Electricity Storage for Hawaii: Technologies and Issues to Facilitate High Penetration of Renewables

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Introduction

This report reviews the characteristics, commercial status and cost of various storage technologies and how they act, or could act in Hawaii electric grids to facilitate high penetrations of renewables. It is intended to inform policy and decision makers on the potential barriers, uncertainties, and regulatory initiatives that may hinder or facilitate even higher penetrations of renewables as the Hawaii grids adapt to their operating environment.

Executive Summary

This report is organized in nine major sections to review storage technologies and discuss various issues related to the use of energy storage to facilitate a high penetration of variable renewable resources on the Oahu grid.

Sections I and II discuss the need for storage and how storage acts to mitigate the effects of variability of renewable generation output on the host grid. While there are different ways of discussing the technical aspects of the use of storage to achieve the desired effect, this report attempts to explain this in terms of three time domains that storage needs to act in: short-duration, mid-duration and long-duration. This allows the various storage technologies to be evaluated in the time domain that best matches their performance characteristics. The short and mid-duration storage technologies include Advanced Lead-acid batteries and the Li-family of batteries, and flywheels. The long-duration technologies include a wider selection: pumped hydro; high temperature batteries: Sodium Sulfur and Sodium Nickel Chloride; and flow batteries: Zinc Bromine, Vanadium Redox and Compressed Air Energy Storage (CAES).

Section III discusses the storage technologies listed above in greater detail including their commercial readiness and identifies key vendors who are supplying these storage systems. It is to be noted that traditional pumped hydro plants are generally too large and pose significant environmental concerns regarding land and water use and are deemed unsuitable for Hawaii. However, a variant of this technology using seawater as the storage medium is discussed because these could be built in smaller sizes in Hawaii without significant land requirements and with zero impact on fresh and potable water.

Section IV includes storage system cost information and explains some of the difficulties encountered in generalizing storage costs because of the unique nature of storage systems and how they are used in the electric grid. The cost information presented in this section is summarized from the DOE/EPRI 2013 Electricity Storage Handbook[1] and is the most recent information available for the storage technologies of interest. The costs are not absolute values, but ranges expressed in \$/kW and \$/kWh.

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[1] Akhil, Huff, Currier et.al. "*DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*" July 2013
Handbook URL: http://www.sandia.gov/ess/publications/SAND2013-5131.pdf

Sections V through IX discuss integration issues, barriers to deployment, risks and uncertainties, and lessons-learnt recommendations for Hawaii specific applications. Three regulatory and policy drivers that could facilitate larger deployments of storage systems are discussed in Section IV. These include establishing requirements for spinning and regulating reserves and allowing storage to provide these services; modifying feed-in-tariffs to recover addition of storage to renewable projects; reviewing reliability metrics and using storage to relax limits on renewable penetration; and seeking incentivizing more storage siting studies and projects through the existing Renewable Energy Infrastructure Program[2]

[2] As of May 15, 2013, the approved Renewable Energy Infrastructure surcharge for HECO is 0.0211 ¢/kWh:

Section I: Need for Storage with Renewables

Normal electric grid operations are based on the fundamental assumption that the generation sources within its boundaries have a predictable certainty of providing the constant power requirements determined by the system operator. Abnormal operational conditions exist when there is an unexpected loss of a generation unit or other system component that requires the rapid addition of reserve power to meet the load requirements and maintain stable operation of the grid. Similar conditions are created when a large penetration of renewable resources occurs in the grid, because their power output is not constant and depends on the availability of wind to support wind generation or clear sky conditions in the case of photovoltaic (PV) generation. The output from both wind and PV fluctuates rapidly when the wind shifts or there are intermittent clouds shadowing the PV array. These rapid and sudden fluctuations or "ramps" require other generation sources in the grid to modulate the power up or down in the opposite direction of the renewable sources to maintain a stable grid.

The secondary impact of large penetrations of renewables in the grid is the inability of the fossil generators to operate at or below their minimum power generation limits to maximize the intake of all renewable energy available to the grid at any given instant. Maximizing the renewable energy intake while maintaining optimal fossil-based generation is a delicate balancing act orchestrated in real time by the grid operator. Grid operators balance both sources to keep the voltage and frequency within normal ranges to maintain grid stability. The operator has two choices when the renewable generation exceeds the load on the grid – either spill or curtail the renewable energy production, or turn down the power generation of the fossil units sufficiently to absorb the available renewable generation. In some instances, especially in the smaller electric grids on islands, this condition is more critical, because the fossil units can only be "turn-downed" to fixed minimum limits and cannot be operated below these set points.

These conditions are illustrated in Figure 1 which shows a typical "ramp" event at the Tawhiri wind farm on the Big Island and its effect on the rest of the HELCO system[3]. The green color trace in the lower part of the plot shows the wind farm output steady at 10 MW until there is a sharp down ramp and the output dips to almost zero megawatts. The purple trace at the top of the plot shows a consequent dip in the system frequency from the nominal 60 Hz to below 59.4 Hz and Unit 5 and CT5 ramp up their generation to stabilize the grid frequency to nominal 60 Hz.

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[3] Source: Presentation to HCEI, October 20, 2010, by Dora Nakafuji, HECO, *"Forecasting Activities: Improving WindSENSE and Solar Forecasting Capabilities for Control Rooms"*

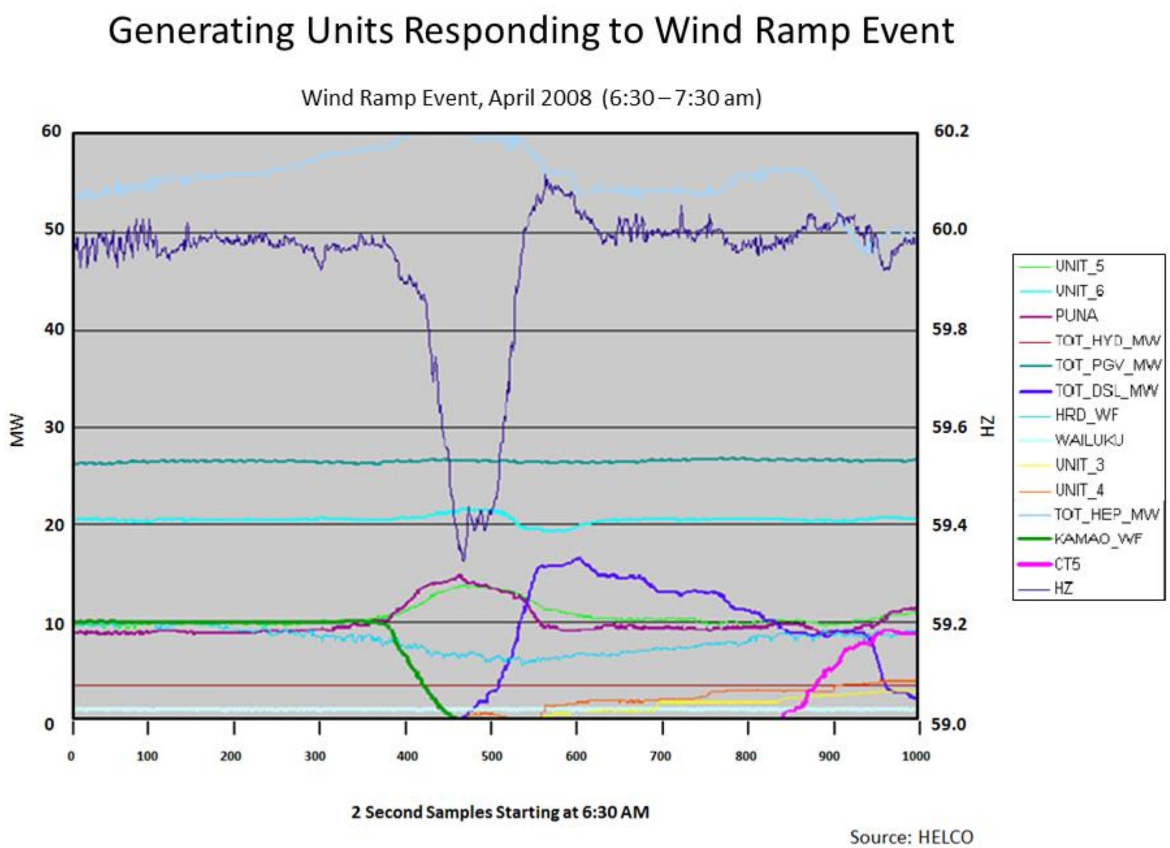

Figure 1: "Ramp" Event at Big Island Wind Farm

The second condition, where fossil units are "turned-down" to absorb more wind and reduce curtailment can be described by using the MECO example on Maui when future additions to the existing wind farms are expected to bring total renewable generation capacity to 72 MW, exceeding the 70 MW projected minimum system load. In this scenario, MECO would need to curtail wind generation substantially and run the minimum required fossil generation at low and inefficient set points. A recent study[4] by Sandia National Laboratories examining the various options for MECO found that storage would reduce both wind curtailment and the annual cost of producing energy due to the more efficient operation of MECO's diesel units, which would have otherwise operated at less efficient set points.

Electricity storage is currently being utilized to mitigate or eliminate these grid operating conditions and to provide additional services to the grid such as time shifting and ancillary services. Electric storage applications can be characterized as acting over three time domains in island grids to mitigate the effects of high penetrations of renewables and

[4] "Maui Energy Storage Study" by James Ellison, Dhruv Bhatnagar, and Benjamin Karlson, Sandia National Laboratories, December 2012.

provide other operational needs of the grid to enhance its stability and reliability. These three time domains can be characterized as short-, mid- and long-duration as described below.

Short-duration storage acts to mitigate the effects of rapid up or down ramps in power output as shown in Figure 1 and provides stability in the one second to one minute time window when the renewable generation is varying rapidly due to volatile solar or wind conditions.

Mid-duration storage acts in the one minute[5] to 30 minute time window, mitigates the effects of momentary changes in grid frequency due to changing loads and serves as a rapid reserve to compensate for the sudden failure of a generator.

Long-duration storage acts in the one to six hour window to store energy from wind or PV plants that would otherwise be curtailed or "spilled", and, where applicable, time shift energy for operational or economic advantage.

This report discusses these three uses of storage in the Hawaii grids to facilitate the increased penetration of renewable resources including wind and PV. The report includes a discussion of the storage technologies, their commercial status, barriers and challenges for deployment and recommendations to support wider deployment in Hawaii.

[5] The operational capability of storage technologies that are available today spans both the short- and mid-duration time domains. The characterization of time domains in this report is mostly to clarify their functional use in the grid.

Section II: How Storage Acts

Short-duration Storage – 1 second to 1 minute

The plot in Figure 2 is a hypothetical representation illustrating how the fast response of an energy storage system compensates for the sudden drop of power of a PV system when clouds shadow the array. This simplified example uses the La Ola PV plant in Lanai as an example with a hypothetical 375 kW battery storage system to control its ramps.

In Figure 2, it is assumed that the Lanai system load is 5.5 MW at T = 0 seconds. At that instant, the PV array is producing 1.2 MW with the remaining 4.3 MW being supplied by diesel generation and the battery storage system is in idle mode. At T = 10 seconds, the PV output drops suddenly due to cloud cover producing a shortage of power in the grid. The diesels do not increase their output as rapidly as the drop in PV output occurs. However, the storage system detects this grid condition and responds by instantaneously discharging its rated capacity of 375 kW for the next 30 seconds; this allows sufficient time for the diesels to gradually increase their output to make up for the lost generation from the PV plant, and the storage system goes to a standby mode again at the T = 40 second mark.

In the real-life implementation, the battery storage system installed at La Ola PV plant is much larger with a rating of is 1.125 MW[6]. However, its functionality is similar to this illustrative example and its ability to "smooth" the variability in the PV output is working as designed.

Similar short-duration storage systems that mitigate the variability of the PV and wind output are successfully operating on Maui, Oahu, Kauai and Hawaii.

[6] The 375 kW size of the storage system shown in a the example is larger than the 250 kW battery storage size originally specified in the Power Purchase Contract between MECO and Lanai Sustainability Research, LLC, the owner and operator of the La Ola PV station in Lanai. The 250 kW battery size was later increased to its present 1.125 MW rating as a result of studies performed by Sandia National Laboratories, National Renwable Energy Laboratory and Sunpower that showed that the larger battery size was necessary to control the ramp rate of the 1.2 MW PV plant within MECO's specified limits.

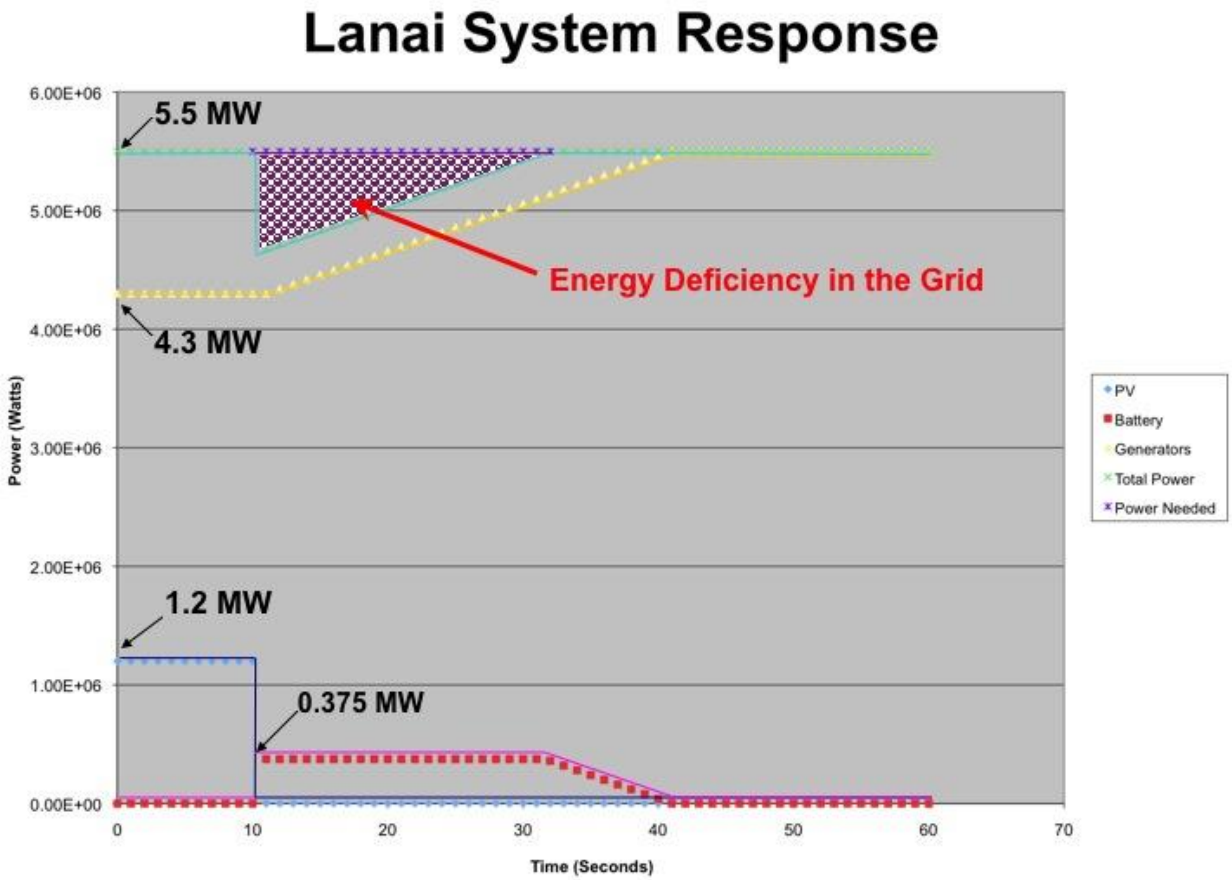

Figure 2: Simplified representation of Storage System Response in the Lanai Grid

Mid-duration Storage – 1 minute to 30 minutes

The sudden loss of a generating unit triggers both a drop in frequency and an immediate need to replace the power lost with other reserves. The rate of frequency decay following the loss of generation is proportional to the mechanical inertia of the units that remain online and is faster when the electric grid is made up of smaller generating units. The typical system response as soon as a generation unit is lost till it stabilizes 20 - 30 minutes later is shown in Figure 3, in which the upper portion represents the frequency excursion following the outage. The initial dip triggers a governor response shown in the lower plot. This is followed by the Automatic Generation Control (AGC) response to stabilize and restore the frequency to the desired 60 Hz. The sustained recovery of the grid then relies on operating reserves that replace the lost generation and return the grid to a "normal" state.

Energy storage systems have been effectively used both in mainland and island electric grids to provide the reserve power necessary to restore the electric grid to normalcy following the loss of a generating unit. Their fast response characteristic-- faster than the response of any conventional generator--is perfectly matched to provide the energy in the first second and subsequent minutes that are critical to stabilize the frequency and maintain continuity of supply to the customer. Studies have also shown that the fast response of batteries and flywheels is at least twice as effective as a comparable conventional generator[7], which means that a 20 MW storage system can stabilize the system as effectively as a 40 MW fossil-fired unit following a contingency.

Battery and flywheel energy storage systems designed for reserve power can also provide frequency regulation on a 24/7 basis. The combination of these two grid services into a single storage system makes optimal use of the inherent properties of these technologies. The frequency regulation duty requires a continuous shallow discharge/recharge operation of the storage system, which has a minimal life-limiting impact on the battery and flywheel. The reserve power duty requires a deep discharge that does impact the operational life of the battery system.

[7] *Energy Storage – a Cheaper, Faster and Cleaner Alternative to Conventional Frequency Regulation.* Whitepaper by the California Energy Storage Alliance (CESA) (http://www.ice-energy.com/stuff/contentmgr/files/1/76d44bfc1077e7fad6425102e55c0491/download/cesa_energy_storage_for_frequency_regulation.pdf

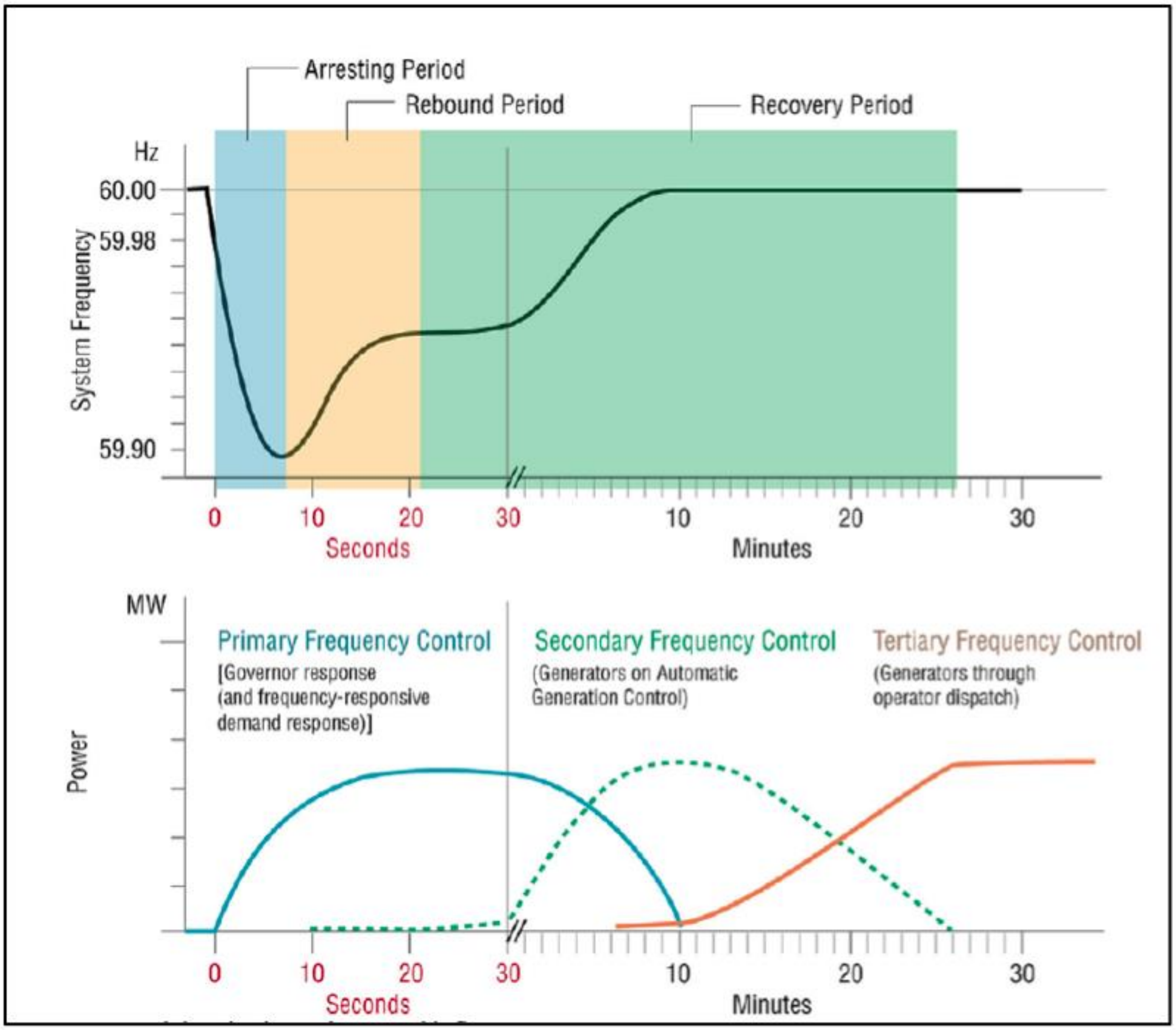

Figure 3: The Sequential Actions of Primary, Secondary, and Tertiary Frequency Controls Following the Sudden Loss of Generation and Their Impacts on System Frequency[8]

Long-duration Storage – 1 hour to 6 hours

Long-duration storage spanning from one to six hours can capture energy from renewables that would otherwise be spilled or curtailed due to low system load or other operational constraints on the utility side. Unlike the short- and mid-duration storage use described in the prior section, long-duration storage is designed for sustained discharges over longer durations at its rated power.

Battery storage systems are operating on Maui and Oahu to mitigate the curtailment of wind farm output. These are early battery storage projects in Hawaii and have lower

[8] *Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation*. Joseph H. Eto, Principal Investigator Lawrence Berkeley National Laboratory, et al. (http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf) 03/25/2013

power-to-energy ratios than indicated above, but are still mitigating curtailments to a certain degree. Recent studies by NREL[9], HNEI[10] and Sandia Labs[11] have shown that more powerful and longer duration storage systems can prevent even more curtailments as the renewable generation component increases in the future.

Other reports[12,13] have noted a wide range of services that energy storage can provide to the grid and have classified these services according to their location within the grid as generation, transmission or distribution services. The time duration-based classification used in this report differs from that approach and is specifically used to characterize how storage could promote the penetration of renewable resources in Hawaii. However, the wider range of storage services for other grid applications described in those reports could be of value to Hawaii as Smart Grid and other adaptive changes occur to Hawaii's electric grids.

Section III: Storage Technologies: Description, Commercial Status

Each of the three storage types described above has unique attributes and utilizes technologies that have correspondingly unique characteristics. The short and mid-duration storage is best supplied by Lead-acid (Pb-acid) batteries, the lithium family of batteries, and flywheels. The long duration storage requirements are best met by pumped hydro, compressed air energy storage (CAES) or high temperature batteries such as Sodium/Sulfur (NaS)[14] and Sodium Nickel Chloride (NaNiCl) or flow batteries such as Zinc Bromine (ZnBr) and Vanadium Redox (VR).

The technology characteristics, maturity and experience as well as the system vendors working in these technology types are described in the following section.

[9] Hawaii Solar Integration Study: Final Technical Report for Maui, December 2012

[10] Oahu EV Charging Study, September 2012

[11] Maui Energy Storage Study, December 2012

[12] "Battery Energy Storage for Utility Applications: Phase I Opportunities Analysis," SAND94-2605, and, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide," SAND2010-0815

[13] "DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA"; due for release in June/July 2013.

[14] "NaS" is a generic term used to refer to sodium-sulfur batteries based on atomic symbols "Na" and "S". Whereas the capitalized "NAS" is a registered trademark for NGK's sodium-sulfur battery systems.

Short- and Mid-Duration Storage Technologies

Advanced Lead-acid (Adv. Pb-acid) Batteries

Lead-acid batteries have been used in the electric grid in one form or the other for over 100 years – to energize switchgear in distribution substations or as back up to auxiliary systems in power stations. Starting in the mid-1980's, large lead-acid based storage systems were built to provide grid support for load leveling, spinning reserve and frequency regulation to electric utility grids in North Carolina, California, and Puerto Rico and in some overseas grids as well.

The lead-acid batteries that were used at that time have been further refined in recent years into "advanced", robust versions with improved cycle life, and higher power and energy capabilities. These modern versions of lead-acid batteries are being referred to as "advanced" lead-acid technologies because of these recent innovations. Their chemistries have been modified with carbon or other additives and some changes to the design of internal components contribute to their improved performance. Some Advanced Pb-acid batteries incorporate capacitor-like internal components to meet high power application requirements, especially suited for short and mid-duration ramping duty to support renewable technologies.

Since the lead-acid battery type, including the advanced variants, is widely used, its end-of-life disposal and recycling processes are well established for all commercial applications. Non-lead-acid battery types, on the other hand, are still in the process of establishing a reliable recycling chain. Procurement contracts for utility scale stationary storage systems using lead-acid batteries have contractual clauses that ensure that the batteries are sent to a regional recycling center at the end of their operational life.

Advanced Pb-acid turnkey storage systems for stationary electricity storage applications are available from Xtreme Power, Ecoult/EastPenn, and Axion Power International. Each supplier has a different implementation of the advanced lead-acid chemistry and each developer is targeting a specific niche market. Xtreme Power's systems have established a strong foothold in Hawaii with an early installation in Maui, followed by systems in Lanai, Kauai and Oahu. Ecoult/East Penn has demonstration projects on the mainland with promising results and is seeking opportunities in Hawaii. Its mainland demonstrations are showing promising results and its system design and performance are backed by East Penn's long history of in-house R&D and manufacturing expertise in traditional lead-acid batteries.

Figure 4: Xtreme Power Advanced Lead-acid System at the Kaheawa, Maui, Wind Farm

Lithium Family of Batteries

Within the past few years, there has been a strong interest in Lithium-ion (Li-ion) batteries for stationary applications due to their high energy density, high power and robust cycle life. The Li-based battery chemistries are already commercially mature for consumer electronic applications, and Li-ion is positioned to be the preferred technology for plug-in hybrid electric vehicle (PHEV) and electric vehicles (EV), which will use larger-format cells and packs with capacities of 15 to 20 kWh for PHEVs and 50 to 85 kWh for EVs.

The more common type of liquid Li-ion cells are cylindrical or prismatic cells found in the battery packs of laptops, notebook computers, digital cameras and other consumer electronic products. A variation using prismatic polymer Li-ion cells is also used for small portable products such as cellular phones and MP3 players. Li-ion batteries used in consumer electronic products make up the bulk of the worldwide production volume of 10 to 12 GWh per year. This production volume is projected to grow to 30 GWh by 2015 and this growth could result in potentially lower cost battery systems for stationary utility scale storage system deployments.

Many utility-scale systems have already been deployed in the field and are providing valuable experience in siting, grid integration and operation of Li-based systems. Figure 5 shows some of the Li-ion energy storage system deployments in the past two years. The stars represent the most significant projects; several additional Li-ion projects are underway in other locations.

The major manufacturing base for Li- family of batteries is in China, Korea and Japan. From a commercial status perspective, the US-manufacturer/system supplier base for Lithium batteries for stationary applications is currently in a fluid state. International Batteries, A123 and Altairnano are the three prominent US suppliers, and each has either been through bankruptcy or is re-organizing their corporate structure in some form or other. This uncertainty is impacting further deployments of Li-based stationary storage systems and will remain so in the near future.

Figure 5: Current and Planned Li-ion System Demonstrations.

Flywheel Energy Storage Systems

Flywheels store energy in the form of the angular momentum of a spinning mass, called a rotor. The work done to spin the rotor is stored in the form of kinetic energy and during discharge this energy is converted into alternating current (ac) power via use of controls and power conversion systems. Rotational speeds on the order 16,000+ revolutions per minute are needed to generate sufficient power for electric grid applications.

Historically, flywheel designs were flat, pancake-shaped wheels and required even higher rotational speeds to deliver useful power. The design of flywheels for grid applications has since evolved into a cylindrical configuration that is typically seven feet tall and about four feet in diameter as shown in Figure 6. This wheel has a safer failure mode and has proved to be more stable in practical applications.

Flywheel systems available today have containment vessels for safety and performance enhancement purposes. This is a thick steel vessel surrounding the rotor, motor-generator, and other rotational components of the flywheel. If the wheel fractures while spinning, the delaminated layers rub against the containment vessel which slows them down and stops the fragments preventing damage to surrounding equipment and injury to personnel. Containment vessels also serve as vacuum chambers or are filled with a low-friction gas such as helium to reduce the effect of friction on the rotor and further enhance the performance of the flywheel.

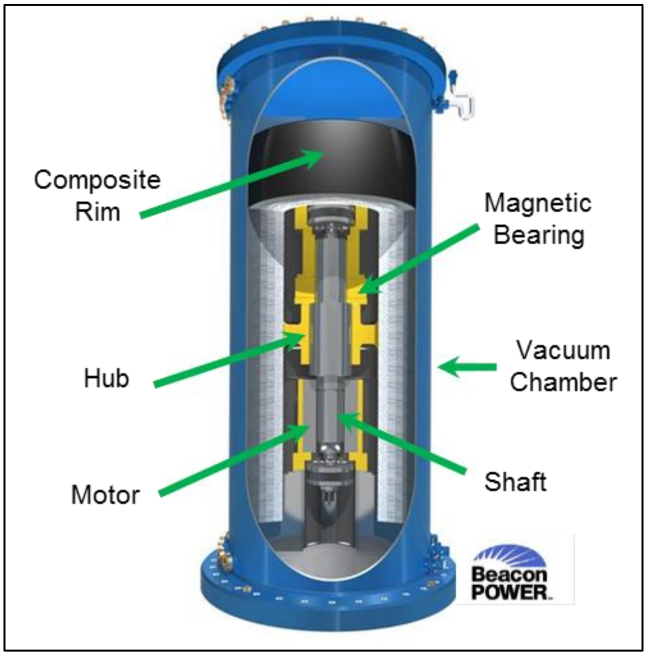

Figure 6. A Flywheel System Cutaway Diagram

(Courtesy of Beacon Power)

Flywheels have excellent cycle life in comparison to battery-based energy storage systems. Most flywheel developers estimate cycle life in excess of 100,000 full charge-discharge cycles, making them an attractive option for renewable support and frequency regulation service. Flywheels also have a very fast response time of four milliseconds or less, which also makes these systems more suitable for renewable ramp support and frequency regulation services. But, flywheel storage systems can support only short duration discharge requirements and are not useful for the long-duration applications that require discharge times greater than 30 minutes. For example, the flywheel storage system that is available from Beacon Power, is rated for a 15 minute discharge time.

Beacon Power is the sole manufacturer and supplier of large-scale flywheel storage systems in the US. The building block of their storage system is a 100 KW/25 kWh flywheel and the larger systems are built by aggregating multiple building blocks. Beacon has successfully built and operated 10 to 20 MW flywheel systems based on this aggregated configuration to provide regulation services to Independent System Operator's (ISO's) in NY and California.

Beacon's original business model was to build flywheels and own merchant plants to provide ancillary services to independent grid operators. This business model initially failed to generate sufficient revenue to support Beacon's operations due to lower than projected income from market operations. Consequently, Beacon Power declared bankruptcy in October 2011 and was acquired by Rockland Capital in early 2012. The acquisition gave Rockland Capital access to Beacon's flywheel intellectual property and the revenue generated by the 20 MW flywheel storage plant in Stephentown, NY. Figure 7 shows a one MW system installed at Beacon's headquarters in Tyngsboro, MA.

Rockland Capital also formed Spindle Grid Regulation, LLC, to develop and own merchant plants that provide ancillary services to various grid operators. They are currently building a 20 MW flywheel plant in Hazle Township, PA, to provide fast regulation services to PJM, which is the ISO for the Pennsylvania, New Jersey and Maryland region.

Figure 7: Beacon's 1-MW Smart Energy Matrix Plant with Ten 100 kW Flywheels Housed in the Blue Silos

(Photo courtesy: Beacon Power)

Long-Duration Storage Technologies

Pumped Hydro

Pumped hydro (PH) storage works on the simple principle of pumping and discharging water between an upper and lower reservoir. The water is pumped into the upper reservoir during periods when there is excess or low-cost energy in the grid and the stored energy is recovered by allowing the stored water to run through a turbine to a lower reservoir when there is a need for energy in the grid, or when the price of electricity is greater. This is illustrated in Figure 8, which shows the upper reservoir, lower discharge, the connection between the two and the prime mover that functions both as the pump when the upper reservoir is being filled and as a turbine when the stored water is discharged.

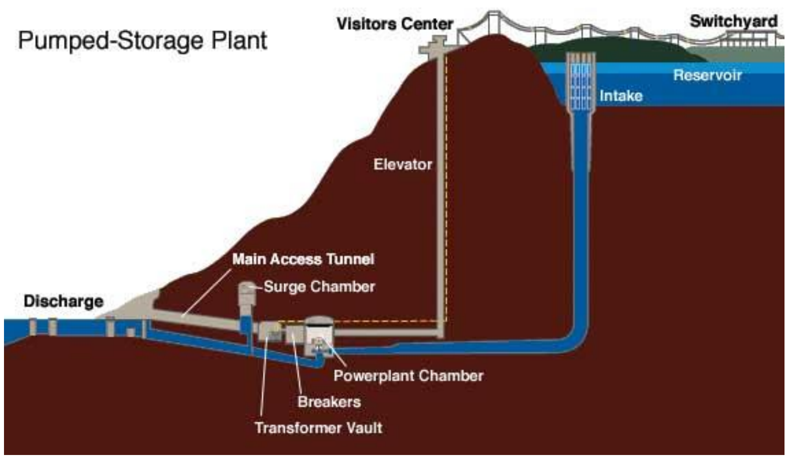

Figure 8: Schematic of a Pumped Storage Plant

(Source: http://upload.wikimedia.org/wikipedia/commons/9/9a/Pumpstor_racoon_mtn.jpg)

PH is the most widely deployed form of electricity storage in the US mainland grid, and 24,000 MW of pumped storage systems have been in operation for 50 years or more and continue to provide reliable service.

While the principle of PH operation is simple, the practical implementation is much more complex, because the economies of scale dictate that these plants are economically viable only when discharge rates are in the hundreds of megawatts and discharge durations are ten hours or more. The construction of reservoirs to fit this size requires massive upfront capital investments. In addition, the engineering challenges of building such large PH plants are compounded by opposition from environmental groups due to significant impacts on land and water use. Consequently, PH projects have not been built in the US since the last 1,000 MW Rocky Mountain pumped storage plant was commissioned in Georgia in 1995.

The environmental impacts and scale of this technology make it unsuitable for Hawaii, where the island grids are smaller and land and fresh water requirements will conflict with other uses. However, a variation of the original technology using seawater to store only a few tens of megawatts with only one upper reservoir is being successfully used in Japan and Ireland. These smaller plants do not require large land areas and do not impact fresh water, because only sea water is used as the storage medium. The water stored in the upper reservoir is pumped up and discharged back into the sea with negligible losses and it is at the same temperature since there is no thermal process involved in the generation of electricity. These plants are located close to the coastline utilizing existing cliff shorelines to provide the gradient. Figure 9 is a photo of a sea water PH plant in Okinawa, Japan. As shown in Figure 9, only the upper reservoir needs to be constructed since the sea serves as the infinite lower reservoir.

Figure 9: Okinawa Seawater Pumped Storage

In a smaller, 10 – 30 MW configuration, the scale of the plant is orders of magnitude smaller than its conventional full-size, two-reservoir counterparts. For example, an upper reservoir located 300 feet above sea level, with a diameter of 400 feet and 20 foot depth, will provide 20 MWh of storage capacity, or 10 MW for two hours at constant discharge. An upper reservoir for such a plant could be built on coastal cliffs in any of the islands without a significant impact on land use and zero net impact on fresh water sources.

In Hawaii, seawater PH offers the ability to build larger storage systems that are otherwise impractical with battery and flywheel systems. Seawater PH could effectively bridge the gap between short- and mid-duration and the long-duration storage needs as Hawaii heads into higher penetrations of renewable resources. This assertion is further supported by the fact that seawater PH uses existing off-the-shelf hardware and is based on operating principles that electric utilities are already familiar with.

Sodium Sulfur Batteries

Next to lead-acid, sodium-sulfur (NaS) batteries have found the most prevalent use in electric utility storage service. NaS batteries have been used for distribution grid support, wind power integration, and other high-value grid services because they are capable of long discharges of up to six hours and have longer cycle life than comparable lead-acid batteries. Like many other storage technologies, they are capable of prompt, precise responses to the grid's needs such as mitigation of renewable generation variability and spinning reserve disruption events.

NaS batteries are high temperature batteries with a normal operating range of 330 °C to 350 °C. Therefore, they are assembled in air tight, double-walled stainless steel enclosures that contain a series-parallel array of multiple NaS cells. As shown in Figure 10, each cluster of cells is hermetically sealed in a module filled with sand. The sand inside the module serves to both anchor the cells and mitigate the effects of individual cell failures that could otherwise ignite and start a fire in the larger system. Other safety features include fused electrical isolation and a battery management system that monitors the module voltages and temperatures. The sodium, sulfur, beta-alumina ceramic electrolyte, and sulfur polysulfide components of the battery are disposed of, or recycled at the end of the NaS battery life by routine industrial processes.

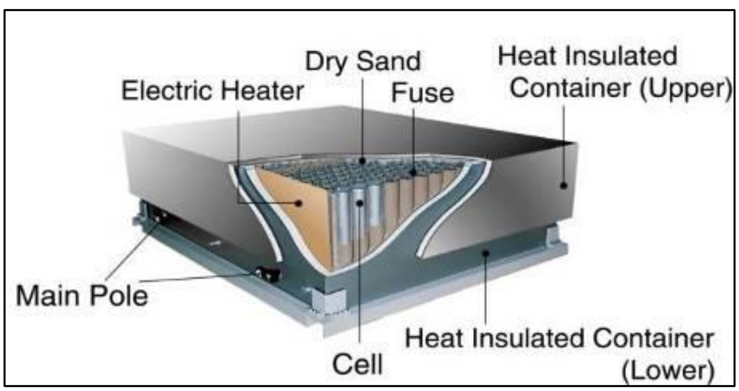

Figure 10: NaS Battery Module Components

(Courtesy NGK Insulators, Ltd.)

NGK Insulators, Ltd., and Tokyo Electric Power Co. (TEPCO) jointly developed NaS battery technology over the past 25 years and NGK is the sole supplier of NaS battery systems worldwide. Standard building blocks used in NGK's system contain five 50-kW NaS modules that include a control unit, heater, heater controller, and voltage and current measurement sensors. NGK's NAS storage systems are only available in multiples of 1-MW/6-MWh units with installations typically in the range of 2 to 10 MW.

NAS installations providing the functional equivalent of about 160 MW of pumped hydro storage are currently deployed within Tokyo. The largest single installation is the 34-MW Rokkasho wind-stabilization project in Northern Japan that has been operational since August 1, 2008. Currently, over 400 MW of NAS installations have been deployed globally at over 230 sites, representing 2,000 MWh of capacity.

Sodium Nickel Chloride

Sodium nickel chloride batteries are high-temperature battery devices like NaS but operate between 270 °C and 350 °C. These batteries are also assembled in hermetically sealed modules that are typically 20 kWh each.

General Electric (GE) and FIAMM are the two leading suppliers and pre-production units in the 200 kWh size range have been installed at Duke Energy and other mainland US utilities. GE, with both name recognition and established products dedicated to electric utilities, is best positioned to deploy its stationary battery systems. GE, moreover, operates a parallel business in deploying this battery technology in hybrid locomotives that it already manufactures and markets to a worldwide customer base. The hybrid locomotive market initially represents a much larger market opportunity than the stationary market, and its existing higher volume manufacturing could provide GE a cost advantage in developing a lower cost stationary storage.

Figure 11: FIAMM's 220 kWh Pre-production Unit at Duke Energy Site

Flow Batteries

Unlike other battery types, flow batteries have aqueous electrolyte that is circulated through a stack where an electrical potential is produced through their reaction, hence the label "flow" batteries. These batteries were originally developed for long-duration grid and EV applications with development work starting in the late 1960's, because they can be configured for discharge durations of three to six hours, and scaled up to megawatt size systems. A simplified schematic is shown in Figure 12.

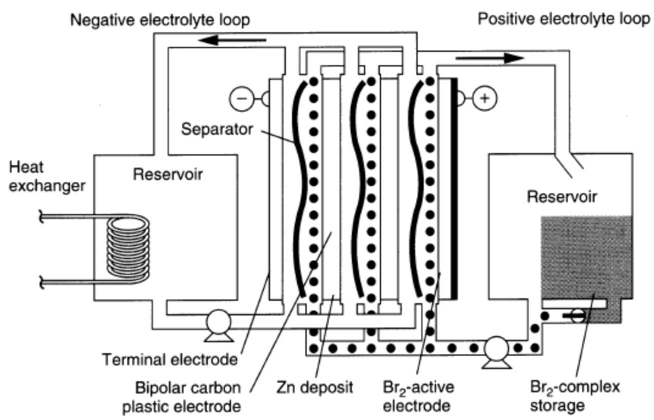

Figure 12: Schematic of Zinc/Bromine Flow Battery

Development work in flow batteries branched into several chemistries with limited success; recently, attention has focused on two types - Zn/Br and Vanadium Redox - which will be the likely candidates for near-term use in the electric grid. Kilowatt size systems have been deployed in small numbers in utility applications, but, these technologies have not shown reliable performance in the larger megawatt size range.

Zinc Bromine

Zinc Bromine batteries are currently under development by ZBB Corporation (ZBB) and Premium Power. ZBB Energy Corporation designed and manufactured a 50 kWh battery module in the late 1990s that served as a building block for larger systems. A trailer-mounted 200 kW, 400 kWh battery shown in Figure 10 was built for demonstration at two sites in the Detroit Edison service area in 2000 and 2001.

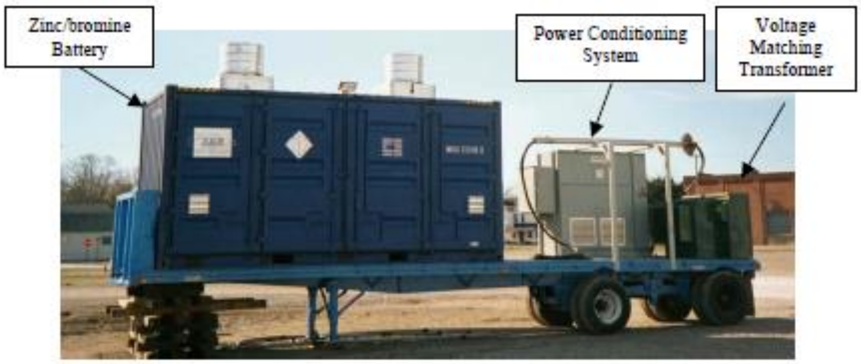

Figure 13: Trailer-mounted 200 kW/400 kWh Demonstration Battery System

by ZBB Corporation

Subsequent systems have been fielded at other demonstration sites. However, scaling up to the megawatt size systems has encountered technical issues and the ZBB systems remain in the 200 kW to 500 kW size range.

Another flow battery is made by Premium Power (Premium) which announced plans for the production of TransFlow 2000. This was projected to be a low-cost storage system, with a rating of 500kW/ 2.8MWh in a single 53' enclosure and was scheduled to be available in 2009/2010. Several US utilities, including MECO, entered into agreements with Premium to purchase the TransFlow storage system. However, production plans were delayed and most were nullified. One pre-production unit was shipped to Kotzebue Electric, Alaska, in 2011, to support the integration of wind turbines into the town's electric grid. The unit did not meet its operational requirements and was shipped back to Premium in late 2012. Premium is under new management and future development of the Premium storage systems remains somewhat uncertain at this time.

Figure 14: Premium Power TransFlow 2000 System Being Unloaded at Kotzebue – 2011.

Vanadium Redox Batteries

The vanadium redox flow battery is based on redox (reduction and oxidation) reactions of different ionic forms of vanadium and is somewhat similar to the Zinc Bromine battery in its construction. The cells are separated by a proton exchange membrane, which allows for the flow of ionic charge to complete the electrical circuit; the electrolytes are stored in external tanks and pumped as needed.

As with other flow batteries, the vanadium redox systems tend to be physically large due to the large volumes of electrolyte required when sized for utility-scale (megawatt size) projects. Unlike many other battery technologies, the 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 in about two years' time.

Vanadium redox systems made by VRB, now Prudent Energy, have been demonstrated in two projects in the US. The first deployment was in Utah followed by a larger 600 kW/3,600 kWh at an onion processing facility in California, see Figure 15.

Figure 15: Prudent Energy 600-kW/3,600-kWh VRB System at Gills Onions, Oxnard, California.

Compressed Air Energy Storage (CAES)

CAES is the only other long-duration energy storage option available besides pumped hydro. CAES works by storing compressed air in an underground reservoir or above ground in pressure vessels. During discharge, electricity is produced by allowing the compressed air to expand through an expander or conventional turbine-generator while adding heat. Figure 16 is a schematic of a CAES plant with compressed air storage in an underground cavern created in a salt dome.

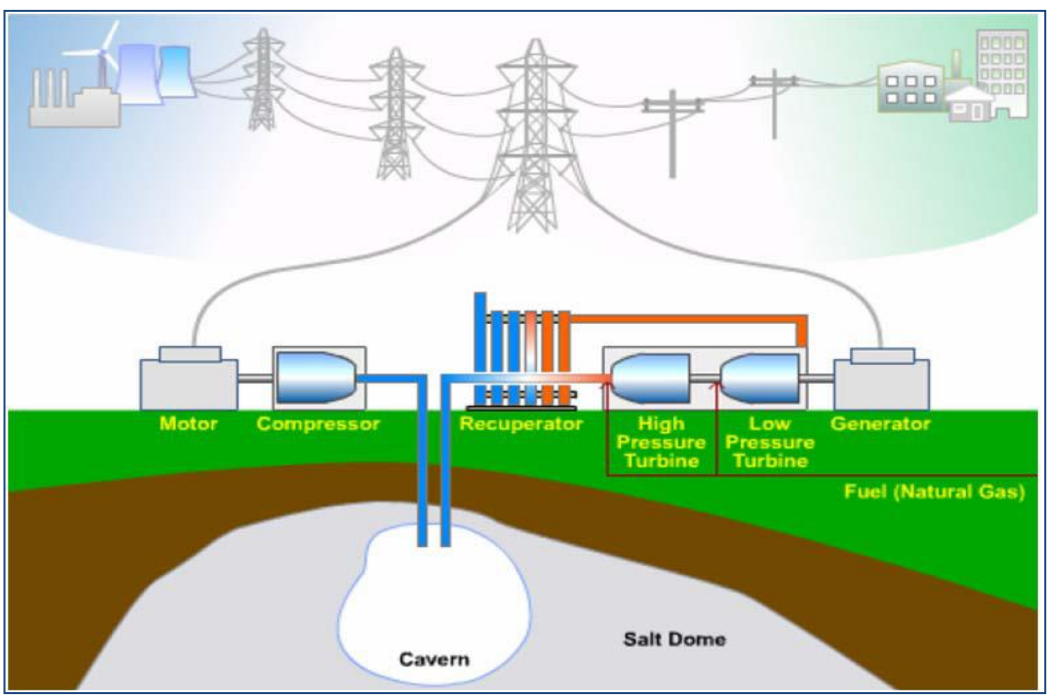

Figure 16: Schematic of a CAES plant with Underground Compressed Air Storage

(Source: Electric Power Research Institute)

So far only two CAES systems have been built: one in Germany and one in Alabama. The plant in Germany has been operating since 1978. It is rated at 290 MW with four hours of storage and uses two man-made, solution-mined salt caverns to store the compressed air. The plant in Alabama is located in McIntosh, AL, and is operated by PowerSouth Energy Cooperative (formerly Alabama Electric Cooperative). It was commissioned in 1991, has a rating of 110 MW with a 14 hour discharge duration, and stores compressed air in underground caverns at 1,000+ psi.

Creating a cavern in existing salt domes or finding suitable geologic formations to store the compressed air reliably over a twenty or thirty year operating life has been challenging and additional CAES plants with underground storage have not been built. Second-generation CAES concepts with above-ground storage in pressure vessels have been proposed and could hold potential for future applications in Hawaii. These would be smaller in the 10 to 30 MW size range and discharge durations in the two to six hour range. The further development of above-ground CAES technology should be tracked closely by HNEI or DBEDT, but, any prototype demonstrations should be tested at mainland sites and re-located to Hawaii only after specific performance metrics are achieved.

Other variations of CAES utilizing air storage vessels immersed in deep-sea locations, especially in channels near several Hawaii locations have also been proposed. The designs for these types of CAES are still in the concept stage, and practical implementation could present even greater challenges than the above-ground CAES because of pressure and temperature gradients and the survivability of the storage vessels in a deep-sea environment. It is also very unlikely that the built-cost of the deep-sea CAES systems would offer any advantages over the above-ground CAES systems, because of the obvious ease of construction, maintenance and repair of hardware above-ground compared to hardware in a deep sea environment.

Section IV: Storage Technologies - Cost of Systems

Unlike other grid resources such as combustion turbines or diesel generators, the cost of a storage system is difficult to bracket due to the various technologies and applications of storage. And, unlike a pure generation resource such as a combustion turbine, a storage system has a power component, measured in kW or MW, and an energy component, measured in kWh or MWh, the combination of which determines the cost. For example, a two MW, 14 MWh battery system such as the NGK NAS system will have a total cost that is very different from the same 2 MW power battery system with lower energy of one MWh.

Estimating the cost of the storage systems is further complicated by the various maturity levels of the storage technologies and vendor products. Cost estimates from vendors who have more experience and those who have systems successfully operating in the field are more accurate than from vendors whose systems are in earlier development stages and have not reached full commercial maturity.

Several studies have presented cost estimates, but, the most recent cost information is available from the soon to be released DOE/EPRI Electricity Storage Handbook and the Storage Technology Assessment report of the Congressional Research Service[15]. The cost data presented in these two reports for the storage technologies and applications of interest in Hawaii is summarized in the Table 1. The Congressional Service report presents cost information on only three storage technologies of interest. These include Sodium Sulfur, Zinc Bromine and Vanadium Redox and their variations highlight the difficulty in comparing and generalizing cost estimates obtained from different sources and for different applications.

Table 1: Cost Estimates for Select Storage Technologies

Technology	$/KW	$/kWh
Advanced Lead-acid	4,000 – 8,000	1,000 – 2,000
Li – family	2,500 – 12,000	2,500 – 4,500
Flywheels	4,000 – 5,000	20,000 – 22,000
Pumped Hydro	5,000 – 7,000	2,000 – 3,000
Sodium Sulfur	5,000 – 7,000 ***2,970 – 3,450***	1,000 – 2,500
Sodium Nickel Chloride	5,000 – 10,000	2,000 – 5,000
Zinc Bromine	2,500 – 6,000 ***3,400***	1,500 – 3,000
Vanadium Redox	3,000 – 7,000 ***2,450***	1,500 – 3,000
Compressed Air	4,000 – 5,500	1,000 – 3,000

Note: The estimates reported in the Congressional Research Service report for select technologies are ***bold italics*** in the table above.

[15] "Energy Storage for Power Grids and ElectricTransportation: A Technology Assessment" by Paul W. Parfomak for the Congressional Research Service, March 27, 2012.

Section V: Energy Storage Integration in Hawaii Grids

Types of storage deployments

Future storage system deployments in Hawaii present opportunities to adopt new and non-traditional approaches to the operation and ownership of such systems while promoting the increased penetration of renewables in the grid. A few of these are discussed in this section.

Technology Diversification:

The storage systems deployed in Hawaii to date are all battery-based systems. Other, non-battery storage technologies, such as flywheels and sea-water pumped storage offer viable alternatives and technical advantages as well. For example, flywheel systems have orders of magnitude longer cycle lives compared to batteries, and this technical characteristic makes flywheel storage a superior alternative to battery-based storage systems where continuous shallow depth of discharge cycles are needed. As stated elsewhere in this report, flywheel systems are already providing regulation services to grids on the mainland and should be included in future assessments to verify their applicability in Hawaii-specific cases.

Similarly, Sodium-Sulfur or Sodium-Nickel-Chloride battery storage systems available today can meet long duration discharge requirements of four to six hours. In this discharge duration range, sea-water pumped storage systems can offer matching discharge times, but, without the cycle life limitations of batteries. Pumped sea-water storage systems could greatly benefit Hawaii grids by providing 10+ MW of power for four to six hours without the cycle life limitations of batteries, especially as the penetration of wind generation increases and curtailment becomes a significant issue.

Utility-side Storage System Deployments

The storage systems deployed in Hawaii to date are predominantly on the developer-side of the meter. This electrical placement and ownership of the storage system limits it to serve the needs of the renewable project only, and it cannot be used for other services that it could provide to the grid. Moving the storage to the utility-side would enable the storage to provide other services such as regulation, spinning reserve or load leveling, while still damping the effects of the renewable generation ramps. However, this placement also requires that the cost of the storage be equitably split and shared between the utility and the renewable project developer. However, agreement of how the cost should be split and other considerations of warranty coverage by the storage system supplier may pose some hurdles, but, suitable guidelines by the HPUC to allow such dual use and ownership could open broader opportunities for future storage deployments.

Distributed Storage Systems Deployment

The storage systems deployed in Hawaii to date are predominantly larger, megawatt-size systems. A "distributed" approach combined with larger storage systems, for future deployments would offer greater operating advantages to each island's grid. The smaller size systems would be greater in number, but would be in the 10 – 100 kW size range, with one to three hours of discharge capacity, located deeper in the distribution network and in proximity to residential or commercial/industrial customer loads. In sufficiently large numbers, storage systems deployed in this manner could offer multiple benefits to the grid. They would significantly off-load the substation transformer during peak times, increase distribution system reliability, and hence customer reliability, and provide local voltage support. The distributed deployment also does not require a single, large capital expense that the mega-watt scale systems require. Instead, it requires smaller investments spread out over a longer period of time to acquire individual systems or a block purchase of ten or more units. Such a staged deployment not only offers an easier financial planning scenario, but allows the acquisition to be made as and where needed – almost a just-in-time approach to storage. An additional advantage of the distributed, staged deployment is that it does not commit the owning utility to one specific technology or vendor. Different technologies and vendors can be selected at any stage. Distributed, smaller-size storage systems can be integrated in any Smart Grid communication and control scheme so that they can be controlled individually or collectively dispatched to support the grid needs at even the transmission level.

American Electric Power has proposed a similar approach through their Community Energy Storage systems and has written a specification for such a storage system that is publicly available at:

http://www.dolantechcenter.com/Focus/DistributedEnergy/docs/CESHubSpecifications_rev2_1.pdf

Section VI: Barriers for Energy Storage Deployment in Hawaii

Until recently, pumped hydro was the only viable storage technology for electric utility service and, as a result, 24 GW of pumped storage systems are operating in the national grid. To date, battery energy storage systems have found only a niche foothold in electric grids with early projects that were mostly demonstrations to validate performance and provide hands-on experience with large systems. However, improvements in battery technology, a regulatory environment that recognizes the beneficial role of storage in the grid, and the need to mitigate the variability of increasing penetration levels of renewables are creating greater opportunities for deployment of battery storage systems.

The electric grids in Hawaii will soon have a rapidly increasing portfolio of wind and PV generation and Smart Grid options. These future grid configurations could greatly benefit from the services that energy storage can offer to enhance this imminent reality. The storage systems that have been deployed recently have demonstrated important, but limited, roles in the Hawaii grids. As described in this report, storage can offer an expanded portfolio of grid services as the Hawaii grids evolve. However, some barriers and challenges need to be overcome before such widespread deployment of storage can occur. Some of these are discussed below.

Economics/Markets

The prevailing opinion about storage systems is that the total capital cost, especially battery and flywheel systems, are higher in comparison to other utility options such as upgrading substations or adding new peaking capacity. The counter argument to that is that the benefits[16] of these storage systems are not fully quantified or, more frequently, cannot be monetized by the utility due to restrictive or non-existent regulatory structures that prevent cost recovery of energy storage systems. This leads to the misconception by utility planners and commission regulators that storage is "expensive" and is justifiably excluded as a viable technology option in most utility planning scenarios. The regulatory aspect will be discussed in further detail in the "Political/Regulatory" subsection below, and issues directly related to cost will be addressed here.

The cost of a storage system is composed of three components. These are: (1) the "energy" component, which is the battery or flywheel, (2) the power conversion system (PCS) component that performs the bi-directional conversion between ac and dc, and (3) the balance-of-plant component that includes controls/communications, housing, switchgear and miscellaneous equipment to connect the load. On a percentage basis, these three components have been almost equal contributors to the total cost of the storage system over the last 20+ years.

The energy component costs are storage technology specific and their future trend is influenced by complex factors. For example, storage systems using advanced lead-acid batteries are unlikely to see any great reductions in price. Because, its close cousins – the starter battery for cars, trucks, recreational vehicles, boats, etc. - are already produced in very high volumes in existing factories and their raw material supply chains and other related infrastructure are already mature. The overriding cost contributor for the advanced lead-acid batteries will be the recovery of the research and development (R&D) investments made in developing this variation of technology, and not in building their manufacturing infrastructure. Similarly, Li-ion batteries for stationary, utility-scale systems are close cousins to the Li-ion batteries used for consumer appliances and battery

[16] A "benefit" is generally quantified in terms of the monetary or financial value, whereas a grid service or application is a use whereas "benefit" equates to a value.

packs for the growing number of EV's and PHEV's. The R&D and manufacturing investments made to produce those batteries should lead to cost reductions in Li-ion batteries needed for electric utility stationary applications.

NaS batteries have a unique situation because NGK Insulators, Japan, is the sole worldwide supplier/producer of NaS storage systems for electric utility applications. NGK NAS storage systems have a strong market demand, and they currently have a lead time of over six months for new orders. With over 400 MWs of installed storage systems in overseas markets and the continuing high demand for their product line, it is unlikely that there will be significant price reductions in NaS storage systems in the foreseeable future.

Flow batteries have shown great promise as a low-cost storage option for electric utility use, but their production volume is very limited and at least one supplier, Premium Power, has a containerized system that needs extensive re-engineering to bring it to market. The other suppliers are producing their systems in limited quantities and the low volumes cannot benefit from the cost reductions that can be expected from high production volumes of the other storage technologies discussed above.

The power conversion subsystem (PCS) costs have seen reductions in recent years, driven mainly by lower costs of its silicon-based switches, improvements in overall engineering design, and production efficiencies. Further cost reductions may occur only if sales volumes of energy storage systems increase significantly.

While the high initial cost of the storage systems has been a barrier, the valuation of the services that storage provides to the grid is also difficult to quantify in most cases and becomes another barrier. For example, in Hawaii's specific case, the value of providing spinning reserves with storage is difficult to quantify, because this service is already rolled into the total cost of operations for each utility and cannot be easily broken out. Similarly, the value of providing ramp support or reducing curtailment is also location and resource specific, and generally difficult to quantify.

Several reports have estimated the value for various grid services and the Congressional Service report summarizes these estimates as shown Figure 17.

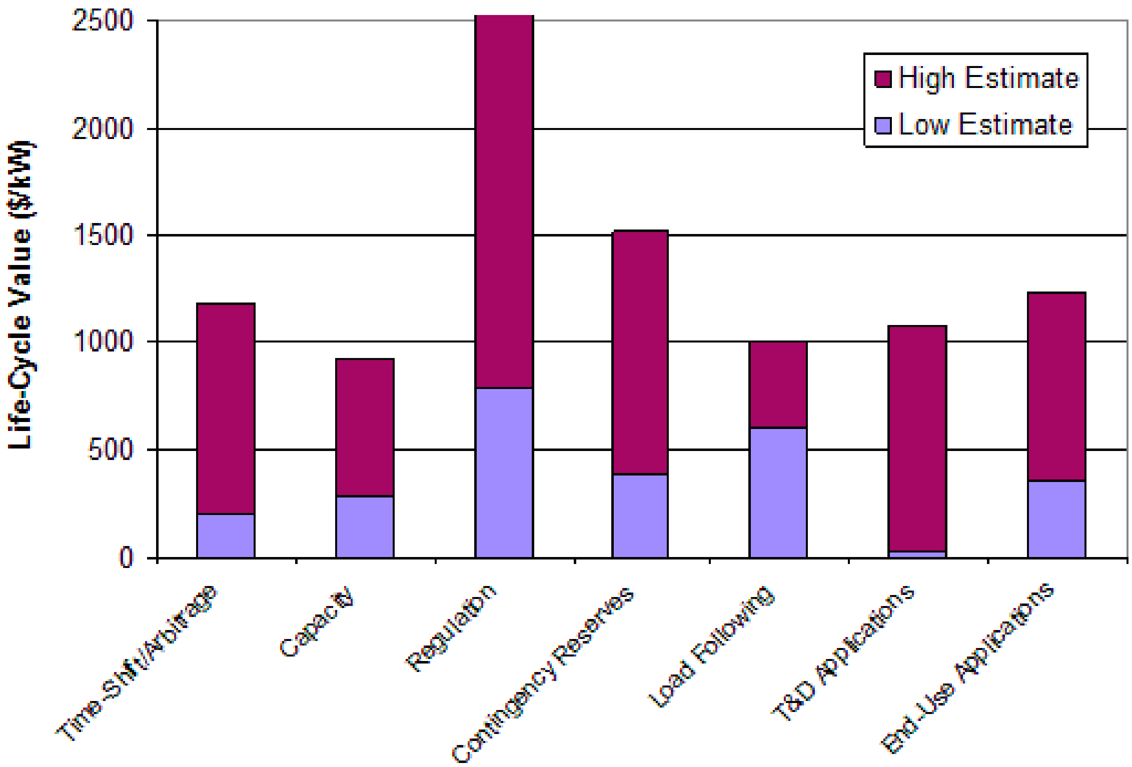

Figure 17: Value Estimates for Various Storage Services[17]

Regulatory and Policy Drivers

Policies set forth by the State and Federal regulatory bodies do not affect the capital cost of storage systems, but they provide the framework for utilities and third party investors to monetize the benefits of storage and recover their investment in a predictable manner. Recent regulatory actions have recognized the services that storage can offer to the grid and policies are in place by Federal Energy Regulatory Commission (FERC) and some State Public Utility Commissions (PUCs), notably the California PUC (CPUC), to allow recovery of investments in storage assets as a grid resource. Table 2 summarizes recent rules and their impact on creating direct and indirect opportunities for energy storage deployment.

[17] "Energy Storage for Power Grids and ElectricTransportation: A Technology Assessment" by Paul W. Parfomak for the Congressional Research Service, March 27, 2012.

Table 2: Regulatory Agency Rules and Their Impacts on Energy Storage System Deployment

AGENCY	RULE/ACTION	INTENT OF THE RULE OR ACTION	IMPACT
Federal Energy Regulatory Commission (FERC)	Rule 755	Directs ISOs to compensate suppliers for frequency regulation resources based on the actual service provided, including a capacity payment for the marginal unit's opportunity costs and a payment for performance that reflects the quantity of frequency regulation service provided.	This benefits energy storage because storage suppliers are compensated for their ability to supply power to full capacity instantly.
	Rule 719	Directs ISOs/regional transmission organizations (RTOs) to accept bids from demand response resources for certain ancillary services on a basis comparable to other resources.	Opens up the possibility for meeting commercial and industrial customers' critical loads using storage that enables frequent demand response participation.
	Rule 745	FERC's Market-Based Demand Response (DR) Compensation Rule requires electric utilities and retail market operators to pay for resources at the market price for energy, known as the LMP, when load reductions are able to balance the grid's supply and demand as an alternative to a generation resource.	May allow utilities or demand response aggregators to include energy storage in their portfolio of assets for DR.
	Rule 1000	In an effort to address deficiencies in regional and interregional transmission planning and cost allocations, FERC Order 1000 requires Public Utility Transmission providers to participate in transmission planning at the regional level. These plans must include a comprehensive evaluation of transmission solutions in coordination with transmission providers from neighboring regions to ensure cost effectiveness and must account for public policy requirements. Second, the order requires that the costs of transmission facilities be allocated fairly to estimated beneficiaries. Finally, the order identifies non-incumbent developer requirements.	Because Order 1000 requires alternatives in transmission planning, non-transmission alternatives such as energy storage could potentially see an increased deployment and in some instances may provide a more cost effective solution than other transmission investments.

AGENCY	RULE/ACTION	INTENT OF THE RULE OR ACTION	IMPACT
California Independent System Operator (CAISO)	Modified Rules to Allow Non-Generation Resources	Removed resource type restrictions and reduced minimum rated capacity to 500 kW from 1 MW to provide certain ancillary services. Reduced minimum continuous energy requirement from 2 hours to: Day-Ahead Regulation Up/Down: 60 minutes; Real-Time Regulation Up/Down: 30 minutes; Spin and Non-Spin: 30 minutes. Will allow minimum continuous energy measured from the period that the resource reaches the awarded energy output. Measurement starts once resource reaches awarded energy, not end of 10 minute ramp requirement.	Allows energy storage resources, such as batteries and flywheels, to provide regulation service by fully utilizing their fast response, fast ramping capabilities. Allows new storage technologies to provide regulation energy over a continued sustained period that does not have seemingly inexhaustible energy like fossil fuel resources.
	Flexible Capacity Procurement to Integrate Renewables	CAISO is considering various electricity capacity sources to help manage the steep ups and downs due to wind and solar coming on line under the Renewable Portfolio Standards (RPS) mandate. CAISO defines the characteristics of the acceptable resources to manage steep & sudden ramps.	If superior abilities of energy storage to ramp up quickly in response to needs and reach full capacity are included in the characteristics required, energy storage systems can participate in this market.
California Public Utilities Commission (CPUC)	Energy Storage rule making for AB2514	AB2514 sets up a framework for identifying storage services to the grid, evaluating their cost-effectiveness, and identifying barriers to implementation of storage projects and possibly setting storage deployment targets if deemed necessary.	Requires California utilities to procure energy storage to a set target, provided cost-effectiveness criteria are met.
	Self-Generation Incentive Program (SGIP) rules	Self-Generation Incentive Program (SGIP) offers incentives to customers who produce electricity with wind turbines and fuel cells. Recent revision has made advanced energy storage systems eligible for rebate.	Either as stand-alone or combined with other eligible technologies, owners of energy storage systems receive rebates of $2/watt.

The FERC and State policies and rules shown in Table 1 are an indication of the trends on the mainland that are favorable for the widespread deployment of storage. In Hawaii, regulatory initiatives, derived from or related to some of the policies listed above could have a significant impact on the widespread use of storage. Some of these are outlined below.

1. Establish requirements for spinning and operating reserves on island-specific basis

At present there are no policies for utilities to provide such reserves and each utility adjusts generation unit output to provide appropriate levels of headroom to meet anticipated regulation needs which often leads to non-optimal operation of generating units. This mode of operation could become more inefficient as the proportion of variable renewable generation increases. A policy that sets a requirement for spinning reserves and regulation, and allows recovery of this service through the rate base, would create an opportunity for using storage in lieu of providing these services with fossil generation. But, the present cost of storage systems may be too high to make this an economically viable option, so it may be necessary to make provisions to allow the same storage system to also be used for reserve duty to concurrently provide other grid service(s) such as renewable ramp support.

FERC Rule 755 and CAISO Flexible Capacity Procurement rules can provide guidance to frame Hawaii-specific regulations for storage.

2. Modify the existing feed-in tariffs (FITs) to recover the additional cost of energy storage if it is integral to the proposed renewable energy project.

At present, the existing FITs do not differentiate between renewable projects with storage and those without storage resulting in developer bearing the additional cost of the storage component. The addition of storage to a renewable project, especially a photovoltaic system, provides a more grid-friendly resource with system-wide services. Thus, creating a framework to recover the additional cost of storage through a "rider" to the FIT could incentivize the addition of storage in future renewable energy projects. The PUC rules would have to provide guidance for the storage system size for a specific renewable system or allow the utility and developer to mutually agree on the storage size best suited for that particular renewable project and location.

The regulations listed in the table above do not address this issue and it is unlikely that FERC or mainland PUC's will be considering this. However, a Hawaii-specific rule may incentivize future storage applications.

3. Establish electric system reliability metrics and re-examine the penetration limits of renewable systems integrated with energy storage on feeders.

The Hawaii PUC recently received a report from the Independent Facilitator (IF)[18] summarizing the findings and recommending future actions for the Reliability Standards Working Group (RSWG) including a recommendation for the formation of a Hawaii Electricity Reliability Administrator (HERA). Among other issues, the IF report will impact the feeder penetration levels of PV and the minimum operating levels of fossil generators and could open new opportunities for the use of energy storage. It is recommended that the recently submitted IF report be reviewed to identify opportunities for energy storage and how it can be integrated into future studies and activities of HERA.

4. Modify the Renewable Energy Infrastructure Program (REIP) to allow recovery of future energy storage studies and projects:

The HPUC recently approved a request by HECO to recover the deferred cost of Big Wind Implementation Studies through REIP[19]. But, REIP, as it currently stands, does not allow the recovery of storage studies or the full or partial cost of storage project costs, even when it is recognized that energy storage is a technology enabling greater penetrations of renewables.

A HPUC initiative is needed to modify REIP to allow the recovery of costs of future storage integration studies and implementation of large or distributed energy storage projects that support or facilitate renewable projects.

[18] "Reliability Standards Working Group Independent Facilitators Submittal – Final Report", March 13, 2013. http://puc.hawaii.gov/reports/RSWG%20Facilitators%20Report.PDF

[19] HPUC Decision and Order Number 31137 in Docket Number 2011-0112: HECO Tariff Sheets for REIP Surcharge: http://dms.puc.hawaii.gov/dms/OpenDocServlet?RT=&document_id=91+3+ICM4+LSDB15+PC_DocketReport59+26+A1001001A13D08B12531E2239918+A13D08B12531E223991+14+1960

Section VII: Technical Barriers

Various reports have cited technical barriers that inhibit the widespread use of storage. Most notably, the Congressional Research Service report[20] listed these three barriers as being the most prevalent in the US:

- Unquantified and uncaptured benefits,
- Regulatory and market uncertainty and risk, and
- Lack of incentives for customer-sited storage.

All three of these cited barriers exist in Hawaii as well. The unquantified and uncaptured benefits barrier is evident in the fact that Hawaiian utilities do not have a regulatory requirement for reserves as discussed in the earlier Regulatory and Policy Drivers section.

Similarly, customer-sited, *but* utility-owned storage is not presently incentivized or valued. This falls under the "distributed" approach to storage deployment and is presently a barrier which if removed could spur further deployment of storage in Hawaii.

The sizing of storage systems also emerges as a technical barrier. At present, there is not a set, commonly accepted methodology for sizing a storage system, especially in combination with renewable generation. Thus, sizing the storage system is presently a project/location-specific exercise mostly based on assumptions of the size of the renewable project and ramp rates specified by the utility. Experience from existing storage systems in Hawaii is showing that a single ramp rate specification may provide insufficient guidance for sizing the storage system, because it ignores the possibility of multiple ramps occurring in rapid succession and the possibility that the battery has insufficient capacity to handle them.

Another barrier that is being addressed by a DOE and EPRI initiative is defining test protocols to qualify storage systems for specific applications such as frequency regulation or time shifting renewable energy. At present, there is not a standard specification that states required performance parameters such as the number of cycles or depth-of-discharge that a storage system has to meet to perform these services. The lack of such a standard creates a barrier and an uncertainty for the utility in procuring a storage system with the confidence that it will meet certain performance goals in the short and long term. At present, vendor performance warranties are presently bridging this uncertainty gap and a specification standard or test protocol to verify the vendor claims would greatly increase the confidence in storage system performance.

[20] "Energy Storage for Power Grids and ElectricTransportation: A Technology Assessment" by Paul W. Parfomak for the Congressional Research Service, March 27, 2012.

Environmental constraints

The environmental constraints for siting electrical storage plants vary by technology. The footprint of the complete battery system plays an important role when it is located within an existing substation or other utility-owned installation such as a switching station. The gravimetric, Wh/kg, or volumetric, Wh/L, densities reported in literature or provided by battery manufacturers for various battery types are somewhat misleading metrics from this practical perspective. These metrics not only discount the space requirements of the balance-of-system components, but also the fact that most battery systems are packaged in containers that are a standard shipping size. Thus, regardless of battery chemistry, sub-megawatt or 1 MW size systems are all packaged in containers with a nominal footprint of 12' x 40'. Therefore, the footprint of the entire system as sold, including all the system components, not just the battery stack, is of greater practical importance than the stated energy densities of the battery alone.

Battery and flywheel storage systems are relatively easy to site due to nominal land area requirements. By contrast, pumped hydro facilities require significantly larger land area for their reservoirs and land use is an environmental constraint that needs to be addressed at the earliest stages of project planning.

All the storage technologies described in this report are non-emitters of pollution at the project site. However, storage systems derive their charging energy from external sources such as a fossil-fired generation unit or a wind farm or PV plant. If the charging energy is derived only from a fossil-fueled source, then source emissions could increase depending on when and how the unit is used as the charging energy source.

Public Perception/Cultural

The August 2012 fire at the Xtreme Power storage system at Kahuku, Oahu, will likely create a heightened sensitivity to locating future storage facilities in populated settings. This constraint, if it is needed, should be addressed in the early planning phases of the project to address specific concerns in siting the storage facility.

Electric utilities that have implemented storage projects have simultaneously provided training and awareness education to emergency first responders, including local fire departments, to equip them to handle the unique needs of each battery technology. The equipment layout of the storage project also takes into consideration the access needs of emergency personnel and equipment so that there is sufficient clearance between buildings and system components to accommodate their needs. This requires an additional interaction between the electric utility and the storage system vendor to ensure that this critical detail is addressed satisfactorily to comply with all the requirements.

Traditional pumped hydro storage projects that require two reservoirs and use fresh water have justifiably been rejected in the past due to the inevitable conflict over land and water use issues. However, the seawater pumped hydro systems discussed in this report require only one reservoir, use only sea water that is fully recycled and does not produce a thermal plume at the sea water discharge flumes. Their land use impact is much less and there is zero impact on fresh water use. These systems offer a viable long-duration storage option that is superior to battery based long-duration storage systems since their operational life is not constrained by life-cycle limitations. The use of such sea water pumped hydro systems could be revisited through town-hall meetings with the community to explain their merits over previously held notions about traditional pumped hydro systems.

Section VIII: Risks and Uncertainties

Some of the battery technologies deployed or to be deployed in Hawaii have limited full-scale operational histories in the field. There is an element of risk in how these battery technologies perform in the latter phases of their operational life, especially if several storage systems use the same battery type and are supplied by the same vendor.

The lack of proper training and familiarity of utility operators and maintenance personnel who oversee the storage system is a related risk that lies on the host utility side. Storage systems have very different physical and operational characteristics than the traditional utility resources such as generators and transformers. Proper training and familiarity of the all personnel with the storage system reduces this risk factor.

Similarly, as indicated earlier in the storage technologies section of this report, some of the storage system vendors are recently formed companies or recent startups. Most of these companies rely heavily on venture capital to sustain their operations, including warranties on their products. The venture capital funding introduces another element of business risk, whereby the longevity and ability to provide field maintenance and repair services could become questionable or cease altogether.

The use of storage to smooth and shift renewable generation is still in relative infancy. The algorithms developed by storage system vendors have been mostly developed using solar irradiance and wind data recorded at non-Hawaii sites, which introduces an uncertainty about the optimal performance of the algorithms. There has not been a critical assessment of these algorithms and questions remain about their complexity and efficiency.

Similarly, the correct sizing of the storage system, both in power and energy rating, is still not based on a standardized methodology which fully considers all the relevant parameters of the renewable system that it is meant to support.

Another uncertainty is the effect other technologies, which are likely to be introduced into the Oahu grid in the near future, will have on the storage systems that will already be in the field at that time. For example, a high penetration of vehicle-to-grid storage could introduce an uncertainty on the effectiveness and operational impact of distributed, community storage systems, if these are already in place.

Section IX: Lessons Learnt and Performance Assessment of Existing Storage Systems

There are over twenty storage systems deployed in Hawaii, and each system has some unique lessons learnt through all stages - from its initial planning, technology and vendor selection, procurement, and field installation and startup. Lessons learnt from these experiences need to be documented, shared and used to simplify the deployment of future storage projects.

There also has to be a coordinated effort to record the predicted and actual performance of storage systems so these data can be publicly shared. Such a comparative evaluation could lead to several improvements for future systems, including sizing, technology selection and monitoring.

Section X: Conclusions

Energy storage can play a key role in facilitating high penetrations of variable renewable energy sources in Hawaii. Over twenty systems have already been installed and are providing valuable operational experience to the host utilities. While a large number of novel storage technologies are being investigated, only a handful of storage technologies have currently achieved commercial maturity and are deployable. As a result, the deployments of storage system have thus far been limited to two or three battery technologies. It is recommended that other technologies such as flywheels and seawater pumped storage be included in future project opportunities.

Total system costs of storage systems has always been difficult to present on a generalized basis without having application, technology and system size specific information. Nevertheless, some recent cost estimates for the technologies included in this report have been shown.

Regulatory initiatives have also been outlined that could facilitate the wider deployment of storage systems. And, it is also recommended that a “distributed”, smaller-size deployment approach be combined with larger sized systems to capture benefits at the distribution and customer service level.

Several technical barriers such as valuation of storage services and sizing of storage systems exist and need to be addressed to facilitate future deployments. Finally, it is recommended that performance data and lessons learnt from the existing systems be gathered and made available to facilitate the deployment of future system.