

Moving Energy Storage from Concept to Reality:

Southern California Edison's Approach to Evaluating Energy Storage

Abstract:

The electric industry has pursued cost-effective energy storage for many decades. In a business traditionally constrained by the need to instantaneously match demand with supply, the potential to store generated electricity for use during more valuable periods has been long recognized. In recent years a series of factors, including technological progress, legislative and regulatory tailwinds, and new grid challenges associated with integrating variable renewable generation, have propelled energy storage to the forefront of industry consciousness. This excitement, however, does not by itself resolve the various complexities facing energy storage. Even the definition of “storage” can be confusing, as the term refers to multiple different technologies and potential uses across the electrical grid. Additionally, while these options continue to develop and emerge, there is little consensus on how their worth should be evaluated. Recognizing these challenges, this white paper offers a methodology for contextualizing and analyzing the broad and heterogeneous space of energy storage, and it ultimately identifies applications currently viewed as having the greatest potential value from Southern California Edison's (SCE) perspective. It is SCE's goal to advance the storage discussion towards the vision of a more reliable grid, with reduced environmental impacts, at overall lower costs to electric consumers.

Primary Authors:

Johannes Rittershausen
Mariko McDonagh

Acknowledgements:

The authors would like to recognize Southern California Edison’s energy storage project team for their efforts in helping to develop and review the contents of this report:

Alexander Morris
Benjamin Hodges
Bernice Maldonado
Christopher Elias
Dana Cabbell
Deanne Nelsen
Janos Kakuk
Juan Castaneda
Loic Gaillac
Matt Sheriff
Michael Kramek
Nathaniel Moore
Naum Pinsky
Ross Boomer
Steve Powell
Thomas Dossey

Eric Morton, Viral Shah, and Will Savage deserve special mention for their assistance in drafting, researching, and editing this white paper. SCE’s past and current executive leadership, including Doug Kim, Gary Stern, Paul De Martini, Pedro Pizarro, and Stuart Hemphill also provided valuable guidance and support throughout this year-long project.

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Executive Summary

Introduction

Excitement and a growing sense of promise accompany energy storage in the electric industry. In a business constrained since its inception by the need to instantaneously match demand with supply, energy storage's vast potential has been long recognized. More recently a series of factors, including technological progress, legislative and regulatory tailwinds, coupled with new grid challenges associated with intermittent renewable generation, have propelled energy storage to the forefront of industry consciousness. However, long-standing uncertainties concerning feasible uses, valuation methods, and ultimate cost-effectiveness remain, impeding informed decision-making. Recognizing these challenges, this white paper offers a methodology for contextualizing and analyzing the broad and heterogeneous space of energy storage, and it ultimately identifies applications currently viewed as having the greatest potential value from Southern California Edison's (SCE) perspective. It is SCE's goal to advance the storage discussion towards the vision of a more reliable grid, with reduced environmental impacts, at overall lower costs to electric consumers.

To think of energy storage as a unified concept is to underestimate its complexity. The traditional electric system – from central generation to end user including the extensive transmission and distribution grid in between – provides numerous theoretical opportunities for storage's deployment. To serve these diverse uses, a wide variety of technology choices have or are being developed to store electricity as chemical, thermal, and mechanical energy. Each option comes with distinctive operating qualities and specifications, complicating efforts to formalize consistent standards and conduct meaningful economic comparisons. Effective storage assessments have also been hampered by the following roadblock: technology manufacturers continually seek direction from potential buyers, including utilities, on value propositions and technical needs, whereas utilities traditionally require upfront project parameters to analyze in the context of existing infrastructure. SCE's effort to overcome these hurdles has concentrated on the development of an application-focused valuation methodology.

Several recent studies have attempted to clarify energy storage uses, technologies, and potential value streams. Sandia National Laboratories¹ provided a list of twenty-six discrete potential uses of energy storage, supplying explanations and initial evaluations for each. A California Energy Commission report prepared by KEMA² approached storage from the perspective of one particular operational circumstance, assessing the effect of higher penetrations of renewable energy generation on California's electricity system. The authors also provided storage policy and further research recommendations associated with addressing intermittent resource concerns. Finally, a paper from the

¹ Eyer, Jim & Corey, Garth; Sandia National Laboratories, *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, SAND2010-0815, February 2010

² California Energy Commission and KEMA, Inc., *Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid*, CEC PIER Final Project Report, CEC-500-2010-010, June 2010

Electric Power Research Institute (EPRI)³ evaluated the system benefits of selected bulk and distributed energy storage options assuming high intermittent wind scenarios in Texas. Given these parameters, this report calculated theoretical technology-specific societal benefit/cost ratios, system greenhouse gas emission changes, and investor internal rates of return.

These studies highlight a few examples of the rapidly expanding breadth of energy storage research. While such efforts have advanced the industry's collective understanding, SCE concluded that additional work was needed to develop and apply a practical valuation structure for reviewing wide-ranging energy storage uses and continually emerging technologies. Following this imperative, SCE developed an application-specific approach to assessing energy storage.

Southern California Edison's Valuation Approach:

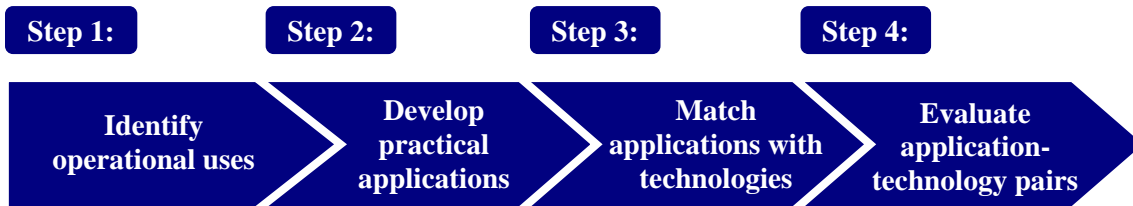
The authors and contributors to this paper propose a valuation methodology consisting of four distinctive steps (see Figure 1):

1. We first identified discrete *operational uses* where storage theoretically could be deployed across the electric value chain. Each of these uses independently derived value, providing a potential benefit stream.
2. Using the operational uses as "building blocks," we developed specific and practical *applications*, otherwise defined as a practical "bundling" of potential operational uses of energy storage across the value chain as a function of both physical location and operating profile. Twelve representative applications were defined, each with individual requirements and preferences.
3. Using these requirements and preferences, we matched each application with "best fit" technology options. Developing an understanding of the various technology options, including their capabilities, cost projections, and commercial availability timelines was also a necessary task during this phase.
4. We assessed the resulting application-technology pairs from economic and feasibility perspectives, developing a high-level assessment of each.

This paper's valuation perspective is thus driven by application development, and not technological capability. Our methodology also reflects SCE's core competencies, which include a deep understanding of electric systems and markets, as well as visibility to the entire grid from central generation to end user.

³ Electric Power Research Institute, *Economic and Greenhouse Gas Emission Assessment of Utilizing Energy Storage Systems in ERCOT*, 1017824, Technical Update: November 2009

Figure 1: SCE’s Valuation Methodology



SCE defined over 20 discrete *operational uses* of energy storage (Figure 2). These uses were mapped to a specific location on the electric value chain. This process clarifies where the benefit is accrued and not necessarily the physical location of the storage project. For example, a device situated at the end user might provide overall system peak capacity, a use traditionally associated with central generation. Additionally, each operational use requires a minimum duration of expected continuous energy output. Some uses call for many hours of energy discharge, whereas in others a few minutes are sufficient. These factors – grid location and duration of energy output – provide a useful framework for organizing and presenting divergent operational uses.

Figure 2: Operational Uses

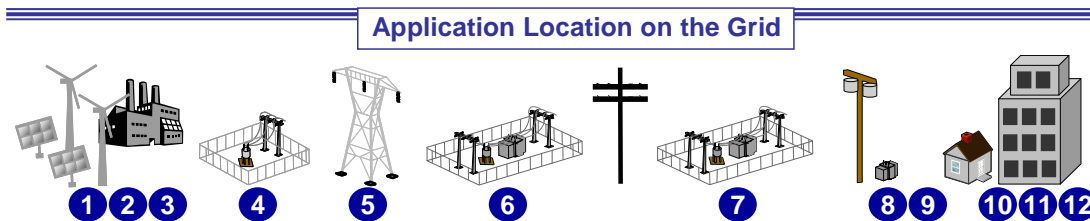
POTENTIAL OPERATIONAL USES FOR STORAGE SYSTEMS

Grid location	Minimum duration of output energy (continuous)		
	Short (< 2 min)	Medium (2 min – 1 hour)	Long (1 hour +)
Generation		① Provide spin / non-spin ② Provide ramping	④ Provide capacity ⑤ “Firm” renewable output ⑥ Shift energy ⑦ Avoid dump energy and/or minimum load issues ⑧ Provide black start ⑨ Provide in-basin generation
	← ③ Provide frequency regulation services →		
	← ⑩ Smooth intermittent resource output →		
Transmission	⑪ Improve short-duration performance ⑫ Provide system inertia		⑬ Avoid congestion fees ⑭ Defer system upgrades
	← ⑮ Improve system reliability →		
Distribution	⑯ Improve power quality		⑰ Defer system upgrades
	← ⑱ Integrate intermittent distributed generation →		
End user	⑳ Maintain power quality		㉑ Optimize retail rates
	← ㉒ Provide uninterruptible power supply →		

These operational uses are the "building blocks" for the applications defined in Figure 3. The ensuing pages of this paper describe each application in detail, following the process flow introduced in Figure 1. While potentially not exhaustive, SCE believes the below twelve applications are a representative set, together encompassing every potential operational use in logical bundled configurations across the grid.

Figure 3: Applications

Application	Description
1 Off-to-on peak intermittent energy shifting & firming	Charge at the site of off-peak renewable and / or intermittent energy sources; discharge "firmed" energy onto grid during on-peak periods.
2 On-peak intermittent energy smoothing & shaping	Charge / discharge seconds-to-minutes to smooth intermittent generation, and / or charge / discharge minutes-to-hours to shape energy profile.
3 Ancillary service provision	Provide ancillary service capacity in day-ahead markets and respond to ISO signaling in real time.
4 Black start provision	Unit sits fully charged, discharging when black start capability is required.
5 Transmission infrastructure	Use an energy storage device to defer upgrades or other technology on the transmission system.
6 Distribution infrastructure	Use an energy storage device to defer upgrades or other technology on the distribution system.
7 Transportable distribution-level overload mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short-term distribution overload situations.
8 Peak load shifting downstream of distribution system	Charge device during off-peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peak period.
9 Variable distributed generation integration	Charge / discharge device to balance local energy use with generation. Sited between the distributed generation & distribution grid to defer otherwise necessary distribution infrastructure upgrades.
10 End user time-of-use rate optimization	Charge device when retail time-of-use prices are low, discharge when high (and / or to avoid demand response curtailment periods / charges).
11 Uninterruptible power supply	End user deploys energy storage to improve power quality and / or provide back-up power during outages.
12 Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid.



Application Evaluation

In step three, each application is matched with “best fit” technology options, based on several requirements such as the duration and frequency of charge-discharge cycles. Resulting valuations reflect the combined benefit streams of an application’s operational uses set against the installation and operating costs of its paired technology. A few examples of these application-technology valuations can be found in Figure 4 below:

Figure 4: Select Application Evaluation Examples

	Applications	2011 Benefit / Cost Ratio	Comments
1	Off-to-on peak intermittent energy shifting & firming	0.5	Valuation will vary based on the chosen technology match (there are several potential “best fit” options) and its associated costs.
2	On-peak intermittent energy smoothing & shaping	0.01	Little-to-no explicit value for this application currently. Valuation may improve if requirements for integrating variable energy resources increase.
3	Ancillary service provision	0.3	High variability for this valuation given the uncertainty of future California ancillary service market design and how storage might participate.
7	Transportable distribution-level outage mitigation	0.2	Valuation will vary widely based on individual circumstances. If / when cost effective, potential opportunities are low in number.
8	Peak load shifting downstream of distribution system	0.4	Valuation will vary based on where and how much is installed on the system.
10	End user retail rate optimization	0.1	Valuation is for small residential customers under current circumstances. Future value will vary on the usage patterns of end users and their rate options.

These benefit-cost evaluations reflect SCE’s high-level understanding of the cost-effectiveness of particular applications in today’s environment. This analysis, however, does not necessarily represent the future world, nor does it comment on which applications may be the most promising over the long run. To find this, SCE calculated benefit-cost under a variety of 2020 scenarios, including falling installed technology costs and growing integration value due to the system demands of increasing variable-output renewable generation. The results of this process are discussed in the next section.

Conclusions

By the end of a year long effort, the 4-step evaluation approach yielded several strategic conclusions, defined both broadly and specifically to each application.

Overall Conclusions:

- Potential storage solutions should be evaluated in connection with clearly defined applications.
- Storage application evaluations should identify a specific location and system / portfolio circumstance, which together provide the foundation for relevant benefit stream calculations. A broader evaluation would not capture truly reflective benefits and costs. Narrower evaluations at the operational use level fail to fully realize the aggregated values of a particular project.

Specific Application Assessments:

- Applications which target peak capacity over several hours (e.g., applications 1 and 8) tend to have higher cost-effectiveness potential. This primarily reflects the aggregated operating and capital cost reductions of several bundled operational uses. In addition, the closer a device to the end user, the more peak capacity infrastructure cost is potentially deferred across the electric system.
- Direct revenue applications, where benefits are defined by market rents or contractual payments (e.g., applications 2 and 3), have longer roads to cost-effectiveness as they tend to rely on highly volatile and uncertain pricing as well as yet-to-be-determined regulatory fiats. By targeting time-variable markets, these applications also forgo the significant value associated with avoiding peak capacity costs.
- Specific niche applications⁴ (e.g., applications 7 and 9) in the transmission and distribution (T&D) system are promising. Their opportunities are also, however, limited in size, and the number of potential cost-effective projects will vary based on individual circumstances.
- End user applications (e.g., applications 10, 11, and 12) will require a mix of circumstances to approach cost-effectiveness, including reflective retail time-of-use pricing and significant device cost reductions. Ultimately, individual end users' value propositions and motivations will vary widely, and as such the phrase "application-specific" assumes an increased degree of descriptive rigor.

In summary, SCE found that applications with the greatest potential directly address the longer duration decoupling of supply and demand. This does not preclude other applications, such as those targeting niche distribution system uses or specific market products, from being pursued. Yet, from SCE's perspective, the aggregated benefit streams associated with deferring or displacing peak-related costs over several hour durations present the most promising opportunities for energy storage.

⁴ Applications 5 and 6 also involve niche T&D grid upgrades, but given the extremely situation-specific nature of their involved problems and solutions (see page 28), systemic evaluations are difficult.

Remaining Challenges and Next Steps

While identifying promising applications is an important initial step in the successful and cost-effective grid adoption of energy storage, at the end of the day, only so much can be achieved through assumption-driven strategic planning efforts. For example, significant regulatory uncertainty remains, including defining the circumstances under which a storage application might qualify to provide peak capacity under California's Resource Adequacy process, as well as better understanding the parameters around storage's potential participation in both the integration of renewable resources and the provision of ancillary services. Inclusive stakeholder forums scheduled in the near future at both national and state regulatory bodies should address many of these uncertainties.

Southern California Edison has made every effort to construct accurate assessments for energy storage applications given currently available information and the best, expert-informed assumptions. However, readers should note that valuations in this study are highly situation dependent. Furthermore, each potentially promising application will require engineering tests and demonstration, preferably through targeted grid projects. These should authenticate operating specifications while validating economic feasibility and technology viability. SCE is currently in the multi-year process of piloting many of the operational uses and applications identified in this report. Finally, given a rapidly changing industry landscape, including increasing renewable generation, electric vehicle charging, and Smart Grid development, future system needs and market conditions may vary significantly from today's. Therefore, further developing analyses which simulate "tomorrow's grid" will be imperative for the accurate financial assessment of various energy storage applications.

Despite these unresolved issues and future challenges, Southern California Edison is encouraged by the promise of energy storage. The authors further hope that this white paper provides a degree of methodological order to an otherwise complex and emerging area. As a company, SCE looks forward to helping develop applications of cost-effective energy storage as a means for serving our customers' energy needs with increasingly reliable and environmentally sensitive electricity.

Southern California Edison’s Energy Storage White Paper in Context:

While this white paper is the most recent evidence of Southern California Edison’s engagement in the energy storage space, the company’s interest spans several decades. In the late 1980s, SCE invested in a pair of energy storage projects. The first was a 200 megawatt (MW) pumped hydro facility christened the Eastwood Power Station, which has been operating since 1987 as part of the larger Big Creek Hydro Project.⁵ During the same period, SCE collaborated with the Electric Power Research Institute (EPRI) to bring about the first large-scale battery pilot targeting grid stability. A 10 MW, 4 hour (or 40 MW-hour) lead acid battery was installed at SCE’s Chino substation, which operated intermittently from 1988 to 1996.⁶ The project proved to be a useful source of data, especially concerning the numerous technical challenges associated with operating over 8,000 cells in 56,000 total square feet of warehouse.⁷ The legacy of the Chino battery continues to emerge in today’s literature, serving most recently and with some interpretive flexibility as a model for analyses performed by storage industry advocates.⁸ In the early-1990s, SCE’s Electric Vehicle Test Center (EVTC) began validating battery technologies for both automobile and stationary uses. To date, the center has shepherded an all-electric fleet of nickel metal hydride battery-powered vehicles over 19 million miles, while also testing diverse advanced battery modules in a laboratory recognized with a presidential visit from Barack Obama in March 2009.⁹

In accordance with its historical leadership in the technical arena, SCE launched a dedicated energy storage strategic planning effort in January 2010. A variety of drivers brought about this endeavor. First, advances in science and manufacturing compelled a revisiting of technologies previously confined to research and development activities. Second, federal stimulus funds targeted the “green tech” sector through 2009’s American Recovery and Reinvestment Act, totaling \$620 million explicitly for energy storage projects with a further \$3.5 billion in related smart grid investment.¹⁰ Other nationwide events also addressed storage, including attention from the Federal Energy Regulatory Commission¹¹ and Congress.¹² Third, California regulatory and legislative bodies have expressed interest in encouraging the nascent industry.¹³ Finally, increasing mandates for renewable energy focused attention on potential intermittency and grid stability issues, where storage may provide potential solutions. All told, the time was right for SCE to strategically reassess energy storage.

Others in the industry also formed similar conclusions about the need to re-examine energy storage. In the next section, this paper reviews three notable efforts in more detail.

⁵ See <http://www.sce.com/PowerandEnvironment/PowerGeneration/BigCreekHydro/>

⁶ See *Chino Battery Energy Storage Power Plant: First Year of Operation*, EPRI TR-101786, Dec. 1992 at http://my.epri.com/portal/server.pt?Abstract_id=TR-101786

⁷ Ibid, see pps. S-4 through S-5

⁸ See the California Energy Storage Alliance June 2010 white paper comparing storage to a gas-fired peaker at http://www.storagealliance.org/presentations/CESA_Peaker_vs_Storage_2010-06-16.pdf

As an additional historical footnote, members of the Chino EPRI-SCE project team went on to found the national Energy Storage Association (ESA).

⁹ See <http://www.sce.com/Feature/Obama-EV-Tech-Center.htm> and <http://www.sce.com/PowerandEnvironment/PEV/background-information-tc.htm>

¹⁰ See <http://www.energy.gov/recovery/smartgrid.htm>

¹¹ See FERC Energy Storage Request for Comments at <http://www.ferc.gov/media/headlines/2010/2010-2/06-14-10-notice.pdf>

¹² See Storage Technology of Renewable and Green Energy (STORAGE) Act at <http://wyden.senate.gov/imo/media/doc/storage.pdf>

¹³ See California Senate Bill 2514 at http://www.leginfo.ca.gov/pub/09-10/bill/asm/ab_2501-2550/ab_2514_bill_20100929_chaptered.pdf

Selected Literature Review:

Thoroughly reviewing all the relevant literature recently published on energy storage would require a lengthy paper unto itself. However, SCE's team found three studies of particular interest based on their respective approaches, results, and frequent industry references. While SCE independently arrived at its application-based methodology and associated conclusions, a comparison with these reports provides readers with useful context and background on how others in the industry are thinking about storage.

Sandia National Laboratories published a weighty examination of energy storage in February 2010.¹⁴ The authors established an ambitious scope, providing a methodology for interested parties to quantify energy storage benefits. Their approach 1) defined the discrete benefits for utilities, 2) estimated the market potential and economic impact of these individual benefits, and 3) identified “synergies” of paired benefit streams which could magnify potential financial returns. It did not, however, assess the combined value of potential synergies beyond a qualitative depiction.¹⁵

Seventeen discrete uses of energy storage (labeled as applications) were defined and described in the Sandia report. Respective benefits were also calculated at a high level and quoted in dollars per kilowatt. The applications were not mapped to particular technologies, rendering precise benefit-cost analysis infeasible. Instead, the authors highlighted relevant technological considerations. Paired applications formed the proposed synergies, but these were not grouped into larger “bundles” of benefits. Unless explicitly detailed by the application (e.g., end-use), potential synergies also were not associated with a specific physical location on the electric value chain.

Sandia's investigation thus concludes by creating financially attractive “value propositions” using pairings of generic benefits. However, this falls short of a full benefit-cost evaluation which would incorporate more specific technology and project parameters. Each discrete benefit may be used to provide high level cost targets, without further understanding the constraints set by a project's technological costs and physical location. In SCE's opinion, however, such valuations are narrowly applicable in real world situations.

The California Energy Commission (CEC) commissioned KEMA, Inc. to evaluate the impact of intermittent resources on California's grid with a specific bent towards evaluating energy storage.¹⁶ Resulting analysis provided policy and research options to ensure the optimum use of energy storage associated with increasing amounts of

¹⁴ Eyer, Jim & Corey, Garth; Sandia National Laboratories, *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, SAND2010-0815, February 2010

¹⁵ *ibid*, see Table 37, pp. 121

¹⁶ California Energy Commission and KEMA, Inc., *Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid*, CEC PIER Final Project Report, CEC-500-2010-010, June 2010

renewable energy. The project further measured the effects of renewable variability on system operation, and then ascertained how energy storage and changes in energy dispatch strategies could improve grid performance. The white paper, therefore, was not intended to provide a holistic assessment of storage, and instead modeled the specific operational impacts associated with pre-defined renewable penetration scenarios.

Major paper conclusions include:

- The CAISO (California Independent Service Operator) control area may require between 3,000 and 5,000 MW of additional regulation/ramping services from fast (5-10 MW per second) resources in 2020. These ramping requirements are driven by longer-duration solar and wind variability.
- The short-duration volatility of renewable resource output will require additional automatic generation control (up to double current levels).
- Fast (defined as 10 MW per second) storage is two to three times more effective than conventional generation in meeting ramping requirements. Consequently, 30-50 MW of storage is equivalent to 100 MW of conventional generation.
- Energy storage may reduce the greenhouse gas emissions associated with committing combustion turbines for regulation, balancing, and ramping duty.

In summary, this report provides an analysis of renewable resource impacts on California's grid operations – particularly the changes in ramping and regulation requirements – and offers storage as a promising mitigation option. While insinuating that storage could be the most cost-effective solution for renewables integration, the authors do not thoroughly demonstrate this through full benefit-cost modeling. Additionally, the analysis is by design bounded in scope and therefore lacks the breadth of potential operational uses necessary to fully evaluate energy storage applications, even those addressing renewable intermittency, across the electric value chain.

In late 2009, **EPRI** published a report valuing specific energy storage projects and technologies.¹⁷ Like the CEC white paper, it focused on storage's potential to provide solutions for renewables integration issues, specifically those caused by excess wind in the Electric Reliability Council of Texas (ERCOT) region. In contrast, EPRI approached its assessment through the lens of market-based analyses on four broad storage technology options: 1) Compressed Air Energy Storage (CAES), 2) Liquid Air Energy Storage (LAES), 3) bulk batteries, and 4) distributed batteries.

For each technology, the report assessed the rate of return from a potential independent investor's perspective by computing net operating incomes. These were driven primarily by the costs and revenues associated with arbitrated on and off peak energy price spreads and the market rents from offering ancillary services. The authors also assessed a broader societal benefit-cost ratio which included congestion relief and the impact on carbon

¹⁷ Electric Power Research Institute, *Economic and Greenhouse Gas Emission Assessment of Utilizing Energy Storage Systems in ERCOT*, 1017824, Technical Update: November 2009

dioxide emissions (e.g., CAES and LAES make combustion turbines more efficient, and batteries are charged by electricity with off-peak portfolio emissions).

Three high level conclusions emerged from the study. First, the second generation CAES system provided attractive investor rates of return. Second, distributed batteries were the only storage options which provided higher societal benefits than costs, but high capital costs kept rates of return low. Finally, considering Texas' resource portfolio and efficiencies lost during the charge-discharge cycle, all storage devices led to slight increases in CO₂ emissions.

Unlike SCE's approach, EPRI's analysis evaluated energy storage from a technology-driven perspective. Its focus on hypothetical projects in defined locations on the electric system and resulting benefit-cost comparisons also provided noteworthy private return and societal benefit estimates. These assessments, however, failed to account for other potential operational uses and associated value streams (such as avoided T&D cost for distributed batteries) which might accrue to similar applications.

While this literature review does not delve into the intricate modeling and analysis assumptions of each report, higher level commentaries on others' methodology and conclusions illuminate SCE's methodology in relative terms:

- Focusing on one bounded use from the outset (e.g., integrating intermittent renewable energy into ISO operations) fails to capture all of the potential uses of energy storage. A complete strategic assessment of storage should ***develop and evaluate applications which reflect all operational uses*** on the electric value chain.
- Commenting on storage's desirability in a particular application is difficult without an understanding of potential cost-effectiveness. Such ***benefit-cost valuations should be undertaken with location-specific application-technology pairs in mind***. Otherwise benefit numbers are too broadly defined and cost numbers often do not exist.
- ***An application-focused valuation approach is optimal***. First, all relevant operational uses (and their resulting benefits) can be captured at the outset during application development. Second, each application is grounded in a physical location and grid context. Third, best-fit technologies can be identified based on an application's operational preferences and other situational constraints. Finally, focusing on applications defines "the problem" before assessing "the solution." Otherwise, valuations appear as specific project or technology justifications instead of broader strategic estimations of the most promising storage uses.

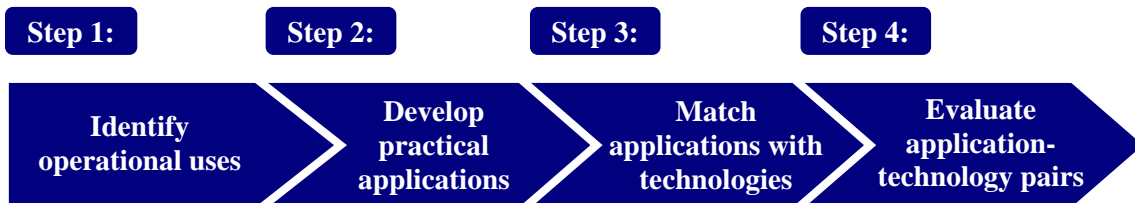
Now that the industry and analytical background have been introduced, readers are positioned to better conceptualize SCE's valuation methodology.

Southern California Edison’s Valuation Approach:

The authors and contributors to this paper propose a valuation methodology consisting of four distinct steps (Figure 1):

1. We first identified the discrete *operational uses* where storage could theoretically be deployed across the electric value chain. Each of these uses independently derived value, providing a potential benefit stream.
2. These operational uses were used as “building blocks” by which we developed specific and practical applications. An *application* was defined as a practical combination of potential operational uses of energy storage across the value chain as a function of both physical location and operating profile. Twelve representative applications were developed, each of which prescribed individual requirements and preferences.
3. Using these requirements and preferences, we matched each application with “best fit” technology options. Developing an understanding of the various technology options, including their capabilities, cost projections, and commercial availability timelines was also a necessary task during this phase.
4. We assessed the resultant application-technology pairs from feasibility and economic perspectives, developing a high-level assessment of each.

Figure 1: SCE Valuation Methodology



This methodology has the additional benefit of firmly reflecting SCE's core competencies, which include a deep understanding of electric systems and markets, as well as visibility to the entire grid from central generation to end user. The remainder of this report will expand in detail on these steps, eventually providing strategic conclusions and recommendations.

Step 1: Identifying Operational Uses

A major task of the SCE energy storage effort was to comprehensively identify the operational uses energy storage could potentially fill. *An operational use is a discrete single use for storage that can independently derive value.* These were not based on technological capabilities, but rather all the different functions energy storage (regardless of the technology utilized) might serve on the electric grid from central generation to end user. Once an exhaustive list of operational uses was created, they were bundled into practical applications through a process described later in this report.

In an attempt to populate an exhaustive list of operational uses, it was necessary to determine:

- what “fills the need” now (e.g., current solutions)
- a clear definition of the use
- potential issues with current solutions
- technical specifications of operational uses (e.g., high/low capacity and/or energy requirements)
- the time frame (duration) of charge/discharge periods required (e.g., seconds, minutes, hours)
- the length of time the solution will be needed (e.g., one season, two years, permanently)
- market considerations (e.g., CAISO regulations and/or product definition)

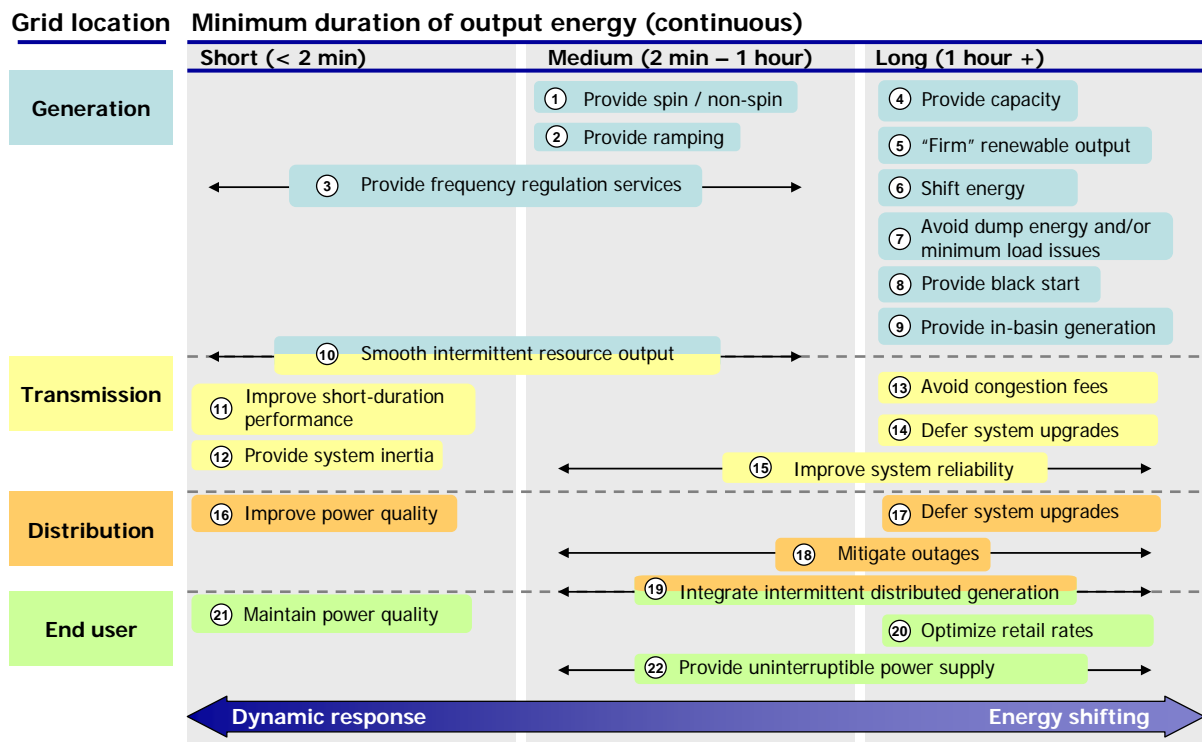
From this analysis, 22 discrete operational uses were identified and are shown below in Figure 2. Potential operational uses for energy storage systems are categorized by both location on the grid (e.g., generation, transmission, etc.) and the duration of output energy required. The location specified in Figure 2 is the location of the operational use, and not necessarily the location of the energy storage device. For example, the operational use "distribution system upgrade deferral" (#17), is a benefit located at the distribution level. In other words, the avoided cost is that of upgraded or additional distribution conduit or equipment. However, the energy storage device that provides this benefit may be located at one of many locations. For example, the device could replace a capacitor bank or other equipment at a distribution substation. On the other hand, a storage device located at a distributed generation (DG) solar installation (i.e., at the end user) could also avoid or defer a distribution circuit upgrade by limiting backflow from the DG system onto the electric grid. In this way, the storage location is not necessarily where a device is physically sited, but rather where the desired services are provided to the electric system.

The charge/discharge characteristics or requirements of an energy storage device are the other key parameters in defining and understanding potential operational uses. “Discharge duration” defines the period during which a storage device must be able to provide energy and capacity to the electric system. On one end of the spectrum of energy/capacity requirements are *dynamic response* uses, such as “power quality” (voltage support) (#21) and “renewable output smoothing” (#10). Dynamic response applications require quick reactions to a system event or signal. These uses involve short bursts of power to maintain system reliability and consistent operation. They are also

more easily compared to quick-response generation, used for ancillary services, or transmission / distribution equipment such as capacitors. On the other end of the spectrum are operational uses associated with *energy shifting*. These can be compared to today's demand response and time-of-use tariff programs that either shape load to lower system peak or lower the need for generation resources like “peaking” natural gas combustion turbines. Even before the full storage applications (groupings of operational uses) are defined, the diversity of potential uses for energy storage is clear. For example, it is not practical to make economic or technical comparisons of a device providing intermittent resource output smoothing (#10) and a device providing distribution system upgrade deferral (#17) in a meaningful way. This difficulty is a major driver for SCE's application-specific approach in which SCE sets up a framework to compare energy storage devices within a specific application.

Figure 2: Operational Use Location and Duration Matrix

POTENTIAL OPERATIONAL USES FOR STORAGE SYSTEMS



A description of each operational use (within SCE’s context) is provided below.

1. Spin / non-spin

An energy storage device could provide spin / non-spin products in California Independent Service Operator (CAISO) markets. These “operation reserves” ancillary services require ten minute response time when called, either while already operating (spin) or ready for fast response (non-spin). The CAISO currently procures 7% (split 50-50 between spin and non spin) of any given hour’s load in operating reserves, with

marginally lower procurement requirements if they are provided by hydro resources. Previously, participation in these separate hourly-bid markets required two hours of energy, although this is being altered to half an hour.

2. Ramping

While “ramping” is not currently a formal CAISO market product, initial research has indicated that it may be a potential service in the future, particularly to help with renewables integration. Ramping would provide a longer duration (15-30 minute) ancillary service to ensure daily ramping capabilities match load profiles.

3. Frequency regulation

Frequency regulation provides four-second Automatic Generation Control (AGC) adjustments to maintain a constant frequency on the grid (60 Hz in the U.S.). In contrast to other regions of the country, in the CAISO, regulation is two distinct services: reg-up and reg-down. While current rules and engineering requirements preclude storage from these markets, the CAISO has opened a stakeholder process to explore allowing for the participation of limited energy resources. As with all ancillary services, it is important to note that regulation markets procure capacity. Energy awards (or repayments) are settled from real-time interval prices as “called” by system dispatchers.

4. Capacity: Resource Adequacy and / or dependable operating

Currently, Resource Adequacy (a regulatory California Public Utilities Commission requirement to ensure generation system reliability) and dependable operating capacity needs are met by various generation resources. System load “super-peaks” (i.e., those requiring dispatch less than 5% of the year) are met today using traditional peak resource options, and in particular Combustion Turbine (CT) peakers and demand response (DR) measures. However, such peaks could also be met using an energy storage device, charged with off-peak energy, and discharged during peak hours.

5. Renewables output firming

Renewable energy sources currently do not provide full capacity to the electric system. As an increasing portion of SCE’s energy comes from variable / intermittent renewable generation, “firmed” capacity will become less available and future needs may even require new “dispatchable” generation to be built. Instead, an energy storage device could be paired with a renewable energy supply to provide firm capacity. For example, a large energy storage device could be charged using intermittent wind energy during off peak hours, when wind energy is more often produced in California. The device could then be discharged during peak hours, providing a firmed, dispatchable energy source.

6. Energy shifting

An energy storage device can shift energy demand from peak hours to off-peak periods, or conversely, shift energy supply from off-peak to peak hours. Specifically, a device could be charged using off-peak energy, and discharged to serve load during peak hours, thereby arbitraging between peak and off-peak energy prices. This “arbitrage” might also occur during other periods, such as in Real Time markets between sub-hour intervals.

7. Dump energy / minimum load issues

As must-take resources (particularly those producing energy during off-peak hours such as wind turbines) grow in proportion to other resources in SCE's energy portfolio, dump energy and / or minimum load issues may become a challenge for the system. These problems occur when the system is producing more must-take energy than the load requires. One such example might be during off-peak hours in April when electricity demand is low, yet there are large amounts of must-take hydro and wind generation. In this case, the system may have excess energy. Either the energy will have to be "dumped," (i.e., sold at a negative price) or operational issues may arise on the grid. Energy storage devices could absorb excess energy through charging, making it available to meet system load at another time when it is needed.

8. Black start

Resources such as hydroelectric generators exist today that can start without electric energy input when a system event occurs and the grid goes black. An energy storage device could also fulfill this need. The benefit from this operational use is difficult to monetize, as current resources providing black start are not explicitly compensated for this service in California. The "black start capability" is one of many attributes considered when selecting a generation resource through contractual procurement.

9. "In-basin" (or local) generation

Generation located close to load is required to provide system reliability. In SCE's case, this means a substantial amount of generation must be sited in the Los Angeles basin. As a rule-of-thumb, SCE's system planners and the ISO in real-time ensure that approximately 40% of load is met by in-basin resources, and the remaining 60% of needed energy can be imported. Therefore, the aggregate capacity of in-basin resources must exceed 40% of peak load in order to fulfill this requirement. This poses a particular challenge for SCE, given the stringent air quality requirements in urban areas and difficulty of building new conventional power plants. However, energy storage could serve the same operational use as a "local" generation resource such as a CT. The energy storage device (or many energy storage devices, distributed across the load center) could be charged off-peak, using imported energy, and discharged during peak hours. During the discharge period, the energy provided from the energy storage devices would count as peak period "in-basin" generation.

10. Renewables output smoothing

Many sources of renewable energy provide power intermittently on a minute-to-minute basis. For example, if a cloud overhead shields an array of photovoltaic panels from the sun for 2 minutes, the energy output of that array drops during that time. Once the cloud passes, the array may be back to full production. Such minute-to-minute variability can have negative effects on the system (e.g., transmission and distribution loading and voltage fluctuations, etc.). An energy storage device / system can react to PV output and respond instantaneously to drops in production by discharging its own energy. Similarly, it could soften the increase in energy production after a cloud passes over, by charging the device. Such "smoothing" of these short-duration fluctuations could lessen the

potential operational challenges associated with integrating large amounts of intermittent, must-take renewable energy into the electric grid.

11. Transmission system short-duration performance

Energy storage, if installed in large enough quantities, could be used to improve short-duration performance on the transmission system. This includes improving system voltage or providing capacity (fault duty) during system faults. The clearest way in which energy storage could perform this operational use is if it were to replace a device that currently improves transmission system performance (e.g., capacitor banks or Flexible AC Transmission System (FACTS) devices). If a storage device can be shown to provide one or more useful transmission services, the device could be included in a transmission planner's toolkit, and taken into consideration in the transmission planning process. Another way in which a storage device could perform this operational use is by preventing an issue causing problems on the transmission grid. For example, if extremely variable wind production was causing transmission system performance issues, and a large energy storage device firmed or smoothed this energy, it could be simultaneously providing the renewable energy smoothing / firming use while also improving transmission system performance.

12. System inertia

System inertia is provided today by large, conventional generation resources. The "spinning mass" of these devices can provide large amounts of power to the grid instantaneously in the case of a system reliability event. While storage would not do this exactly, the power electronics associated with a device could be designed such that they *simulate* system inertia by quickly discharging power onto the grid, if and when required.

13. Congestion fee avoidance

When a transmission line is congested, higher "fees" are incurred when transmitting energy. Avoiding such congestion would therefore circumvent these costs. Using an energy storage device to time-shift energy demand or supply, by transporting energy during off-peak hours and storing that energy downstream of the transmission line, would avoid such congestion and associated fees.

14. Transmission system upgrade deferral

When a transmission line or component is consistently overloaded, an infrastructure upgrade may be required. An energy storage device could be used to time-shift energy demand / supply (as per use #13, above) to avoid such problematic transmission congestion. The upgrade could be deferred until additional load growth ultimately necessitates the infrastructure improvement or if load requirements for that transmission path remain stable, energy storage could defer the upgrade more permanently.

15. Transmission system reliability

An energy storage device could be used to improve the reliability of the transmission grid in two ways. First, the energy storage device could replace a technology solution that currently improves system reliability (e.g., a Static VAR Compensator). As explained in use #11, if a storage device can be shown to provide one or more useful transmission

services, it could be included as a potential solution in the transmission planning process. Another way in which an energy storage device could improve system reliability is if it were located downstream (on the load side) of a system component outage. For example, if a transmission line had a planned or unplanned outage and a large energy storage device downstream of it were available to discharge its energy during the outage, customers could continue to have electric service during that period. It should be noted that such a use of energy storage would require a device with an extremely large energy capacity. Further, it should be noted that most energy storage systems are not designed for isolated or “islanded” operation, so another tie with the main system would need to be maintained to take advantage of the excess capacity/energy that may be provided.

16. Distribution system power quality

The clearest way in which energy storage could perform this operational use is if it were to replace a device that currently regulates distribution system voltage (e.g., capacitors or voltage regulators). If a storage device can be shown to improve the loading, power factor, and/or voltage profile for a distribution system, the device could be included in the distribution planner’s toolkit.

17. Distribution system upgrade deferral

When a distribution circuit is consistently overloaded, an infrastructure upgrade may be required. However, an energy storage device could be used to time-shift energy demand or supply (as per uses #13 and #14, above) in order to avoid these distribution line overloads. If these overloads can be avoided, the upgrade could be deferred until additional load growth necessitates infrastructure improvement or until aging infrastructure requires replacement.

18. Distribution-level outage mitigation

In order to provide outage mitigation at the distribution level, the storage device would have to be located downstream of a system outage. For example, if a distribution line had a planned or unplanned outage, and an energy storage device downstream (on the load side) of that outage were available for discharge, customers could continue to have electric service during the outage if an alternate “tie” can also be maintained with the source system. (Energy storage devices are not currently designed for islanded or isolated operation.) For planned outages, a mobile energy storage device placed in key locations to support the load and mitigate the impacts on customers could fill the need.

19. Distributed Generation (DG) renewable integration

Renewable DG penetrations (in particular solar photovoltaic (PV) generation) are projected to steadily increase across SCE’s service territory. SCE has also begun development of 500 MWs of DG solar, an initiative approved by the CPUC in 2009. One of the challenges with non-dispatchable DG, like solar PV, is that it may create “backflow” onto the distribution grid. The grid was designed and built for power to flow in one direction: from the transmission system to the customer. However, in many instances, a DG installation may “push” electricity upstream and away from the customer. While current SCE distribution system planning protocols state that 15% backflow on the distribution grid at any given time may be acceptable, further study is

required to understand the exact limitations of individual circuits beyond this limit. An energy storage device, located adjacent to the DG installation, could minimize potential issues or avoid them altogether. At times when the generation at the site exceeds power consumption, the storage device could be charged using the energy that would have otherwise flowed back onto the grid. When consumption exceeds generation at a later time (e.g., at night when the PV installation is not producing energy), the storage device would be discharged to meet demand. If the DG installation is substantially larger than the site, an energy storage device could be located further upstream in the distribution system. While substantial backflow (and related circuit upgrades) downstream of the device could not be avoided, it would eliminate the need for upgrades upstream of its location.

20. Retail rate optimization

Like many utilities, SCE has several programs that pay customers to turn off their loads during system peaks (e.g. SCE's air-conditioning cycling and industrial demand bidding programs). SCE also has TOU rate structures for certain customers that discourage on-peak energy use with higher prices. While participation in these programs is strong, it is limited by customers' willingness to be inconvenienced by DR / TOU rate program requirements and costs (e.g., customers must agree to not use an air conditioner during a hot summer day with a high system peak). If an energy storage device were located at the customer's home or business, the customer could take advantage of a DR program or TOU rates without changing their behavior. The system would see the load drop off as required, but the customer would in fact be temporarily serving his/her own load, using a charged energy storage device, rather than system generation.

21. Power quality maintenance

Certain electric customers require a level of power quality above and beyond what the system offers (e.g., critical load). In order to meet this need, these customers often invest in their own power conditioning and energy storage systems. Many already have employed energy storage technologies such as batteries and flywheels to fill this need.

22. Uninterruptible power supply

As in use #21, some customers (e.g., advanced manufacturers or technology companies) cannot tolerate interruptions in their power supply. In order to ensure uninterrupted power, these customers often invest in back-up generators (e.g., diesel generators) and quick-response technologies to buffer between a system event and the startup of a back-up generator. Energy storage technologies with integrated battery bank systems and flywheels already fill this need for many customers.

Each operational use provides a quantifiable value that can be used to perform further calculations. For each of the 22 benefits identified, Figure 3 summarizes the value metrics and continuing uncertainties (non-engineering related) that are associated with monetizing those potential benefit streams. For the purposes of further application analyses, many of the uncertainties had to be resolved through assumptions, which are described in further detail as part of Appendix A. The circumstances surrounding these operational uses will also vary by application.

Figure 3: SCE's Value Metrics for Operational Uses

Operational Use	Value Metric	Value Metric Uncertainty
1 Spin / non-spin	Hourly capacity prices for operating reserves	Rules around storage's participation in CAISO ancillary service markets are not yet determined
2 Ramping	No products currently available	Product not yet defined in CAISO region
3 Regulation up & regulation down	Hourly regulation up / regulation down capacity prices for frequency regulation	Rules around storage's participation in CAISO ancillary service markets are not yet determined
4 Resource Adequacy / dependable operating capacity	Avoided cost of generation capacity, from purchasing existing capacity or in later years building a new combustion turbine	Rules under which a storage device may qualify for RA are yet to be determined (and will vary based on different applications as well)
5 Renewable output firming	Specific renewable integration costs attributed to "firming" different variable energy sources	Integration costs and associated markets / rules are not yet fully developed or understood in future scenarios
6 Energy shifting - arbitrage	Price differential between charging off peak and discharging on peak less efficiency losses	Market liquidity impacts (see Appendix B)
7 Dump energy / minimum load operational issues	Price differential between charging off peak and discharging on peak less efficiency losses during effected periods	Potential contract negotiations around economic curtailment of "must-take" energy could mitigate potential storage benefits
8 Black start	Either 1) estimated premium paid for generation black start or 2) avoided cost of black start transmission infrastructure	N/A
9 In-basin generation	Operational flexibility and potentially the premium of procuring in-basin generation, comparable to an in-basin CT	Future difficulty of siting and licensing in-basin generation (e.g., obtaining emissions permits)
10 Intermittent energy smoothing	Specific renewable integration costs attributed to time specific "energy smoothing" services or generation projects	Integration costs and associated markets / rules are not yet fully developed or understood in future scenarios
11 Short duration performance	Avoided / deferred cost of additional infrastructure to address a problem	N/A
12 Inertia	Avoided / deferred cost of additional infrastructure to address a problem	Future system planning questions with anticipated in-basin once-through-cooling plant shut-downs
13 System reliability	Avoided / deferred cost of additional infrastructure to address a problem	N/A
14 Congestion fee avoidance	Transmission congestion fees avoided	N/A
15 Transmission upgrade deferral	Avoided / deferred cost of additional infrastructure to address a problem	N/A
16 Power quality	Avoided / deferred cost of additional infrastructure to address a problem	N/A
17 Distribution upgrade deferral	Avoided / deferred cost of additional peak infrastructure	N/A
18 Outage mitigation	Reliability / customer satisfaction / potential cost of substituting technology	N/A
19 Intermittent DG integration	Avoided / deferred cost of distribution upgrades or additional infrastructure to address a specific problem	N/A
20 Retail rate optimization	Rate differential between on-to-off peak TOU pricing and / or demand charge payment avoidance	Requires full deployment of smart metrology and associated time-of-use rate options
21 Power quality	End user value proposition or cost of an alternate back-up power system	N/A
22 Uninterruptible power supply	End user value proposition or cost of back-up power system or convenience / reliability benefits for selective customers	N/A

Step 2: Developing Applications

Having identified and defined 22 discrete operational uses and their associated value metrics, the next step is to bundle these uses into separate applications. *SCE defines an energy storage application as the combination of distinct operational uses a storage system might provide when sited at a specific place and managed in a particular way.* Four key questions were addressed when developing practical applications:

- How would a storage device performing this application be operated (e.g., charge several hours off-peak, discharge several hours on-peak; or charge / discharge numerous times during an hour)?
- Where would a storage device performing this application be physically located on the electric system (e.g., at a central generator or in an end user's residence)? See Figure 4 for a simplified pictorial representation of the electric value chain.
- What are the primary operational uses driving this application?
- What other operational use(s) could accrue for this application, depending on specific grid situations, the external environment, and/or owner operating preferences?

These questions helped assess how storage can be practically used to simultaneously provide a wide variety of benefits. Additionally, the values associated with each individual operational use vary depending on their synergistic interactions within the application. As such, SCE does not value each individual use separately, but only in the context of a specific application's operating profile and grid location.

In total, twelve practical applications were developed. These were created through collaboration with subject matter experts across SCE and, while not intended to be all encompassing, were felt by the overall team to be representative across the electric value chain. Descriptions of these applications are provided in Figure 5, with a more detailed mapping of the operational uses supplied in Figure 6.

Figure 4: Simplified Visual Representation of the Electric Value Chain

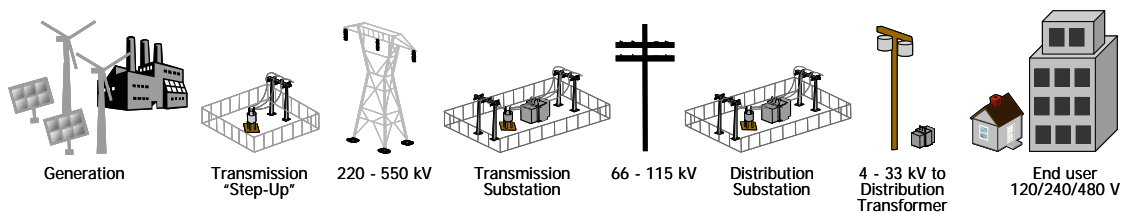


Figure 5: Application Descriptions

Application	Description
1 Off-to-on peak intermittent energy shifting & firming	Charge at the site of off-peak renewable and / or intermittent energy sources; discharge “firmed” energy onto grid during on-peak periods.
2 On-peak intermittent energy smoothing & shaping	Charge / discharge seconds-to-minutes to smooth intermittent generation, and / or charge / discharge minutes-to-hours to shape energy profile.
3 Ancillary service provision	Provide ancillary service capacity in day-ahead markets and respond to ISO signaling in real time.
4 Black start provision	Unit sits fully charged, discharging when black start capability is required.
5 Transmission infrastructure	Use an energy storage device to defer upgrades or other technology on the transmission system.
6 Distribution infrastructure	Use an energy storage device to defer upgrades or other technology on the distribution system.
7 Transportable distribution-level overload mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short-term distribution overload situations.
8 Peak load shifting downstream of distribution system	Charge device during off-peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peak period.
9 Variable distributed generation integration	Charge / discharge device to balance local energy use with generation. Sited between the distributed generation & distribution grid to defer otherwise necessary distribution infrastructure upgrades.
10 End user time-of-use rate optimization	Charge device when retail time-of-use prices are low, discharge when high (and / or to avoid demand response curtailment periods / charges).
11 Uninterruptible power supply	End user deploys energy storage to improve power quality and / or provide back-up power during outages.
12 Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid.

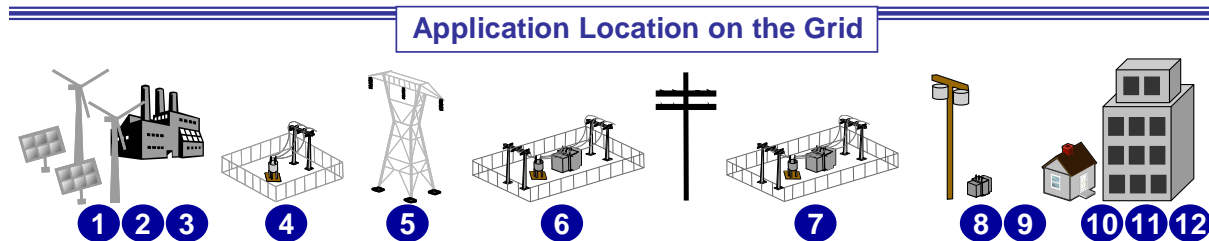


Figure 6: Operational Uses and Applications

Application #:	1	2	3	4	5	6	7	8	9	10	11	12
Operational uses	Off-to-on peak energy firming (G)	On-peak energy smoothing (G)	Ancillary services (G)	Black start (G or T)	Infra-structure improvement (T)	Infra-structure improvement (D)	Transportable storage (D)	Peak shaving (D)	Intermittent DG integration (D or E)	TOU rate optimization (E)	UPS (E)	End user micro-grid (E)
Spin / non spin	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>									
Ramping	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>									
Reg up / reg down	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>									
Resource adequacy / dependable operating capacity	<input checked="" type="checkbox"/>							<input checked="" type="checkbox"/>				
Renewable output firming	<input checked="" type="checkbox"/>											
Energy shifting - arbitrage	<input checked="" type="checkbox"/>						<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>				
Avoid dump energy / minimum load issues												
Black start				<input checked="" type="checkbox"/>								
In-basin generation												
Intermittent energy smoothing	<input checked="" type="checkbox"/>											
Short duration performance												
Inertia												
Congestion fee avoidance												
Upgrade deferral												
System reliability												
Power quality												
Upgrade deferral												
Outage mitigation												
Intermittent DG integration												
Customer rate optimization / DR												
Power quality												
Back-up power												

<input checked="" type="checkbox"/> Generation (G)	<input checked="" type="checkbox"/> Transmission (T)	<input checked="" type="checkbox"/> Distribution (D)	<input checked="" type="checkbox"/> End user (E)	<input checked="" type="checkbox"/> Primary drivers	<input checked="" type="checkbox"/> Other potential uses
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Of these twelve identified applications, only eight were selected for further analysis. The four applications which were not selected and the respective reasons for stopping further evaluation are the following:

- **Application 4:** Black start – This is a niche application with no current explicit market valuation in California. The requirements of a black start unit are highly situation specific. Furthermore, black start units must be ready over their entire lifespan, waiting for an event which hopefully will never happen. Less expensive alternatives also exist.
- **Application 5:** Infrastructure improvement (transmission) – This application uses a storage device to replace / upgrade a specific component in the transmission system and thus may need a more nuanced evaluation than traditional transmission infrastructure. Furthermore, many of these specific upgrades are currently addressed with proven (often lower tech) solutions and lower cost components. An accurate valuation would need to be highly situation specific. Nevertheless, transmission planners should note that energy storage devices may provide more options for their “toolbox.”
- **Application 6:** Infrastructure development (distribution) – Similar to application 5, application 6 uses a storage device to replace / upgrade a specific component in the distribution system which requires a more nuanced approach. Likewise, distribution planners should note that storage may be an option in their “toolbox.”
- **Application 11:** Uninterruptible Power Supply (UPS) – This is a niche application for specific end users who require greater reliability and / or power quality. While SCE has an obligation to serve within certain distribution guidelines, anything above and beyond would be the responsibility of individual customers. Furthermore, lead acid batteries and flywheels have been in this market segment for decades.

While all applications are described in further detail later in this paper, the remaining eight applications are also matched to specific technologies, developing the framework for analyzing the benefits and costs of energy storage. The below discussion provides an introduction to several energy storage technology options.

Step 3: Matching Applications with Technology Options

Before assessing applications, SCE conducted a technology review. While some technologies are now commercially available, others are in the development and testing phase, and still others are in their research infancy. Across the board, however, energy storage solutions are undergoing rapid development. SCE employs a technology-neutral perspective when determining the potential uses of energy storage. This said, each technology option had to be researched in order to perform the benefit-cost analyses which fully assess the potential desirability of energy storage on the electric grid. The technologies listed below are matched to applications based on their respective preferences as discussed in this section.

SCE researched 13 energy storage technologies by soliciting internal expert information as well as by conducting interviews with numerous external storage developers. Based on this review, SCE arrived at six broad conclusions:

- *Many technologies are approaching commercial availability.* These have been tested for viability, are actively looking for partnerships, and are beginning to sign substantial contracts with customers.
- *Energy storage companies are actively targeting the utility storage market* and have established strong external support and momentum. Storage companies are developing internal knowledge about utility interests and priorities and are providing more sophisticated value propositions for their products.
- *The vast majority of energy storage products are not in direct competition with one another,* due to different power-to-energy ratios, cycling capabilities, and other attributes (see the technology comparison sidebar).

Technology Comparison Sidebar: “Race Cars and Tractors”

There is a natural tendency to want to compare the various storage technologies across common metrics: power-to-energy ratio, cost per kW, cycle life, etc. The “technology comparison matrix” is indeed a staple chart in many reports on storage. SCE has found, however, that such comparisons are misleading, which is explained by the following analogy.

One could theoretically weigh race cars and tractors against one another under the broad heading of “transportation technologies.” Horsepower, engine torque, cost, seconds from 0-60 mph, consumer satisfaction, reliability ratings, etc. could all be contrasted. Except such an exercise does not recognize the totally different purposes for which each technology exists. Few customers are going to be interested in comparing a tractor to a race car.

A potential consumer must first decide “do I want to go really fast, or do I want to plow a field with my transportation technology?” Only when the relevant *application* has been identified and defined does it make sense to balance technology options and their specifications.

While somewhat simplified, the same idea applies to storage. Juxtaposing pumped hydro with flywheels or lithium ion batteries is of little use unless this occurs with application requirements in mind. As such, this report identifies “best fit” technologies and compares their qualities only in the context of an acknowledged application.

- *While many technologies have been demonstrated from developers' perspectives, the grid "operational uses" of each have yet to be conclusively established. Results of current tests and pilot projects will help push technologies toward commercial viability for electric utility investment.*
- *It is still unclear if storage can be cost-competitive with conventional solutions for energy related challenges. While many companies are predicting steep downward cost curves due to increases in manufacturing volume, cost reduction paths are as of yet unproven.*
- *SCE maintains some concern related to the nascent "start-up" status of many energy storage companies; partnering with younger, less established companies may have higher risk. In addition, many companies' manufacturing capabilities are unproven, and this may hinder plans for rapid expansion even if the technology is scientifically ready.*

The purpose of SCE's technology assessment was not to determine which technologies are normatively better, nor to pick "winners" and "losers." Nor does this list encompass all storage technologies (e.g., Liquid Air Energy Storage is absent), some of which could be promising. For the purposes of simplification, other "storage-like" technologies, such as super-critical water heaters, were also considered out of scope. The goal of this examination, instead, was to understand a representative set of technologies at a deep enough level to determine how they might align with applications. It should be noted again that this report focused on the electric grid and the determining of potential operational uses and applications for energy storage, not in assessing or hypothesizing about developing technologies. SCE simply sought to understand each technology, its current commercial availability, and how it might match with applications and their preferences. The results of this effort are provided below.

Lithium ion battery

This storage technology is a type of rechargeable battery. The device charges when lithium ions move from a negative electrode to a positive electrode and discharges by the movement of ions in the reverse direction. Numerous different chemistries make up the family of lithium ion batteries, including but not limited to lithium iron-phosphate, lithium manganese-spinel, and nickel-manganese-cobalt. Lithium ion batteries have a range of power-to-energy ratios depending on the chemistry and specific design of the battery system. Compared to other electrochemical energy storage technologies, lithium ion batteries are energy and power dense. Due to their smaller size and low operating and maintenance needs, the obstacles to implementation are limited. Lithium ion batteries are already commercially available for use in personal electronics and various other applications and are nearing commercial availability for widespread use on the electric grid. They are also the focus of several utility-scale pilot programs across the country.

Advanced lead acid battery:

This storage technology is a type of rechargeable battery. One specific type of an advanced lead acid battery is the valve-regulated lead-acid battery (VRLA), a technology

that is largely maintenance-free. Manufacturers claim that these advanced batteries have an improved performance and cycle life over conventional lead-acid batteries, reducing one of the major limitations of this technology. Power-to-energy ratios for advanced lead batteries can be configured to match a utility's specific needs. While advanced lead acid batteries show promise in providing an economical solution for energy storage applications, tests proving their usability on the electric system are limited. Furthermore, advanced lead-acid batteries for utility applications are approaching commercial availability.

Sodium sulfur (NaS) battery:

This storage technology is a type of rechargeable battery. Sodium sulfur batteries are charged by high temperature electrochemical reactions between sodium and molten sulfur. The battery operates at 300°C, and can be cooled to ambient temperature fewer than 10 times over its life-span. These batteries have lower power-to-energy ratios (e.g., a 6 MWh battery system can be discharged at the 1 MW rate over six hours). While there is industry disagreement on the O&M needs of this technology, some users reported O&M complications and complex installation procedures. Sodium sulfur batteries are the most commercially advanced large-scale electric energy storage technology today, but they are only produced by one company.

Sodium metal halide battery:

This storage technology is a type of rechargeable battery. Sodium metal halide batteries are charged by moving sodium ions released from chemical conversion of sodium chloride to nickel chloride. Sodium metal halide batteries are similar to sodium sulfur batteries in that they operate at high temperatures (300 C degrees). In contrast, however, sodium metal halide batteries have inherent overcharge capabilities and lower operation temperatures. Also unlike sodium sulfur, they may have a flexible power-to-energy ratio and can be cooled to ambient temperature without component damage. However, sodium metal halide batteries are still in a limited production stage and are not yet fully commercially available for utility application.

Flow battery:

This group of storage technologies provides types of rechargeable batteries. In a flow battery, an electrolyte flows through an electrochemical cell to convert chemical (stored) energy into electricity during discharge. This is then reversed during the charge cycle. Common chemistry examples include vanadium redox and zinc-bromine mixtures. The liquid electrolyte used for charge-discharge reactions is stored externally and pumped through the cell. This allows the energy capacity of the battery to be increased at a moderate cost. This feature also means that energy and power are decoupled, since energy content is based on the amount of electrolyte stored in the device. Flow batteries are typically large facilities with many components (e.g., pumps, tanks, pipes) that may present some operational and maintenance challenges, though developers are currently working to limit these issues. While flow batteries have been tested on electric grids in several pilot programs, the technology is not yet fully commercially developed.

Metal air battery:

This storage technology is a type of battery. In this battery, a metal (for example zinc) acts as the anode and the outside air acts as the cathode. Using the oxygen in the air greatly increases the energy capacity of this type of battery compared with alternative chemistries. Current applications of this technology, such as in earphones, exist for un-rechargeable versions. There is, however, difficulty creating a rechargeable design, due to the formation of dendrites, which cause malfunctions after only a few cycles. Additional problems may also arise from the evaporation of the electrolyte, which reduces battery life. Some companies have claimed to have solved these problems. While rechargeable metal air batteries have the potential to be lower-power, long-duration energy storage devices, they are currently commercially unavailable for utility application.

Flywheel:

Flywheels are charged by storing mechanical energy in a large rotating mass inside a friction-less container. The mass increases in velocity when charging, and decreases in velocity when discharging. Flywheels are high-power, low-energy devices, and usually can provide seconds-to-minutes of discharge energy. Given proper maintenance, they can be charged and discharged hundreds of thousands of times over their lifespan with very high reaction times. For high-power, short-duration energy storage applications, flywheels are a commercially available option.

Thermal storage – Ice:

Ice storage works in conjunction with existing heating, ventilating and air conditioning systems (HVAC) to provide cooling while minimizing on-peak power usage. The system uses grid electricity to freeze water to ice off-peak, and the unit uses the ice to cool refrigerant on-peak (thus limiting on-peak energy use). Ice storage is currently being retailed to the broader marketplace and is commercially available for utility applications.

Thermal storage – Solar thermal:

Like ice storage, solar thermal storage also works in conjunction with other systems and is not “stand-alone.” Solar thermal storage is “charged” by heating a salt medium using solar collectors, which is used later to run a steam-generator. This technology essentially modifies a solar-thermal generator to create a mostly dispatchable resource. However, it is potentially limited by overall energy availability (i.e., energy cannot be stored if there is limited sun for one or more days and thus the system may no longer be available for dispatch). Solar thermal storage is not yet completely commercially realized for utility application, although numerous concepts and developers are offering projects.

Compressed Air Energy Storage (CAES):

This technology uses energy to compress air under or above ground. Traditional CAES uses air from the storage reserve in conjunction with a gas fired turbine. Adiabatic CAES, on the other hand, does not require separate natural gas input and does not produce incremental carbon emissions, beyond that of the energy with which it is charged (and efficiency losses). While there are no utility-scale Adiabatic CAES plants today, there are utility-scale traditional CAES plants (e.g., a 110 MW plant in McIntosh, Alabama). Siting and licensing for CAES units poses challenges to its commercial viability. Current

studies evaluating potential use of salt domes and porous rock structures for CAES plants should provide additional insight into siting challenges and strategies to overcome them. Currently, CAES has limited demonstrated commercial availability and a long project development cycle for utility applications.

Pumped hydro:

Pumped hydro facilities store potential energy by pumping water uphill into a reservoir, discharging energy by releasing water through a hydroelectric generator at a lower elevation. It can provide 10-100 hours of output energy, at several hundred MWs of rated power. However, pumped hydro installations face major siting and licensing challenges, particularly in regions with strict water and environmental regulations (e.g., California). Pumped hydro is the most commercially available bulk energy storage solution today, although it also usually requires longer project development cycles.

Super capacitor:

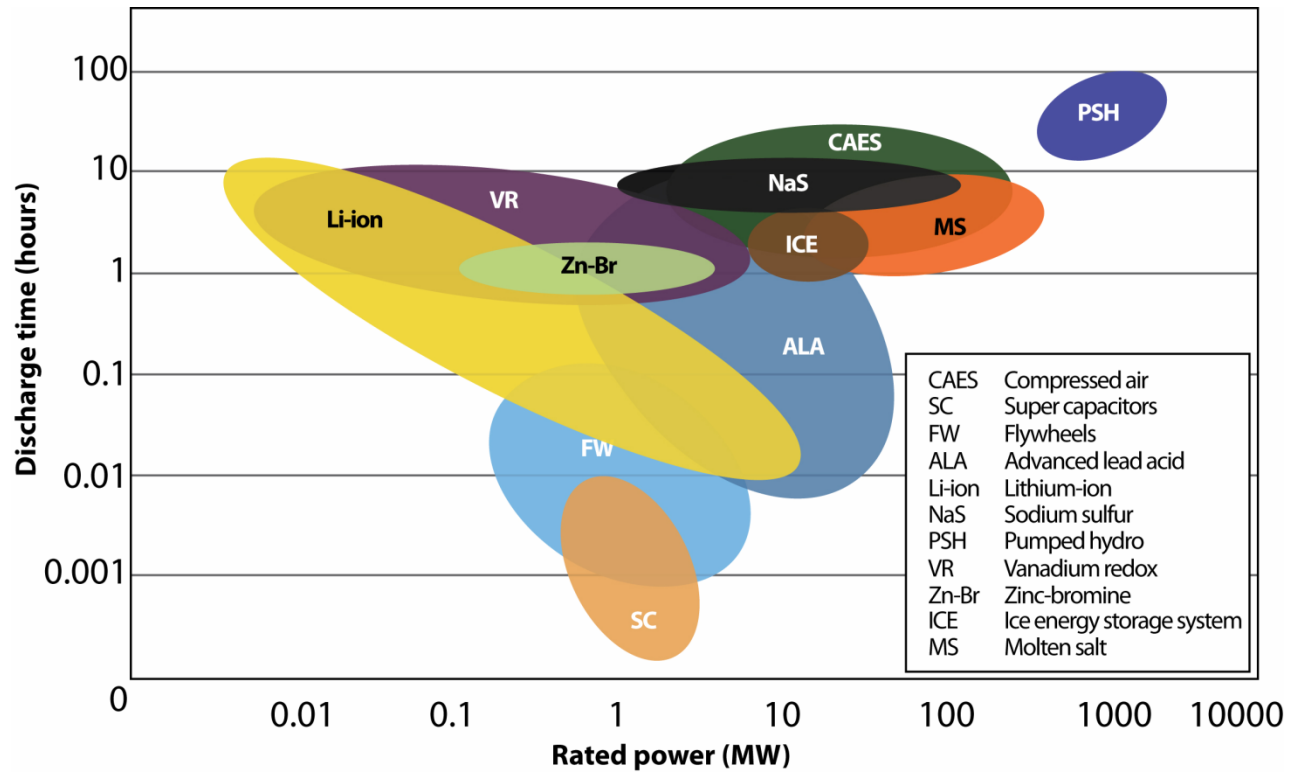
This device consists of an electrochemical double-layer capacitor which stores energy in the form of separated electrical charge. In general, super capacitors improve storage density through the use of a nano-porous material like activated charcoal. Super capacitors can provide high-power, low-energy storage, but are not currently at or near commercial viability and therefore are not considered potential near-term solutions for SCE's applications.

Superconducting Magnetic Energy Storage (SMES):

This device stores energy in a magnetic field created by the flow of direct current in a coil of cryogenically cooled, superconducting material. SMES can provide high-power, low-energy storage. However, this technology is not at or near commercial availability and therefore is not considered a potential near-term solution for SCE's applications.

The differences in rated power and energy discharge duration for the various technologies are outlined in Figure 7. The reader should note that the axes of the chart are exponential. These parameters, along with the technology characteristics discussed above, help define the relevant application(s) for each technology.

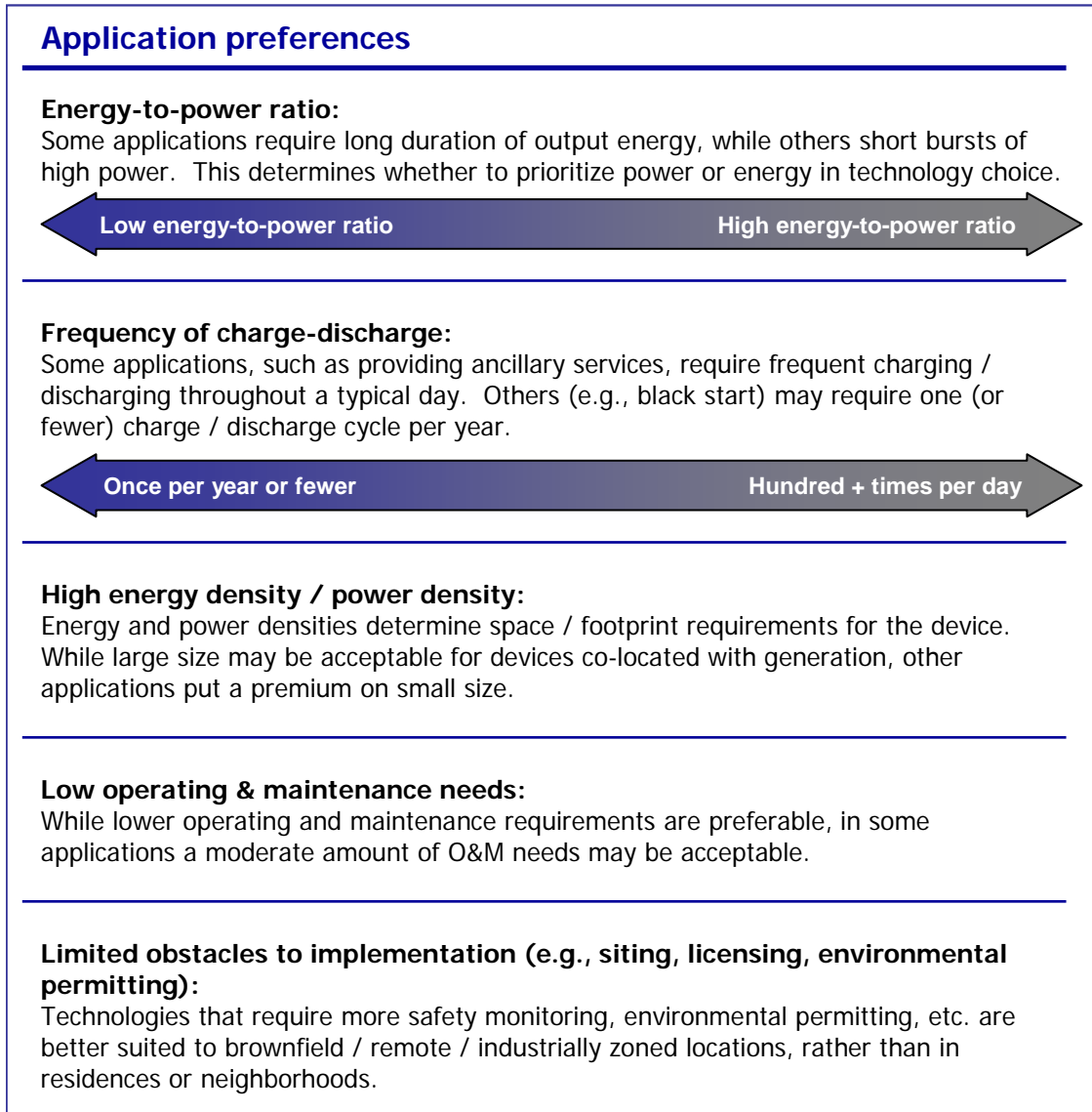
Figure 7: Technology Comparison of Rated Power vs. Discharge Time



Source: Adapted from the Energy Storage Association

Understanding the specifications of the various diverse technologies, “best-fit” options can be matched by developing application preferences. *Application preferences are defined as the characteristics required for optimal operation of the storage device in each specific application.* Five application preferences were identified: two non-normative and three normative. The non-normative preferences include the energy-to-power ratio and the required frequency of charge-discharge. Technologies not meeting these requirements are not well suited for an application. The three normative preferences include high energy or power density, low operating and maintenance needs, and limited obstacles to implementations. While these preferences are all desired, applications have varying tolerances to exact specifications. Descriptions of these application preferences are found in Figure 8 below.

Figure 8: Application Preferences



Given completed application-technology pairs and their associated benefits and costs, SCE was able to develop “pathways to cost-effectiveness.” The value metrics assigned to each bundled set of operational uses provide the benefits while technology expenditure estimates provide the costs. Pathways to cost-effectiveness use industry forecasts where available to identify scenarios that would yield benefit-cost ratios greater than one. In some cases, extreme changes (e.g., significant technology cost drops) are prerequisite for cost-effectiveness. It is important to note that while SCE used the best available industry knowledge to develop these scenarios, the pathways identified for each application-technology pair do not represent an exclusive set of conditions that must be met to reach cost-effectiveness.

The next section will evaluate each application-technology pair in more detail.

Step 4: Evaluating Applications

Application 1: *Off-to-on peak intermittent energy shifting and firming at or near generation*

In this application, the storage device is located at or near the generation site. The generation associated with the device is a renewable and/or intermittent energy source which primarily produces off-peak (e.g., wind energy).¹⁸ This application uses the volatile intermittent energy profile to charge a storage device during off-peak hours, and provides firming, on-peak energy to the system. Co-locating the energy storage device with generation also reduces the potential negative impacts of variable/unpredictable energy on the grid, including but not limited to: frequency issues, additional need for ramping services, and the lack of dependable operating capacity.

The primary operational use drivers for this application and their corresponding value metrics are:

1. *Resource Adequacy (RA) and dependable operating capacity (#4)* – Intermittent renewable energy cannot provide its nameplate capacity for RA and / or dependable operating capacity to the grid. However, by firming energy via a storage device, the energy produced from intermittent sources can provide dependable capacity and RA. Benefits consist of the avoided cost of either generation capacity procurement or the estimated deferred cost of building new peaking units.
2. *Intermittent energy firming (#5)* – Intermittent energy is used to charge a storage device. Once charged, the device can discharge reliably, providing consistent, dispatchable energy. The benefits are calculated by avoiding intermittent energy integration costs and premiums associated with firming renewable generation.
3. *Energy shifting / wholesale price arbitrage (#6)* – Less valuable intermittent off-peak energy can be stored and sold at higher on-peak prices. Benefits are calculated as the price differential between charge and discharge, minus any efficiency losses. The reader should note, however, that the on-off peak spread (and therefore, arbitrage opportunities) will likely decrease with increasing energy storage penetration.
4. *Renewables output smoothing (#10)* – Although this application does not literally perform the “smoothing” operational use, it provides this benefit by providing a firming energy product, as per drivers 1 and 2, above. The “firming” capacity provided in this application also smoothes the output of otherwise variable off-peak renewable generation.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Avoid dump energy / minimum load issues (#7)* – When must-take energy supply exceeds demand, as may occur during off-peak periods on a system with high

¹⁸ This application may also be conceived of without the intermittent generation, which is to say storage coupled with a base load or “non-dispatchable” resource. In this case, the valuation is very similar, except the renewables integration benefit streams (numbers 2 and 4 above) would be subtracted.

- renewable penetration, a storage device can be charged to avoid “dump energy”. These benefits may be captured through the price differential between charge and discharge, less associated efficiency losses.
2. *Transmission short duration performance improvement (#11)* – By placing the storage device at or near the generation system, the resultant “smoothed” energy provided to the transmission system may improve voltage, frequency, and/or fault duty compared with the unmitigated intermittent output. Benefits are calculated as the avoided cost of deferred or replaced infrastructure.
 3. *Transmission system reliability (#15)* – If the intermittent nature of the renewable generation creates transmission system reliability problems, removing such intermittency addresses these issues. Benefits consist of the avoided / deferred costs of infrastructure.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

- *High energy-to-power ratio:* Requires energy output over several hour durations.
- *Moderate frequency of charge-discharge:* Requires one daily charge-discharge cycle.
- *Low energy density / power density:* Physical space is not usually a concern for generation-type projects, so high density is not required. However, there may be some location-specific exceptions (e.g., a generation site with space constraints.)
- *Does not require low operating and maintenance (O&M):* While lower O&M needs are always preferable, the technology selected for this application can have some O&M requirements. Due to the co-location of the storage device with generation, staff from the generation site would likely be available to perform such monitoring / maintenance requirements.
- *Limited obstacles to implementation:* Implementation obstacles are always undesirable and therefore avoided in ideal situations. However, complex implementation needs for a storage device are less likely to pose a major challenge, as the device would be a “brown-field” development co-located with renewable generation developments.

To provide this application for a commercial wind farm, the energy storage device would likely be sized between 20 and 100+ MW. Such a MW requirement is not out of the range of what is commercially available from chemical energy storage on the small end of the scale (e.g., sodium sulfur batteries) and “bulk” storage at the large end of the scale (e.g., pumped hydro and CAES). It was assumed that six or more hours of daily energy discharge would be required to effectively shift meaningful amounts of off-peak production to meet on-peak demand. Thus, the storage device could provide up to 120 – 600+ MWh of energy during each discharge cycle. As discussed above, a facility on the higher end of the MW range would favor the use of CAES and pumped hydro, while a smaller facility would likely favor “high energy” batteries. The two figures below (figures 9 and 10) are a summary of our evaluation of the cost-effectiveness of these two different technologies for this application.

Figure 9: Benefit / Cost Analysis for Application 1 & Large Hydro

APPLICATION 1a BENEFIT/COST SUMMARY

Off-to-on peak intermittent energy shifting & firming at or near generation 300 MW pumped hydro

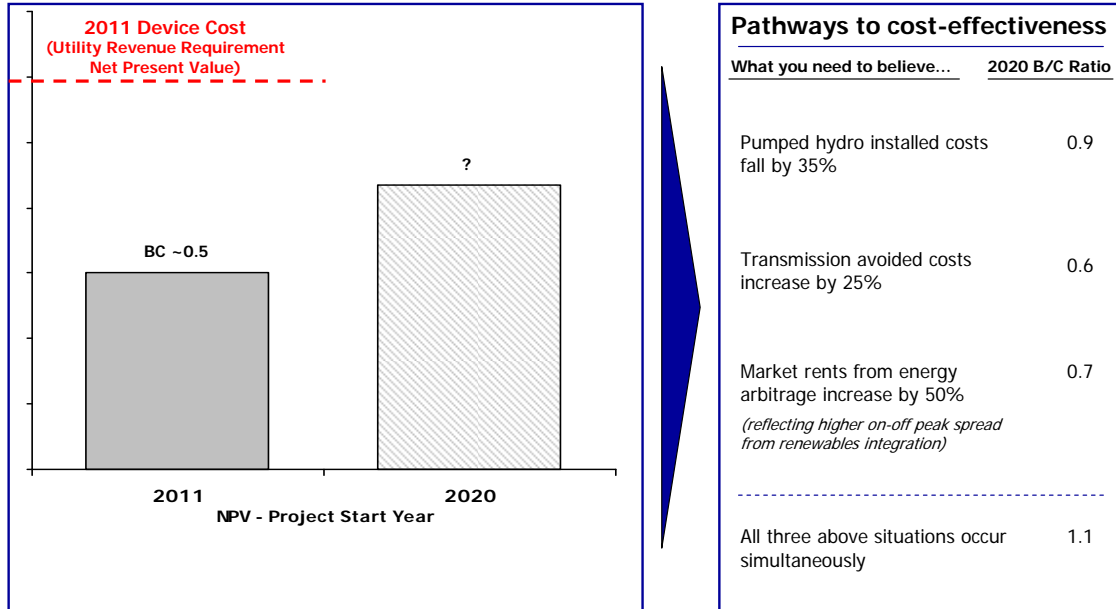
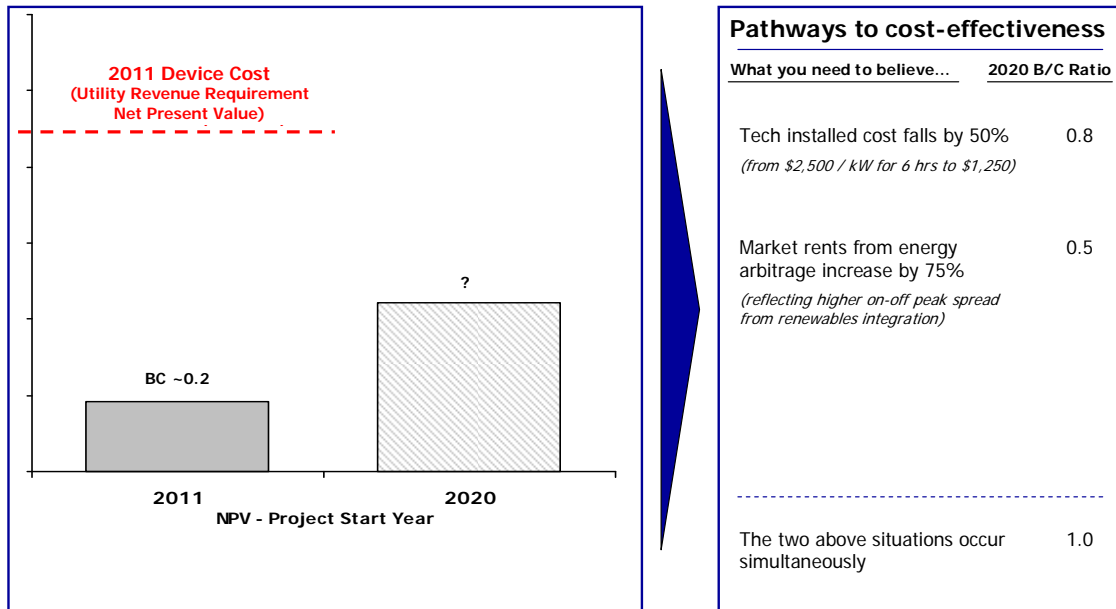


Figure 10: Benefit / Cost Analysis for Application 1 & a Sodium Sulfur Battery

APPLICATION 1b BENEFIT/COST SUMMARY

Off-to-on peak intermittent energy shifting & firming at or near generation 20 MW, 6 hour NaS battery



As both charts show, both examples are not currently cost-effective; however SCE sees promise for this application. From a cost-effectiveness standpoint, this application derives its primary value from arbitrage – energy shifting – market rents and avoided generation capacity procurement. For a 300 MW pumped hydro station, SCE estimates current station install costs would need to fall by 30 percent, transmission avoided costs increase by 25 percent, and market rents increase by 50 percent for this application to be cost-effective by 2020. Transmission benefits and intermittency smoothing provide a small amount of total value over a longer time horizon and do not apply to “high energy” batteries (see Appendix A for additional information). For a 20 MW, 6-hour battery, SCE estimates that current device installed costs would need to fall by 50 percent and energy market rents increase by 75 percent for this application to be cost-effective by 2020. This is not an unfathomable prospect, considering the pace of technology development and the high likelihood of more off-peak intermittent renewable energy as a result of increasing mandates.

Application 2: *Intermittent energy smoothing and shaping at or near generation*

As in application 1, the storage device is located at or near the generation site. The device is associated with an intermittent on-peak energy source such as a solar plant. This application uses volatile intermittent energy to charge a storage device on a second-to-minute basis when supply momentarily peaks. The storage device would discharge on a second-to-minute basis when supply momentarily dips, providing “smoothed” energy to the system. “Shaping” this minute-to-minute production into 15 minute increments is another potential operational use. Co-locating the energy storage device with generation reduces the potential negative impacts of variable must-take energy on the grid, including but not limited to, transmission and distribution reliability issues and frequency fluctuations.

The operational uses that are primary drivers for this application and corresponding value metrics for each are:

1. *Intermittent resource output smoothing and shaping (#10)* – When energy supply momentarily drops (e.g., when a cloud covers a PV array) a charged battery can instantaneously provide energy to the system. Likewise, when supply momentarily jumps (e.g., when sunlight momentarily passes through clouds), the battery can absorb this sudden increase in output by charging the battery. This provides “smoothed” energy to the grid. If the storage device has over one hour of energy output duration, it can also provide ramp “shaping” to meet longer duration load fluctuations in addition to minute-by-minute energy smoothing. Benefits are captured by avoiding intermittent energy integration cost.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Energy shifting: real time price arbitrage (#6)* – Given fluctuations in real-time energy prices, this application has the potential to realize arbitrage value. Due to constant battery cycling, it will likely charge and discharge at different real time

- prices (which are currently set in 5 minute increments). It is unlikely that real-time energy price arbitrage will accrue substantial value, since the charge / discharge timing will not be driven by price arbitrage, but rather operational needs associated with the intermittent generation source.
2. *Transmission short duration performance improvement (#11)* – Smoothing of energy at the generation source provides higher quality energy to the transmission system, thereby potentially improving voltage, reducing loading, or providing capacity (duty) during system faults. Benefits consist of the value of deferred or avoided costs of infrastructure replacement and / or upgrade.
 3. *Transmission system reliability (#15)* – If the intermittent nature of the renewable generation creates transmission system reliability issues, removing such intermittency addresses these issues. As stated above, value is captured through avoiding / deferring costs of infrastructure.

This application requires an energy storage technology that can meet the following application preferences:

- *Low energy-to-power ratio:* Requires high power output over several, minute-length durations.
- *High frequency of charge-discharge:* Can require hundreds of partial charge-discharge cycles per day.
- *Low energy density/power density:* Space is not usually a concern for generation-type projects, though there may be site-specific exceptions.
- *Does not require low O&M:* While low O&M needs are always preferable, the technology selected for application 2 can have some O&M requirements, due to the co-location of the storage device with generation, and the likely availability of maintenance staff at that site.
- *Limited obstacles to implementation:* Implementation obstacles are naturally always undesirable and therefore avoided in ideal situations. However, intermittent renewable energy is generally located at “brown-field” generation sites, so overcoming implementation obstacles in this case may be less of a challenge than for other energy storage applications.

In order to provide this application for a commercial 20-30 MW wind or solar farm, the energy storage device would be sized at around 10 MW. A fast-responding energy storage system with advanced forecasting and control algorithms may be required to smooth variable generation output and minimize adverse impacts to local systems. It was assumed that 15+ minutes of energy output duration would be required to effectively smooth the generation. For “shaping”, it was assumed that 2+ hours of energy output duration would be required to effectively match meaningful amounts of production with demand variations.

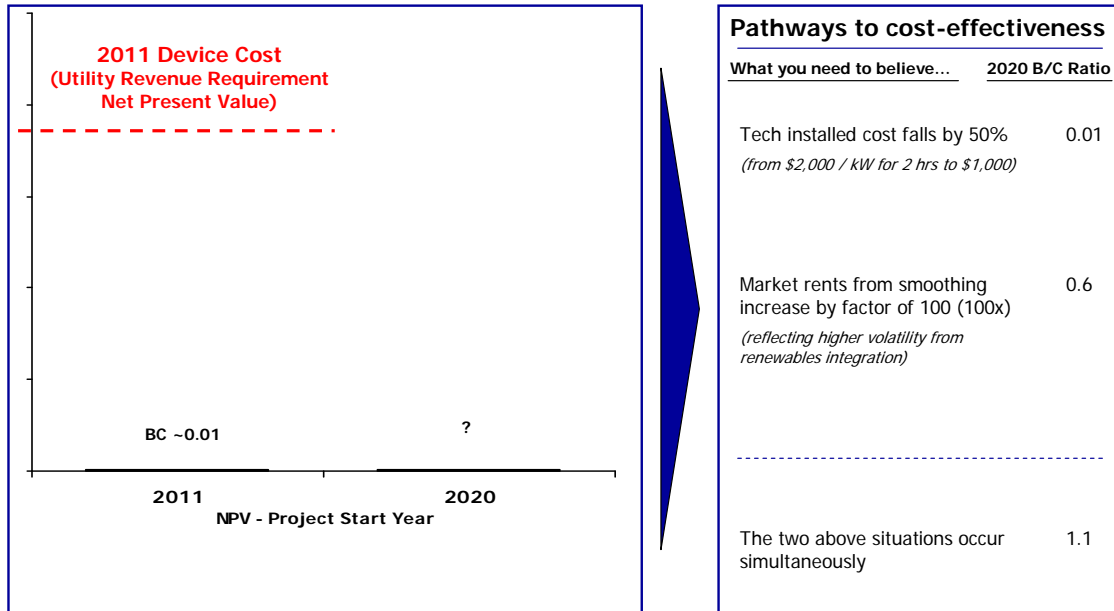
Based on the application preferences detailed above, the optimal storage technologies to provide smoothing services commercially available today are flywheels. For shaping, lithium ion batteries are a better fit due to a longer energy discharge capability. While generation-linked storage systems (e.g., molten salt) could also provide smoothing and

shaping, such technologies cannot be separated from the generation itself (e.g., molten salt storage works in conjunction with solar thermal generation) and therefore are not examined in this assessment of energy storage. Figure 11 below shows the summary of our benefit / cost analysis.

Figure 11: Benefit / Cost Analysis of Application 2 & a Flywheel

APPLICATION 2 BENEFIT/COST SUMMARY

Intermittent energy smoothing at generator 10 MW, 30 min flywheel



As the chart shows, with current technology, it is not cost-effective to use energy storage in this application. It is difficult to assess the cost-effectiveness of an application which derives its primary value from avoided renewable integration costs, as there are few current metrics on the topic. It is recognized, however, that intermittency has a cost, and as such, avoiding it a value. Approximating this value from the avoided need to procure balancing ancillary services (e.g., regulation and spin) yields very low lifetime valuations (see Appendix A for additional information). To achieve cost-effectiveness with a 10 MW, 15-minute discharge device, SCE estimates that current costs will need to decrease by 50%, while benefits increase one-hundred fold (i.e., an annual revenue stream of \$10,000 increases to \$1,000,000) for this application to become cost-effective by 2020. Although regulatory changes concerning the allocation of intermittency charges could drastically alter the landscape for application 2, SCE expects a low likelihood of cost-effectiveness in the near or medium-term future.

Application 3: Offering ancillary services

In this application, the storage device is located at or near the generation site, allowing storage to bid ancillary service capacity into CAISO markets, while responding to dispatch signals in real time.

The application's primary operational uses and corresponding value metrics are listed below. The reader should note that, in this particular application, only one of the primary operational uses below can be performed at a given time, since a market participant cannot be awarded bids for the same capacity simultaneously in CAISO's markets.

1. *Spin / non-spin operating reserves (#1)* – An energy storage device provides spin / non-spin products in the CAISO. In order for energy storage to perform this operational use, market rules would have to be adjusted to allow for bids from resources with less than one hour of energy capacity. The benefit is the revenue stream from the CAISO for providing spin / non-spin services.
2. *Ramping (#2)* – Fast-acting storage can provide the ramping required to follow steep load increases and decreases. While ramping is not currently a CAISO market product, the CAISO has indicated that it may develop one. The benefit is the to-be-determined revenue stream for providing ramping services.
3. *Regulation up / regulation down (#3)* – Storage devices can discharge energy when regulation up is required and charge when regulation down is required to maintain steady system frequency. Though CAISO markets are not currently structured to allow for energy storage participation, other ISO (e.g., New England ISO) markets do allow for energy storage participation. As above, the benefit is a market rent revenue stream from the CAISO for providing regulation services.

In certain situations, though not all, one additional operational use may occur:

1. *Energy shifting: real-time energy price arbitrage (#6)* – Arbitrage on a 5-minute charge / discharge basis may provide opportunities to realize benefits through the price differential between charge and discharge, minus efficiency losses. As in Application 2, real-time energy price arbitrage is unlikely to accrue substantial value, since the charge / discharge timing will be driven by CAISO reliability signaling, rather than energy price arbitrage.

In order to provide the ancillary services outlined above, a storage technology must be able to accommodate the following application preferences:

- *Low energy-to-power ratio:* Requires high power over minute-length durations.
- *High frequency of charge-discharge:* Can require tens (for ramping and spin) to thousands (for regulation) of partial charge-discharge cycles per day.
- *Low energy density/power density:* Space is not usually a concern for generation-type projects, though there may be site-specific exceptions.
- *Does not require low O&M:* While low O&M needs are always preferable, the technology selected for application 3 does not need to be maintenance-free. Due to the co-location of the device with generation, O&M staff will likely be available on-site.
- *Limited obstacles to implementation:* Obstacles to implementation are naturally always undesirable and therefore avoided in ideal situations. However, siting an energy storage device close to generation is less challenging than in other

locations, such as residential communities and, as such, technology limitations in this area may be more acceptable.

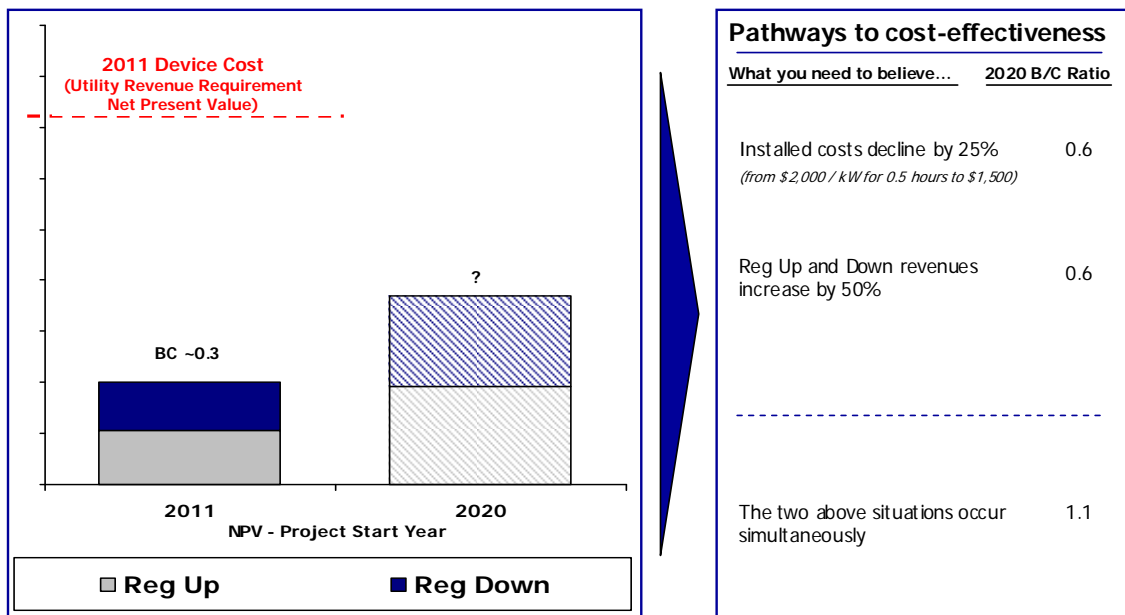
To provide the services of this application, an energy storage device would be sized at approximately 20 MW. It was assumed that 30 minutes of energy would be required to effectively provide frequency regulation, in accordance with new CAISO rules on the topic. The team’s analysis focused on energy storage’s provision of frequency regulation in the CAISO, since ramping is not a current product and market payments for regulation are generally higher than those for spin and non-spin.

Based on the application preferences detailed above, an optimal storage technology available today is flywheels. As the technology matures, lithium ion batteries could also become a major player in this space. Figure 12 shows the summary of our benefit-cost analysis.

Figure 12: Benefit / Cost Analysis of Application 3 & a Flywheel

APPLICATION 3 BENEFIT/COST SUMMARY

Offering ancillary services 20 MW, 30 minute flywheel



As the graph shows, this application is not currently cost-effective using the below described assumptions. This application is a popular topic for industry discussion, owing in part to the availability of historical ancillary service pricing data and several existing pilot projects. Accessible pricing information, however, does not reduce analytical complexity. First and foremost, storage devices are not able to participate in CAISO markets at this time due to engineering signaling, tariff, and software constraints. Market mechanisms existing in other ISOs, for example throughput or “mileage” payments, are complicated by a regulation market separated by two discrete products, regulation-up and regulation-down. Also, there is ongoing discussion and analysis concerning future

ancillary service procurement given increasing variable renewable energy mandates. For all of these reasons, historical pricing is a poor, at best, predictor of future cost-effectiveness in the CAISO region.

If, however, one assumed a device would participate in both regulation-up (during the day) and regulation-down (during the night) markets, being called for five 1-minute ramps each hour, an initial, rough, valuation is possible (see Appendix A for additional information). We assumed this operating profile with prices set at the three year average of 2007-2010 prices. Given these parameters, in order to achieve cost-effectiveness, a 20 MW, 30 minute flywheel would need current installed costs to decrease by over 25% and market rents from both regulation-up and regulation-down markets to increase by 50%. In summary, future valuations of this application are dependent on the market design decisions of the CAISO as well as the future behaviors of market participants, including intricate bidding behavior and market liquidity considerations (see Appendix B). SCE found that application 3, which on the surface seems like one of the easiest to evaluate given a surfeit of historical data, is actually one of the most complex and uncertain.

Application 4: *Black Start*

In this application, the location of the storage device depends largely on the black-start issue being addressed: generation or transmission. If located near a generator to provide generation black-start, this device can provide start-up energy in the event of a system wide black-out. If the device is used to provide voltage to maintain a transmission “cranking path” in the event of a system black-out, the storage device would be located along the transmission system.

Black-start capability (#9) is the only operational use associated with this application. As mentioned in the “operational uses” section of this paper, the benefit of black-start capability is extremely difficult to monetize since resources currently providing this capability are not explicitly compensated. However, black-start value could be determined by estimating premiums paid to generators for black start, or by calculating the avoided cost of black-start transmission infrastructure.

As described on page 28, further valuations on this application were not performed.

Application 5: *Transmission infrastructure improvement*

In this application, the storage device is located on the transmission system. It uses storage to avoid or defer either transmission system upgrades or other transmission system components. If a storage device can be proven to provide one or more transmission services, the device could be included as a potential solution in the transmission planning process. It is difficult to provide much additional detail on this application, as it is highly dependent on the specific transmission infrastructure issue the storage device is solving.

The primary driver and corresponding value metric of this application is:

1. *Transmission upgrade deferral (#14)* – An energy storage device is used to alleviate system reliability or congestion issues by replacing a specific piece of transmission infrastructure. Benefits consist of the avoided cost of an alternative technology solution to the transmission issue.

In certain situations, though not all, additional operational uses may be provided:

1. *Transmission short duration performance improvement (#11)* – An upgraded component on the transmission grid, such as an energy storage device, could improve voltage, reduce loading, or provide capacity (duty) during system faults.
2. *Providing system inertia (#12)* – The power electronics associated with some storage devices can be designed so that it simulates system inertia by pushing large amounts of power onto the grid if and when it is required.
3. *Transmission congestion fee avoidance (#13)* – An energy storage device either directly upstream or downstream of a congested transmission line could reduce congestion. If the congestion were due to peak load, a device downstream of the line could charge over a longer period of time, and provide additional energy to the system during peak periods without requiring transmission of energy on the congested line at that time. On the other hand, the congestion could be due to must-take energy generation (e.g., wind), in which case an energy storage device upstream of the line could charge during peak production hours, and discharge that energy onto the line during periods of lower production.
4. *Transmission system reliability (#15)* – An upgraded component on the transmission grid could also improve system reliability by either replacing a specific component that provides reliability (e.g., static VAR compensator), or by providing outage mitigation downstream of the storage device.

As described on page 28, further analysis of this application was not performed.

Application 6: Distribution infrastructure improvement

In this application, the storage device is located on the distribution system. This application avoids or defers distribution system circuit or component upgrades by locating a storage device at problem areas on the distribution grid.

The primary driver and corresponding value metric of this application is:

1. *Distribution upgrade deferral (#14)* – An energy storage device reduces overloads on distribution lines (which may or may not be coincident with system peaks), which inevitably necessitate upgrades. The benefits consist of the avoided upgrade costs and depend on the location of the device.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Distribution power quality (#16)* – Downstream energy sent through the distribution system is of higher quality and may improve voltage and harmonics. Benefits consist of the avoided cost of deferred or replaced infrastructure.
2. *Distribution-level outage mitigation (#18)* – An upgraded component on the distribution system could also improve distribution reliability by providing outage mitigation downstream of the storage device. An energy storage device located downstream of a system outage could provide energy to continue to serve customers during that time.
3. *Intermittent DG integration (#19)* – An energy storage device providing distribution system improvement may be located adjacent to a DG installation. In such a case, the device could minimize potential issues associated with increased backflow of energy onto the grid.

As mentioned on page 28, further analysis of this application was not performed.

Application 7: Primary distribution level peak shaving and outage mitigation

In this application, the storage device is located on the “primary” distribution system, downstream of an outage or overload situation. It uses a transportable storage unit to provide supplemental power to end users during outages (both planned and unplanned) due to short-term distribution overload situations. The storage units operate by discharging during the outage / overload situation, and are charged in preparation for the situation (likely during off-peak hours).

The operational uses that are primary drivers for this application and corresponding value metrics for each are:

1. *Resource adequacy (RA) and dependable operating capacity (#4)* – Storage devices can meet peak demand by charging off-peak and discharging when needed on-peak. The benefits consist of the avoided cost of either procurement of capacity in the short term or building new peaking units in the long term. Though the device is transportable, RA can be demonstrated to regulators on a month-ahead basis, and one month is far less than the amount of time a device would be located at a site. Benefits consist of the avoided cost of either capacity procurement or, in the long term, building new peaking units. Technically speaking, changes in the RA regulatory process (specifically demonstration of distribution-level RA deliverability) need to be made for this value stream to be realized.
2. *Energy shifting / wholesale price arbitrage (#6)* – As in application 1, less valuable off-peak energy can be stored and sold at higher on-peak energy prices. In this application, the energy is stored downstream of the transmission system, rather than at the generation site and as such the actual value stream is an avoided procurement cost instead of a direct market revenue. Benefits consist of the

difference between charge and discharge prices, minus efficiency losses. The reader should note, however, that on-off peak spreads (and therefore arbitrage value) will likely decrease with increasing energy storage penetration.

3. *Outage mitigation (end user curtailment) (#18)* – Storage devices located on the distribution system can provide energy downstream of the device in the event of an outage upstream of the device. Benefits are evaluated as the value associated with averting customer outages and are highly dependent on individual circumstances and customers.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Avoid dump energy / minimum load issues (#7)* – When energy supply exceeds demand (e.g., during off-peak periods on a system with high renewable penetration), a storage device can be charged to avoid dump energy. In this application, this excess energy is transported through the transmission system and primary distribution system to the device, and stored until demand increases, at which point it is transmitted to the end consumer. Benefits consist of the price differential between charge and discharge, less associated efficiency losses.
2. *Distribution upgrade deferral (#14)* – An energy storage device reduces overloads on distribution lines (which may or may not be coincident with system peak), or other occurrences which necessitate upgrades. Benefits consist of the avoided costs associated with upgrades and depend on the location of the device.
3. *Distribution power quality (#16)* – Due to the energy storage device on the distribution system, energy on the distribution system is of higher quality, and may improve voltage and harmonic issues. Benefits may be evaluated by calculating the avoided cost of deferred or replaced infrastructure.
4. *Maintain power quality (#21)* – End users may benefit from improved power quality if the device is located within the customer’s distribution system. Benefits consist of the value associated with convenience and reliability benefits for selected customers.
5. *Back-up power (#22)* – End users may benefit from energy available from the device during an upstream outage. However, customers with higher reliability needs still must provide their own back-up. Benefits are evaluated as the value associated with convenience and reliability benefits for certain customers.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

1. *Balanced energy-to-power ratio:* Balanced energy and power capabilities are required for hour-long durations.
2. *Moderate frequency of charge-discharge:* This application can require several charge-discharge cycles per day or as few as 1 cycle per day.
3. *High energy density and power density:* As the device is likely located in urban areas with location space constraints, this application requires high power and energy in a transportable device.

4. *Requires moderately infrequent O&M:* While low O&M needs are always preferable, the technology selected for this application can have some, though infrequent, hands-on maintenance requirements. Trained staff would likely be available to perform any such requirements during device relocations.
5. *Moderate obstacles to implementation:* Implementation obstacles are always undesirable and therefore avoided in ideal situations. Since this device will be located at often space-constrained distribution level sites, it must be relatively modular and unobtrusive for deploying in residential and densely populated areas.

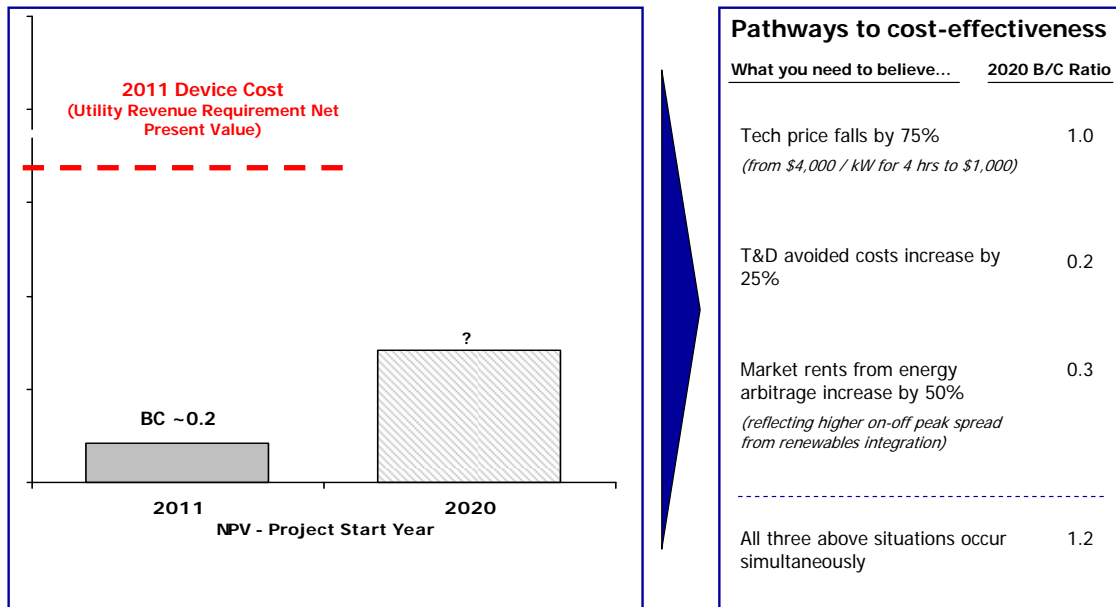
A 2 MW storage device could shave 25% off an overloaded 12kV distribution system load. It was assumed that four or more hours of energy discharge would be required to effectively provide this application’s services. Thus, the storage device could provide up to 8 MWh of energy during each discharge cycle while also providing a four hour support period during which other remedial actions can be taken.

Based on the application preferences detailed above, the optimal and most commercially available storage technology to perform this application is a lithium ion battery. Despite the commercial availability of sodium-sulfur batteries, the device is unable to fill the application preferences due to its lack of transportability. Figure 13 below shows the summary of our benefit-cost analysis.

Figure 13: Benefit / Cost Analysis of Application 7 & a Lithium Ion Battery

APPLICATION 7 BENEFIT/COST SUMMARY

Primary distribution level peak shaving / outage mitigation using transportable device 2 MW, 4 hour lithium ion battery



As the chart shows this application is not cost-effective given current technology costs. The primary value from this application is in avoided generation procurement costs (both energy and capacity) and the deferring of distribution level costs (see Appendix A for additional information). It is important to note that the distribution cost component will

vary widely, and to a large extent determine eventual valuations. As such, it is difficult to place a value on this application without field trials. Additionally, the more locations where the device for this application defers capital (the number of relocations) and the length of field deployment over its lifetime, the more value it will accrue. While opportunities for this application are likely limited, SCE will continue to research specific circumstances to gain more insight on technical specifications as well as economic feasibility.

Application 8: *Peak shaving below the ‘secondary’ distribution system level*

In this application, the storage device is located downstream of the secondary distribution system. It charges during off-peak hours and discharges during a 2-4 hour daily peak period, altering end user load shapes.

The primary operational use drivers for this application and corresponding value metrics are:

1. *Resource adequacy (RA) and dependable operating capacity (#4)* – As mentioned many times earlier in this report, storage devices can displace generation capacity requirements by charging off-peak and discharging when needed on-peak. Benefits are calculated from the avoided cost of either procuring capacity or building new peaking units.
2. *Energy shifting / wholesale price arbitrage (#6)* – As in other applications, less valuable off-peak energy can be stored and sold at higher on peak energy prices, allowing the storage-user to capture the differential between charge and discharge energy prices, minus any efficiency losses.
3. *Distribution upgrade deferral (#14)* – An energy storage device reduces overloading on distribution lines. Benefits are realized through deferred circuit or other distribution component (e.g., pole top/underground transformer) upgrades.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Avoid dump energy / minimum load issues (#7)* – When must-take energy supply exceeds demand, a storage device can be charged with dump generation. Benefits may be captured by calculating the price differential between charge and discharge, less associated efficiency losses.
2. *In-basin generation (#8)* – Storage devices located near load can serve as local (in-basin) generation. Benefits are captured through the avoided additional premiums of building or procuring local generation and the value associated with operational flexibility.
3. *Transmission congestion fee avoidance (#13)* – If installed in large enough amounts, storage can defer congestion fees by providing energy from a device located further downstream in the distribution system. This can reduce the amount of energy flowing through congested lines on-peak. Benefits may be captured using avoided congestion fees.

4. *Distribution system power quality (#16)* – An energy storage device on the distribution grid improves system power quality. Benefits consist of the avoided or deferred cost of power-quality-related infrastructure.
5. *Outage mitigation (#18)* – Storage devices located on the “secondary” distribution system can provide energy downstream of the device in the event of an outage. Benefits are calculated as the value associated with averting customer outages and are highly dependent on individual circumstances and customers. Although this clearly does have a benefit it is difficult to quantify and as such did not receive any quantitative value.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

1. *Balanced energy-to-power ratio*: Balanced energy and power capabilities are required for multiple hours of discharge.
2. *Moderate frequency of charge-discharge*: Requires one charge-discharge cycle per day.
3. *High energy density and power density*: As the device is likely located in urban areas with location space constraints, this application requires a solution with high power and energy densities.
4. *Requires infrequent O&M*: This application requires minimal maintenance needs due to the large number and broad dispersal of deployments across a service territory.
5. *Large obstacles to implementation*: Limiting obstacles to implementation is a priority for this application for several reasons. First, since the devices are sited close to end users, there is a premium on safe and unobtrusive deployment in residential and densely populated areas. Additionally, the technology solution must be relatively modular, quick to install, and fit into space-constrained areas.

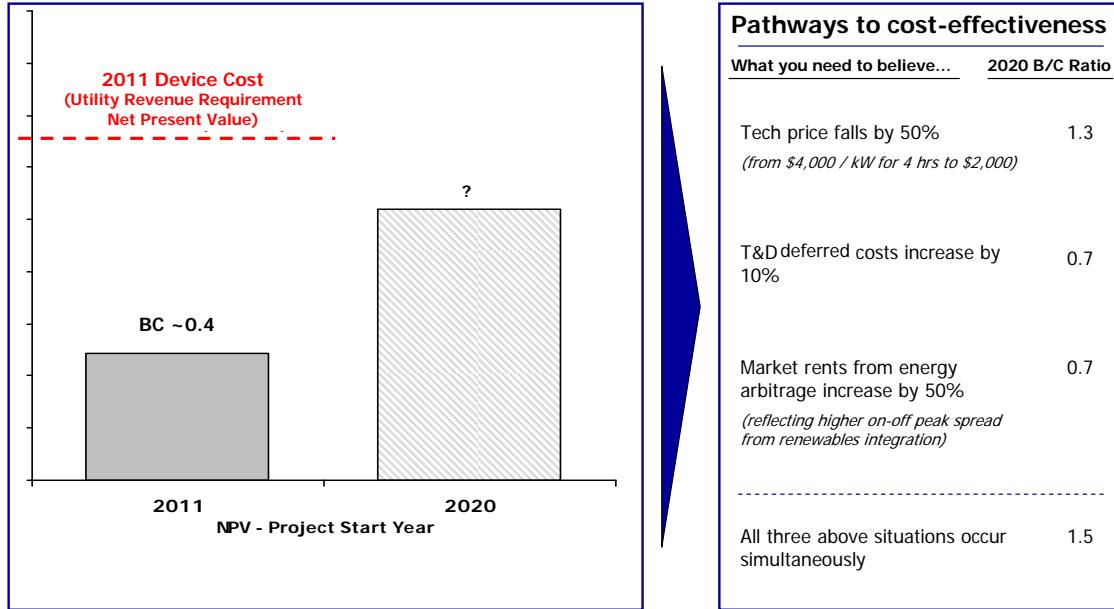
A 25 kW storage device either reduces 50% of load for a 50 kW residential transformer or allows load to exceed its rating by 150%. Four hours or more of energy discharge are required to effectively provide this application’s services. Thus, the storage device could provide up to 100 kWh of energy during a full discharge cycle.

Based on the application preferences detailed above, the optimal storage technology to perform this application is a high energy lithium ion battery. Despite the commercial availability of sodium-sulfur batteries, the device is not small enough (both in kW rating and physical size) for this application. Other technology solutions, such as sodium metal halide and advanced lead acid are potential options in the future. Figure 14 below shows the summary of our benefit-cost analysis.

Figure 14: Benefit / Cost Analysis of Application 8 & a Lithium Ion Battery

APPLICATION 8 BENEFIT/COST SUMMARY

Peak shaving downstream of the “secondary” distribution system 25 kW, 4 hour lithium ion battery



As the chart shows, this is currently not a cost-effective application for energy storage given current technological prices; however, if certain conditions are met, this application could show great promise. Value from application 8 is distributed between the avoided procurement of energy and generation capacity, as well as deferred distribution infrastructure (see Appendix A for additional information). It is important to note, however, that the deployed hours of operation should be optimized between system and distribution peaks, which sometimes are not the same. Valuations will also fluctuate based on the specific distribution situations being addressed. Taking these caveats into account, SCE estimates that a reduction in installed device cost by 50% will make this application cost-effective by 2020. Increasing distribution deferred costs by 10% and market rents from energy arbitrage by 50% creates an even more attractive investment. As such, SCE sees this as a high potential application of energy storage. In addition, the device for this application may also be extended into locations further “downstream,” including at the customer site. Generally speaking, the closer to the customer this application is sited, the more potential distribution system components may be deferred.

Application 9: Intermittent DG ‘output smoothing’ and integration

In this application, the storage device is located between distributed generation sources and the distribution system. At times when generation at the site exceeds power consumption, the storage device could be charged using energy that would have otherwise flowed back onto the grid. When consumption at the site exceeds generation at a later time, the storage device is discharged.

The primary driver and corresponding value metric of this application is:

1. *Intermittent DG integration (#19)* – An energy storage device, located at or near a DG installation, could minimize or avoid potential issues associated with backflow of energy onto the grid. Benefits are captured by calculating avoided upgrade costs and depend on the location of the storage unit. For example, a device located directly adjacent to the DG might limit backflow onto the entire distribution grid. On the other hand, if a DG installation is much larger than the load at the installation site, an energy storage device could be located further upstream. In this situation, substantial backflow (and therefore line upgrades) downstream of the device could not be avoided, but the storage device would eliminate the need for upgrades upstream of its location.

In certain situations, though not all, this application may facilitate additional operational uses:

1. *Avoid dump energy / minimum load issues (#7)* – When energy supply exceeds demand (e.g., during off-peak periods on a system with high renewable penetration), a storage device can be charged to avoid energy dumping. Benefits are captured through the price differential between charge and discharge, less associated efficiency losses.
2. *In-basin generation (#8)* – A storage device at the distribution level can serve as in-basin generation. Benefits are calculated from the potential premium for building or procuring in-basin generation and additional operational flexibility.
3. *Intermittent resource output smoothing and shaping (#10)* – As mentioned in Application #2, when energy supply momentarily drops (e.g., when a cloud covers a PV array), a charged battery can instantaneously provide energy to the system. When supply jumps momentarily, the device can absorb this sudden increase in output by charging the battery. This provides smoothed energy to the grid. Benefits consist of the avoided intermittent energy integration costs.
4. *Distribution power quality (#16)* – Storage performing DG integration may also improve the power quality on the distribution system which may improve voltage and harmonics. Benefits are realized through the deferred cost of infrastructure.
5. *Outage mitigation (#18)* – Storage devices located on the distribution system can provide energy downstream of the device in the event of an outage. Benefits are evaluated as the value associated with averting customer outages and are highly dependent on individual circumstances and customers.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

1. *Balanced energy-to-power ratio:* Balanced energy and power capabilities are required for multiple potential hours of discharge.
2. *Variable frequency of charge-discharge:* Depending on ownership and use, a storage device providing this application can require as few as one or as many as hundreds of partial charge-discharge cycles per day.

3. *High energy density / power density:* This application requires a device near the DG source, either in a commercial or residential area with space constraints. The amount of energy / power required depends on the size of the DG installation.
4. *Requires infrequent O&M:* This application requires minimal maintenance needs given the higher costs of deploying maintenance and/or monitoring personal to various distributed sites where they otherwise wouldn't be needed.
5. *Large obstacles to implementation:* Limiting obstacles to implementation is a priority for this application for several reasons. First, since the devices are sited close to end users, there is a premium on safe and unobtrusive deployment in commercial areas. Additionally, the technology solution must be relatively modular, quick to install, and fit into space-constrained areas.

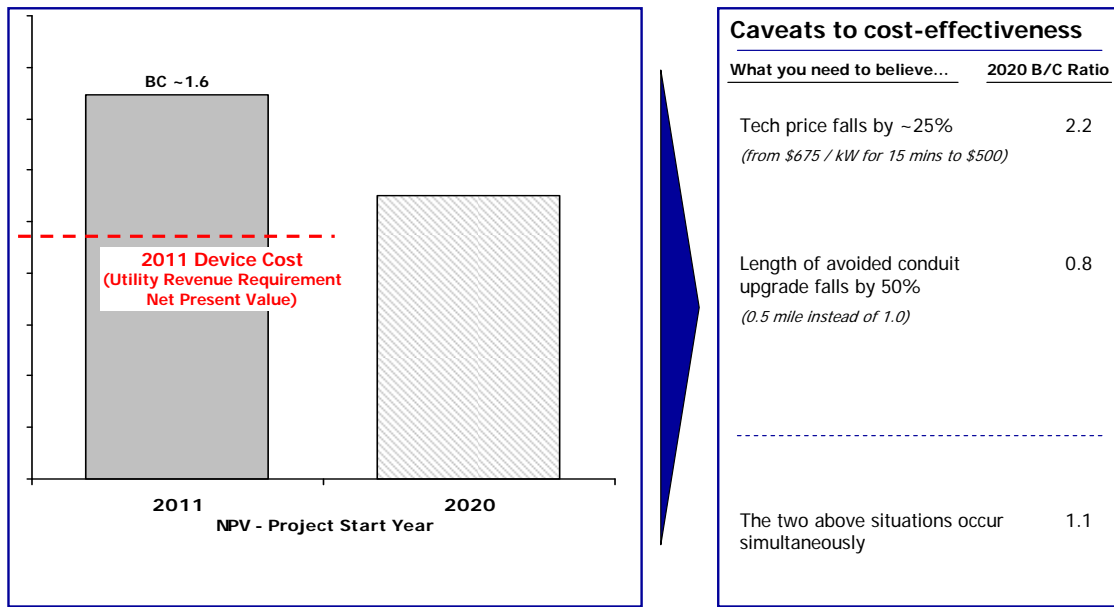
A 500 kW storage device may provide a suitable match for a 1 MW photovoltaic system. It was assumed for this analysis that 15 minutes of energy discharge would be required to effectively meet this application's need. Charge-discharge control algorithms must be able to match output variability of the DG system, with reserve storage capacity and headroom to allow for major output fluctuations. The device must be able to provide at least several charge-discharge cycles per day and must be able to sit idle at other times.

Based on the application preferences detailed above, the optimal storage technology to perform this application is a lithium ion battery. Sodium-sulfur batteries are sub-optimal due to their inability to withstand such large numbers of charge-discharge cycles over a short period of time. Figure 15 below shows the summary of our benefit-cost analysis.

Figure 15: Benefit / Cost Analysis of Application 9 & a Lithium Ion Battery

APPLICATION 9 BENEFIT/COST SUMMARY

Intermittent DG "output smoothing" and integration 500 kW, 15 min lithium ion battery



As the chart shows, this application could be cost-effective in niche applications on the grid using current technology. Value for this application is relatively straightforward, as it is almost completely determined by the specific avoided / deferred distribution upgrades associated with each deployment. As such, initial valuations could in fact be cost-effective at current technology costs (see figure 15 and Appendix A for additional information). However, in the near term (next few years), large DG sites requiring costly infrastructure upgrades will be passed over for those which do not. In other words, given the current availability of suitable sites, DG deployments will naturally gravitate first towards projects which will not require distribution upgrades. While a potentially promising use of storage, at best SCE believes actual deployments will be limited to extremely specific projects which do not currently exist but might in the future.

Application 10: *End user Time-Of-Use (TOU) rate optimization*

In this application, the storage device is located “behind the customer meter,” allowing the end user to optimize retail TOU rates. Customers can elect to charge the device when retail TOU prices are low and discharge when high (or during demand response curtailment periods).

The primary driver and corresponding value metric of this application is:

1. *Customer rate optimization (#20)* – A customer can optimize when to draw energy from a storage unit and when to charge the unit to take advantage of variable on-off peak TOU pricing and / or mitigate demand response impacts while retaining preferable rate regimes.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Outage mitigation (#18)* – Storage devices located “behind the meter” can provide energy downstream of the device in the event of an outage. Since the device is not used primarily for this purpose, it may or may not be fully available (i.e., charged) during unforeseen system outages. Benefits are evaluated as the value to the utility associated with averting customer outages.
2. *Maintain power quality (#21)* – End users desiring high levels of power quality may be able to use a storage device to this end. The benefit is the value of higher power quality for the end user. Deployment for this use will also preclude its ability to perform other uses simultaneously.
3. *Uninterruptible power supply (#22)* – End users desiring high levels of reliability can benefit from storage devices located behind the meter. Since the device is not used primarily for this purpose, it may or may not be fully available (i.e., charged) for this operational use. Benefits are evaluated as the value associated with the end user cost of a back-up power system.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

1. *Balanced energy-to-power ratio:* Balanced energy and power capabilities are required for multiple hours of discharge.
2. *Moderate frequency of charge-discharge:* The application can require several charge-discharge cycles per day, with as few as one.
3. *Moderate energy density / power density:* This application has limited power / energy needs as the application only serves an end user, and could take up a moderate amount of space (e.g., part of a garage, a server room). Therefore, while higher power and energy density are desirable, the customer may not be willing to pay a substantial premium for this attribute.
4. *Requires infrequent operating and maintenance (O&M) needs:* Depending on the device user (e.g., an individual or company), there may or may not be willingness to service the device.
5. *Limited obstacles to implementation:* Due to its small size and private ownership (and therefore siting on private land), obstacles to implementation will likely be limited. However, since the device is sited close to end users, it must be safe and reliable for deployment in residential and densely populated areas.

A 5 kW storage device may effectively provide this application's services for large residential or small commercial needs. It was assumed for this analysis that six hours or more of energy discharge would be required to effectively provide this application's services. Thus, the storage device could provide up to 30 kWh of energy during each discharge cycle. However, the capacity and energy capabilities selected depend largely on customer load characteristics, profile and preferences.

Based on the application preferences detailed above, the optimal storage technology to perform this application is a lithium ion battery, although advanced lead-acid could also be attractive based on cost. Figures 16 and 17 below show the summaries of our benefit-cost analyses for both a 30 kWh household and 300 kW businesses.

Figure 16: Benefit / Cost for Application 10 with a 30 kWh-Day Household Usage

APPLICATION 10a BENEFIT/COST SUMMARY

TOU rate optimization: 30 kWh-daily household; 5 kW, 6 hour lithium ion battery

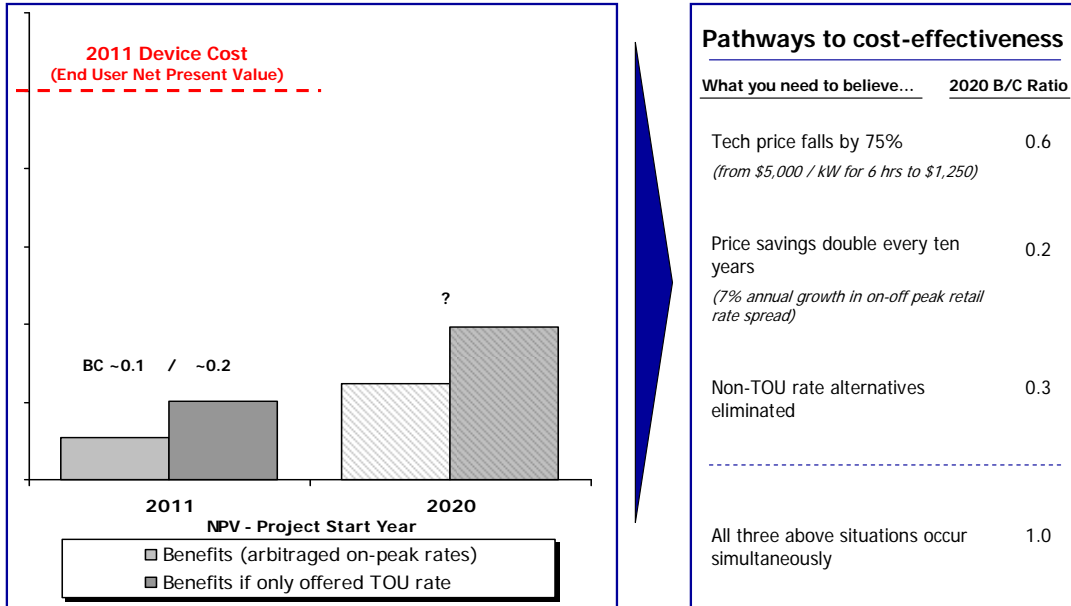
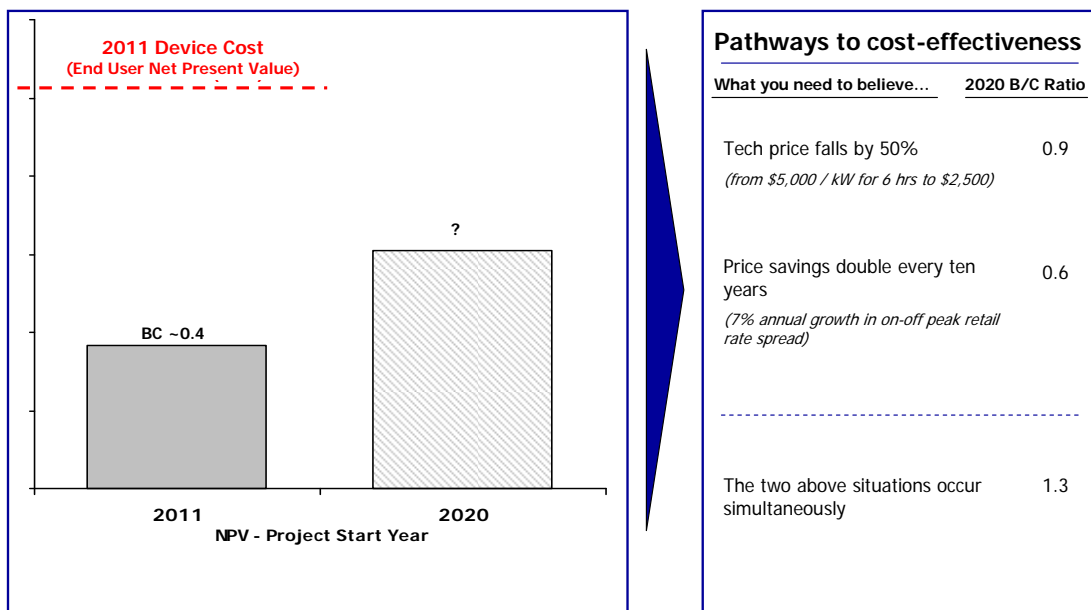


Figure 17: Benefit/Cost Analysis of Application 10 as a 300 kW Business

APPLICATION 10b BENEFIT/COST SUMMARY

TOU rate optimization: 300 kW business 10 kW, 6 hour Li+ battery



Both charts show that this is currently not a cost-effective option, although it does indicate that customers already on TOU rates (such as commercial customers) would receive a higher value than non-TOU customers. Determining cost-effectiveness for this application is a highly variable prospect. (See Appendix A for additional information). Numerous scenarios, including the size of a customer's overall load (both kW and kWh), the flexibility of his or her demand, and the rate choices available will drastically impact valuations. For example, a residential customer with an aversion to peak pricing currently has a choice between tiered domestic rates and hourly variation TOU-rates; he or she will select the tiered rate to avoid peak pricing, not buy an energy storage device. SCE estimates that, to reach cost-effectiveness, a 30 kWh-day usage household with a 5 kW, 6 hour energy output device would require technology costs to fall by 75%, a 7% annual growth in on-off peak retail rate spreads, and an elimination of non-TOU rate alternatives. Larger business customers (300 kW peak load), however, are often already on TOU rate schedules with higher peak demand charges. As such, it is estimated that cost-effectiveness for this type of customer would require a reduction in device costs by 50% with a similar 7% annual growth in on-off peak retail rate spreads. It should be noted, however, that these examples are purely hypothetical, and any particular business or residential customer will need to make calculations using their exact situations. In summary, in most scenarios, this application will require significant device cost reductions and high expectations of peak-period retail rate growth to reach cost-effectiveness.

Application 11: *Uninterruptible power supply*

Some electricity customers require a level of power quality and reliability above and beyond what the system provides (e.g., chip manufacturers, hospitals, etc.). In this application, the storage device is located behind the meter at the customer to meet these needs. It is important to note, however, that when capacity is reserved for outages, it cannot be used in any other function.

The value for this application is driven by two operational uses, listed below:

1. *Maintain power quality (#21)* – An energy storage device is used to provide a higher power quality level than a Load-Serving Entity (e.g., utility) can provide. The power electronics associated with the energy storage device are key to ensuring high power quality. Benefits are captured through an end user value proposition.
2. *Uninterruptible power supply (UPS) (#22)* – End users that cannot tolerate any interruption in their power supply (e.g., advanced manufacturers or technology companies) may invest in energy storage and / or other back-up generation to provide UPS. An energy storage device must be sized to cover expected outage duration (or to “bridge” the time between a system outage and back-up generator start up) to provide the benefits associated with this application. Benefits are captured through an end user value proposition.

As per page 28, further analysis of this application was not performed.

Application 12: Secondary system “islanding” / forming a “micro-grid”

In this application, the storage device is located off the grid and near distributed generation (DG). The size and type of battery installed varies based on the micro-grid desired and the overall load being covered. The micro-grid created could range in size from a single house to a larger community or commercial/industrial facility.

The operational uses that are primary drivers for this application and corresponding value metrics for each are:

1. *Outage mitigation (#18)* – Storage devices located off the grid can provide energy generated on site in the event of a utility outage. Benefits are evaluated as the value associated with averting customer outages.
2. *Customer rate optimization (#20)* – A customer avoids the cost of retail rates.

In certain situations, though not all, additional operational uses may be provided by this application:

1. *Resource adequacy (RA) and dependable operating capacity (#4)* – By creating a micro-grid not served by the utility, the compliance burden for RA is reduced. Benefits consist of the avoided cost of either procurement of capacity or building new peaking units.
2. *Distribution upgrade deferral (#14)* – By not serving the islanded load, the utility may avoid incremental distribution upgrades. Benefits consist of the avoided line or component upgrades.
3. *Maintain power quality (#21)* – An energy storage device is used to provide a higher power quality level than a load serving entity (e.g., utility) can provide. The power electronics associated with the energy storage device are key to ensuring high power quality. Benefits are captured as an end user value proposition.

In order to optimally provide the above-mentioned benefits, technologies must be able to accommodate the following application preferences:

- *Balanced energy-to-power ratio:* Balanced energy and power capabilities are required for multiple hours of discharge.
- *Moderate frequency of charge-discharge:* The application can require several charge-discharge cycles per day.
- *Low energy density / power density:* Space requirements depend greatly on end user, but likely “islanders” will have adequate space for an energy storage device.
- *Requires variable O&M:* Depending on the individual, business, or community, there may or may not be willingness to service a device.
- *High obstacles to implementation:* Implementation obstacles are always undesirable and therefore avoided in ideal situations. Specific community space constraints installations may present challenges for siting. Due to close proximity to end users, environmental and safety concerns remain high.

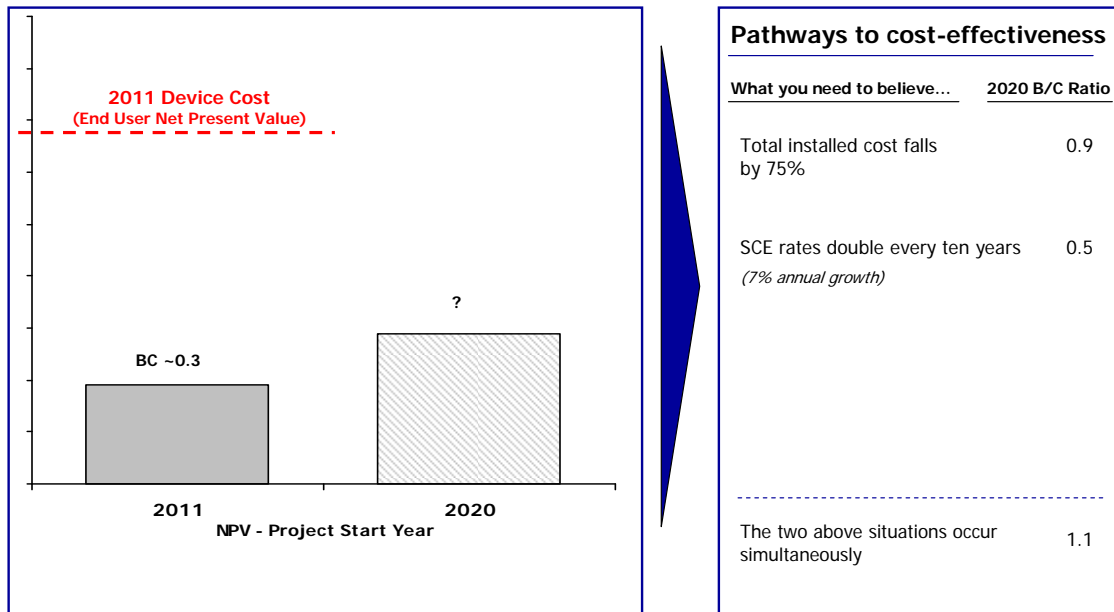
While there are a variety of potential scenarios, to provide this application for a 100 kW PV array DG system with a 5 kW load, the energy storage device may be sized at around 50 kWh. It was assumed that 10 or more hours of energy discharge at peak power would be required to provide the services of this application. The recharge period assumed puts priority on reliability rather than energy cost. The storage device must be used in combination with controls and switching to “island.” This assessment also assumes a device’s interactive participation with customer loads to balance demands with resource capability.

Based on the application preferences detailed above, the optimal storage technology for this application that is commercially available today is an energy optimized lithium ion battery. However, this fit will vary substantially based on the size of the “islanded” micro grid and the availability / cost of other options such as sodium metal halide and advanced lead acid batteries. Figure 18 below details the summary of our benefit-cost analysis for the best case scenario (20 homes using 1 kW each micro-grid).

Figure 18: Benefit / Cost Analysis of Application 12 in a 20 Home Community

APPLICATION 12 BENEFIT/COST SUMMARY

Islanding a household; using a 3 kW, 10 hour Li+ battery



As the chart shows, this application is currently not cost-effective given prices of the technologies available. Pathways to cost-effectiveness for this application will fluctuate widely based on the demands of individual micro-grids defined by total capacity, energy, and reliability reserve requirements (see Appendix A for additional information). In the situation described above, one would need to assume the cost of the bundled storage device and solar photovoltaic array would decrease by 75% and SCE rates increase at 7% a year to approach cost-effectiveness. This also assumes only ten hours of storage

reliability reserve at the load's peak operating capacity. It should be noted, however, that this example is purely hypothetical, and any particular micro-grid situation will need to tailor the numbers using exact preferences, constraints, and costs.

Caveats to Cost-Effectiveness Estimates:

Southern California Edison has made every effort to create accurate, high-level strategic evaluations for energy storage applications given the best currently available information. However, the reader should note that the cost-effectiveness estimates performed in this study are highly situation dependent and are driven by numerous uncertain variables. Assumptions about the time value of money (discount rates), lifetime maintenance, and specific site preparation / land costs, among numerous other variables have significant impacts on the end numbers.

SCE has attempted to capture accurate and useful estimates on energy storage technologies as well. However, it should also be understood that energy storage is a rapidly evolving area. As research and development continues, significant changes to technology costs and capabilities are expected. As such, SCE has taken a technology-neutral perspective and has attempted to assess energy storage through the lens of specific applications. Nevertheless, best-estimate cost assumptions of various technologies were necessary to evaluate the potential of such applications. SCE hopes that, by taking this technology-neutral perspective, it has provided a study that energy storage stakeholders can use to better understand the potential needs of the electric utility sector as well as opportunity areas for energy storage.

Further, it must be understood that uses of energy storage are highly situation specific. As such, more rigorous and detailed assessments will be required to fully capture the nuances of energy storage applications on a circumstance-by-circumstance basis. It is also important to notice that the potential benefits under specific 2020 future scenarios do not always sum together. The effects of different scenarios are indeed cumulative but not additive (there is often both "push" and "pull" on the relevant benefit calculations).

Finally, though dynamic system modeling was out of the scope of this project, the development and use of accurate models can significantly enhance the accuracy of energy storage assessments. With the continuing increases of energy from variable renewable energy resources and the advent of electric vehicle and smart grid technologies, among other trends, the electric utility industry may change dramatically over the next decades. Models that more accurately forecast future conditions will better inform potential opportunities for energy storage both now and in the longer-term.

It should be noted that energy storage is not an end solution by itself. Instead it should be viewed as an emerging part of a new smart grid. This new smart grid will utilize many different technologies, including two-way communication devices, advanced metrology, and customer energy management software. Storage is just one of the technologies that will help improve the grid along with these other advances.

Conclusions

This report provides a broader stakeholder audience with SCE's approach for practically assessing energy storage on the electric system as well as its initial identification of high potential applications. Conclusions derived during this process are offered below on the specific applications of and overarching "takeaways" for energy storage.

Application Assessments:

Applications which exhibit the highest potential valuations address the aggregated operational uses associated with deferring or displacing peak-related costs over several hour intervals. This economic assessment reflects the benefits of avoiding higher-cost peak-period requirements, as well as the ability to bundle more potential value streams as compared to other niche, targeted applications. Discussion of **applications 1 and 8** clearly highlight this conclusion by taking advantage of their ability to disassociate peak load demand from the need to simultaneously generate energy. By firming intermittent energy on-peak, application 1 also avoids renewable integration costs, which, while uncertain, with increasing renewable mandates are expected to command more value in the future. Application 8, by contrast, adds potential deferrals of transmission and distribution infrastructure to the equation, as well as extra boosts for averting peak congestion and providing localized on-peak resources. In accordance with the above findings, these applications are primary focuses of SCE's technological piloting, as will be discussed later in more detail.

Specific niche applications in the T&D system also exhibit a strong potential for cost-effectiveness, though such opportunities may be limited in size and are extremely situation-dependent. **Applications 7 and 9** address separate aspects of deferring distribution infrastructure upgrades, concerning circuit overloading and renewable distributed generation integration respectively. Other secondary benefits, including generation capacity and energy shifting, may also accrue to devices as they are deployed and operated. However, instances of cost-effectiveness will be extremely limited. As one of SCE's senior distribution system experts explained, "if deploying large amounts of batteries on your system is consistently necessary to prevent overloads or fluctuating voltage due to intermittent distributed generation, someone hasn't planned correctly." In most situations, conventional solutions are sufficient. While providing a potentially promising tool for distribution planners in unique situations, SCE anticipates that these applications will be limited in scope. SCE is also in the process of technically demonstrating these applications through pilot programs.

The remaining applications SCE assessed as having limited or exceedingly uncertain valuations. In the cases of **applications 2 and 3**, valuations are highly dependent on market design and eventual regulatory action in the renewable integration and ancillary service arenas, respectively. Also, underlying value propositions will have to increase substantially as a result of regulatory actions and / or market conditions to achieve cost-effectiveness. This primarily reflects a device's inability to realize other operational uses in these applications, having been specially optimized for numerous short duration

charge-discharge cycles. **Applications 10 through 12** are end user focused. While SCE projected high-level hypothetical scenarios, at the end of the day, valuations will depend on the circumstances, constraints, and preferences of individual consumers. Insofar as these applications are facilitated by utility actions, for example “smart” metrology and time-of-use rates, SCE will remain engaged. However, over the long term, value in these applications will be determined ultimately by end users.

Overarching “Takeaways”

During the process of developing and evaluating energy storage applications, larger overarching themes became apparent. The following list explains these in more detail:

- *Storage is an exciting but complex space.* Energy storage undoubtedly has high potential, but it is important for the industry to be realistic about its significant remaining challenges and complexities. In order to understand the potential value of each storage technology, one must first have a precise understanding of specific and practical applications. Thus, SCE developed “application preferences,” or the characteristics required to meet the goals of a given application. As an aside, storage technology stakeholders can refer to these preferences when trying to maximize the potential uses of and opportunities for energy storage.
- *Applications must be defined in advance of evaluation.* The application-specific method introduced by SCE proposes a way to practically assess energy storage. Energy storage benefits are best captured by bundling the wide array of potential operational uses. In addition, alternatives to energy storage for each application must be considered to best assess the most cost-effective solution.
- *Policy should be driven by application-based needs.* Storage-related regulation and / or market design should not be based on technological capabilities, but rather derived from application requirements reflecting overall system needs. Storage may be a key tool for meeting broader policy goals (e.g., renewable integration), and should be evaluated as such, rather than as a policy goal in and of itself.
- *Regulatory forums or market agencies such as the FERC, CPUC, CAISO, are the appropriate authorities to address energy storage issues.* These regulatory bodies encourage the use of inclusive stakeholder forums and proceedings. Given the complexity of the energy storage space, and the relevance of energy storage across all parts of the electric value chain, such regulatory forums will be the best entities to facilitate energy storage discussion and ensuing policy. Inclusive forums will promote both broad and deep understanding of the space, including its opportunities and challenges.
- *Research and development is continually needed for energy storage.* Decision-making on storage applications must be based ultimately on the results of R&D and piloting efforts which identify technical and / or operation specifications, as well as demonstrating theoretical benefit streams in reality. As many technologies exist, proving their ability to perform as an integrated part of the electric value chain will be a key rung in the ladder towards larger commercial deployment.

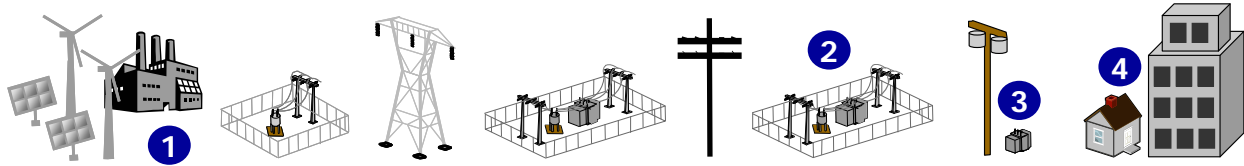
Next Steps for Energy Storage

While identifying promising applications is an important initial step in the successful and cost-effective grid adoption of energy storage, at the end of the day, there is only so much that can be achieved through assumption-driven “strategic assessment” efforts. First, significant regulatory uncertainty remains at the FERC and state utility commission levels, especially concerning cost recovery regimes and asset classification. Other examples include defining the circumstances where a storage application might qualify to provide peak capacity under California’s Resource Adequacy process, as well as better understanding the parameters around storage’s potential participation in both the integration of renewable resources and the provision of ancillary services. Inclusive stakeholder forums scheduled in the near future at both national and state levels should address many of these uncertainties.

Southern California Edison has made every effort to accurately evaluate energy storage applications given currently available information. However, the reader should note that the benefit valuations performed in this study are situation dependent. For example, in the case of distributed intermittent photovoltaic solar energy integration (application 9), benefits accrued from distribution upgrade deferrals are highly specific. The degree of value associated with deferring a system upgrade can vary significantly based on the layout and age of the affected distribution circuit. Also, numerous uncertainties remain concerning future market structures, generation portfolio resource mixes, and the impacts of smart grid components such as electric vehicle charging and smart metrology, not to mention the traditional vagaries of forecasting developments in commodity prices, technology maturation, policy trends, and customer preference. Nevertheless, SCE has attempted to accurately estimate the benefits based on the best available internal and external knowledge.

Each potentially promising application will also require engineering tests and demonstration, preferably through specifically targeted grid projects. These should authenticate operating specifications while validating technology viability and theoretical value propositions. SCE currently is in the process of piloting numerous operational uses in part through its American Recovery and Reinvestment Act funded awards (see Figure 19). In total, SCE has received approximately \$65 million in stimulus funds either for energy storage or related smart grid demonstrations. Such projects can also serve as a bridge between the current “emerging” technology environment and the traditionally risk averse philosophy necessary when considering large long-term investments on behalf of utility customers.

Figure 19: SCE's Primary Energy Storage Pilot Projects



1 Large-Scale Battery Storage		2 Large Transportable Battery System		3 Secondary Distribution-Level Storage		4 Residential Home Energy Storage	
Name	Tehachapi Storage Project (TSP)	Name	Distributed Generation Storage Services Evaluation	Name	Small Distribution Energy Storage System Research	Name	Home Battery Pilot (HBP)
Objective	Evaluate a large lithium-ion battery's ability to increase grid performance & integrate wind generation	Objective	Evaluate transportable, containerized Li-Ion battery systems in field & laboratory trials	Objective	Enhance circuit and system efficiency and reliability by shifting system peaks	Objective	Evaluate home storage integration with customer appliances, solar PV, electric vehicles, etc.
Size	8 MW for 4 hours or 32 MWh	Size	Two 2 MW / 500 kWh units	Size	Distributed units (25kW / 50kWh)	Size	4kW / 10 kWh
Cost	\$53.5 million ~50% ARRA*	Cost	~ \$3 million Part of ISGD** (sub-project 3) as well as other funding	Cost	Part of ISGD** (sub-project 4)	Cost	~ \$3 million Part of ISGD** (sub-project 1)
Timeline	2010-2014	Timeline	2010-2013	Timeline	2011-2013	Timeline	2010-2013

* American Recovery and Reinvestment Act (federal stimulus funding)

** Irvine SmartGrid Demonstration: \$80.2 million project; ~ 50% ARRA funded

Despite numerous unresolved questions and future challenges, Southern California Edison is encouraged by the promise of energy storage. The authors further hope that this white paper provides a degree of methodological order to an otherwise complex and emerging area. As a company, we at SCE look forward to helping develop cost-effective energy storage applications as a means for serving our customers' energy needs with increasingly reliable and environmentally sensitive electricity.¹⁹

¹⁹ For inquires or questions on this paper, please contact energystorage@sce.com

APPENDICES

Appendix A: Benefit / Cost Analysis Assumptions and Data

Overview

SCE's benefit / cost ratios were calculated by setting the complete lifetime operational use-derived value streams (both one-time capital deferrals and ongoing annual operating benefits) over the combined lifetime installed and operating costs of a device.

Figure 20 below describes the main assumptions used in the benefit-cost analyses described earlier in this paper. The rest of this appendix details the specific benefit and cost assumptions used for evaluating each application. The following baseline assumptions apply to each application as appropriate:

Figure 20: Key Assumptions

Benefits (operational use valuation)	Costs (tech installation and operating)
<p>1. Generation capacity:</p> <ul style="list-style-type: none"> • 2011 represented by current procurement price • 2020 uses cost of a new-build peaker <p>2. Energy price forecast:</p> <ul style="list-style-type: none"> • Prices forecasted using historical shapes and values escalated to target end years • Potential intermittent renewables price volatility is not fully captured • Forecast includes GHG pricing assumptions <p>3. Ancillary service forecasting:</p> <ul style="list-style-type: none"> • 3-year average of historical pricing • Escalated at a higher rate than inflation (using preliminary shadow prices of CAISO 33% study) <p>4. T&D capital avoided/deferred cost:</p> <ul style="list-style-type: none"> • Avoided peak D based on SmartConnect and peak DR valuation testimony (apps 7 & 8) • Avoided DG integration D and large-scale T based on SME estimates 	<p>1. Technology system cost:</p> <ul style="list-style-type: none"> • For full systems (e.g., not just battery module) • Uses vendor supplied indicative pricing based on existing technology specifications <p>2. Site preparation and land cost:</p> <ul style="list-style-type: none"> • SME provided based on current storage installations, although this will vary substantially by specific site and technology parameters <p>3. Operating cost:</p> <ul style="list-style-type: none"> • Estimated based on other existing installations, warranty costs, and SME input <p>4. 2020 technology cost forecast:</p> <ul style="list-style-type: none"> • Escalated 2011 pricing for consistency <p>5. Assumed 30% Investment Tax Credit (ITC)</p> <ul style="list-style-type: none"> • Consistent with proposed federal legislation

Many of the benefit-cost analyses were based on a similar set of circumstances. Most of the different applications analyzed shared at least one basic assumption with another application. In particular, the initial and future benefits derived from generation capacity were useful in applications 1, 7 and 8. The benefits derived from ancillary services were useful in evaluating applications 2, 3, 7, 8 and 9. Benefits derived from transmission and / or distribution deferral were used to calculate benefits in applications 1, 7, 8 and in particular 9. The avoided costs of transmission losses due to congestion were also utilized to evaluate applications 7 and 8. The only two applications that did not share assumptions were 10 and 12, which were both end user specific. They derived their primary value from the avoided costs of consumers paying SCE retail rates for electricity. Application 3

was also unique in that it required the hypothetical inclusion of energy storage into regulation up and down markets. In that case, a small change in the basic parameters of the model could drastically change the end result of the analysis. We believe this model represents a reasonable possibility of what could happen in the coming years in CAISO ancillary markets. As such, there was no assumption regarding a large restructuring of these markets; rather small “tweaks” to accommodate an energy storage device under current circumstances.

Costs used a consistent framework for applications 1-9. All costs used actual vendor-supplied indicative pricing. Also considered were the Investment Tax Credit, Federal and State Taxes, asset life, average O&M, the salvage value (or cost to decommission), and installation costs. These costs used the utility revenue requirement capital model including standard debt / equity, tax, and depreciation assumptions as well as a consistent discount rate. In applications 10 and 12, the costs were incurred by end users. Hence, we did not address federal or state investment credits or subsidies, or use utility capital models. Instead, the costs simulate the simplified end user costs of purchasing, installing and maintaining the energy storage system over its lifetime.

Application 1

Benefits:

- Initial costs of **capacity** are based on the market price from open solicitations for existing generation; however the potential benefits increase dramatically in future years to reflect that the cost has to include the price of building new generation capacity. In 2002, the CPUC estimated \$71.82 / kW-yr²⁰ in fixed costs to build a Combustion Turbine power plant, which was escalated at 3% annually to 2020.
- The **integration adder for wind** according to initial BPA estimates is \$4 / MWh, which was escalated at 2% annually.
- **Transmission upgrade deferral** savings were based on a study done by the Berkeley National Laboratory. This estimated that median transmission costs equal \$300 / kW with a mean cost of \$450 / kW²¹.
- **Energy arbitrage** values are based on the three year average (2007-2010) of CAISO market prices for 2011. The 2020 forecast escalates these 2011 prices at 8%, which reflects both aggressive increases in energy price growth as well as carbon emission adders.

Costs:

- For 300 MW pumped hydro station
 - 60 year asset life
 - 30% Investment Tax Credit (ITC)
 - DB (declining balance) 20 federal tax

²⁰ E3: Energy + Environmental Economics. “CPUC Avoided Cost Workshop” Powerpoint presentation for CPUC forum on June 30 and July 31, 2004.

²¹ Mills, Andrew, Ryan Wisser and Kevin Porter. *The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies*. Rep. no. LBNL-1471E. Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory, 2009

- DDB (double declining balance) 50 state tax
- 0% salvage value; 9.5% clean-up cost (cost to decommission)
- Capital and benefit escalation 2% annually
- Total all-in cost of \$3,000 / kW
- \$172,000 annual O&M (based on current pumped hydro plant experience)
- For 20 MW sodium sulfur battery
 - 15 year asset life
 - 30% ITC (federal Investment Tax Credit)
 - DDB 5 federal tax
 - DDB 28 state tax
 - 0% salvage value; 0% clean-up cost
 - Capital and benefit escalation 2% annually
 - Total system cost of \$4,250 / kW, of which 40% was installation related (site preparation, power conditioning system, controls, etc.) and 60% was for the battery technology purchase
 - \$200,000 annual O&M (based on warranty costs)

Application 2

Benefits:

- Used current regulation pricing as a proxy for the value of a minute-to-minute hypothetical “smoothing cost.” The cost of regulation is based on a three year average (2007-2010) of CAISO market prices for both regulation up and regulation down escalated 7% annually. The 7% annual inflation represents the reasonable, if perhaps aggressive, assumption that the total value of regulation ancillary services will double in ten years.
- Used current spin pricing as a proxy for the value of a 15-30 min hypothetical “shaping cost.” The cost of spin utilized the three year average (2007-2010) of CAISO market prices for spin escalated at 4% annually. We chose 4% based on the historical trend of spin ancillary prices, which were above the annual inflation rate, but did not suggest that prices would double in ten years.

Costs:

- 10 MW flywheel
 - 20 year asset life
 - 30% ITC
 - DDB 5 federal tax
 - DDB 28 state tax
 - 0% salvage value; 0% clean-up cost
 - Capital and benefit escalation 2% annually
 - Total system cost of \$3,400 / kW, of which 33% was installation related (site preparation, interconnection, land cost, etc.) and 66% was for the all-in flywheel system technology purchase.
 - \$100,000 annual O&M
- 10 MW lithium ion battery
 - 20 year asset life

- 30% ITC
- DDB 5 Federal Tax
- DDB 28 State Tax
- 0% salvage value; 0% clean-up cost
- Capital and benefit escalation 2% annually
- Total system cost of \$3,400 / kW, of which 33% was installation related (site preparation, interconnection, land cost, etc.) and 66% was for the all-in battery system technology purchase.
- \$100,000 annual O&M

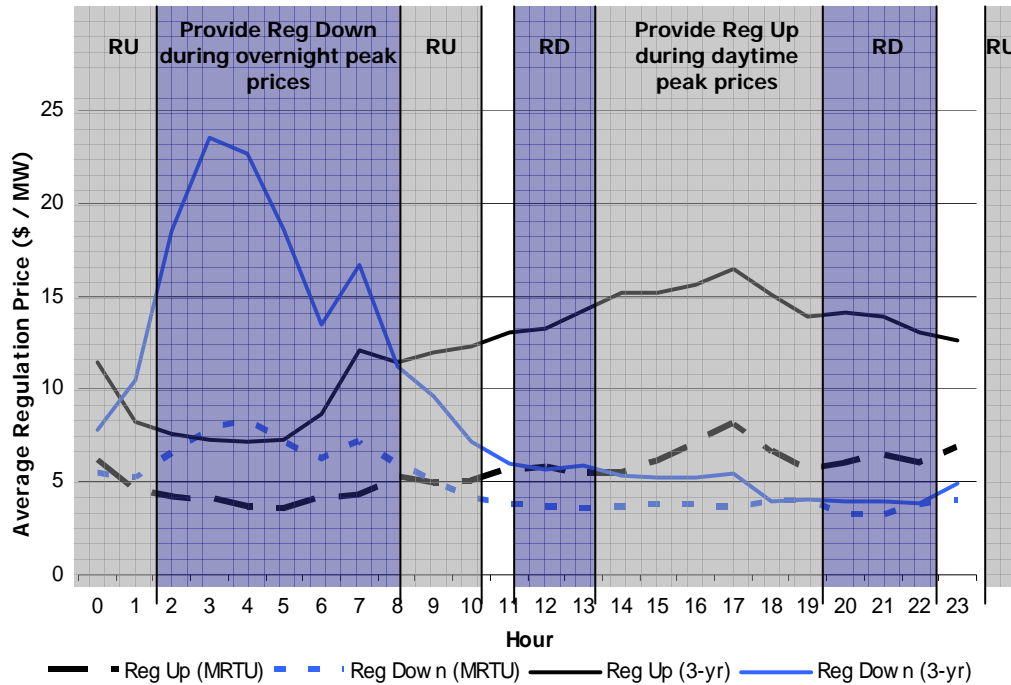
Application 3

Market Structure Assumptions and Benefit Analysis:

- Regulation pricing is based on the three year (2007-2010) average of CAISO market prices from both reg-up and reg-down, escalated 7% annually. The 7% annual escalation represents the reasonable, if perhaps aggressive, assumption that the total value of regulation services will double in ten years.
- Our hypothetical model considered a variety of aspects about current market design, and made assumptions in order to accommodate storage's limited energy resource constraints.
 - The separation of regulation up and regulation down into two distinct market products limits the ability to effectively manage charge on storage devices as well as excludes the possibility of "mileage" payments.
 - The market is relatively small. In 2009 the total ancillary service market value (MW procured times marginal price) was about \$60 million, which was heavily influenced by peak regulation up and spin prices.
 - SCE's obligation is less than 50% of the total market
 - The CA market does not yet "pay for performance." Speed of delivery does not affect the price paid for an ancillary service. (The one exception is for operating reserves (spin and non-spin), where obligations are slightly reduced if provided by hydro resources.) This said, we assumed per current protocols that storage assets would be automatically dispatched first due to their faster response times.
 - Storage resources are only paid for regulation capacity (and availability). Real-time energy was assumed to be revenue neutral (over the long run).
 - Prices tend to be volatile, with oversupply dropping prices rapidly. However, this reduction may be offset over the long-run by increased demand from renewable integration. Ancillary service pricing is also highly sensitive to bidding behavior and market liquidity.
 - Current AS markets require two hours of energy to participate, although this is being changed to half an hour, which was assumed for this work.
 - The 2009 Market Redesign and Technology Upgrade (MRTU) has caused shifts in historical AS pricing. Using a three-year average may help to balance out the "new market" effect.
 - Given the limited energy aspect of storage, this work assumed dispatches in 1 minute increments to allow for other resources to ramp.

- Figure 21 below shows our attempt to model a theoretical energy market for regulation capacity given the above constraints. The energy device can bid for both regulation down and regulation up capability (but not be awarded both simultaneously). The CAISO calls a device for 5 1-minute ramps (either up or down) each hour it provides capacity, such that the device is optimized to fully discharge during higher on-peak regulation up prices and fully recharge during higher off-peak regulation down prices.

Figure 21: Hypothetical Model of Reg Up / Reg Down for CAISO



- As shown by the above chart, revenues are maximized by selling regulation up and regulation down around their known price variations (e.g., sell regulation down from about 1 AM to 8 AM during peak prices and sell regulation up from 1 PM to 7 PM during its peak pricing.)
- Use “shoulder” periods to bid services which prepare storage device for the next primary period. Two total hours are reserved without bidding to allow the device to charge / discharge in anticipation of needs for the next period (i.e., empty off-peak, full on-peak) as required.

Costs:

- 20 MW flywheel
 - 20 year asset life
 - 30% ITC
 - DDB 5 Federal Tax
 - DDB 28 State Tax
 - 0% salvage value; 0% clean-up cost

- Capital and benefit escalation 2% annually
- Total system cost of \$2,700 / kW, of which 25% was installation related and 75% was for the all-in flywheel technology purchase.
- \$100,000 annual O&M

Application 4

- No further analysis, see page 28.

Application 5

- No further analysis, see page 28.

Application 6

- No further analysis, see page 28.

Application 7

Benefits:

- Initial costs of **capacity** are based on the market price from open solicitations for existing generation; however the potential benefits increase dramatically in future years to reflect that the cost has to include the price of building new generation capacity. In 2002, the CPUC estimated \$71.82 / kW-yr¹⁷ in fixed costs to build a Combustion Turbine power plant which was escalated at 3% annually. Additional value was also given to this application for its **in-basin** location attributes.
- **Transmission upgrade deferral** savings were based on a study done by the Berkeley National Laboratory. This estimated that the median transmission costs will be \$300 / kW and mean costs will be \$450 / kW¹⁸.
- The value associated with the benefits of **deferred upgrades** for peaking infrastructure costs in the distribution system amounted to a sizable proportion of the total benefits and was based on demand response's cost-effectiveness methodology testimony in June 2008.
- The value associated with the avoided cost of **congestion fees** and losses was calculated using one year of historical data (2009-2010) from a representative pathway (Four Corners-Moenkopi) escalated at 2% annually.
- **Energy arbitrage** values are based on the three year average (2007-2010) of CAISO market prices for 2011. The 2020 forecast escalates these 2011 prices at 7%, which reflects both aggressive increases in energy price growth as well as carbon emission adders.

Costs:

- 2 MW lithium ion battery
 - 20 year asset life
 - 30% ITC
 - DDB 5 federal tax

- DDB 28 state tax
- 0% salvage value; 0% clean-up cost
- Capital and benefit escalation 2% annually
- Total system cost of \$7,200 / kW, of which 45% are installation costs (relocation, site preparation, interconnection, etc.) and 55% are for technology purchase.
- \$10,000 annual O&M

Application 8

Benefits:

- Initial costs of **capacity** are based on the market price from open solicitations for existing generation; however the potential benefits increase dramatically in future years to reflect that the cost has to include the price of building new generation capacity. In 2002 the CPUC estimated \$71.82 / kW-yr¹⁷ in fixed costs to build a Combustion Turbine power plant which was escalated at 3% annually. Additional value was also given to this application for its **in-basin** location attributes.
- **Transmission upgrade deferral** savings were based on a study done by the Berkeley National Laboratory. This estimated that the median transmission costs will be \$300 / kW and mean costs will be \$450 / kW¹⁸.
- The **deferred cost of distribution** system upgrades was based on peak reduction valuations associated with the SmartConnect AMI business case, as testified to the CPUC in July 2006.
- The value associated with the avoided cost of **congestion fees** and losses was calculated using one year of historical data (2009-2010) from a representative pathway (Four Corners-Moenkopi) escalated at 2% annually.
- **Energy arbitrage** values are based on the three year average (2007-2010) of CAISO market prices for 2011. The 2020 forecast escalates these 2011 prices at 7%, which reflects both aggressive increases in energy price growth as well as carbon emission adders.

Costs:

- 25 kW lithium ion battery (4 hours of energy)
 - 20 year asset life
 - 30% ITC
 - DDB 5 federal tax
 - DDB 28 state tax
 - 0% salvage value; 0% clean-up cost
 - Capital and benefit escalation 2% annually
 - Total system cost of \$4,800 / kW, of which about 15% are installation costs with 85% for the all-in battery system technology purchase.

Application 9

Benefits:

- The primary benefits are derived from the **deferred cost of distribution upgrades** which reflect internal subject matter as expertise on the cost of a potential representative upgrade. This value will be extremely project specific.
- There would be a net wash of positive **real-time arbitrage opportunities** and negative losses of efficiency over time as the storage device would be optimized to support distribution deferral and not take advantage of arbitrage opportunities.
- The **avoided cost of regulation procurement** is based on the three year average of CAISO market prices from both regulatory up and regulatory down (2007-2010) and escalated 7% annually. The 7% annual inflation represents the reasonable assumption, if perhaps aggressive, that the total value of CAISO ancillary services will double in ten years.
- **Outage mitigation** did not receive a quantitative value in this evaluation.

Costs:

- 500 kW lithium ion battery (15 mins of energy)
 - 20 year asset life
 - 30% ITC
 - DDB 5 federal tax
 - DDB 28 state tax
 - 0% salvage value; 0% clean-up cost
 - Capital and benefit escalation 2% annually
 - \$3,000 annual O&M
 - Total system cost of \$810 / kW, of which 15% is installation related and 85% is for the all-in battery system technology purchase.

Application 10

Benefits:

- Revenues from arbitraging on and off-peak retail TOU rates with the following assumptions:
 - There were a variety of potential sizes ranging from 3-10 kW homes, to 10-300 kW businesses. These various types of end users have different preferences, rate structures, and consumption patterns.
 - Consumers are rational in that they are able to choose between TOU rates and non-TOU rates. Additionally, they will install the amount of battery capacities that best suits their needs.
 - SCE increases their peak period retail rates by the extremely aggressive assumption of 5% annually.

Costs:

- Technical assumptions for a 30 kWh-per day usage home, the primary focus of our analysis, include the following aggressive assumptions:
 - 10 kW / 60 kWh lithium ion battery

- 20 year asset life
- 95% AC-to-AC battery efficiency
- 8% discount rate (10% for 300kW business)
- \$1,000 / kW
- \$100 O&M annually over a 20 year asset life

Application 11

- No further analysis, see page 28.

Application 12

Benefits:

- There were three primary groups analyzed, including single family homes, 20 person communities and large businesses, each with their own optimal battery and photovoltaic system.
- Benefits are derived from the avoided costs of paying SCE retail rates for electricity which were escalated at the extremely aggressive assumption of 5% annually.
- The cost of the forming a micro-grid assumes that the community is completely isolated from an alternative power grid; if the end user is attached to an outside grid then homes with net metering derive no value from storage. If a home is connected to the broader system, then under current net metering programs the grid acts as a “battery”, supplying the home with electricity when the photovoltaic system is no longer producing. Therefore, the battery only has value to an end user if he / she is completely separated from the grid.

Costs:

- Technical assumptions for a single residence, the primary focus of our analysis, include the following aggressive assumptions:
 - 3 kW / 30 kWh lithium ion battery
 - 20 year asset life
 - 95% battery efficiency
 - 10% discount rate
 - \$1,000 / kW
 - \$100 O&M annually over a 20 year asset life
 - Solar PV installed system cost of \$6 / Watt

Appendix B: The Effect of Diminishing Returns on Energy Shifting Value

Problem Definition

There are limits to the market potential for energy storage, especially concerning energy shifting uses. This addresses the situation where a storage device charges (purchasing energy) during off-peak times when prices are low, to then discharge (selling energy) during more expensive on-peak hours. Each additional unit of storage is less valuable than the last, as the most expensive on-peak and least expensive off-peak hours give way to more moderate pricing. In addition to this “marginal decline”, every one MW of shifted energy has a dual effect on prices, as the off-peak increases by a MW, and the on peak decreases by a MW less the efficiency lost of the device. For example, a one MW device with 80% efficiency has a quantitative impact of 1.8 MWs on the on-off peak spread. While initial application valuations did not utilize such a “diminishing returns to scale” model, SCE conducted further analysis to better illustrate the liquidity boundaries of energy shifting. This model does not claim predictive capabilities, and instead should be considered a preliminary illustrative attempt to address a complex analysis question.

Methodology

SCE used historical data and regression analysis to model the question, “If the gas price is held constant, how much does an additional megawatt of storage affect the difference between the on-peak, off-peak pricing spread in California day ahead energy markets?” The results of this analysis were used to model the optimal performance and market limit for storage in each relevant application.

Analysis Example

A key benefit of application 1 was derived from energy shifting revenues. Given declining returns to scale, benefits associated with this application prove to be a decreasing function of market penetration as shown in Figures 22 and 23.

Figure 22: Total Marginal Benefit of Additional MW of Storage

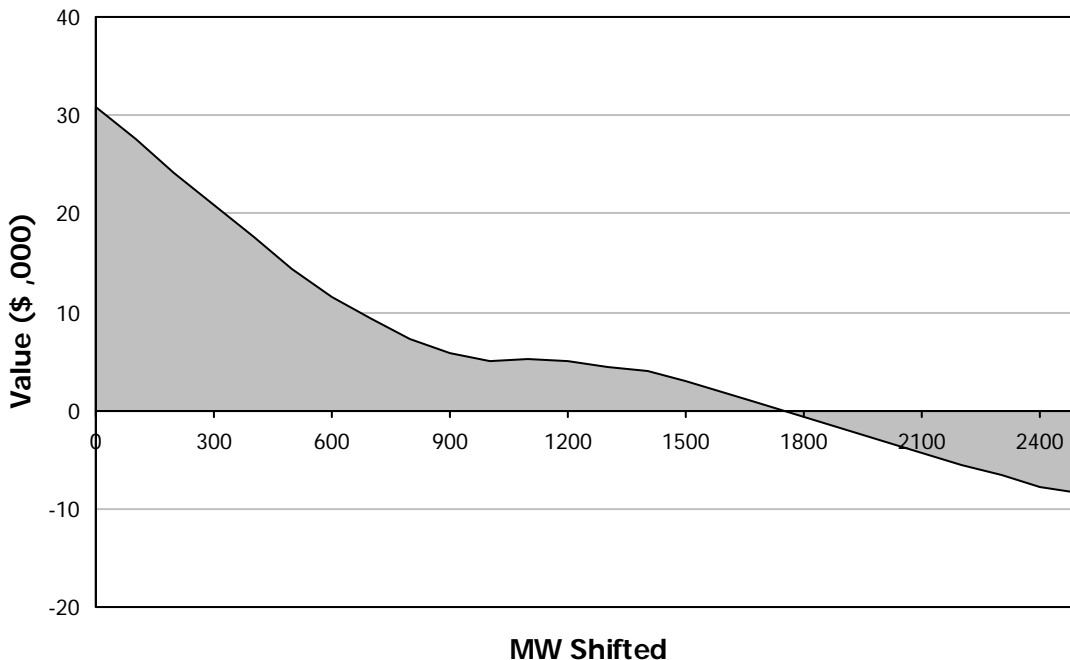
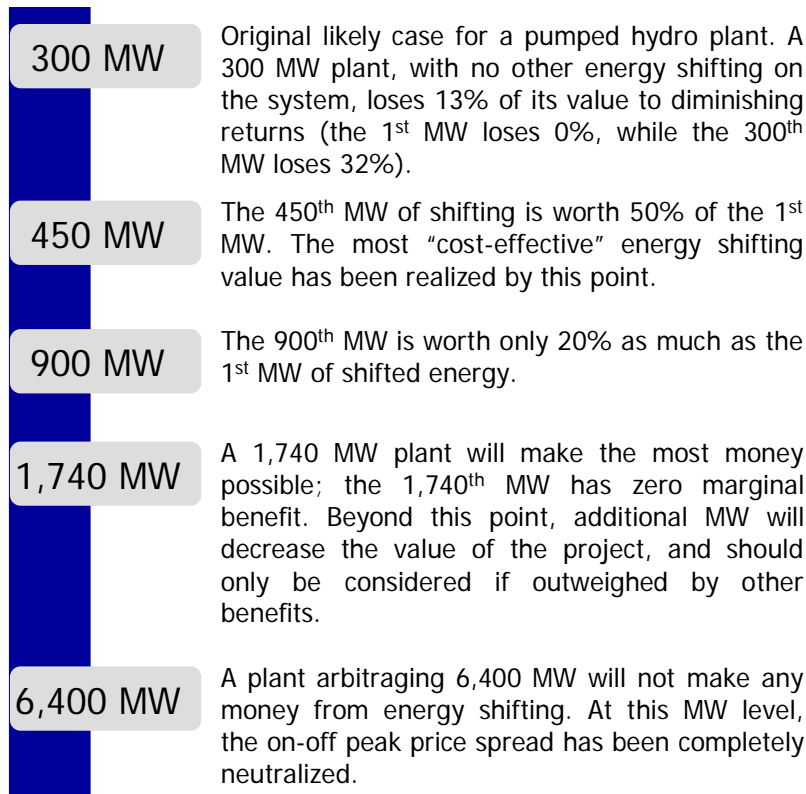


Figure 23: Description of Application 1 at Benchmark MW Levels

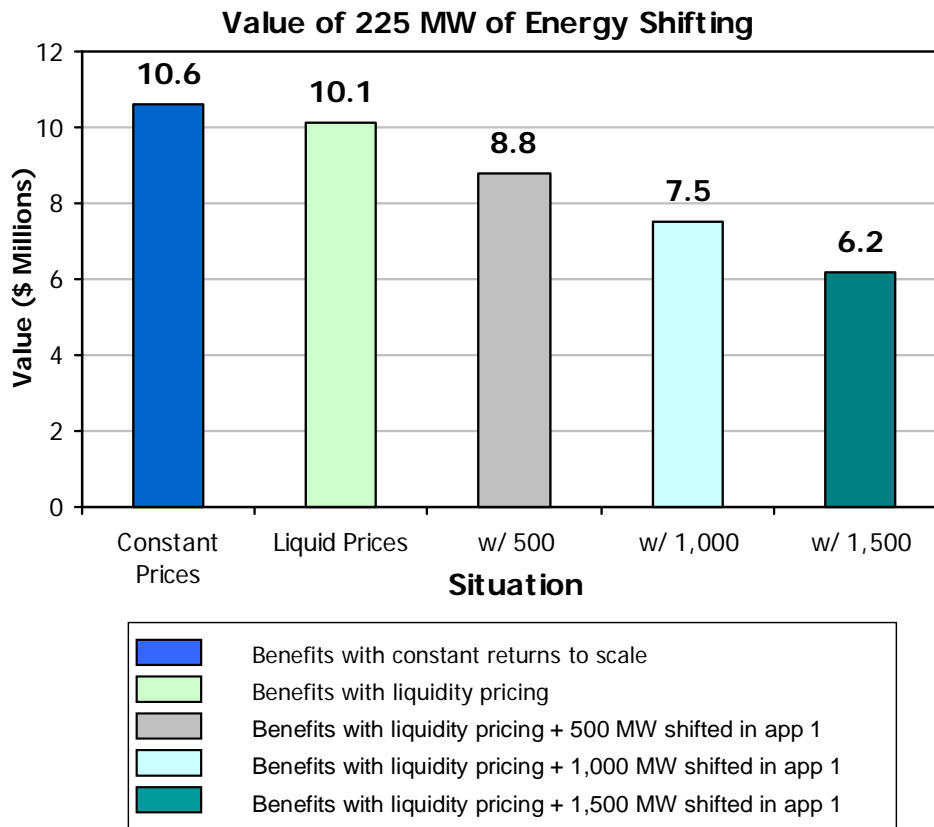
Benchmark MW Levels with Market Description



As figures 22 and 23 demonstrate, only the first few large scale products will realize marginal energy shifting benefits that can be captured by an energy storage system. Additional projects would need to be justified from other benefits and would additionally erode the future value of the original projects.

While applications 1 and 8 are both affected by the diminishing returns pricing model SCE developed, application 8 has less of an overall impact on the market. While six 300 MW pumped hydro plants could completely eliminate the marginal benefits from energy shifting, even as many as 9000 25 kW units only aggregates to 225 MWs of storage. 225 MWs corresponds with approximately 1% of SCE’s peak system load, and also reflects a reasonable-to-high assumption of deployed units to mitigate distribution concerns. Because of its relative size, application 8 will be dependent on the market pricing instead of driving it (as in application 1). Figure 24 below shows that while 225 MW of storage only decreases total energy shifting value \$500,000 or roughly 5%, 500 MW of additional peak load shifted through application 1 will reduce the value by an additional \$1.3 million or about 13%.

Figure 24: Value as a Function of Total Amount of Peak Load Shifted



Diminishing returns to scale also impact ancillary service markets and thus the value associated with application 3 (and potentially application 2). It is widely understood by industry experts that ancillary service prices are especially inclined to follow changes in market liquidity. However, calculating these effects requires a complex understanding of bidding behavior, future market design, and localized system constraints. Such an analysis was out of scope for this storage report.

Caveats to the diminishing returns analysis:

The regression coefficients used to calculate diminishing returns to scale for this analysis are based on several years of historical hourly price forecasting. There are two primary issues with this data set:

1. Prior to April 2009, official hourly market pricing did not exist in day-ahead CAISO markets. SCE-internal forecasts were used as a proxy.
2. Historical data will not perfectly predict future trends and changes to on-off peak pricing. Uncertainty around the effects of increasing amounts of variable generation renewable resources, market design changes, commodity prices, and state / federal policy will likely deviate from historical pricing trends.

This analysis and associated conclusions should be considered as an informed attempt to address an extremely complex market question; and not a definitive reflection of SCE’s procurement or market viewpoints.

Appendix C: Energy Storage and Greenhouse Gas (GHG) Emissions

Greenhouse gas reductions are an often-referenced benefit of energy storage. Closer examination illuminates the complexity of storage’s impact on GHG emissions. The following variables determine GHG accounting:

1. Application Specificity: as with much of storage, GHG emissions are determined by application. A device which charges off-peak to discharge on-peak will have different emissions calculations than one which smoothes minute-to-minute on-peak output variations. The application will also determine potential system losses between the charge and discharge time periods.
2. Device Efficiency: the more efficient a device, the less energy is lost in the charge-discharge cycle. As such, higher efficiencies often translate to lower emissions.
3. Marginal Portfolio Emissions Rates: Each generating time period will have a marginal emissions profile (the emissions quotient for the next energy unit either created or avoided.) As storage either adds to (charging) or subtracts from (discharging) the existing load stack, marginal metrics are the most accurate. In California, typically single-cycle gas-fired units are marginal on peak, with combined cycle gas turbines off peak. However, in much of the rest of the United States, coal-fired generation is on the margin off peak, compared with gas on peak. In these places, storage will clearly raise emissions rates in an off-to-on peak energy shifting application.

The following chart illustrates monthly GHG savings using 2010 historical monthly implied market heat rate data from the CAISO for off and on peak periods.

Figure 25: Emissions Savings From A Device Shifting Energy Off To On Peak²²

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Weighted Average
4%	4%	7%	14%	18%	26%	16%	13%	18%	11%	8%	3%	12%

Given the above profiles, a 1 MW, 6 hour, 75% roundtrip efficient device operating every day in SCE’s portfolio would abate approximately 95 metric tons of carbon over the course of a year. By way of comparison, the average annual per capita carbon emissions in the United States is approximately 20 metric tons.²³

As noted earlier in Appendix A, to account for the potential benefit of GHG in its evaluations, SCE included a carbon value in its energy price escalation assumptions.

²² Assumptions:

- 75% roundtrip AC-to-AC efficiency
- 2.5% average difference in system losses between on and off peak
- One year of data; nuances of weather and loading order will change percentages every year
- From perspective of SCE’s resource portfolio, loading, and marginal carbon emission factors

²³ <http://www.eia.doe.gov/oiaf/ieo/emissions.html>

END