable to set procurement targets to encourage the development and deployment of new energy storage technologies, and that prior precedent supports the setting of storage procurement targets without a system needs determination. However, in the longer term, the CPUC will consider adjusting procurement target for energy storage to reflect need determinations within the Long Term Procurement Plan proceeding and as part of its regular evaluation of energy storage procurement targets and policies[13].

The CPUC considered the use of EPRI and DNV KEMA models to determine the cost-effectiveness of energy storage. These were two of the models that SCPPA considered that are similar to the Navigant model in many respects. The CPUC rejected the use of these models as the sole methodology for assessing cost effectiveness, and allowed investor-owned utilities instead to propose their own methodology to evaluate the cost and benefits of energy storage proposals, but based on the full range of benefits and costs identified in the use-case framework and the EPRI and DNV KEMA reports submitted in the proceeding.

The decision found that it is reasonable to develop cost containment strategies that protect ratepayers.

5.1.2 ALLOCATION OF IOU PROCUREMENT TARGETS[14]

The following table summarizes how the 1,325 MW of energy storage assigned by the CPUC was allocated among the three investor-owned utilities:

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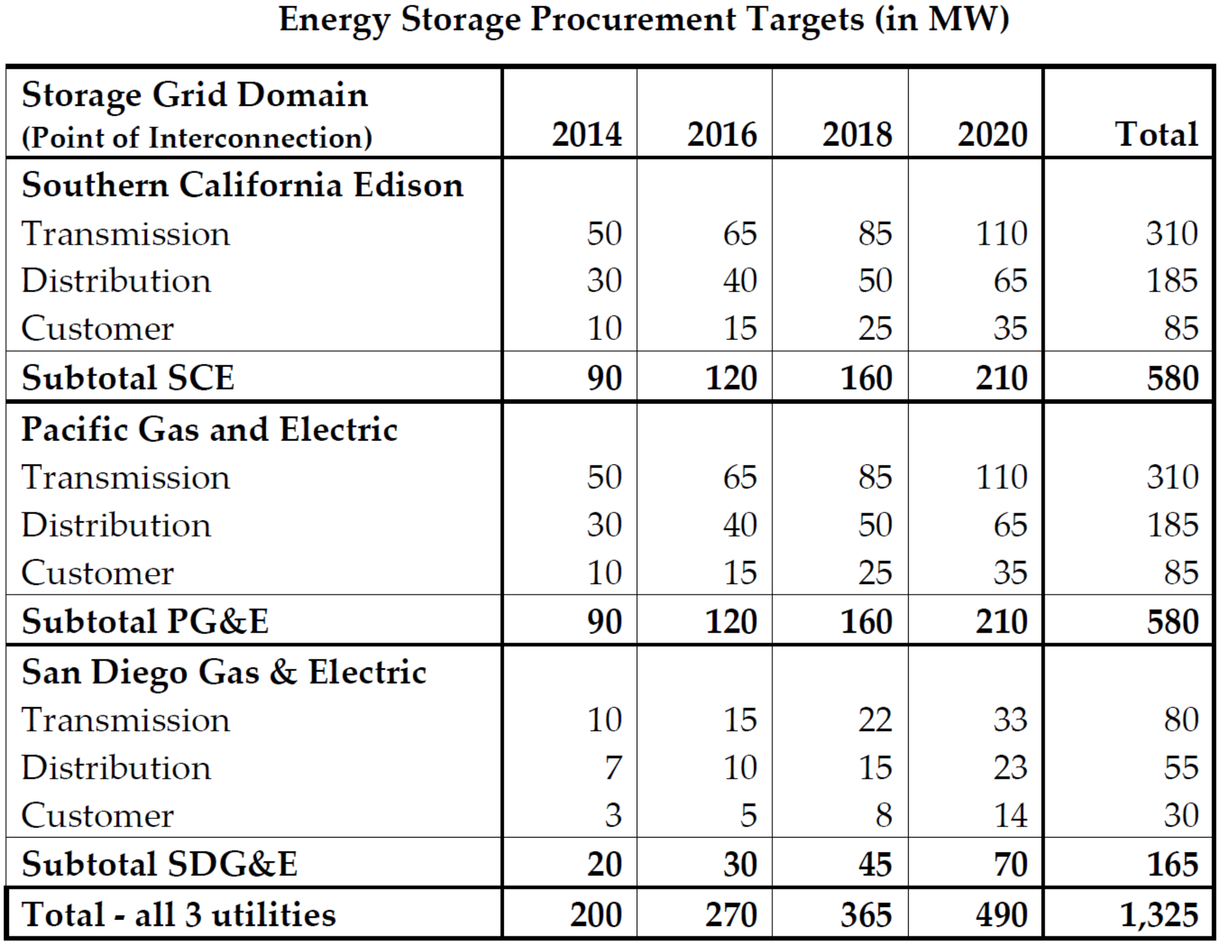
[13] Decision 13-10-040, p. 26

[14] Appendix A of Decision 13-10-040, Ibid.

Table 5.1.2



Energy Storage Procurement Targets (in MW)

Storage Grid Domain (Point of Interconnection)	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal SCE	**90**	**120**	**160**	**210**	**580**
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	**90**	**120**	**160**	**210**	**580**
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	**20**	**30**	**45**	**70**	**165**
Total - all 3 utilities	**200**	**270**	**365**	**490**	**1,325**

5.1.3 PROCUREMENT PROGRESS BY IOUS

5.1.3.1 SCE

SCE states in its 2014 Energy Storage filing that it expects to meet the 90 MW target set for it by the CPUC for 2014. In addition to existing energy storage projects that are eligible to count toward SCE's storage procurement target, SCE has a number of planned storage projects that should count toward its future targets. SCE also expect to procure energy storage through existing procurement mechanisms, including its Local Capacity Requirements solicitation, and potentially its Renewables Portfolio Standard solicitation and its Preferred Resources Pilot. SCE will also procure energy storage through an Energy Storage competitive solicitation that it expects to launch by December 1, 2014, and SCE will consider bilateral contract opportunities, as well as utility-owned storage. SCE's supporting testimony identifies the existing projects that it expects to count towards its procurement target (see Appendix A), its specific valuation and selection process, and outlines the upcoming 2014 Energy Storage Request for Offers.

5.1.3.2 PGE

In PG&E's 2014 Energy Storage filing, PG&E states that it intends to procure sufficient storage to meet its 2014 Biennial Target through:

1) A competitive Request for Offers for energy storage resources connected to the CAISO controlled transmission and distribution systems;
2) CPUC approved programs, including the Self Generation Incentive Program ("SGIP"), Permanent Load Shifting ("PLS") program, Demand Response ("DR") and Electric Vehicle ("EV") pilots where applicable, and any future programs and pilots developed on an on-going basis for customer-connected storage;
3) Mechanisms including but not limited to electric vehicle funding programs that also provide grid storage;
4) Energy Storage projects developed under CPUC approved contracts from other proceeding, such as the Long Term Procurement Plan ("LTPP") proceeding, the Renewables Portfolio Standard ("RPS") Program, and the Resource Adequacy ("RA") proceeding; and
5) Other CPUC approved channels, such as the California Energy Commission's Public Interest Research ("PIER") or the CPUC's Electric Program Investment Charge ("EPIC") funded projects, under certain conditions.

As for existing operational projects that should count towards its 2014 targets, PG&E claims 8.5 MW of distribution level storage projects, 3.5 MW of eligible projects at the customer level, and procurement of 150 MW of transmission level storage from an eligible pre-approved project that will be applied to future procurement targets between 2016 and 2020.

PG&E will seek stranded cost recovery for the cost of energy procured energy storage over the full life of the contract from any departing load (e.g., that switches to a CCA or ESP).

PG&E also seeks to have control of any transmission connected energy storage it procures turned over to the CAISO so that the costs will be incorporated into the Transmission Access Charge and recovered from all transmission connected customers.

PG&E seeks the broadest interpretation of eligibility – PG&E requests that the CPUC determine that electric generation using biogas technology will be considered Eligible Energy Storage. PG&E's argument is that, when biogas is created (e.g., at a dairy from the decomposition of biomass), the energy in the methane produced is captured and stored for later use, rather than wasted, and used to generate electricity at a later time.

5.1.3.3 SDG&E

SDG&E issued its 2014 Energy Storage Request for Offers on September 5, 2014. Offers will be due on January 5, 2015. The Energy Storage System procurement is part of SDG&E's Local Capacity Requirement "All Source" procurement effort. SDG&E is targeting energy storage within its local subarea, and has specified that resources within the transmission and distribution domains must be eligible to contribute to SDG&E's local resource adequacy requirements (e.g., at or electrically west of the Miguel or Suncrest substations and electrically south of the San Onofre Nuclear Generating Station 230 kV switchyard, and follow the appropriate process for obtaining a deliverability study from the CAISO and paying for any necessary deliverability upgrades in order to achieve full capacity deliverability status).

5.2 OTHER PUBLICLY-OWNED CALIFORNIA UTILITIES

5.2.1 SMUD

Staff of the Sacramento Municipal Utility District ("SMUD") prepared an AB2514 Storage Procurement Report dated August 29, 2014. According to the report:

Since 2008, SMUD has invested over $30 million dollars in internally and externally funded research to understand and prepare SMUD and its customers for eventual deployment and utilization of energy storage. Staff has been conducting various field demonstrations, studies, and assessments of different storage technologies, used for different applications ranging from transmission scale to distribution scale to customer scale systems. On technical issues, this body of work has assessed technology performance including such factors as efficiency, reliability, and durability. On economic issues, this body of work has assessed capital costs, installation costs, operation costs, value, and cost effectiveness. Additionally through this body of work, staff has assessed grid integration issues and strategies for interconnecting, aggregating, visualizing and controlling storage systems from grid planning and operations perspectives.

Based upon this body of research, staff finds the storage applications examined are not cost-effective at this time, with the exception of large scale pumped hydro storage. Consequently, staff recommends the SMUD Board of Directors should decline to establish a storage procurement target for December 31, 2016 and December 31, 2020 at this time.

SMUD has been seriously evaluating and developing the Iowa Hill pumped hydro storage project. Analysis to date indicates that the facility will be cost effective under certain market and cost assumptions. The project, however, will not be developed until after 2020, so SMUD is not including the project in its pre-2020 energy storage procurement targets determination. SMUD will continue to study and evaluate the project.

SMUD further notes that, although other energy storage applications are not currently cost-effective, storage costs have continued to decline as technology advancements have been made, as global production capacity has increased, and as the transportation industry has continued development of electric vehicles. Staff anticipates energy storage will become cost effective for some applications within the next ten years. To prepare for cost effective energy storage, staff recommend that SMUD continue investing in energy storage technology assessment, demonstrations and pilots, monitor other storage developments in California, and develop staff expertise in Customer Services to provide assistance to customers considering installation of energy storage systems.

5.2.2 ANAHEIM

On August 12, 2014 the City of Anaheim passed a resolution determining that a procurement target for energy storage systems is not appropriate due to lack of cost effective and viable options. The Anaheim Public Utilities Department prepared an Energy Storage System Evaluation Plan, dated July 2014, and made the following findings:

- *Energy Storage is not cost effective for most applications at this time*. In the City of Anaheim, only thermal energy storage technologies (e.g., Ice Bear) have been cost effective for customers under specific circumstances.
- *Because the City of Anaheim is essentially built-out, siting Energy Storage will be difficult.* Energy Storage technologies are space intensive and difficult to site in urban settings such as Anaheim. As an example, a 5 MW battery system would require enough space to

house 5 semi-trailer sized containers, in addition to all the wiring and balance of plant to connect the batteries to a substation.

- _Peak reduction is one of the primary uses for Energy Storage systems but has already been addressed by the Department with the construction of the Canyon Power Plant._ One of the key benefits of Energy Storage is that it addresses shortfalls in energy supply and allows a utility to call upon it when needed; however, Anaheim Public Utilities has Canyon Power Plan which, similar to PWP's Glenarm units, effectively performs the same function with many other benefits of reducing CAISO fees, providing local and regional grid support, and the ability to bid into the wholesale energy market.
- _Use of Energy Storage Systems to improve reliability is not currently needed by the Anaheim Department of Public Utilities._ The Anaheim Public Utilities Department already has a prominent track record of high system reliability, and has been recognized as a Reliable Public Power Provider (RP3) by the American Public Power Association since 2006. The installation of Energy Storage would have a marginal impact.
- _Many Energy Storage technologies are still maturing._ For example battery systems have been available for many years at locations such as data centers. As additional utility applications are identified, research and innovation will continue to improve the technology and the associated costs will decrease over time. And, the corresponding safety concerns such as batteries catching on fire will need to be addressed by manufacturers.

From the findings above, the Anaheim Public Utilities Department concluded the following:

1. Adoption of procurement targets for either the December 31, 2016 or the December 31, 2021 time periods is premature at this point based on the findings related to costs and viability;
2. Since technology improvements will continue to be made given mandates for investor-owned utilities to invest in ES systems, the Department will closely monitor other utility projects; and,
3. The Department will continue to offer customer choice programs such as time-based rates that encourage shifting energy consumption to off-peak hours.

5.2.3 REDDING

On August 26, 2014, the staff of the Redding Electric Utility ("REU") recommended that the Electric Utility Commission review and recommend the Energy Storage Compliance Plan to the City Council for Approval. According to the report, REU has been actively investing in energy storage systems for nearly 10 years and has been installing thermal energy storage systems in increasing amounts since 2005. These thermal energy systems shift electrical demand from the summer peak period by making ice in the off-peak hours.

REU contracted with Ice Energy, Inc., Redding's main supplier of thermal energy storage systems, to evaluate what level of commercial thermal energy storage could be adopted in REU's service area. The study revealed the potential for up to 14 MW of Permanent Load Shifting. REU proposes to meet the requirements of AB2514 by expanding by its successful thermal energy storage program, which has already procured and installed approximately 1.3 MW of between 2005 and May of 2012.

REU recommends that the City Council approve REU's Energy Storage Procurement Plan, with energy storage targets of 3.6 MW for 2016 and 4.4 MW for 2020.

5.2.4 THE CITY OF PALO ALTO

On December 4, 2013, Staff of the City of Palo Alto Public Utilities recommended that the Utilities Advisory Commission recommend that the City Council adopt a resolution declining to set an energy procurement target for the City of Palo Alto Utilities, or provide thermal energy storage rebate incentives because such targets and incentives are not cost effective. The report found that:

> "*Over the next five years, the costs of utility-owned and operated energy storage exceed the value of benefits, and are therefore not cost-effective for CPAU, its customers or the City. In addition, staff has determined that there is currently no need for the City to procure energy storage systems within Palo Alto for purposes of load-shifting, demand response, deferral of distribution system upgrades, or integration of distributed generation.*"

On February 10, 2014, the Palo Alto City Council adopted Resolution 9396 determining that a target for the city of Palo Alto Utilities to procure energy storage systems is not appropriate due to lack of cost-effective options.

5.2.5 TRUCKEE DONNER PUBLIC UTILITY DISTRICT

On February 20, 2013, staff of the Truckee Donner Public Utility District recommended that its Board of Directors find that energy storage systems are not currently viable and cost effective for the District and the District should not adopt procurement targets.

5.2.6 THE CITY OF LODI

On October 16, 2013, the City Council of the City of Lodi passed Resolution No. 2013-183 regarding the viability of energy storage for the City of Lodi. The City Council supported the staff assessment that no cost-effective energy storage systems are viable for the Lodi community at this time.

5.2.7 LADWP AND IID

The Los Angeles Department of Water and Power (“LADWP”) and the Imperial Irrigation District (“IID”) are each expected to set procurement targets for energy storage. Both of these utilities have relatively large service territories and operate their own balancing areas outside of the CAISO, so have a potential need for services that many smaller municipalities do not. It is also expected that these utilities may set their targets administratively for reasons other than a pre-determination of cost-effectiveness or need.

There may be a few other municipalities that also set modest energy storage procurement targets, but the vast majority are expected to find that energy storage is not currently cost-effective for them, and will decline to set procurement targets at this time.

6.0 PWP ANALYSIS

6.1 PRIOR PWP ENERGY STORAGE EXPERIENCE

In a pilot demonstration program commissioned by SCPPA, an Ice Bear[15] thermal storage pilot project was contracted and installed at a few SCPPA member utilities' facilities in 2010. An Ice Bear demonstration project was also installed at the SCPPA office in Glendora, CA as well as. This early pilot program was undertaken primarily to investigate the load shifting/shaving application of energy storage, i.e., to reduce the on-peak demand created by air conditioning units in order to supply the load with less expensive surplus off-peak generation. During the evening off-peak, the Ice Bear unit freezes water with cheaper off-peak power. During the day, rather than run the normal AC compressor units, cold air is generated using this ice. However, this type of thermal storage utilizes relatively small, distributed storage capacity and is mainly directed at behind-the-meter installations for electric service customers. This particular project was found to be non-cost effective for Pasadena. It was found that to be viable, aggressive revisions of Pasadena's electric rate structure by tailoring Time-of-Use rates to optimize load shifting thermal storage would have been required. However, the Ice Bear unit continues to run at SCPPA offices as a demonstration project for possible adoption in the future should it become necessary and/or cost effective and SCPPA's contract with Ice Bear allows additional installations for those customers who express a desire to do so.

Also, in response to the California Public Utilities Commission ("CPUC") Order Instituting Rulemaking ("OIR") 10-12-007 Pursuant to Assembly Bill 2514 to Consider Adoption of Procurement Targets for Viable and Cost-Effective Targets for Energy Storage Systems, Decision 13-10-040, issued October 17, 2013, Southern California Edison ("SCE") issued a Request for Offers ("RFO") last year to procure energy storage projects in the Los Angeles area. Some energy storage vendors approached PWP about potentially locating energy storage systems at PWP's Broadway/Glenarm site for delivery to SCE at the T.M. Goodrich substation. Such an arrangement would not have caused PWP to incur the costs of a direct investment or contract for energy storage, nor provided the same beneficial services it would have provided to SCE and the CAISO, but could have allowed Pasadena to facilitate the advancement of energy storage systems and potentially gain access to certain black start and reliability benefits, in addition to site rent and, once PWP established a Wholesale Distribution Access Tariff ("WDAT"),

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[15] For more information, go to http://www.scppa.org/pages/projects/ice_energy.html

distribution access charges. Unfortunately, none of these energy storage proposals were shortlisted by SCE in the initial RFO. A policy to continue to pursue such cooperative ventures could be a cost-effective means for PWP to facilitate and promote energy storage systems in the future.

6.2 SCPPA ENERGY STORAGE WORKING GROUP

Since initiating the investigation into energy storage systems in March of 2012, PWP has reviewed energy storage system research and documentation prepared by others, and been involved with the Southern California Public Power Authority ("SCPPA") in several efforts. The most notable of these efforts included participation in the SCPPA Energy Storage Working Group, and the SCPPA Request for Information ("RFI") for Energy Storage proposals.

Through the SCPPA RFI for Energy Storage proposals, the SCPPA 2014 Request for Proposals for Renewable Energy and Energy Storage Projects, and the SCPPA RFI for Generation Replacement and Future Resources, PWP and other SCPPA participants have received and reviewed several innovative energy storage proposals providing real world data to validate the analysis. PWP has also had discussions, through SCPPA and directly, with several energy storage vendors and consultants, and with the California Energy Storage Alliance. PWP reviewed the reports and filings of other utilities, including Southern California Edison ("SCE"), Pacific Gas & Electric ("PG&E"), San Diego Gas & Electric ("SDG&E"), and the Cities of Palo Alto, Truckee, Redding, Lodi, Anaheim, and the Sacramento Municipal Utility District ("SMUD").

6.3 ENERGY STORAGE MODELING TOOL

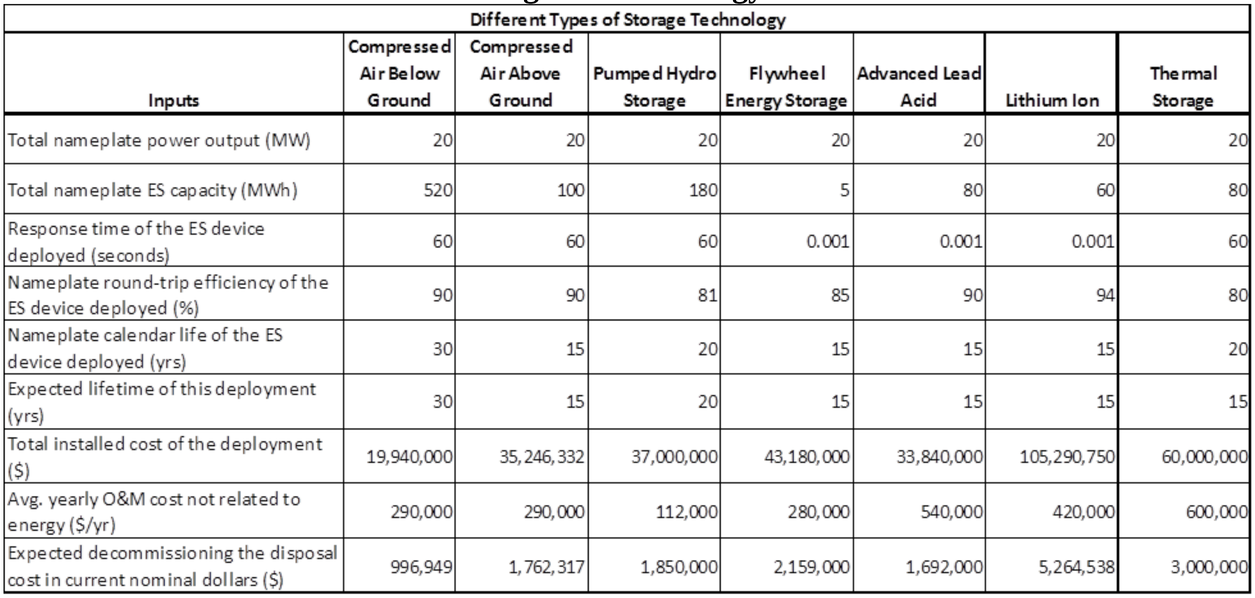
Through the SCPPA Energy Storage Working Group, PWP interviewed several consultants in search of a reasonably priced model to help evaluate the cost-effectiveness of energy storage technologies. The group considered at least three different models, and selected the Navigant SCPPA Energy Storage Tool, V.1.0. ("ES Tool") for licensing. The ES Tool provides a framework for evaluating potential energy storage costs and benefits depending on system characteristics (e.g., location on the grid, regulatory structure, and owner). The ES Tool is based in Microsoft Excel and takes a variety of inputs.

The user first enters the project location, owner, regulatory environment and technology type. Next, the user enters information such as installed cost, operation and maintenance costs, round trip efficiency, and cycle life. Default values are available for many of these inputs, depending on the selected technology. Then the user selects which applications to analyze. Based upon the applications selected, the user is prompted to enter inputs to help calculate benefits, such as amount of energy storage dispatched by application, market prices and rate structures. Finally, the user has the option of selecting to run various scenarios. After inputting all the necessary information, the tool presents the net present costs and benefits of the project. According to Navigant, the tool has gone through extensive review and usage. Sandia National Labs and the US Department of Energy (DOE) conducted formal peer reviews of the framework.

PWP considered the various technologies and functions that energy storage can provide, and narrowed the list to those that PWP believed would have the highest potential viability and best fit for PWP by 2016 and by 2021. The ES Tool is capable of modeling seventeen (17) different energy storage technologies, seven of which were selected by PWP as commercially viable for Pasadena's needs. In order to "level the playing field" between the different technologies, staff standardized all of the energy storage technologies to a 20 MW capacity model, and all costs, outputs, and revenues were scaled accordingly. The 20 MW size was chosen because it seemed to be an applicable energy storage size given the mix of PWP's contracted renewable technologies, PWP's monthly Flexible Resource Adequacy Capacity requirements, market opportunities for Ancillary Services sales, and the current price differentials between off-peak and on-peak power. Proportional scaling of larger (50~250MW capacity) projects is realistic, since PWP could take a fractional share of large scale projects and pay and receive its proportional share of benefits, as it does with other generation projects through SCPPA. Table 6.3.1 lists the technologies that were modeled by PWP using the ES Tool, including:

1. Compressed Air Energy Storage ("CAES") – below ground,
2. Compressed Air Energy Storage – above ground,
3. Pumped Hydro Storage,
4. Flywheel Energy Storage,
5. Advanced Lead Acid Batteries,
6. Lithium Ion Batteries, and
7. Thermal Energy Storage.

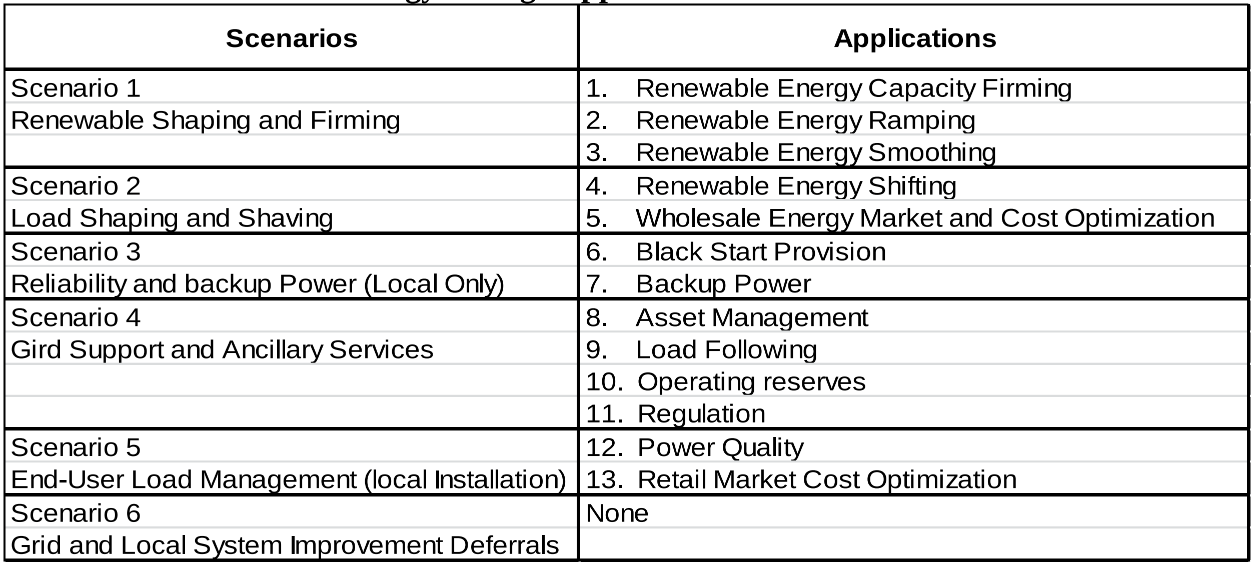
Table 6.3.1
Investigated Technology List



	Different Types of Storage Technology						
Inputs	Compressed Air Below Ground	Compressed Air Above Ground	Pumped Hydro Storage	Flywheel Energy Storage	Advanced Lead Acid	Lithium Ion	Thermal Storage
Total nameplate power output (MW)	20	20	20	20	20	20	20
Total nameplate ES capacity (MWh)	520	100	180	5	80	60	80
Response time of the ES device deployed (seconds)	60	60	60	0.001	0.001	0.001	60
Nameplate round-trip efficiency of the ES device deployed (%)	90	90	81	85	90	94	80
Nameplate calendar life of the ES device deployed (yrs)	30	15	20	15	15	15	20
Expected lifetime of this deployment (yrs)	30	15	20	15	15	15	15
Total installed cost of the deployment ($)	19,940,000	35,246,332	37,000,000	43,180,000	33,840,000	105,290,750	60,000,000
Avg. yearly O&M cost not related to energy ($/yr)	290,000	290,000	112,000	280,000	540,000	420,000	600,000
Expected decommissioning the disposal cost in current nominal dollars ($)	996,949	1,762,317	1,850,000	2,159,000	1,692,000	5,264,538	3,000,000

The ES Tool can evaluate up to thirteen (13) applications for each energy storage technology. Applications which serve a common purpose were bundled into one of six scenarios to maximize the potential savings and/or revenues from each technology option. The applications and scenarios are summarized in Table 6.3.2 below. Analysis was focused on Scenarios 1 through 4, which evaluate transmission and generation level energy storage systems.

Table 6.3.2
Energy Storage Applications and Scenarios



Scenarios	Applications
Scenario 1 Renewable Shaping and Firming	1. Renewable Energy Capacity Firming 2. Renewable Energy Ramping 3. Renewable Energy Smoothing
Scenario 2 Load Shaping and Shaving	4. Renewable Energy Shifting 5. Wholesale Energy Market and Cost Optimization
Scenario 3 Reliability and backup Power (Local Only)	6. Black Start Provision 7. Backup Power
Scenario 4 Gird Support and Ancillary Services	8. Asset Management 9. Load Following 10. Operating reserves 11. Regulation
Scenario 5 End-User Load Management (local Installation)	12. Power Quality 13. Retail Market Cost Optimization
Scenario 6 Grid and Local System Improvement Deferrals	None

Although the ES Tool does include Thermal Storage technology, it is at the end-user levels only, PWP has already investigated such storage through SCPPA by participating in the Ice Bear project. Consequently, no analysis was performed for Scenario 5. In addition, no grid or local (distribution) system deferrals were identified to model in Scenario 6.

The results of the ES Tool modeling are summarized in Table 6.3.3 below.

Compressed Air Energy Storage ("CAES") and Pumped Hydro have a positive benefit-to-cost ratio for the Reliability and Backup Power (Local) Scenario. For applications in this scenario, the storage facility needs to be located within the City's limits. While it may be possible to locate a 20 MW above ground project in the City (as modeled), typically projects are sized around 50 MW to 200 MW or larger, which are much too large for Pasadena to procure alone. Pasadena would have to partner with other utilities, and siting will become a critical issue.

There are no locations identified in the City that would accommodate or can be converted for an underground CAES project. PWP has received, and continues to consider, proposals for a large (up to 1,200 MW) CAES project near the Intermountain Power Project that would accommodate wind energy from Wyoming delivered over the proposed Zephyr transmission line. This proposed energy storage project would not provide the local reliability and backup power benefits required to achieve the positive cost-effectiveness shown below. For renewable shaping and firming, PWP will continue to monitor the development of this project, and advise the City Council if enough interest is expressed by larger utilities to make the project viable for PWP to consider a small participant share.

Along with CAES, advanced lead acid technologies have the lowest installation and operation and maintenance costs, which help the economic performance of these technologies. However, on the benefit side, the ES Tool relies on assumptions about the number of customer-outage minutes with reimbursable economic costs, referred to as "avoided cost and/or loss of revenue due to outages." Pasadena does not collect or produce such data, so PWP had to rely on the tool's default metric. It is unlikely that PWP has a reliability "need" that requires investing in energy storage as a solution.

Based on work completed to date, PWP has not identified any viable energy storage technologies that are cost-effective at a scale that is practical for PWP at this time. The energy storage industry is still in its early stages, with many technologies still evolving, and cost-effectiveness expected to improve rapidly over the coming years. PWP will continue to monitor the situation and continue to provide updates as conditions warrant.

Table 6.3.3
Energy Storage Net Benefit for Projects Scaled to 20 MW

Scenario benefit/cost ratios	CAES Underground	CAES Above Ground	Flywheel	Advanced Lead Acid	Lithium Ion	Pumped Hydro
Renewable Shape/Firm	0.671	0.325	0.227	0.536	0.096	0.002
Load shape/shave	-0.128	-0.21	-0.071	-0.087	-0.005	0.025
Reliability/Backup			1.025	2.419	0.432	
Grid Support	0.18	0.323	0.055	0.13	0.023	0.149

7.0 CONCLUSIONS

There are relatively few viable, cost-effective, integrated, utility scale energy storage systems available today. Those that make the most sense (e.g., pumped hydro and CAES) tend to be very large in scale and dependent on geologic site conditions.

PWP already has at its disposal cost-effective means of achieving most of the functions provided by energy storage systems. For example, conservation and demand response can provide energy time-shift, congestion relief and upgrade deferrals. Existing generation and the market can provide ancillary services such as regulation, reserves, voltage support and reliability services. Time-of-use rates can provide energy time-shift and demand charge management.

As a CAISO participant, with sufficient generation to meet its reliability requirements, PWP does not presently have a “need” for the identified bulk energy, ancillary service, or transmission infrastructure services provided by energy storage systems. If there is a need for these services by the CAISO, market prices do not adequately reflect it. As a consequence, it does not appear that PWP customers would benefit from, nor recover the costs of, energy storage systems procured by PWP to provide these services today. Without a need and a sufficient revenue stream, even viable energy storage systems cannot be cost-effective.

PWP has not identified specific distribution upgrades that could cost-effectively be deferred through the use of energy storage systems. If, at some point in the future, certain radial feeders experience voltage fluctuations or other power quality issues as a result of a high penetration of local solar installations, electric vehicle charging, or other distribution network transformation, energy storage systems on the distribution network or for customer energy management services may begin to make sense from a reliability perspective, although cost-effectiveness may still be difficult to demonstrate. PWP will continue to monitor the situation and will advise the City Council of any recommendations during periodic updates.

The City Council need not set specific procurement targets for PWP to procure or encourage cost-effective deployment of energy storage systems as needs arise, these systems mature and their costs decrease. Through its regular annual updates of its procurement plan, PWP will advise the City Council of any changes in its forecast needs and the least cost/best fit means of satisfying those needs. Furthermore, at least every three years, PWP will reevaluate the issue of energy storage system procurement targets and policies with the City Council pursuant to AB 2514.

8.0 RECOMMENDATIONS

8.1 PROCUREMENT TARGETS

PWP does not recommend at this time that the City Council establish any specific energy storage system procurement targets to be achieved by December 31, 2016, or December 31, 2021, since no cost-effective, viable energy storage systems have been identified by PWP.

8.2 ONGOING EVALUATION

PWP staff will continue to look for appropriate opportunities to encourage cost-effective deployment of energy storage systems as it executes its Integrated Resource Plan, and procures future renewable and conventional energy. PWP staff will continue to work with the Southern California Public Power Authority (“SCPPA”) to evaluate various energy storage technologies through solicitation of proposals for energy storage systems as standalone offers as well as in conjunction with renewable and conventional energy projects.

PWP will reevaluate the issue of energy storage system procurement targets and policies with the City Council at least once every three years.

8.3 CEC REPORTING

PWP will report to the California Energy Commission (CEC) regarding energy storage system procurement targets and policies adopted by the City Council.

If the City Council adopts any energy storage system procurement targets or policies to encourage the cost effective deployment of energy storage systems, then by January 1, 2017, PWP will submit a report to the CEC demonstrating that it has complied with the energy storage system procurement targets, if any, and policies adopted by the City Council. Such report, with confidential information redacted, will be made available to the public by being published by the CEC and/or PWP on their respective websites.

By January 1, 2022, PWP will submit a report to the CEC demonstrating that it complied with any energy storage system procurement targets and policies adopted by the City Council. The report, with confidential information redacted, will be made available to the public by the CEC and/or PWP on their respective websites.

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