Benefit Analysis of Energy Storage: Case Study with the Sacramento Utility Management District

2011 TECHNICAL REPORT

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EPRI Project Manager
D. Rastler

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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Energy and Environmental Economics, Inc.
101 Montgomery St., Suite 1600
San Francisco, CA 94104

Principal Investigator
E. Cutter

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Abstract

Energy storage systems may support several electric utility use cases, including grid support, outage mitigation, capital deferral, and improved services to end users. Electric Power Research Institute (EPRI) research in 2009 developed analytics and methods to quantify the locational value of electric energy storage options. The objectives of this project are to apply previously developed and generic energy storage dispatch models and evaluation methods to several cases and locations in the Sacramento Municipal Utility District (SMUD) service territory.

The following key locations were investigated:

- Commercial and residential energy storage systems on the customer side of the meter
- Neighborhood-located storage systems on the SMUD side of the meter
- Substation and transportable storage systems for grid support

This analysis shows that for applications of energy storage located in the SMUD system, regulation and system capacity are the benefits that drive high values. The highest value utility-owned battery applications—both at the substation and as distributed energy storage systems—involve the accrual of regulation and system capacity benefits. The analysis further shows that storage located at the substation has the potential for the greatest benefit to the utility in the near term; substation storage requires less need for the aggregation of many smaller units to capture benefits. Substation storage is most valuable because it can accrue the high-value benefits of regulation, system capacity, and deferral of transmission and distribution investments.

A behind-the-meter storage system could have retail bill impact benefits for customers, but these benefits are lower than the benefits of utility-operated storage. The aggregation of customer-sited storage systems has the potential to combine the retail rate savings seen by the customer with the higher value system and distribution benefits for the utility. In general, for the applications examined in this report, energy storage system life cycle costs will need to fall to approximately $500/kWh or below in order to make batteries cost effective.

Recommendations detailed in the report include 1) monitoring and following developments and trends in energy storage technologies and 2) conducting studies on the best way to integrate transportable substation battery systems into distribution investment planning and to extract system benefits from applications installed by customers or third parties and operated to optimize customer benefits.

Keywords
Battery applications
Distribution planning
Energy storage systems
Grid support
Renewables

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Section 1: Executive Summary

Introduction

Energy storage systems may support a number of electric utility use cases including grid support, outage mitigation, capital deferral and improved services to end-users. EPRI research in 2009 developed analytics and methods to quantify the locational value of electric energy storage options. This work is reported in EPRI Reports:

- Energy Storage Market Opportunities: Application Value Analysis and Technology Gap Assessment, 2009, Product ID: 1017813
- Electricity Energy Storage Technology Options, A White Paper Primer on Applications, Costs and Benefits, 2010, EPRI Report ID 1020676
- Li-ion Energy Storage Market Opportunities, Application Value Analysis and Technology Gap Assessment, 2010, EPRI Report ID 1017813

The research used generic market data to develop methods and a dispatch model. The Sacramento Municipal Utility District (SMUD) wanted to evaluate the methodology including assessment of the costs and benefits of energy storage applications at up to four locations on SMUD's system. Earlier research used a number data sources to quantify the benefits of energy storage in five ISO markets across the US. This analysis will extend that work by working with SMUD to identify specific system and operational benefits at actual sites.

Objectives

The objectives of this project are to apply earlier developed and generic energy storage dispatch models and evaluation methods to several cases and locations in the SMUD service territory.

- Evaluation of Residential Energy Storage Systems.
- Evaluation of neighborhood located storage systems on the SMUD side of the meter.
- Evaluation of Substation and Transportable Storage systems for Grid support and to provide a comparison for SMUD of all three use cases.

SMUD's Planned Energy Storage Demonstrations

SMUD is planning to host two battery storage demonstration projects. The first storage project will be located at SMUD's headquarters. This battery will study emergency operations such as islanding, and will also be used to charge during off-peak hours and discharge on-peak in order to save wholesale energy charges.

The second storage project will be located at the Anatolia Substation which serves a SolarSmart Homes^{SM} community in Rancho Cordova, California. This project will examine the impact of energy storage as it pertains to management of distributed PV generation within the distribution circuit. SMUD will also be installing smart metering in the Anatolia subdivision so that peak load can be managed in conjunction with distributed PV generation.

Both storage systems will be controlled from a common control system to demonstrate fleet control of multiple distributed storage devices. The SMUD battery storage analysis presented in this report models the potential benefits that battery storage devices could accrue. The report does not try to predict the operating characteristics of the two battery demonstration project but rather examines what the optimal operating characteristics of a battery on the SMUD system would be.

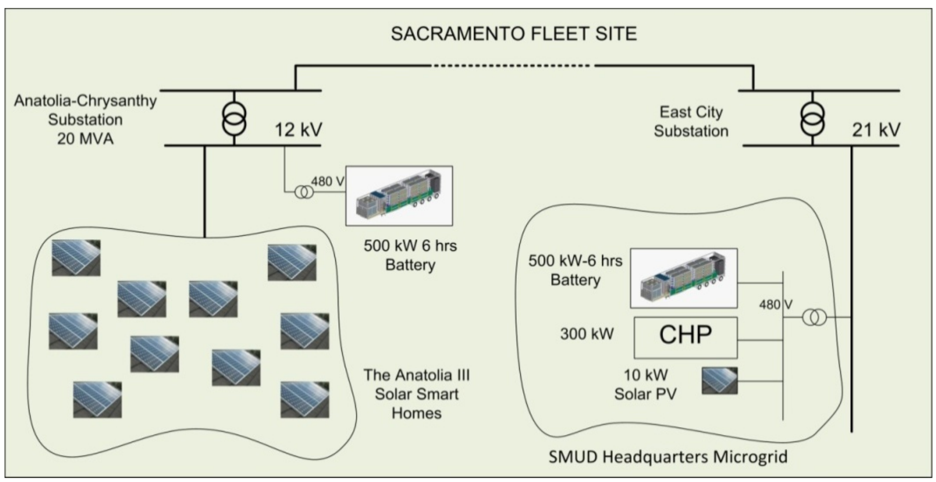

Figure 1-1
SMUD Storage Demonstration Projects

Applications Studied

The list of energy storage applications for study was selected on a combination of factors. One primary concern was to look at applications in which the benefits accrued are similar to those that could be accrued by the SMUD battery demonstrations. This led researchers to choose applications that include the benefits of wholesale energy peak to off-peak arbitrage as well as support for a distribution feeder with high penetration distributed solar. Researchers also, however wanted to model the potential values available to batteries in different locations along the distribution network. For this reason applications where chosen that would be located at the utility substation, the final line transformer/pad mount, and on the customer side of the meter.

Transportable Distribution Deferral

The transportable distribution deferral application represents a battery located at the utility substation. It would be owned and operated by the utility. A 1 MW system with either 2 hours or 4 hours of storage was modeled for this application. The application would most likely take the form of a large battery on a relocatable trailer.

Distributed Energy Storage Systems (DESS/CES)

The distributed energy storage system (DESS) (also known as community energy storage or CES) application represents a system of networked batteries that would be located along the distribution system either pad mounted or at the final line transformer. The batteries would be owned and operated by the utility. Researchers modeled the battery system as an aggregated 1 MW system with 2 hours of storage.

PV Load Shifting

The PV load shifting application models a battery that would be located along a distribution system with a high concentration of distributed solar installations. The battery would be owned and operated by the utility. Researchers modeled the battery as a 1 MW system with 2 hours of storage.

Commercial Energy Management

The commercial energy management application represents a battery located at a commercial site on the customer side of the meter. It would be owned and operated by the customer. Researchers modeled the battery as a 1 MW system with 2 hours of storage. Because the benefit values modeled are presented in a $/kWh basis, the results of this application would be applicable for a smaller commercially owned battery as well.

In general, researchers modeled application benefit values of the Total Resource Cost (TRC) or regional perspective using CAISO and SMUD data. For the energy management applications, however, the benefit values TOU energy charge savings and demand charge reduction represent a loss of revenue to the utility. These benefits, therefore, are modeled from the customer or Participant Cost Test perspective (PCT). The customer would own the system so the customer perspective is more applicable for evaluating the battery investment decision, but researchers modeled the application from both perspectives.

Aggregated Energy Management with Grid Support

The aggregated energy management application represents a system in which multiple customer-owned batteries are aggregated and operated by an energy services company. The batteries would be located at the customer side of the meter, but by aggregating the batteries, it was assumed that the energy services company would be able to negotiate with and provide benefits to the utility or wholesale energy market. Researchers modeled the aggregated system as a 1 MW system with 2 hours of storage. Because the benefit values modeled are presented in a $/kW-h basis, the results of this application would be applicable for the individual commercially owned batteries minus the transaction costs of aggregation. Similar to the commercial energy management application, researchers modeled this application from both the customer and TRC perspective.

Application Value Summary

Figure 1-2 presents a summary of the estimated application benefit values as the present value (PV) in $/kWh of energy storage installed over the life of the battery (15 years). Target values represent the benefits applicable for the broader CAISO – SMUD market while high values represent the benefits available for smaller niche or high value markets within SMUD.

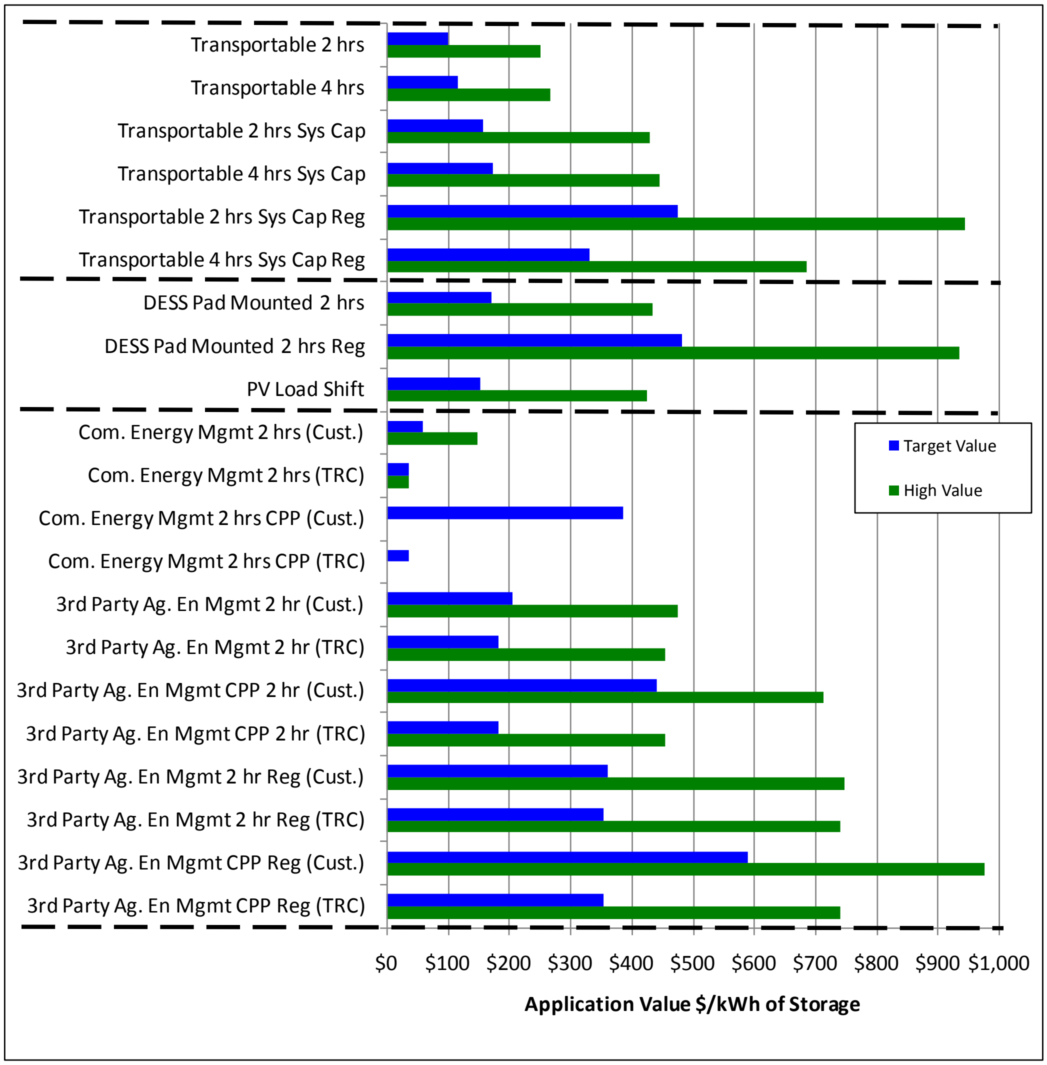

Figure 1-2
Summary of Application Present Value Benefits by Location: Substation, Feeder, Customer-side of Meter

Key Benefits for SMUD

Regulation

In many cases the highest benefit value available to energy storage devices is that of bidding into the wholesale ancillary services market for CAISO regulation service. Researchers modeled the benefit values available in SMUD for this service as those from the CAISO regulation market. These values assume that the battery is able to meet all technical and communication requirements necessary to bid into the CAISO regulation market or alternatively that the battery can provide SMUD with regulation service at SMUD's avoided cost of bidding into the CAISO market.

System Capacity

Another potential benefit value for storage devices is the provision of system capacity. A battery in the SMUD system could provide capacity value for SMUD or participate in bilateral Resource Adequacy markets implemented by the CPUC. Furthermore, there may be congested or capacity-constrained locations in the SMUD system in which providing local capacity would be even more valuable than the California-wide values modeled in this report (a congestion analysis for the SMUD system was not in the scope of this study). System capacity has the potential to be a high value benefit, but it may be limited for some time. Due to the economic slowdown in California and the addition of renewable generation, capacity in excess of the targeted 15% reserve margin is likely to exist past 2020, even when accounting for planned retirements of fossil plants.

Lower Value Benefits

Distribution Deferral

In principal, a battery can be operated by a utility to reduce peak loads and thereby defer distribution system investments needed to accommodate anticipated load growth. Distribution deferral was one of the key high value benefits identified in the 2009 EPRI Storage Valuation and Gap Analysis. SMUD distribution engineers, however, do not believe there are widespread opportunities for distribution deferral in the SMUD system. SMUD's distribution system configuration provides a high degree of flexibility in switching and re-routing to avoid overloading. In addition, in many cases the cost of upgrading distribution equipment is borne by the connecting customer rather than by SMUD. Nevertheless, researchers used the SMUD distribution plan and consultations with SMUD distribution engineers to determine the potential distribution benefit that an energy storage system could receive under the right conditions for deferring investments in the SMUD system.

Benefits Difficult to Quantify

Distributed Solar Smoothing/Integration

Utility engineers are concerned that the increasing penetration of distributed renewable generation will pose challenges for local distribution systems. Energy storage systems can provide services to smooth and integrate distributed generation. The value of such services, however, is difficult to quantify at this point. The primary benefit is allowing utilities to accommodate higher levels of distributed solar generation in support of RPS and GHG policy goals. Because distributed solar generation is one of the more expensive renewable options and because the penalties for not meeting RPS and GHG targets are highly uncertain, it is not possible to calculate a dollar value for this benefit. Nor are the costs of alternative means of accommodating distributed solar generation well known. It is unclear at what level distributed solar generation will cause problems on a particular feeder as equipment and feeder schematics vary. Traditional distribution system equipment cannot address all of the challenges posed by high concentrations of distributed solar generation and alternatives such as advanced inverters are not yet widely commercially available. A survey of available advanced dynamic solar inverters found costs to range from $100-400/kW-yr levelized over 5 years. However, it is uncertain that either the advanced inverter or the battery could mitigate all the potential challenges posed by distributed solar generation to the distribution system.

Customer Benefits

Reliability

Storage, when operating on the customer side of the meter or on the distribution grid for islanding, can be used to ride though outages of a limited duration. The battery at SMUD's headquarters to study emergency islanding operations will shed light on how the operation of batteries for reliability will work. The value of increased reliability in this analysis is done using national surveys of customer value-of-service as well as SMUD-specific outage statistics.

Bill Reduction

The benefit of customer bill reduction comes in the form of both TOU energy charge savings and demand charge reductions. Researchers modeled these savings by looking at examples of SMUD electricity tariffs that include TOU rates and/or demand charges. Researchers also examined the potential savings from storage for a customer on a critical peak pricing tariff (CPP) rate. SMUD does not currently have a CPP rate but may introduce one in the future so researches used as an example a CPP rate currently used in San Diego.

Looking To the Future

All the benefit values and applications modeled are designed to look at the potential values that storage can provide today. There are several developments that are likely to impact the economics of energy storage in the near future.

15 Minute Regulation

CAISO, ISONE, NYSIO and PJM are all moving forward with either pilot programs or tariff changes that will allow energy storage and demand response to provide regulation with 15 minutes of energy delivery capability. Reducing the delivery requirement from 1 hour to 15 minutes dramatically improves the economics of energy storage on a $/kWh basis.

To accommodate limited energy delivery and take advantage of faster response and ramp rates, some ISOs are employing modified dispatch algorithms for non-generation or limited energy resources. These modifications include providing a frequency only based signal (PJM), eliminating the requirement to bid regulation resources into the energy market (NYISO), active ISO control of the energy storage level to maximize regulation capacity (NYISO), dispatching fast responding resources first (ISONE, NYISO) and providing mileage or pay for performance payments (ISONE). Energy neutral dispatch and compensation for fast response provide a particularly attractive opportunity for energy storage, which is often limited either by technology or economics in the amount of energy that can be provided. With some of the alternatives described above, potential revenues on a $/kWh basis could increase significantly from $1,000/kWh to over $6,000 /kWh of energy storage in some markets.

Fast Regulation

Technology companies have argued that storage systems can respond much faster to regulation signals that traditional fossil and hydro generation and that they therefore provide a greater value. As evidence they cite the Pacific Northwest National Laboratory Report "Assessing the Value of Regulation Resources Based on Their Time Response Characteristics." That study finds that a fast regulation device with limited energy is 1.7 times more efficient than the existing mix of resources providing regulation in CAISO. Fast regulation is found to be 2.24 times more efficient than a CT. Storage technology companies argue that a fast regulation product should be created to incentivize these efficient technologies.

Removing Energy Bias in Regulation

ISOs are beginning to take a close look at how to define and/or utilize regulation in a manner that allows or promotes the use of energy limited resources. One possible strategy is to remove the energy bias in regulation signals or to provide an energy-neutral regulation signal for energy storage. This would allow energy storage to provide regulation over longer periods with less cycling or charging. In a preliminary analysis performed by EPRI, the energy required to provide regulation over five days in PJM was reduced from 504 MWh to 490 kWh by relying on 5 minute balancing energy to reduce the energy bias in the regulation signal (Refer to EPRI Report: *A Feasibility Analysis of Limited Energy Storage for Regulation Service*; 1020399, 2009).

Increased Volatility in Energy Prices

Increasing penetration of wind generation is expected to increase the volatility of energy prices in several markets. Wind generation tends to peak during the night. In many regions it will put downward pressure on already lower off-peak energy prices. For example, the frequency of negative prices during off-peak periods in ERCOT has increased dramatically since 2006 with increases in wind generation. This volatility has the potential to improve energy arbitrage revenues from energy storage.

Wind Integration

Multiple integration studies have suggested that the challenge of integrating wind generation increases in a non-linear fashion as penetration levels exceed 20%. The CAISO Integration of Renewable Resources 20% RPS study[1] finds that the maximum regulation up requirement will increase 35% from 278 MW in 2006 to 502 MW in 2012 and then increase an additional 180% to 1,444 MW in 2020. The maximum load following down requirement is expected to roughly double from 2006 to 2012 over most of the year. It does not necessarily follow that prices will increase proportional with demand however, as they are determined primarily by variable operating and fuel costs.

Demand Side Competition

In addition, many participants are also vying for the small but lucrative regulation market. In particular, following FERC Order 890, ISOs are modifying their tariffs to allow demand response to participate in regulation and other ancillary service markets. The regulation market for the entire United States is less than 1% of industrial load. It is entirely possible that alternative technologies will saturate the regulation market even as the size of the market increases to meet wind integration demands, limiting the prices or revenues available for energy storage.

High Penetration Distributed Solar

Distribution engineers anticipate increasing challenges of managing high penetration distributed solar generation on the local distribution system. Energy storage systems can provide local voltage and VAR support and manage intermittent variation in solar loads. These benefits will certainly have value where solar is concentrated on the distribution system, but the value is difficult to quantify at this time.

Locational Value of Energy Storage

Regional and Customer Perspectives

The present value revenue results for most applications sum up revenues across different categories of benefits, irrespective of whether it is the customer, the utility, the ISO, or an independent third party entity that accrues the benefits. This approach is analogous to the Total Resource Cost-effectiveness Test (TRC) that compares costs and benefits for the region as a whole, regardless of who actually pays the cost or receives the benefits. The regional or TRC perspective is often used by utilities and regulators to justify investments in energy efficiency or other programs. In applications where the battery would be owned by the customer rather than the utility, researchers also examined applications from a

[1] Integration of Renewable Resources: Operational Requirements and Generation Fleet Capability at 20% RPS, California Independent System Operator. August 31, 2010.

customer perspective, known as the Participant Cost Test (PCT). It is important to evaluate customer-owned applications from a customer perspective because the customer value will be used to justify investments in storage.

Total Benefits by Location

One of the implications of the application analysis is that there are different values of energy storage in different locations along the distribution system. Figure 1-3 shows how the total storage benefits change with location. The application with the highest present value is chosen to represent the maximum value at each location, with both the target and high benefit values shown. The regional (TRC) perspective is shown with the solid line and is the same as the utility perspective for both the substation and final line transformer locations. For reasons explained below, the total benefits at the substation are higher than those that can be aggregated at the final line transformer. For the customer location, the value from the regional (TRC) perspective is lower still. However, with aggregation it is possible that the cumulative value as perceived by the customer and utility combined is as high as the value shown for the substation.

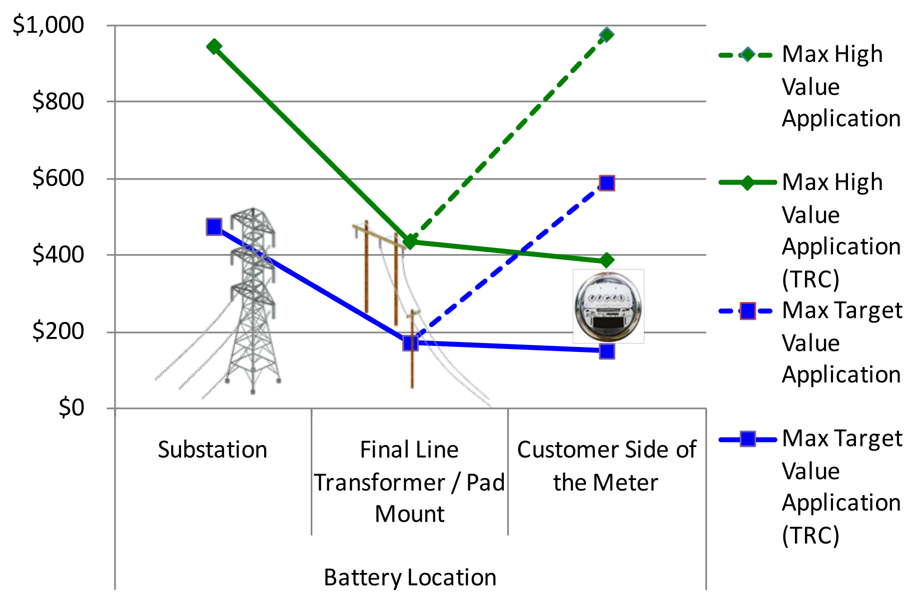

Figure 1-3
Relative Locational Values of Storage

The present value of the regional benefits is highest at the substation where storage can combine three of the higher value benefits of distribution deferral, system capacity and regulation (Figure 1-4). In addition, a transportable system could provide multiple deferral values if used as a strategic tool to the distribution planner. Storage systems located further downstream at the final line transformer pick up some reliability value of service because it can mitigate a higher percentage of outages. However, the base case assumption for the smaller final line transformer storage systems is that they will not be able to provide regulation services, which more than offsets the added reliability value relative to the substation site. For this location application, it was also assumed that only one distribution deferral opportunity is monetized as opposed to the multiple deferrals possible with a larger transportable storage system. On the other hand, if DESS systems can be efficiently aggregated, it may be possible to earn regulation or other AS market revenues and achieve total values similar to the substation location. Larger SMUD capex deferrals may also be possible if DESS units were part of a large 20 year infrastructure build out which was not evaluated in this study.

Customer sited storage systems operated to provide reliability or retail rate reduction cannot be simultaneously managed by the utility for system and distribution benefits. This limits the value from the regional (TRC) perspective. Customer sited energy storage systems can provide modest benefits in retail rate reductions to the customer (from the participant or PCT perspective). The two examples shown in Figure 1-4 are for a SMUD commercial rate and for a Critical Peak Pricing (CPP) rate based on an SDG&E tariff.

Aggregation of customer-sited systems, however, has the potential to combine the retail rate savings seen by the customer with the higher value system and distribution benefits for the utility. The retail rate reduction is a benefit for the customer but a loss of revenue for the utility. Because the revenue lost in retail rates usually outweighs the actual benefits to the utility, it is generally not in the utility's interest to encourage customer sited applications that will result in lost revenue.

Nevertheless, if battery systems will be installed by customers for their own benefit in any case, it could benefit the utility to take advantage of those systems. Combining customer and utility benefits through aggregation provides the highest present value benefits of any of the applications modeled in this report. Customer side of the meter applications can provide high value under the assumption that there is a third party aggregator able to operate the battery customer energy management while simultaneously negotiating with the utility to provide utility benefits. This is particularly true if regulation revenue can be earned through aggregation.

The locational benefit analysis shows that energy storage systems can be owned and operated by either SMUD or third-party aggregators and provide value to the SMUD system. Third-party aggregated energy storage systems are not widely available today, but are worth being explored for future projects.

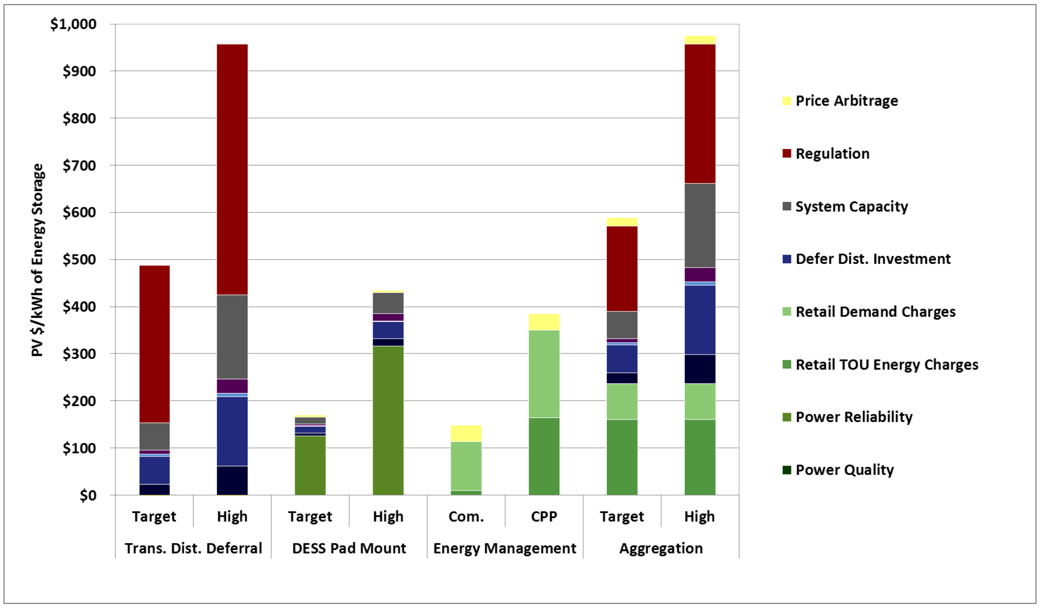

Figure 1-4
Cumulative Storage Application Benefits by Location

Conclusions

High Value Applications

For utility applications of energy storage located in the SMUD system, this analysis finds regulation and system capacity to be the benefits that drive high values. The importance of these two benefits does not change with location; the highest value utility-owned battery applications both at the substation and as distributed systems (DESS) involve accruing regulation and system capacity benefits. The analysis also finds that reliability benefits could be potentially large given assumptions about SMUD outage statistics and customer value of service information. Still, even in cases with a high reliability benefit, other benefits such as regulation and system capacity must be targeted simultaneously in order to accrue estimated high application present values. The value of distribution investment deferral from storage is potentially large, but appears limited for SMUD at this time given the current conditions and practices of the SMUD distribution system.

On the customer side of the meter, applications focused on bill reduction provide potentially large benefits for customers, particularly if SMUD enacts a CPP rate or other higher TOU rates. In addition, the customer applications focused on reliability needs may already be economic for certain customers with very high value of service, but these high values are unlikely to be widespread.

Locational Value of Storage

The analysis shows that storage located at the substation has the potential for the greatest benefit to the utility in the near-term. Substation storage requires less need for aggregation of many smaller units to capture benefits. The reason substation storage is most valuable is that it can accrue the high value benefits of regulation, system capacity and T&D investment deferral. The T&D benefit estimated could be even higher if the storage system is transportable and is able to defer multiple T&D investments over its lifetime.

Distributed utility storage located on the feeder could also be coordinated to pursue the benefits of regulation and capacity. If it is not economic to aggregate DESS systems for participation in AS markets, the value is lower than the substation location. Distributed storage located at the feeder would provide a different value for T&D investment deferral. Distributed storage is unlikely to be able be transportable and integrated in distribution planning such that it can accrue deferral benefit values for multiple years of deferral. On the other hand, distributed storage may be a good way to provide relief to overloaded underground cables that have a high probability of failure during peak load days. This report did not have access to engineering reports regarding how much storage would be needed to "unload" an underground cable in practice.

A behind the meter storage system could have retail bill impact benefits for customers, but these benefits are lower than the benefits for utility operated storage. A CPP rate in SMUD could potentially increase the benefits of storage, but not enough such that customer side of the meter storage is more valuable than utility side of the meter storage. Higher benefit values are only achieved through aggregation of customer or third party owned storage such that it can provide grid benefits of regulation and capacity.

Aggregation of customer sited systems, however, has the potential to combine the retail rate savings seen by the customer with the higher value system and distribution benefits for the utility. The retail rate reduction is a benefit for the customer but a loss of revenue for the utility. Because the revenue lost in retail rates usually outweighs the actual benefits to the utility, it is generally not in the utility's interest to encourage customer sited applications that will result in lost revenue.

Nevertheless, if battery systems will be installed by customers (or a third party) for their own benefit, it could benefit SMUD to take advantage of those systems. Combining customer and utility benefits through aggregation provides the highest present value benefits of any of the applications modeled in this report. Customer side of the meter applications can provide high value under the assumption that there is a third party aggregator able to operate the battery system providing customer energy management services while simultaneously negotiating with the utility to provide utility benefits. This is particularly true if regulation revenue can be earned through aggregation.

Areas of Future Study

In general, for the applications examined by this report, energy storage lifecycle costs will need to fall to approximately $500/kWh or below in order to make batteries cost-effective. While most battery costs today are higher than $500/kWh, SMUD should continue to follow the developments and trends in energy storage technologies. For example researchers anticipate production costs of Li-ion battery systems could be reduced significantly in the near future due to the scale of global production of Li-ion batteries for electric vehicles. Although future cost reductions are uncertain, SMUD may want to study and demonstrate such systems to study their effects and technical capability.

In addition, SMUD may wish to study how best to integrate a transportable substation battery system into distribution investment planning such that one battery would be able to defer multiple projects over a 10-15 year lifetime.

SMUD may also wish to study how to extract system benefits from customer applications that may be installed by customers or third parties and operated to optimize customer benefits.

Finally, the while current analysis did not find high value benefits from local renewable smoothing/integration at this time, but the application merits further attention given future local renewables goals.

Section 2: Storage Benefits

Researchers identified benefit values that storage could provide to the SMUD system based on prior EPRI research. These benefit values are then combined into applications in which the battery optimizes its dispatch to provide multiple benefits.

Power Reliability

Power reliability refers to the value that an energy storage device can provide by preventing outages. In this study, the focus is on managing outages of 4 hours or less. It was assumed that the battery systems considered by SMUD would be unable to provide backup power for longer durations. In order to quantify the value of power reliability, it is necessary to quantify customer outage costs as well as the number of outages of each length that a customer would expect over the course of a year.

Researchers were unable to get SMUD-specific customer outage costs for this study. The best proxy data comes from surveys of customer value of service. The most recent survey is a 2009 study produced by Freeman, Sullivan & Co. (FSC) for Lawrence Berkeley National Lab. The figures shown here are the FSC 50th percentile values for customer value of service. The 50th percentile values are appropriate to use for SMUD because the reliability value is being measured for an entire feeder. Higher values may be appropriate for individual customers but for the aggregate feeder, the 50th percentile values should be the most realistic.

However, because the FSC results for the small C&I class deviated substantially from those for the large C&I class and other studies, researchers chose to use results from a 2004 LBNL Report (LaCommare & Eto 2004) for commercial customers instead. The 50th percentile values are used for the target value while the 95th percentile values are used for the high value. For the small C&I class, the ratio of 95th to 50th percentile values from the FSC study are used to estimate the high value from the average results in the 2004 LBNL Report.

Table 2-1
Customer Value of Service

$/kW	Momen-tary (<5 min)	15 min-utes	30 minutes	1 hr	2 hrs	4 hrs	8 hrs
Res	$0.10	$0.05	$0.60	$2.60	$3.95	$5.30	$5.60
Com.	$0.42	$8.65	$16.01	$23.37	$48.91	$117.76	$189.23
Ind.	$1.40	$4.79	$7.46	$10.12	$17.96	$36.94	$68.36

To quantify the reliability benefits of energy storage to a customer, it is necessary to estimate the number of outages of each length that a given customer would expect over the course of a year. The customer expectation of momentary outages can be calculated using the utility reported MAIFI statistic, but the customer expectation of sustained outages requires outage distributions which vary by utility. Utilities publish system-wide utility statistics, but in order to look at outage distributions from a customer perspective, two weightings are necessary: 1) the expected length of outages from a system perspective, the "duration weighting"; and 2) a customer weighting of how many customers will experience outages of each duration, the "customer weighting."

For example, the most common expected length of outage from a system perspective may be in the 1-2 hour range (duration weighting), but more customers are affected during each of the shorter 15 minute outages (customer weighting). One reason for these distributions could be that it is more common to have outages further out on radial distribution lines. These outages last longer than central outages at a substation but affect fewer customers.

SMUD produces SAIFI and SAIDI statistics for its entire system and also its transformers. These statistics were used to infer the duration and customer weighting based on the SAIFI and SAIDI as well as national outage information.

Researchers estimated the duration weighting based on data from two anonymous U.S. utilities as cited in a 2009 paper for NREL done by GE Global Research (Figure 2-1). The probabilities followed the form of a left skewed distribution. The outage lengths with the highest probability are between 30 minutes and 2 hours.

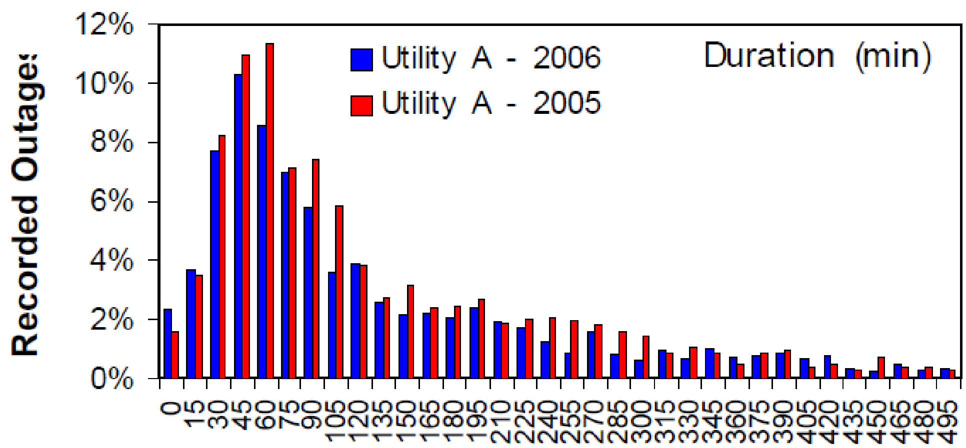

Figure 2-1
Recorded Outage Durations for two U.S. Utilities (NREL 2009)

Next, data from SMUD was used. SMUD provides SAIDI and SAIFI statistics for the system, the Anatolia Chrysanthy substation, and the East City substation from 2008 and 2009. SAIFI provides a measure of the number or frequency of outages and is calculated as the total number of customer outages per year divided by the total number of customers. SAIDI is a measure of the duration of those outages and is calculated as the total number of minutes customers went without power divided by the number of customers. Our study, however, looks at outages not from the perspective of the utility, but of the individual customer. SAIFI and SAIDI were therefore used to calculate a third metric, CAIDI, which is the average number of minutes an individual customer would expect to go without power over the course of a year. CAIDI is calculated simply by dividing SAIFI by SAIDI. This division cancels out the total number of customers from the equation leaving us with the average duration per outage. To get a range of reliability values, researchers model the value of three data points. The SMUD System statistics for 2008 are taken as the base case. The Anatolia Chrysanthy statistics for 2009 are taken as the high case and the Anatolia Chrysanthy statistics for 2008 are taken as the low case.

Table 2-2
SMUD Reliability Statistics

	SAIFI	SAIDI	CAIDI
SMUD System 2008	2.42	303.97	125.78
Anatolia Chrysanthy (1201) 2009	0.01	2.70	200.94
Anatolia Chrysanthy (1201) 2008	7.44	259.64	34.92
East City (2301) 2009	0.02	2.00	93.95
East City (2301) 2008	1.08	102.11	94.29
East City (2304) 2009	0.10	11.26	117.60
East City (2304) 2008	3.06	267.04	87.21

The third step is to create a customer weighting. Researchers entered a customer weighting to reflect the fact that a greater number of customers experience outages of shorter duration while a fewer customers experience outages of longer duration (8 hours or more). The customer weighting created in this step is chosen specifically such that, when combined with the duration weighting created earlier, it will yield a CAIDI similar to that reported by the utilities. This calculation is done by creating another metric, Duration Weighted Probability, which is the product of the Duration Weighting, the Customer Weighting and the average outage time for outages of that category. The sum of Duration Weighted Probabilities divided by the sum of Frequency Weighted Probabilities is equal to the CAIDI number reported in the SMUD statistics.

For the three SMUD cases chosen, the overall shapes of the duration and customer weighting are the same but the values differ in order to align with published SMUD values.

The Customer Perspective Outage Probability number multiplied by SAIFI, total system outages divided by total system customers, gives the expected number of outages of a given duration that customer will see during the year which is used for the avoided cost calculation. Momentary outages are assumed to be of uniform duration and therefore do not require a duration and customer weighting. The number of momentary interruptions expected during a year for an individual customer is the utility reported MAIFI.

Table 2-3
SMUD System 2008 – Base Case – Customer Perspective Outage Calculation

	15 min	30 min	1 hr	2 hrs	4 hrs	8 hrs	1 day	3 days	>3 days	Total
1) Average Min	10	22.5	45	90	180	360	960	2880	10800	-
2) Duration Weighting	10%	20%	35%	22%	5%	2%	1%	2%	3%	100%
3) Customer Weighting	21%	20%	19%	15%	10%	3%	4%	5.00%	3.00%	100%
3) Frequency Weighted Probability [(2) X (3)]	0.021	0.040	0.067	0.033	0.005	0.001	0.000	0.001	0.001	0.17
4) Customer Perspective Outage Probability	12%	24%	39%	20%	3%	0%	0%	1%	1%	100%
5) Duration Weighted Probability [(1) X (2) X (3)]	0.21	0.9	2.99	2.97	0.9	0.216	0.38	2.88	9.72	21.17

Customer Weighting (3) is created such that the Duration Weighted Probability total, 21.17, divided by the Frequency Weighted Probability total, 0.17, is equal to the utility reported CAIDI of 126.
The Customer Perspective Outage Probability (4) multiplied by SAIFI, gives the expected number of outages of a given duration that customer will see during the year.

Table 2-4
Anatolia Chrystanthy 2009 – Low Case – Customer Perspective Outage Calculation

	15 min	30 min	1 hr	2 hrs	4 hrs	8 hrs	1 day	3 days	>3 days	Total
1) Average Min	10	22.5	45	90	180	360	960	2880	10800	-
2) Duration Weighting	10%	20%	30%	16%	5%	5%	5%	4%	5%	100%
3) Customer Weighting	32%	25%	12%	9%	7%	3%	5%	4.00%	3.00%	100%
3) Frequency Weighted Probability [(2) X (3)]	0.032	0.050	0.036	0.014	0.004	0.002	0.003	0.002	0.002	0.14
4) Customer Perspective Outage Probability	22%	35%	25%	10%	2%	1%	2%	1%	1%	100%
5) Duration Weighted Probability [(1) X (2) X (3)]	0.32	1.125	1.62	1.296	0.63	0.54	2.4	4.608	16.2	28.74

Customer Weighting (3) is created such that Duration Weighted Probability total, 28.74, divided by Frequency Weighted Probability Total, 0.14, is equal to the utility reported CAIDI of 201.
The Customer Perspective Outage Probability (4) multiplied by SAIFI gives the expected number of outages of a given duration that customer will see during the year.

Table 2-5
Anatolia Chrystanthy 2008 – High Case – Customer Perspective Outage Calculation

	15 min	30 min	1 hr	2 hrs	4 hrs	8 hrs	1 day	3 days	>3 days	Total
1) Average Min	10	22.5	45	90	180	360	960	2880	10800	-
2) Duration Weighting	38%	21%	20%	10%	5%	2%	1.50%	1.00%	1.000%	100%
3) Customer Weighting	31%	24%	15%	15%	10%	2%	1.00%	1.00%	1.000%	100%
3) Frequency Weighted Probability [(2) X (3)]	0.118	0.050	0.030	0.015	0.005	0.000	0.000	0.000	0.000	0.22
4) Customer Perspective Outage Probability	54%	23%	14%	7%	2%	0%	0%	0%	0%	100%
5) Duration Weighted Probability [(1) X (2) X (3)]	1.178	1.134	1.35	1.35	0.9	0.144	0.144	0.288	1.08	7.57

Customer Weighting (3) is created such that Duration Weighted Probability total, 7.57, divided by Frequency Weighted Probability Total, 0.22, is equal to the utility reported CAIDI of 35.
The Customer Perspective Outage Probability (4) multiplied by SAIFI gives the expected number of outages of a given duration that customer will see during the year.

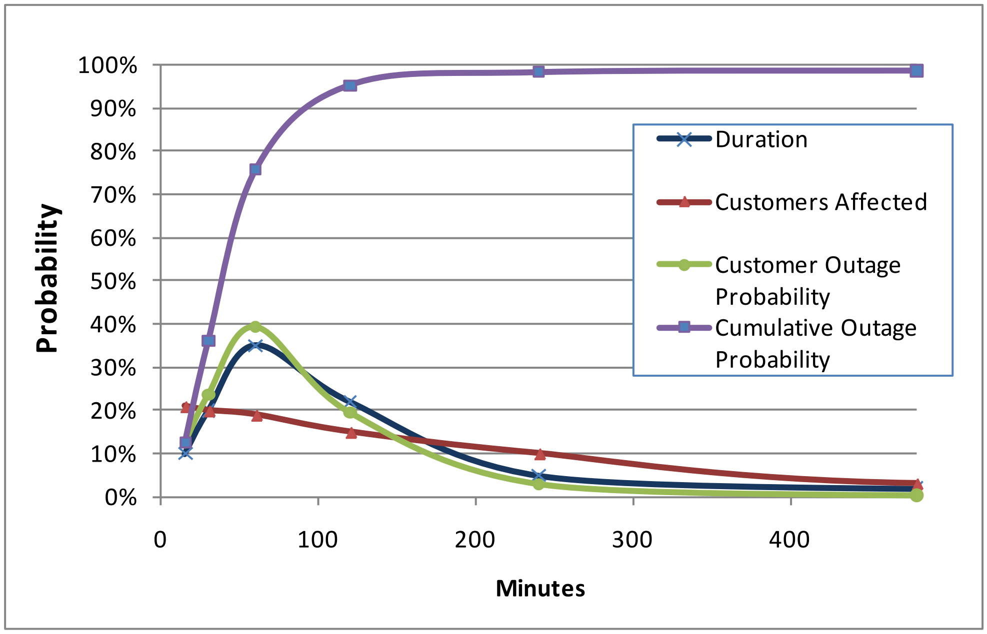

Figure 2-2
SMUD System 2008 – Base Case – Customer Perspective Outage Calculation

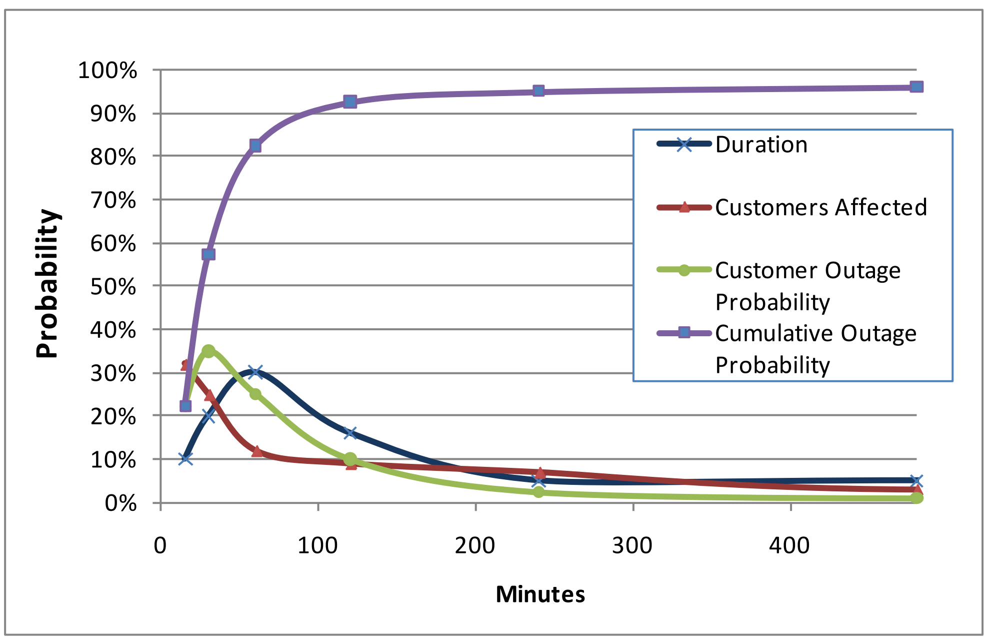

Figure 2-3
Anatolia Chrystanthy 2009 – Low Case – Customer Perspective Outage Calculation

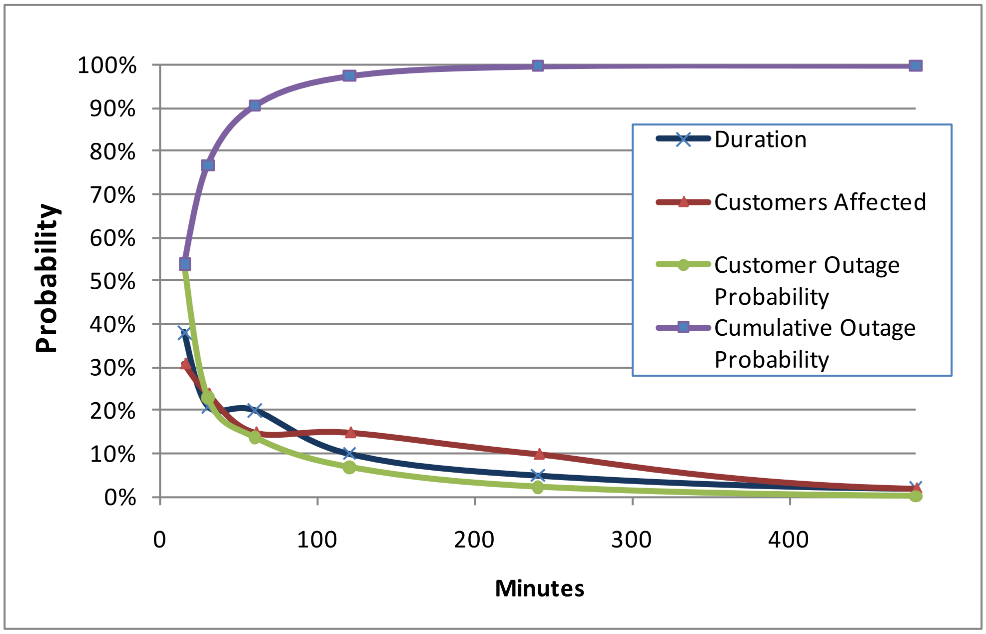

Figure 2-4
Anatolia Chrystanthy 2008 – High Case – Customer Perspective Outage Calculation

Retail TOU Energy Charges

One of the ways energy storage can reduce a customer's cost of electricity is by enabling the customer to purchase energy during Off-Peak periods with lower time-of-use (TOU) charges and then discharge the energy during On-Peak periods. In this case, the battery would need to be owned by the customer and either operated by the customer or by a third party aggregator such as an energy service company. To quantify the customer benefit a battery could provide, researchers examined commercial and residential TOU rates offered by SMUD.

Table 2-6
TOU Rates Offered By SMUD

$/kWh		Summer			Winter		
		On-Peak	Off-Peak	Differential	On-Peak	Off-Peak	Differential
GS-TOU1	Secondary	$ 0.147	$ 0.094	$ 0.053	$ 0.094	$ 0.075	$ 0.020
	Primary	$ 0.121	$ 0.086	$ 0.036	$ 0.090	$ 0.070	$ 0.020
	69kV	$ 0.118	$ 0.084	$ 0.033	$ 0.086	$ 0.068	$ 0.018
GS-TOU2	Secondary	$ 0.171	$ 0.090	$ 0.080	$ 0.090	$ 0.071	$ 0.019
	Primary	$ 0.162	$ 0.086	$ 0.076	$ 0.085	$ 0.067	$ 0.018
	69kV	$ 0.158	$ 0.085	$ 0.073	$ 0.082	$ 0.066	$ 0.016
GS-TOU3	Secondary	$ 0.176	$ 0.095	$ 0.080	$ 0.091	$ 0.072	$ 0.019
	Primary	$ 0.167	$ 0.091	$ 0.076	$ 0.086	$ 0.069	$ 0.018
R-TOU Option 1		$ 0.235	$ 0.109	$ 0.126	$ 0.106	$ 0.098	$ 0.008
R-TOU Option 2		$ 0.237	$ 0.098	$ 0.140	$ 0.107	$ 0.099	$ 0.009

In addition to looking at actual SMUD rates, a critical price peak (CPP) rate was also examined. A CPP rate is one in which the utility is able to invoke a specific high price rate for a limited number of hours a year. The rate used to model a CPP rate for SMUD was the San Diego Gas and Electric (SDG&E) rate: "Electric Commodity Cost Critical Peak Pricing Default." In this rate, SDG&E can trigger a maximum of eighteen CPP Events on any day of the week, year round. During an event period, the SDG&E energy price rises to $1.03396/kWh. Each event period lasts from 11 a.m. – 6 p.m. Customers receiving service under the CPP rate will be notified no later than 3 p.m. the day before a CPP Event will be in effect. Under a CPP rate, the TOU rate differential that a customer is able to save by using a battery is potentially much larger.

Table 2-7
Example CPP Tariff from SDG&E

$/kWh	Summer			Winter			CPP Rate		
	On-Peak	Off-Peak	Differential	On-Peak	Off-Peak	Differential	On-Peak	Off-Peak	Differential
SDG&E EECC-CPP-D Secondary	$ 0.093	$ 0.054	$ 0.039	$ 0.090	$ 0.060	$ 0.030	$ 1.034	$ 0.054	$ 0.980

Retail Demand Charges

It is common for commercial and industrial customers to pay a monthly demand charge based on the customer's peak load measured over a defined period. In SMUD, the rate GS-TOU3 includes a demand charge only in the summer months. The demand charge is charged based on the maximum kW demand during super peak periods. Super peak periods are June through September from 2:00 p.m. to 8:00 p.m. Through strategic load shifting with battery storage, a customer can reduce their demand charges in future bills by consistently reducing the customer's peak load as measured by the utility meter. The amount by which customer's measured peak load can be reduced is a function not only of the size of the battery, but also of the customer's load shape. This application will prove most beneficial for customers with 'peaky' load shapes; that is with peak loads that occur over a relatively short period.

Table 2-8
Retail Demand Charges

$/kW		Summer	Winter
GS-TOU3	Secondary	$6.70	$0.00
	Primary	$6.10	$0.00

Voltage Support

Voltage sag occurs on the distribution system when loads exceed the ability of the distribution system to deliver energy to that location. Voltage sag is of greatest concern during peak load hours and during hot afternoons when distribution lines and transformers are the most stressed. Energy storage can provide voltage support to the grid, reducing the probability of a voltage sag or outage. To determine the value of voltage support, the price of a shunt capacitor was used. Shunt capacitors are the most common technology currently providing voltage support. The range in the price of voltage support services provided by shunt capacitors is estimated to be between \$3/kVAR and \$8/kVAR. These figures are used for the target and high value of voltage support. This analysis assumes that the capability of an energy storage device to deliver both real (kW) and reactive (kVAR) power is the same. In addition, the analysis assumes the battery systems include power electronics and all necessary controls and dispatch functionality.

Table 2-9
Voltage Support Benefit Values

$/kVAR	**Target**	**High**
Voltage Support	$3.00	$8.00

Defer Distribution Investments

Energy storage can potentially be used by a utility to reduce peak loads and thereby defer distribution system investments needed to accommodate anticipated load growth in a particular area. The SMUD 2011 – 2015 draft Distribution System Plan was used to evaluate SMUD distribution deferral possibilities. In evaluating the Plan, EPRI and E3 consulted with SMUD utility distribution engineer David Brown.

Mr. Brown informed the research team that there is not the potential for storage to defer distribution investment in the current SMUD distribution plan. He stated that in general, SMUD's planning process is not complimentary to investment deferral because SMUD builds facilities ahead of customer developments to avoid conflicts. SMUD attempts to build 69kV line extensions and the first phases of their substations before customers move in. Buying substation land and extending the 69kV prior to development results in fewer legal disputes and project delays. For the projects that also include capacity construction which may be deferrable, the site acquisition, site preparation and 69kV extension work may not be deferrable. Furthermore, due to the recent financial crisis, load growth in SMUD is much more limited than previously anticipated. For this reason, there are not opportunities to defer distribution system investments needed to accommodate load growth.

Though the immediate prospects for distribution investment deferral in SMUD are slim, the deferral value that storage could theoretically provide is real. Therefore, this analysis attempts to look at what the deferral value could be assuming load grows as forecasted prior to the recession. Researchers went through the SMUD 2011-2015 draft Distribution System Plan and identified projects that could potentially be deferred by storage. Mr. Brown then went through the list and ranked each deferral opportunity as "Good," "Fair," "Poor," and "None" assuming a storage technology of about 1 MW. E3 then further examined the investments with a rank of either “Fair” or “Good” to determine a target and high range of deferral values for storage.

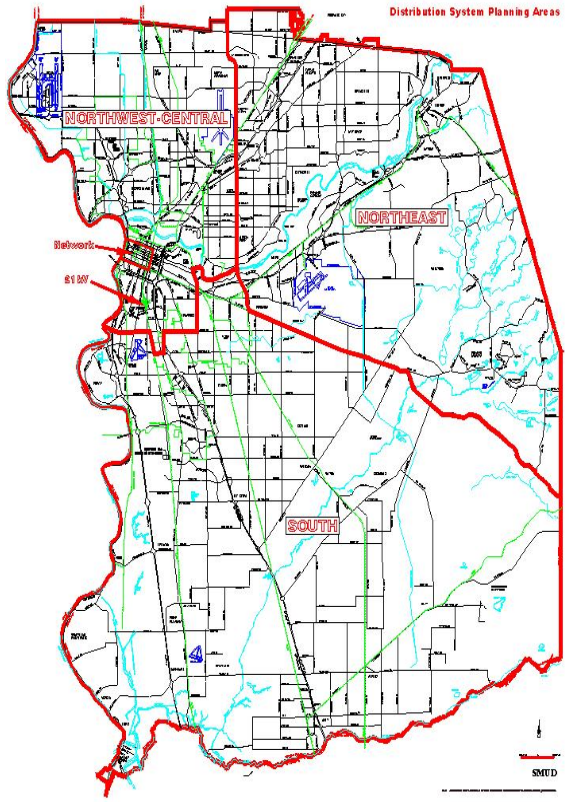

Figure 2-5
SMUD Service Territory

Table 2-10
Potentially Deferrable Distribution Projects in SMUD

Distribution Investment	Deferral Potential	Investment
PFE - Walerga Substation	Good (2015 work only)	$2,827,846
Village Mills - Rancho Cordova		
Parkway Substation	Good (2014 work only)	$2,574,387
San Juan - Fairway Two Line work	Fair	$69,584
Waterman Grant Line #2	Fair	$968,793

Of the projects ranked “Fair” or “Good,” the 50th percentile investment value is taken and assumed to be deferred for 3 year with 1 MW of storage using the present worth method. The value of this deferral is assumed to be the target deferral value. The high deferral value takes the 95th percentile investment value and assumes that investment can be deferred for 5 years.

Table 2-11
Deferral Benefit Values

$/kW-year	Value	Deferral Length
Target Deferral	$100	3 Years
High Deferral	$158	5 Years

To be explicit, this analysis is not assuming that battery storage in SMUD will actually defer any of the projects shown in Table 2-10 above. Instead, the analysis is valuing the deferral value SMUD could theoretically accrue from battery storage given the right conditions. It seems a near certainty that at some point in the future SMUD will have load growth, and therefore it may be possible to defer a capital investment for some time by using storage.

Distribution Losses

An energy storage system upstream of a congested distribution line could reduce losses on that line. On-peak distribution system losses of 4% and 6% are assumed for the target and high cases respectively. In each case, it was assumed that energy storage system could reduce those losses by 10%.

VAR Support

VAR or reactive power support is used to maintain voltage levels on a transmission system by providing or absorbing reactive power (kVAR). VAR support is one of the ancillary services used by grid operators to maintain grid stability and is procured through contracts with generators (CAISO, ERCOT) or through ISO tariffs (ISONE, NYISO, PJM). In other countries, such as England, VAR support is procured competitively. Currently, VAR support is supplied by generators, synchronous condensers, static VAR compensators, and inductor and capacitor banks. With a dynamic inverter and the necessary communications and control equipment, energy storage can also provide and absorb reactive power. Researchers were unable to find SMUD-specific values for VAR support so this analysis takes as a range the values of the three ISOs that publish reactive power tariffs or payments. These VAR support values are $1.05/kVAR for ISONE, $2.93/kVAR for NYISO, and $3.92/kVAR for PJM. The ISONE price of $1.05/kVAR is used to represent the target value, while the PJM price of $3.92/kVAR is used for the high value. It is assumed that a storage device on a distribution system can provide kVAR up to its effective real power (kW) discharge capacity. In actual installations, additional costs for dynamic inverters and communications equipment may be required to provide this capability.

Table 2-12
VAR Support Benefit Values

$/kVAR	Target	High
Reactive Power	$1.05	$3.92

System Capacity

In electricity markets, forward capacity markets exist to ensure sufficient capacity for reliable system operation in future years. Capacity payments encourage the development of new generation resources that will be needed in future years.

The eastern markets, ISONE, NYISO and PJM, have each implemented a centralized capacity market. Though each market differs somewhat in its implementation, the general concept is similar. The ISO identifies the amount of generation capacity needed to meet anticipated peak load in a future year. The ISOs then hold an auction from one to three years in advance soliciting offers from existing and new generators, and in some cases demand side options such as energy efficiency and demand response, to provide that capacity. Because capacity markets inherently involve issues of market power, administrative bid caps or demand curves are generated to limit bid prices to a reasonable level. These demand curves are usually based on the cost of new entry (CONE) for a new combustion turbine in the range of $90-$160/kW-Yr.

In contrast to the eastern markets, California's current market design uses a resource adequacy program for capacity procurement. Resource adequacy procurement is not done via a centralized capacity market but rather through bilateral contracting. The capacity prices for California's resource adequacy procurement are estimated using short-run and long-run capacity costs. In the long-run, the price of capacity is the net cost of a CT, subtracting for its energy market revenues. In the short-run, however, the price of capacity is lower because there is an oversupply of capacity resources in the California market. Researchers projected capacity prices are likely to remain low until at least 2020.

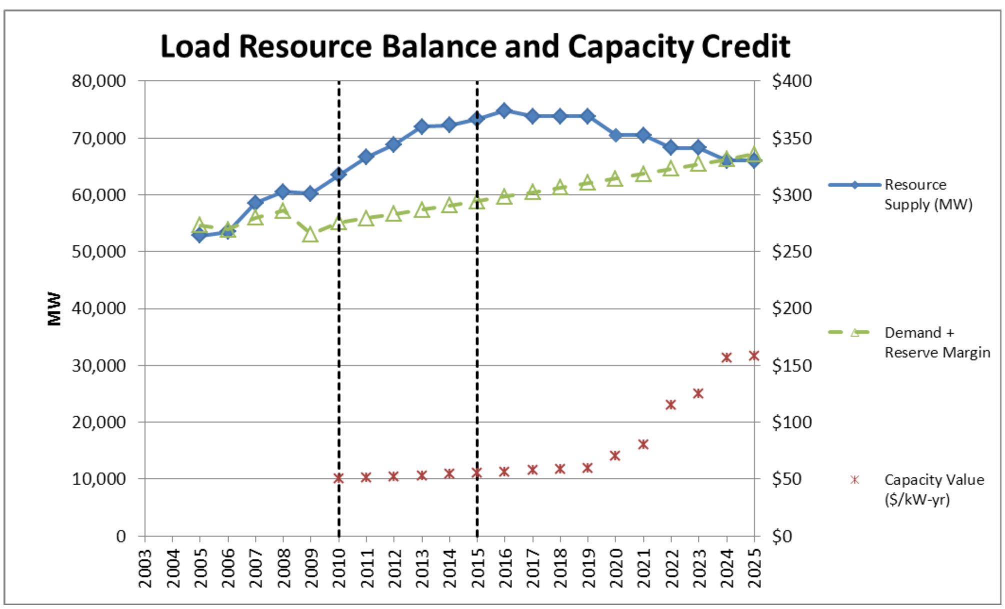

Figure 2-6
Load Resource Balance and Capacity Credit

The target value for resource adequacy in California is $30/kW-year and comes from the CAISO Phase II Testimony for the Sunrise Transmission Project. The high value is $92/kW-year and comes from the capacity value of a CT in 2008 PG&E demand response cost-effectiveness testimony.

Table 2-13
System Capacity Values in California

$/kW-year	Value
Target Deferral	$30
High Deferral	$92

Regulation

Regulation is one of the ancillary services procured by ISOs to match extremely short-term fluctuations in system load, generation and frequency. Regulation is provided by generators that can respond quickly (usually within 4 seconds) under Automatic Generation Control (AGC) to dispatch orders issued by the ISO. Current regulation requirements were designed with traditional generation resources in mind, and require a minimum of 1 hour of energy delivery capability to participate in the market. This provides sufficient capacity to meet the short-term fluctuations and the increased ramp over each hour in the morning and corresponding decrease in hourly loads in the late evening. For this analysis for SMUD, the value of regulation is the competitive price of regulation from the CAISO market because it was assumed that SMUD procures its ancillary services from CAISO. Ancillary services prices vary by year. For CAISO, hourly prices were used from the year 2007 for a target value and from the year 2006 for a high value.

Table 2-14
CAISO Regulation Benefit Values

$/MWh	Target	High
Regulation Up	$11.60	$18.70
Regulation Down	$8.38	$17.06

The "typical" dispatch signal issued by CAISO to individual generators is not readily available. A preliminary analysis of a regulation signal provided by PJM to EPRI showed, on average, a positive energy bias of approximately two percent over the period studied. An energy storage device would be dispatched to provide Regulation Up (provide energy) more often than Regulation Down (reduce generation). The hourly dispatch model assumes that over the course of an hour, the amount of energy stored is reduced by two percent of the MWs bid into the regulation market each hour.

Price Arbitrage

Energy prices are highly volatile, but tend to show a daily pattern of low prices during nighttime Off-Peak hours and high prices during daytime On-Peak hours. Energy storage can take advantage of this typical daily pattern by storing energy when the price is low and selling energy when the price is high. Price patterns vary by location according to the available generating resources and load patterns. Typical average On-Peak to Off-Peak energy price differentials will be in the $5-30/MWh range. The hourly marginal energy prices for SMUD were provided to the research team by SMUD for the analysis.

Section 3: Battery Operation and Assumptions

In a number of the battery applications described in Chapter 5 the battery is operated with a two-mode operation in order to maximize revenue. During a selected number of peak hours during the year, the modeled energy storage system is kept full to provide system capacity and local voltage support (Capacity Mode). However, maintaining full capacity prevents the battery from participating in ancillary service and energy markets. For the remaining hours, the battery is free to cycle up and down to provide a greater range of benefits, including time shifting, energy arbitrage and ancillary services (Dispatch Mode).

One special case is that for the DESS application, the battery engages in both modes simultaneously. 50% of the battery is in Capacity Mode at all times and serves the purpose of customer reliability. The other 50% is also in Capacity Mode during peak hours but is in Dispatch Mode for the remaining hours of the year. The intuition here is that customer reliability events are difficult to predict accurately and thus the battery must have capacity at all times in order to accrue a reliability benefit. In contrast, the system capacity benefit can be met by discharging during the top system load hours which can be predicted in day-ahead and hour ahead forecasting.

Researchers made a number of battery operation assumptions in order to provide comparable values. A 15 year battery lifetime was assumed and a maximum number of cycles of 10,000. In most cases, the battery cycles once a day, so the 15 year lifetime of the battery is the constraint rather than the number of cycles. It was also assumed the battery had a charging efficiency of 80% and a maximum depth of discharge of 80%.

Section 4: Application Present Value Cost Effectiveness Method

For each application use case, the total annual benefits produced by the model were extrapolated over the expected useful life of the storage device. The present value (PV) of those revenues was calculated using a 6.04% discount rate, the WACC of SMUD which SMUD uses to discount future values in investment decisions. That PV was then divided by the energy storage capacity to calculate a $ per kWh of energy storage value for each application. The PV of the benefits can then be compared against battery vendor quotes in $/kWh to estimate the revenue shortfall or surplus of each technology in every application.

The PV revenue results for most applications sum up revenues across different categories of benefits, irrespective of whether it is the customer, the utility, the ISO or an independent third party entity that accrues the benefits. This approach is analogous to the Total Resource Cost-effectiveness Test (TRC) that compares costs and benefits for the region as a whole, regardless of who actually pays the cost or receives the benefits. The regional or TRC perspective is often used by utilities and regulators to justify investments in energy efficiency or other programs. This study does not attempt to identify those benefits that could be monetized by a particular party nor does it address the market or contractual barriers that might prevent the owner of a storage system from earning revenues for some benefits.

There is one application for which the benefits modeled do not follow the TRC approach: Commercial Energy Management. For this application, the primary benefits are reduced Time-of-Use (TOU) energy charges and demand charges. These reductions in the customer's energy bill benefit the customer, but represent a loss of revenue to the utility. As such, the bill savings are a transfer from the utility to the retail customer and are not representative of the benefits to the region as a whole. The important distinction here is that benefits for these applications could be used to justify an investment in energy storage by the customer (or a third-party energy services company or ESCO). They could not, however, justify a similar investment by the utility. For the applications shown from the customer perspective, results are also shown on what that same application would like from the TRC or utility perspective. From the utility perspective, the benefits would be in reduced wholesale energy and capacity procurement costs, which are lower than the retail rates charged to end use customers. It is also worth noting that while a 6.04 percent discount rate was used for all applications for the sake of consistency and comparability, retail customers typical require much higher implicit discount rates (e.g. shorter payback periods) for energy related investments. This would reduce the present value benefits of customer-owned batteries.

Section 5: Storage Applications

Transportable Distribution Deferral

Application Description

The Transportable Distribution Deferral application models the case in which SMUD uses storage to defer investments in the distribution grid. Transportable batteries would likely be located on trailers and could be relocated as needed. This application is modeled as if the batteries are located at the utility substation.

In the modeling of this application, 500 hours are reserved for Capacity Mode operation to provide distribution system benefits. During the remainder of the year, the storage system is able to earn revenue through energy and ancillary services markets.

Researchers assume that in the target case, the storage is able to defer an investment for 3 years and in the high case, the storage in able to defer and investment for 5 years. In making the deferral length assumption, it is not assumed that a single project can be deferred for 5 years. Instead, the transportable system would become a part of the distribution planning process and could be used to defer multiple investments over the course of its useful lifetime. If deferral opportunities are available for multiple SMUD distribution system projects, one transportable battery could theoretically accrue deferral value for 10 years or longer.

Application Results

The first scenario models a 1 MW, 2 hour system in which no ancillary services benefits are included. Application PVs are relatively low, ranging from $99/kWh with target benefit values to $250/kWh with high benefit values. 2 hours of storage is likely insufficient to successfully defer distribution investments, and in that case the battery would operate at a lower power output for a longer period of time. The application PVs from a $/kWh perspective remain the same so long as the investment is successfully deferred.

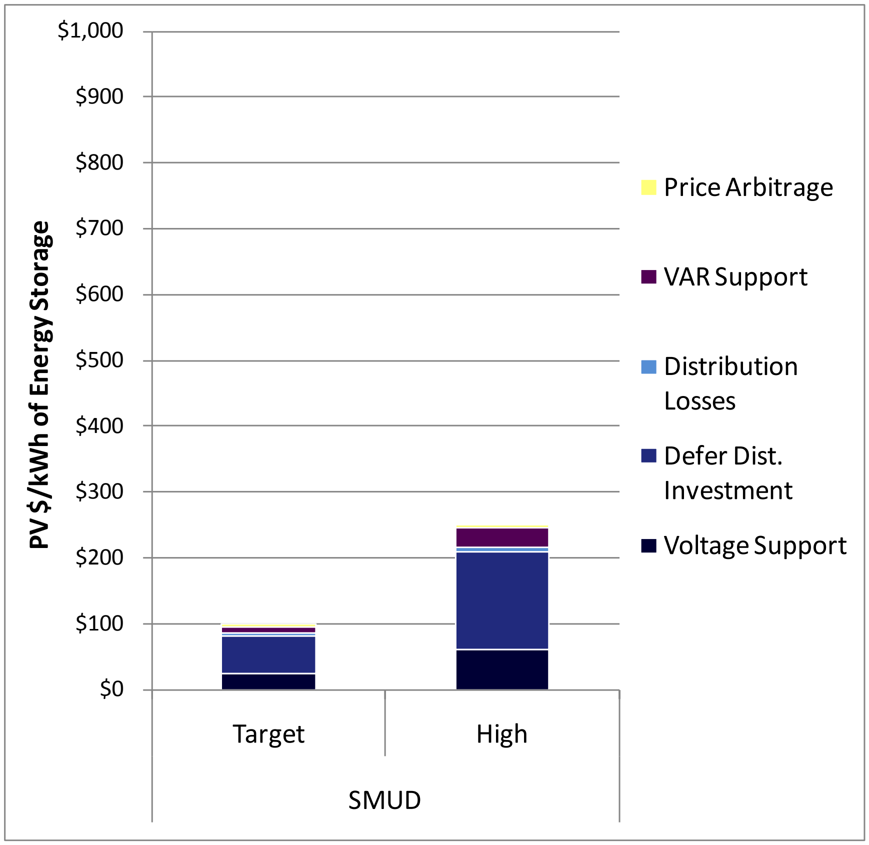

Figure 5-1
Transportable Distribution Deferral - 2 Hrs

Figure 5-2 models a 1 MW, 4 hour system in which no ancillary services benefits are included. Application PVs are again relatively low ranging from $115/kWh with target benefit values to $267/kWh with high benefit values. The cause of the small difference in value from the 2 hour scenario is that the 4 hour battery is able to earn slightly more revenue in the energy market when it is not operating in Capacity Mode.

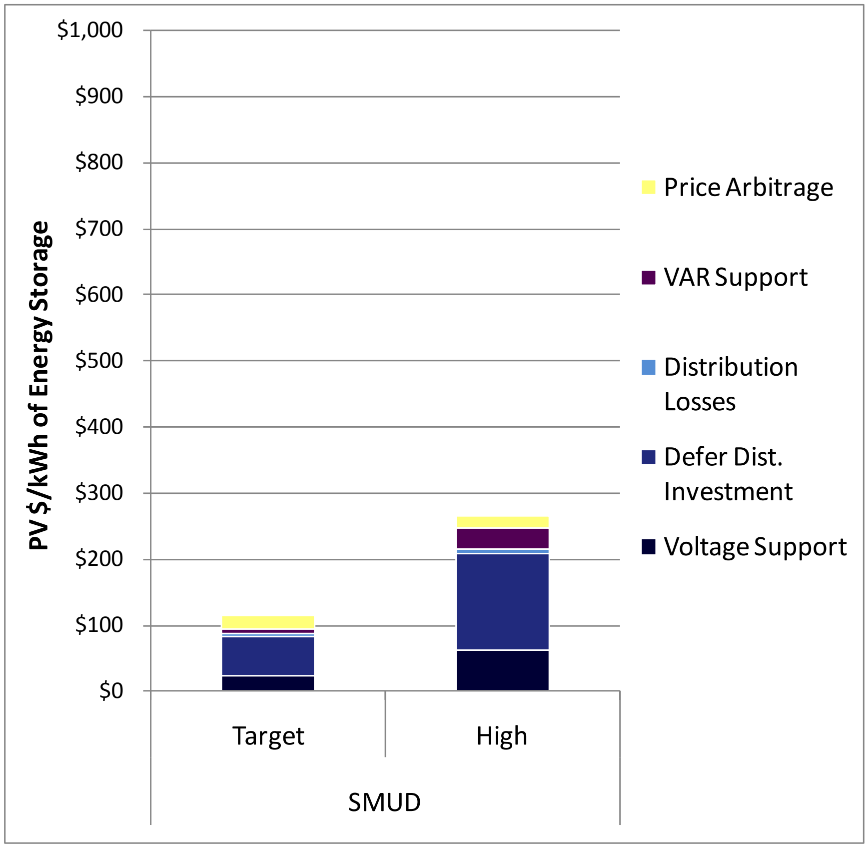

Figure 5-2
Transportable Distribution Deferral – 4 Hrs

The next scenario in Figure 5-3 models a 1 MW, 2 hour system in which no ancillary services benefits are included but the battery is able to receive a system capacity benefit. Application PVs range from $157/kWh with target benefit values to $429/kWh with high benefit values. The dominant benefit value in this scenario is system capacity, showing that a transportable battery could be particularly valuable in a capacity constrained location. In general, generators must be able to provide 4 hours of capacity in order to qualify for capacity payments. This scenario is modeled as though the battery would operate at a lower power output for a longer period of time in order to qualify for the capacity payment, which would be proportionately lower.

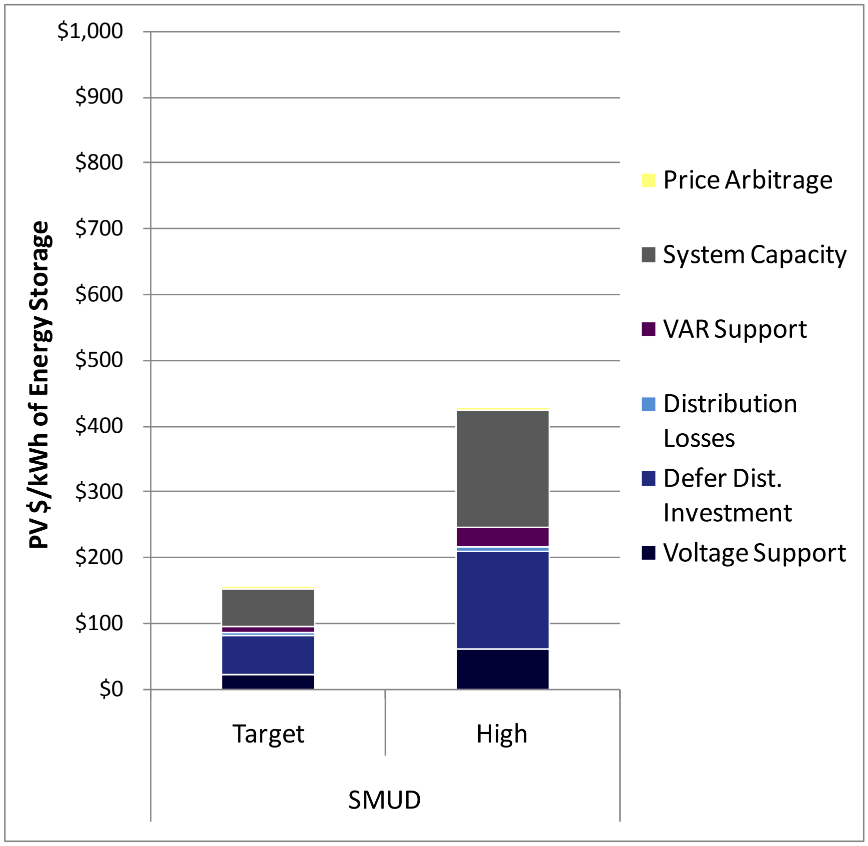

Figure 5-3
Transportable Distribution Deferral – 2 Hrs – Sys Cap

The next scenario in Figure 5-4 models a 1 MW, 4 hour system in which no ancillary services benefits are included but the battery is able to receive a system capacity benefit. Application PVs range from $173/kWh with target benefit values to $445/kWh with high benefit values.

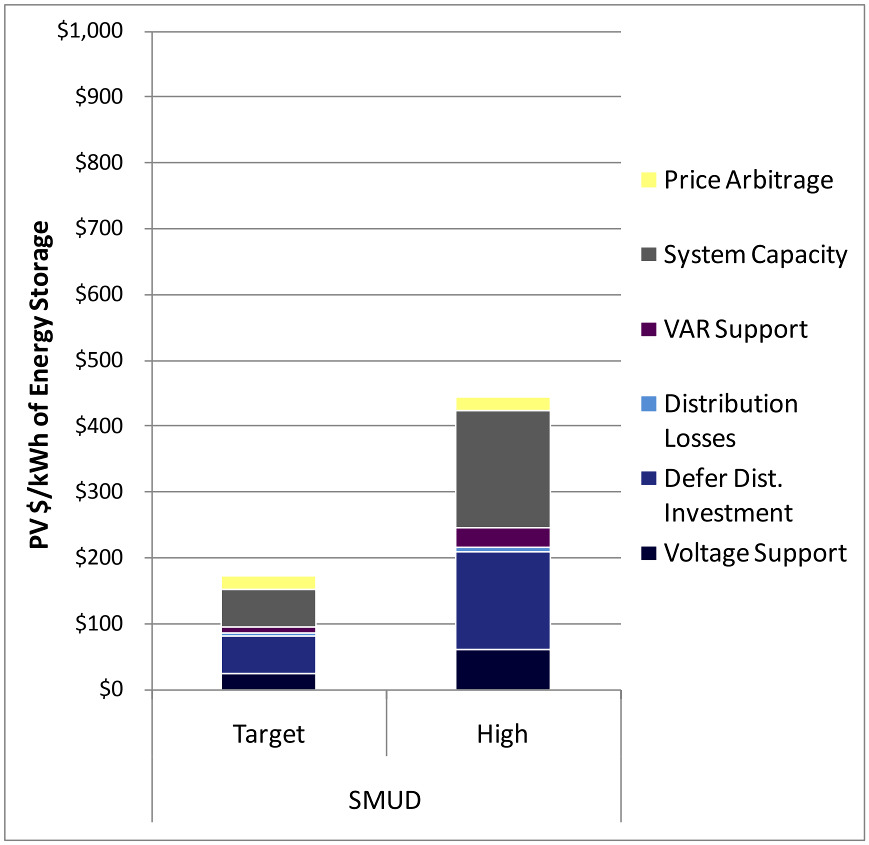

Figure 5-4
Transportable Distribution Deferral – 4 Hrs – Sys Cap

The next scenario models a 1 MW, 2 hour system in which the battery is able to participate in the CAISO regulation market. Application PVs range from $475/kWh with target benefit values to $944/kWh with high benefit values. In this scenario the 2 hour battery is able to earn higher revenues on a PV $/kWh basis because it is able to earn more money in capacity applications such as regulation relative to a 4 hour battery. In the 2 hour case, the benefit value for price arbitrage is negative. The battery is optimizing its dispatch based on regulation prices and system reliability needs rather than on energy prices. In this case, the optimal dispatch led to overall negative values from the wholesale energy which was bought and sold.

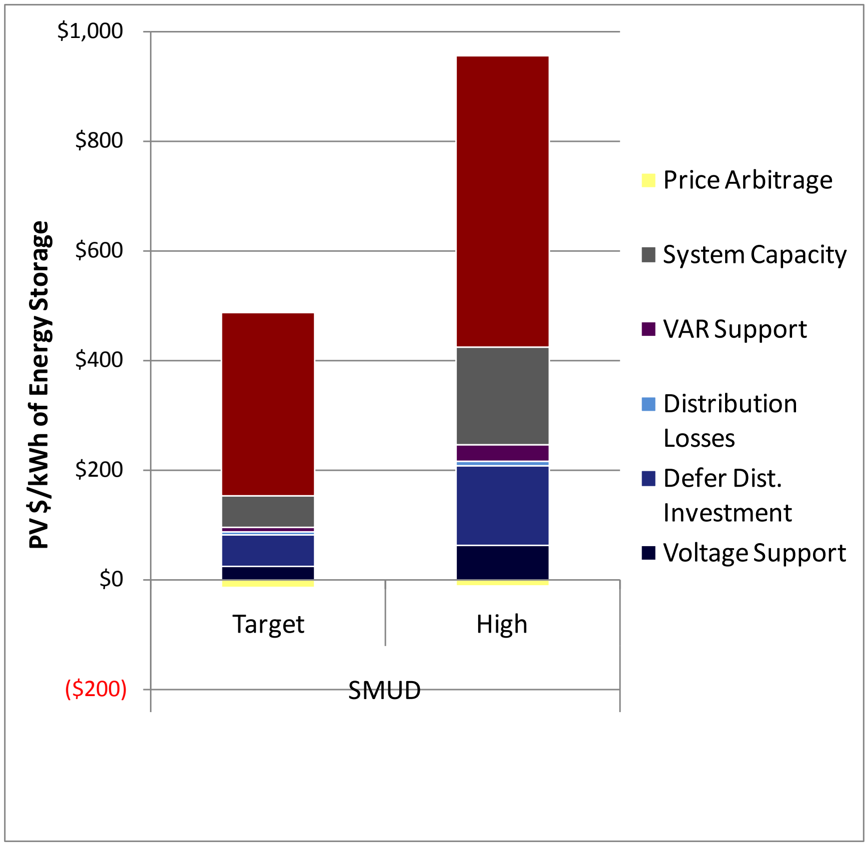

Figure 5-5
Transportable Distribution Deferral – 2 Hrs – Sys Cap – Regulation

The final transportable distribution deferral scenario in Figure 5-6 models a 1 MW, 4 hour system in which the battery is able to participate in the CAISO regulation market. Application PVs range from $331/kWh with target benefit values to $685/kWh with high benefit values.

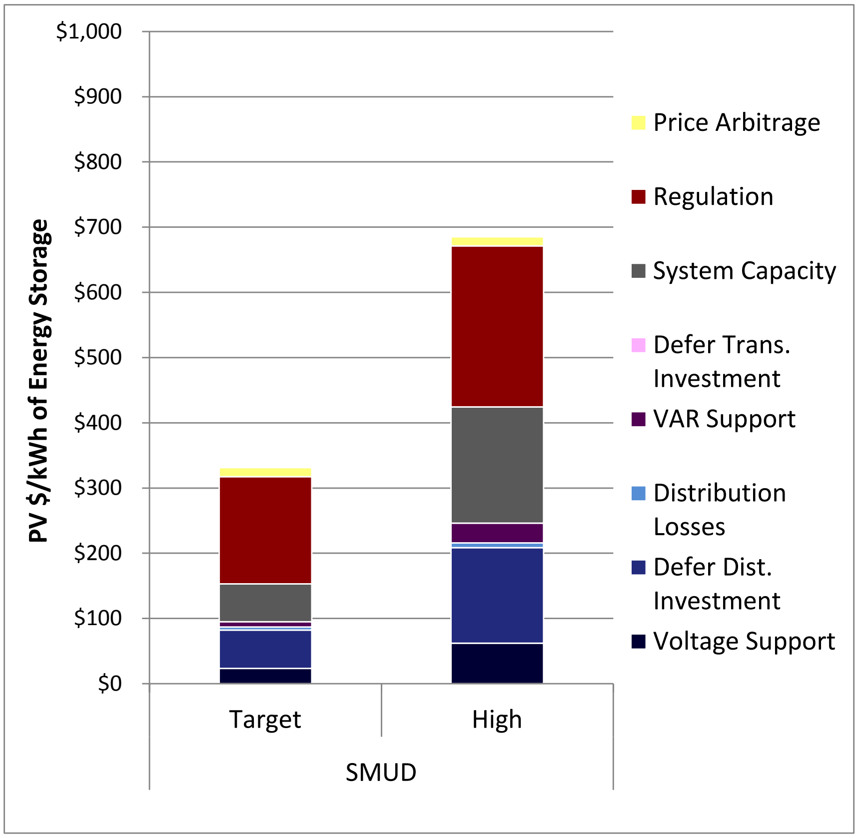

Figure 5-6
Transportable Distribution Deferral – 4 Hrs – Sys Cap – Regulation

Distributed Energy Storage Systems (DESS)

Application Description

DESS envisions a storage device or multiple devices deployed on the distribution system to provide benefits to both the utility system and its customers. This application considers storage located at the final line transformer or pad mounted. All the DESS applications assume a 2 hour battery. The model assumes that 50% of the battery (1 hour) is reserved for customer reliability while 50% is available to provide grid support services. The battery capacity could range from 25 to 500 kW but the application is modeled to assume that 1 MW of DESS is aggregated and operated by the utility.

The outage frequency estimates indicate that 1 hour of energy storage would cover between 76 and 91 percent of a customer's expected outages for the feeders examined on the SMUD system. The model assumes that the storage device at the final line transformer or pad mounted is successful at responding to 80% of the outages lasting 1 hour or less.

As in the transportable distribution deferral application, 500 hours are reserved for Capacity Mode operation. During these 500 hours, the storage not used for backup power (1 hour) provides voltage support, distribution deferral, and system capacity. For the remainder of the year, the storage not used for backup power may either provide reliability for the end-use customer or participate in energy or ancillary services markets. In specific areas with C&I customers with high outage costs, providing reliability throughout the year may provide the highest value. Outside of those areas, however, participating in the AS markets will provide the most revenue. Technologies with capabilities sufficient to provide regulation will choose to do so, as it is the most lucrative AS market. Technologies that lack sufficient delivery capability or response time will be limited to the energy market.

Application Results

The first scenario models a 1 MW, 2 hour distributed energy storage system in which no ancillary services benefits are included. Application PVs are \$171/kWh with target benefit values and \$435/kWh with high benefit values. The most significant high benefit value is customer reliability. For the outage statistics, researchers used the SMUD base case for target values and the SMUD high case for high values. In all cases researchers used the 50th percentile value of service statistics from surveys in order to represent the average value of service of multiple customers on a feeder. One large caveat here is that it was assumed customer outages are accurately represented by outage statistics used from the SMUD outage statistics. It may be possible that the data indicates an outage of a certain length, but that in reality customers are not faced with an outage of that length because SMUD field engineers develop a quick work-around that is not picked up by outage data measurements.

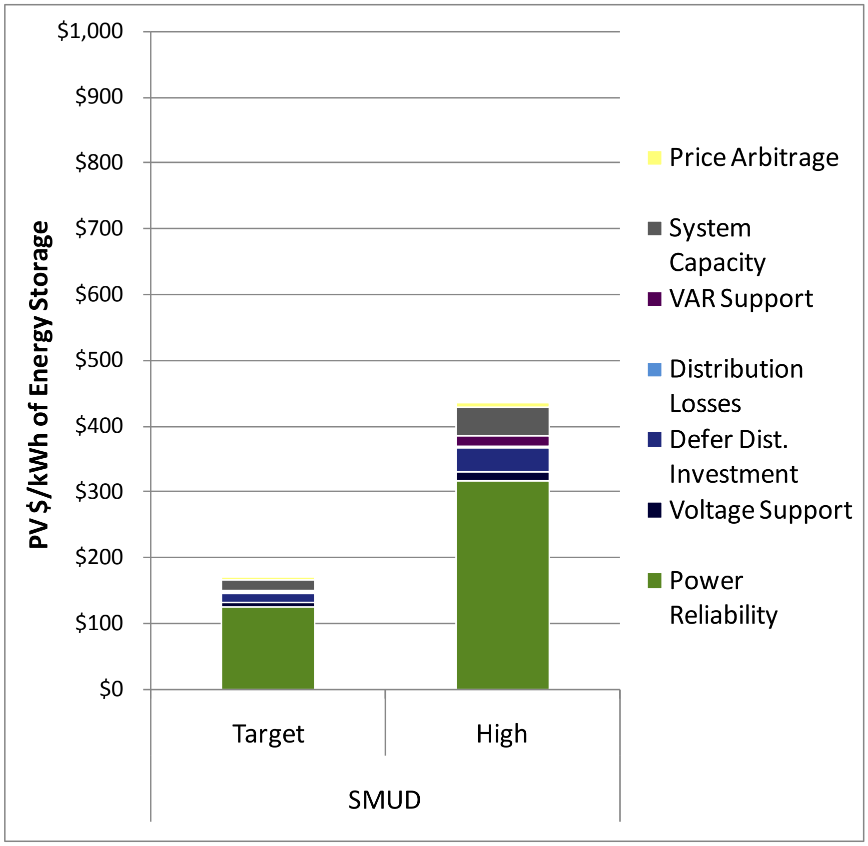

Figure 5-7
DESS Pad Mounted – 2 Hrs

The second DESS scenario in Figure 5-8 models a 1 MW, 2 hour distributed energy storage system in which the storage participates in the regulation market. Application PVs are $482/kWh with target benefit values to $934/kWh with high benefit values. Because the DESS batteries individually are less than 1 MW, this scenario would require sophisticated aggregation on the part of the utility in order to bid the minimum 1 MW into the CAISO regulation market.

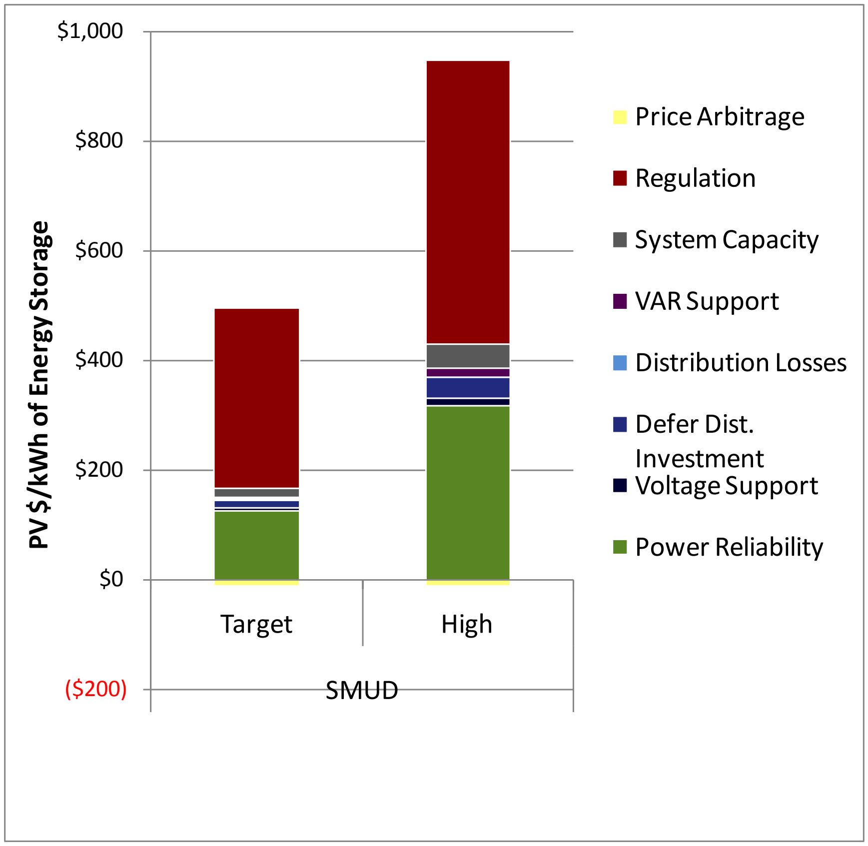

Figure 5-8
DESS Pad Mounted – 2 Hrs – Regulation

Distributed Solar Load Shift

Application Description

Distributed Solar Load Shift models a scenario in which storage is sited on a feeder with high distributed solar penetration. The storage would be used to shift the solar output from morning periods to evening periods in order to better match the SMUD system demand shape. The batteries would be located on the feeder and thus are most similar to the DESS applications. In order to simplify the analysis of the solar shift, it was assumed that the battery is used all the time for solar shifting rather than for additional benefits such as customer reliability or regulation.

Application Results

The Distributed Solar Load Shift application models a 1 MW, 2 hour distributed energy storage system in which no ancillary services benefits are included. Figure 5-9 shows Application PVs are $153/kWh with target benefit values and $424/kWh with high benefit values. The Application PVs are lower for the Distributed Solar Load Shift application than for other DESS applications because the main benefit solar load shift provides is system capacity.

Researchers had already assumed that the DESS batteries could accrue system capacity benefits. In addition, batteries might be able to defer grid upgrades necessary to accommodate high penetration distributed solar, but it had already been assumed that the DESS batteries could accrue distribution investment deferral benefits as well as voltage support benefits, the two values most closely associated with high penetration distributed solar.

When giving storage a capacity benefit for shifting PV duration, it was necessary to first determine whether storage and PV together can effectively reduce the peak load hours. In order to examine the efficacy of shifting of solar we looked at the top net load hours of the SMUD net load duration curve. For distributed solar load researchers used the output of a utility scale 10 MW, 25 Degree, Fixed Tilt array in Sacramento from the PVWatts Database. In storage dispatch model with our 1 MW 2 hour battery, the top net load hour is reduced by 1 MW, the top 4 net load hours are reduced by an average of 0.75 MW and the top 100 net load hours are reduced by an average of 0.73 MW. The dispatch indicates that a simple storage dispatch based on SMUD net load is able to provide a consistent capacity benefit when coupled with distributed PV.

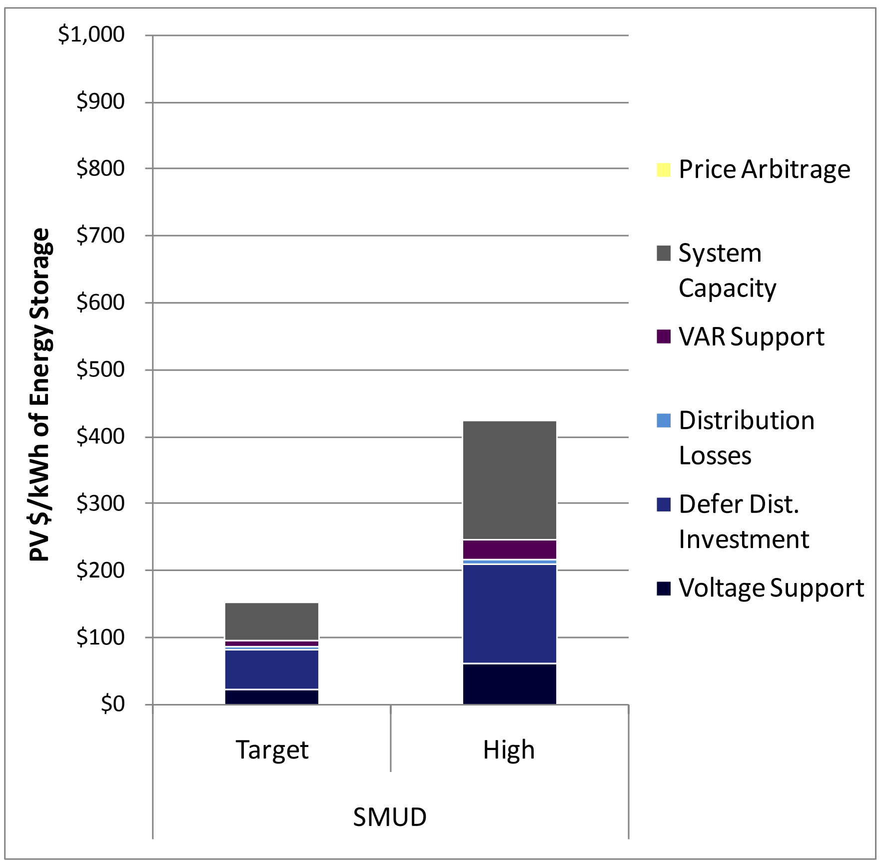

Figure 5-9
DESS Pad Mounted – 2 Hrs – Distributed Solar Load Shift

Commercial Energy Management

Application Description

The Commercial Energy Management application envisions a customer using behind-the-meter storage to reduce retail energy bills. Storage can reduce TOU energy charges by shifting load from on-peak to off-peak periods. Storage can also reduce demand charges, particularly for customers with low load factors and/or peaky load shapes. Providing these benefits will require that the storage functions in Dispatch Mode. The system will store energy during off-peak hours and discharge that energy coincident with the customer's peak load during on-peak hours. This application focuses on the perspective of the retail customer rather than the utility, because the batteries would be owned by the customer. The bill savings to the customer are a revenue loss to the utility. That said, the customer load is shifted in the application, and so the utility does see some benefit in the form of lower wholesale energy prices. The customer perspective benefit is the benefit value from reduced TOU and demand charges and the TRC or regional benefit is the benefit from energy arbitrage on the wholesale market.

Application Results

The first scenario, shown in Figure 5-10 and Figure 5-11, models a 1 MW, 2 hour commercial energy management system. From the customer perspective, application PVs are $24/kWh with target benefit values and $114/kWh with high benefit values. The target values assume that the customer is on SMUD tariff R-TOU Option 1. This tariff does not have a demand charge and therefore the only benefit value seen by customers under this tariff would be reduced TOU energy charges. The high value assumes the customer is on the SMUD tariff GS-TOU3 Secondary. This tariff has time-of-use rates and also includes a demand charge. Demand charge reduction is the most significant benefit in the high case. From the TRC perspective, the application PV is $35/kWh for both the high and the target case.

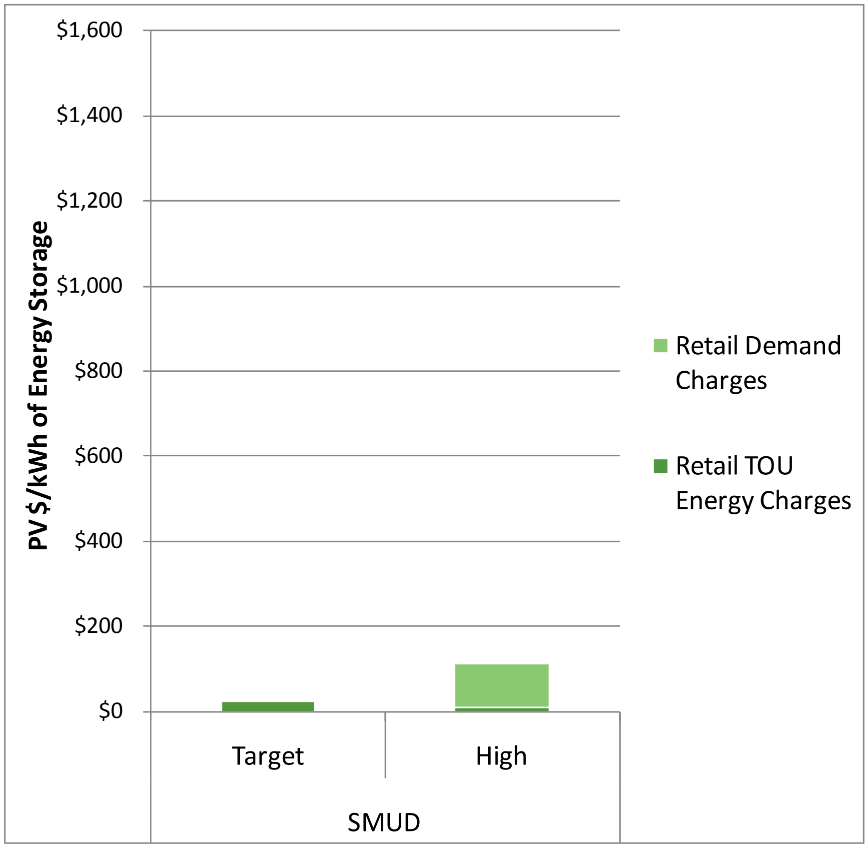

Figure 5-10
Com. Energy Mgmt – 2 Hrs – Customer Perspective

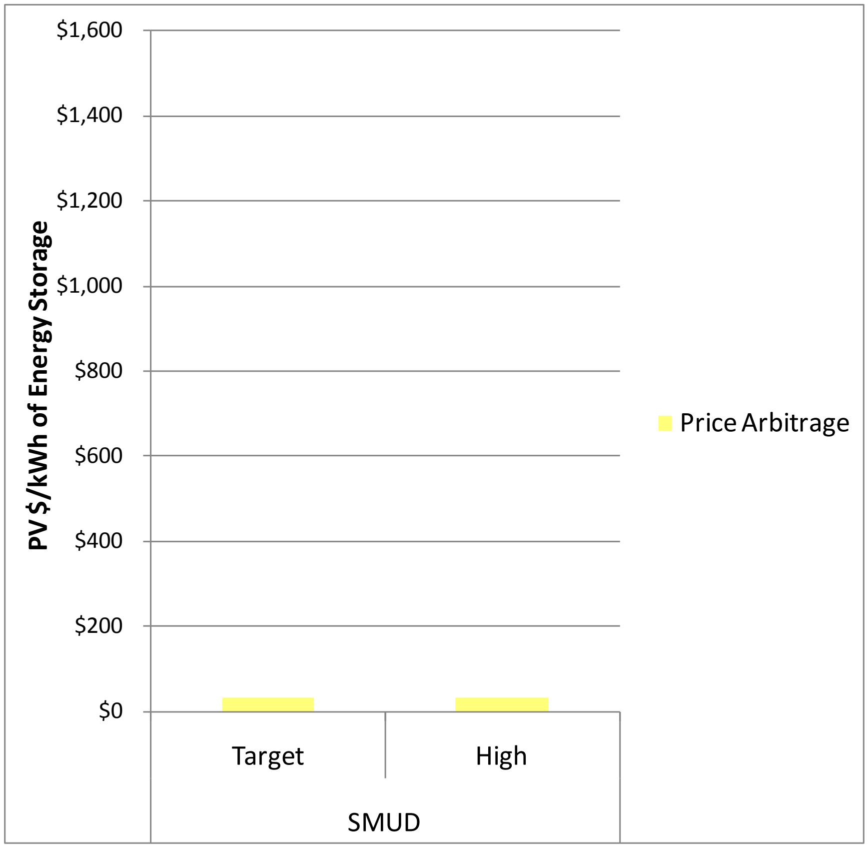

Figure 5-11
Com. Energy Mgmt – 2 Hrs – TRC perspective

The second energy management scenario, shown in Figure 5-12 and Figure 5-13, models a 1 MW, 2 hour commercial energy management system. The difference in this scenario is that the customer is assumed to be served by a critical peak pricing (CPP) rate. SMUD does not currently have a CPP rate, so the CPP rate modeled is that of San Diego Gas & Electric Company (see Section 2, Retail TOU Energy Charges). The SDG&E CPP rate includes both a demand charge and TOU energy charges. The CPP charges are based on hourly energy charges and therefore the reduction in CPP charges is included under the reduce TOU energy charges benefit. Only one tariff is used so there are not target and high values for this scenario.

From the customer perspective, the application PV is $349/kWh. From the TRC perspective, the application PV is $36/kWh.

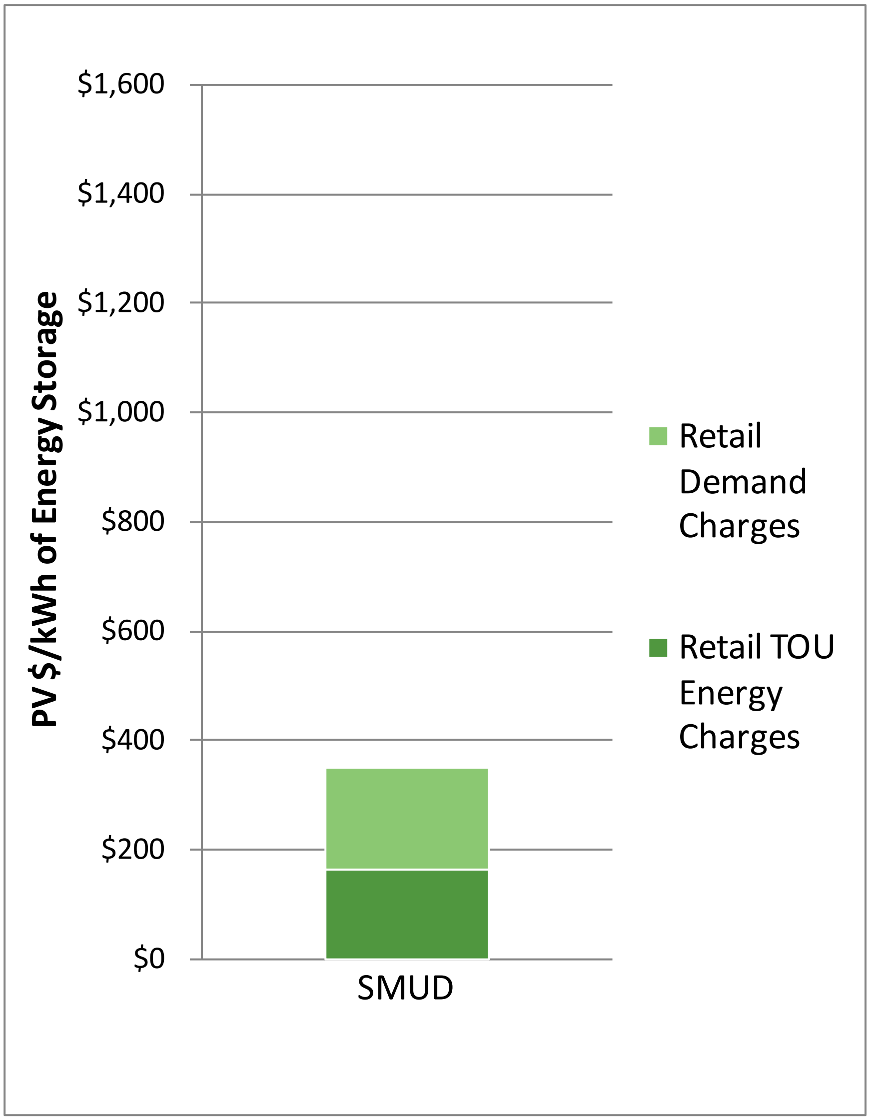

Figure 5-12
Com. Energy Mgmt – 2 hrs – CPP – Customer perspective

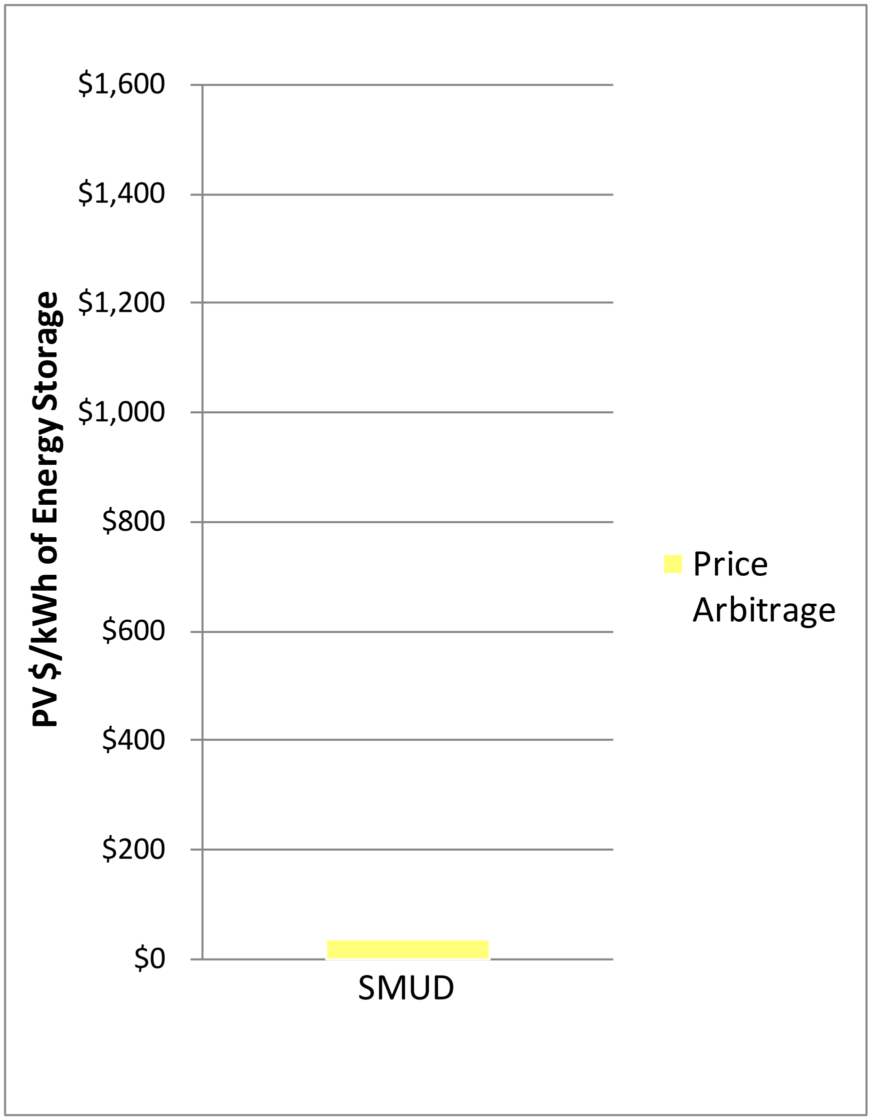

Figure 5-13
Com. Energy Mgmt – 2 hrs – CPP – TRC perspective

Aggregated Energy Management with Grid Support

Application Description

The Aggregated Energy Management with Grid Support application would involve a third party aggregator operating multiple behind-the-meter battery systems in order to provide energy management benefits to customers as well as provide grid services. This application has many similarities to a demand response system. Significantly, this application is modeled without showing any transaction costs or overhead on the part of the third party aggregator. The assumption of zero transaction costs is unrealistic but is done here in order to more clearly present the benefit values possible under this application and present the business case. Anecdotal evidence from the demand response industry suggests that energy service companies that provide aggregation services have overhead costs of 30-50%.

The reason the application must be aggregated by a third party is that the batteries must be behind-the-meter in order to accrue energy management benefits but customers are unlikely to allow a utility to operate a behind-the-meter device. A third party aggregator, such as a demand response provider, could operate the batteries in order to solve the conflict of interest issue. Similar to the energy management application, this application is modeled from the customer perspective because the battery will be owned by the customer. The separate customer and TRC benefit charts will be shown for each scenario. In contrast to the energy management application, the price arbitrage benefit value could theoretically be a customer perspective value because the third party aggregator will be negotiating with the utility on behalf of the customer for every benefit the utility receives from these customer-owned batteries.

Application Results

The first scenario, shown in Figure 5-14 and Figure 5-15, models a 1 MW, 2 hour aggregated energy management system with grid support. From the customer perspective, application PVs are $204/kWh with target benefit values and $476/kWh with high benefit values. The target values assume that the customer is on SMUD tariff R-TOU Option 1. The high value assumes the customer is on the SMUD tariff GS-TOU3 Secondary. From the TRC perspective, the application PV is $183/kWh with target benefit values and $454/kWh with high benefit values. From the customer perspective, retail TOU energy charges are an overall negative value though demand charge reduction is a positive value. In order to operate in capacity mode and accrue benefits such as system capacity and deferral of distribution investments, the battery must occasionally charge during high price TOU hours. In addition, the battery must charge for more hours than it discharges do to its round-trip efficiency, which leads to additional high TOU rate energy charges in some cases.

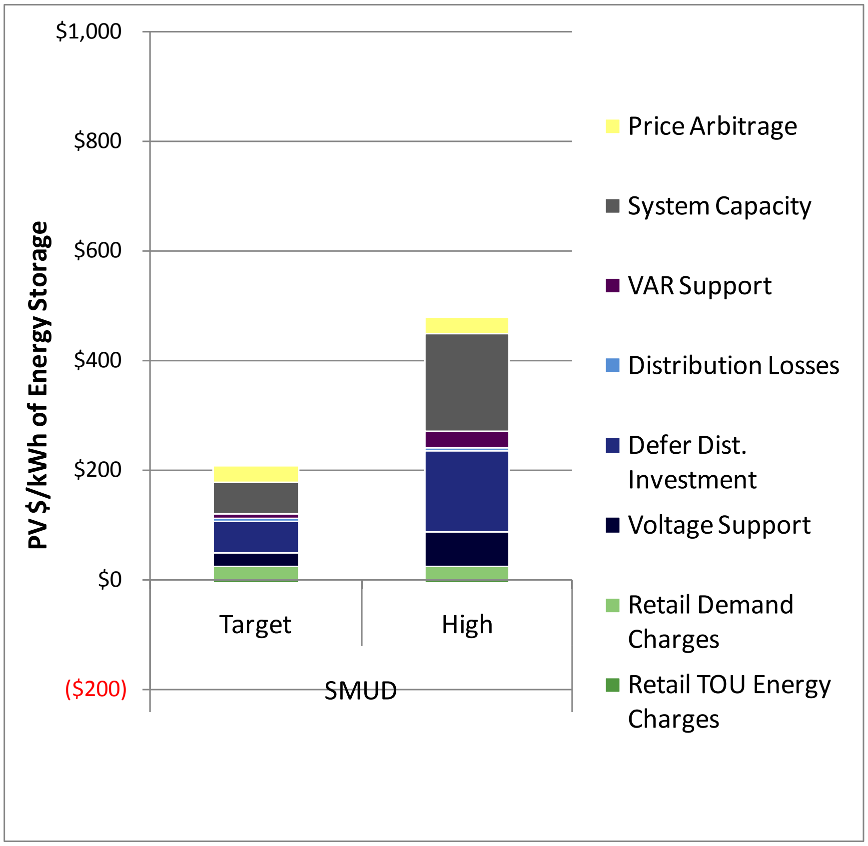

Figure 5-14
3rd Party Aggregated Energy Mgmt. – 2 Hr – Customer Perspective

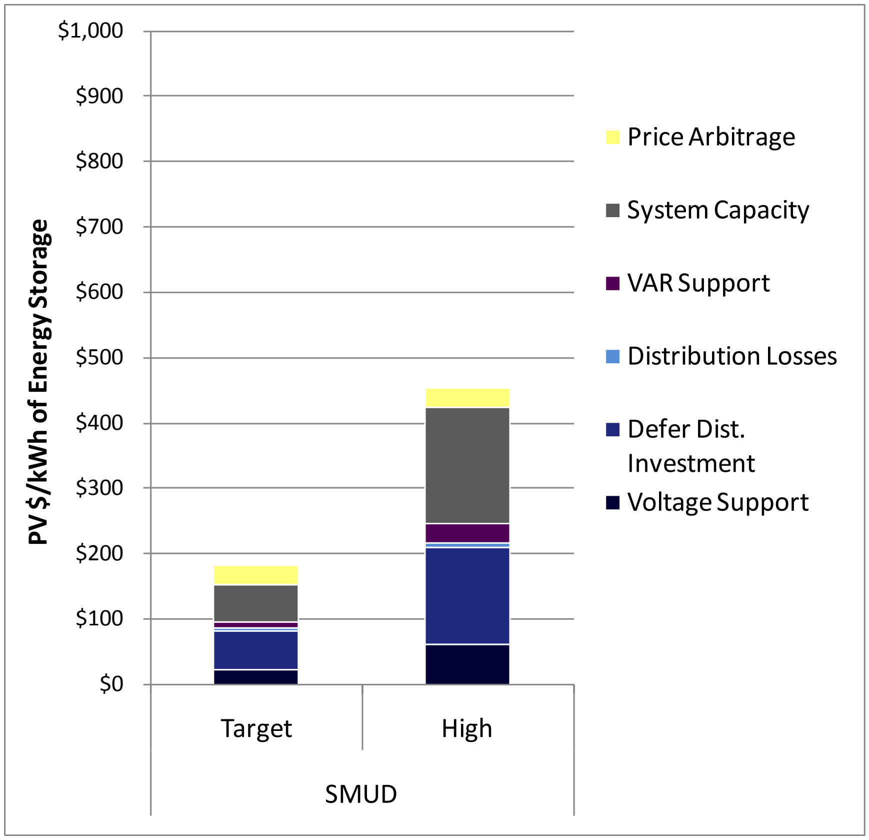

Figure 5-15
3rd Party Aggregated Energy Mgmt. – 2 Hr – TRC Perspective

The second scenario, also shown in Figure 5-16 and Figure 5-17, models a 1 MW, 2 hour aggregated energy management with grid support system if the customer is under a CPP rate. From the customer perspective, application PVs are $442/kWh with target benefit values and $713/kWh with high benefit values. Both the target and high values assume the customer is on the SDG&E CPP tariff. From the TRC perspective, the application PV is $183/kWh with target benefit values and $454/kWh with high benefit values.

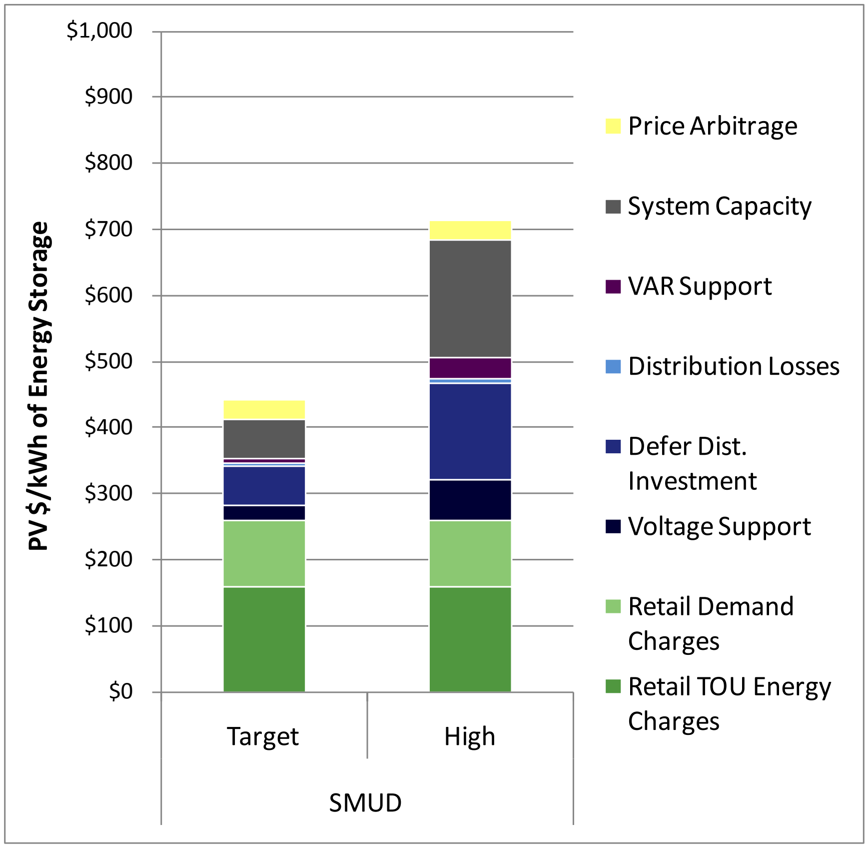

Figure 5-16
3rd Party Aggregated Energy Mgmt. – 2 Hr – CPP – Customer Perspective

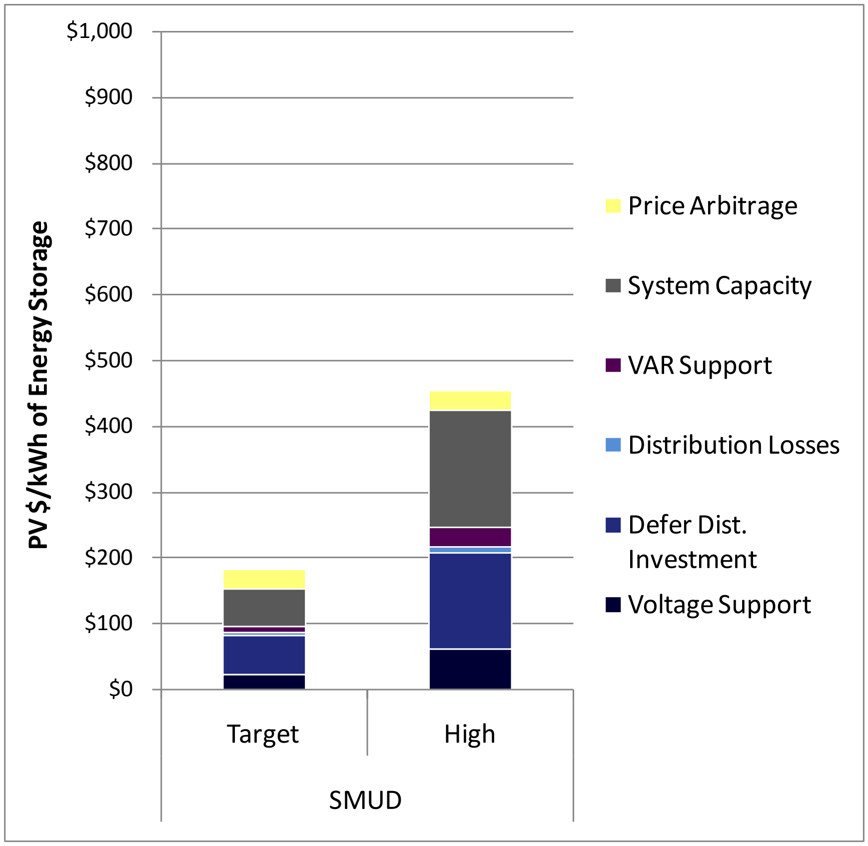

Figure 5-17
3rd Party Aggregated Energy Mgmt. – 2 Hr – CPP – TRC Perspective

The third scenario is identical to the first aggregated scenario except that the aggregated system also is able to bid into the CAISO regulation market. From the customer perspective, application PVs are $361/kWh with target benefit values and $747/kWh with high benefit values. As in the first aggregated case, the TOU rate charges are an overall negative value. From the TRC perspective, the application PV is $353/kWh with target benefit values and $739/kWh with high benefit values.

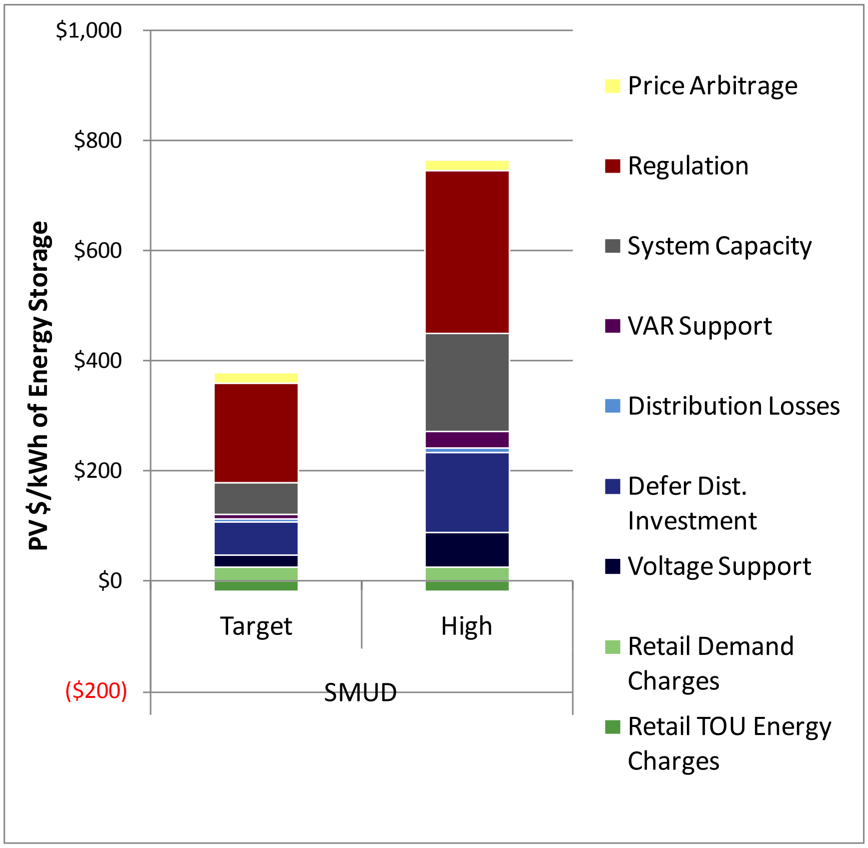

Figure 5-18
3rd Party Aggregated Energy Mgmt. – 2 Hr – Regulation – Customer Perspective

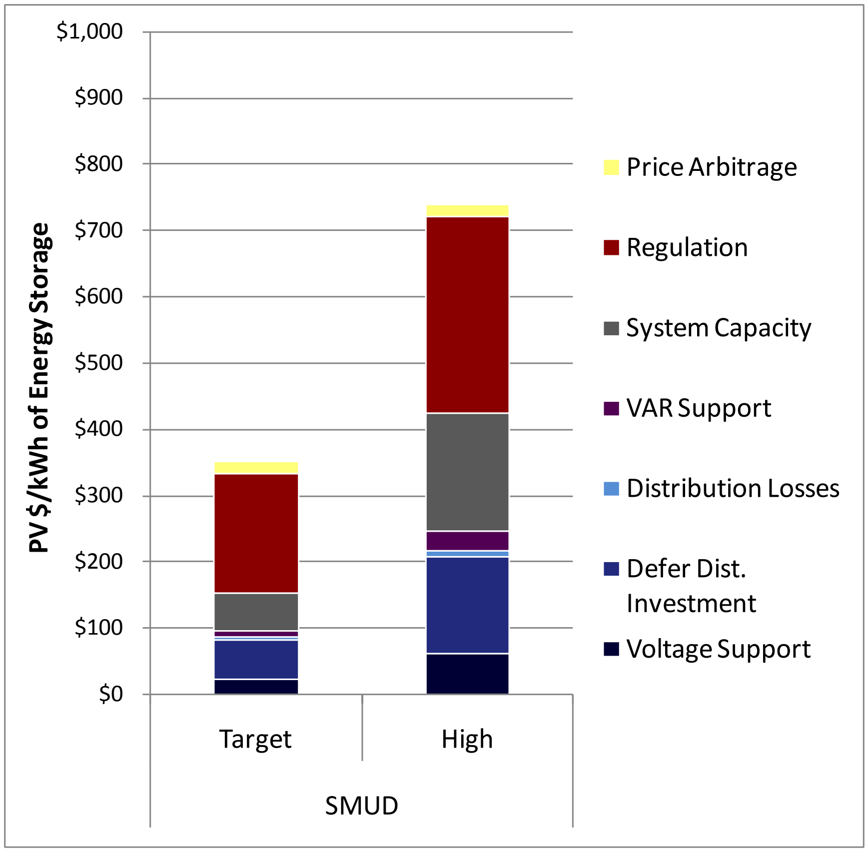

Figure 5-19
3rd Party Aggregated Energy Mgmt. – 2 Hr – Regulation – TRC Perspective

The fourth scenario is identical to the second aggregated scenario except that the aggregated system also is able to bid into the CAISO regulation market. From the customer perspective, application PVs are $589/kWh with target benefit values and $976/kWh with high benefit values. From the TRC perspective, the application PV is $353/kWh with target benefit values and $739/kWh with high benefit values.

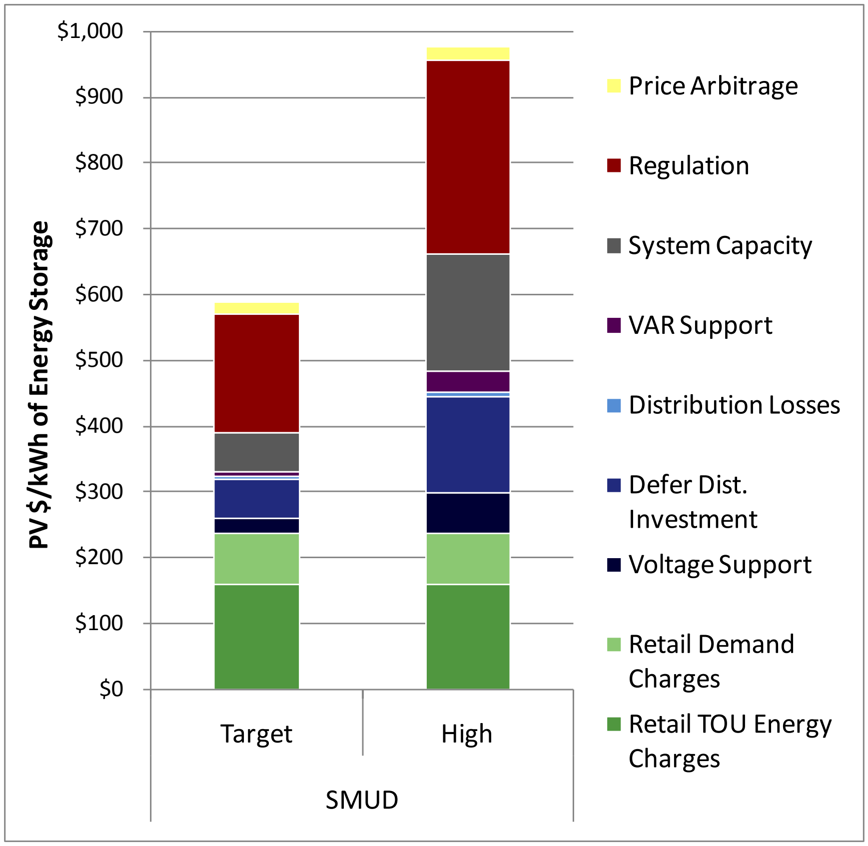

Figure 5-20
3rd Party Aggregated Energy Mgmt. – 2 Hr – CPP – Regulation – Customer Perspective

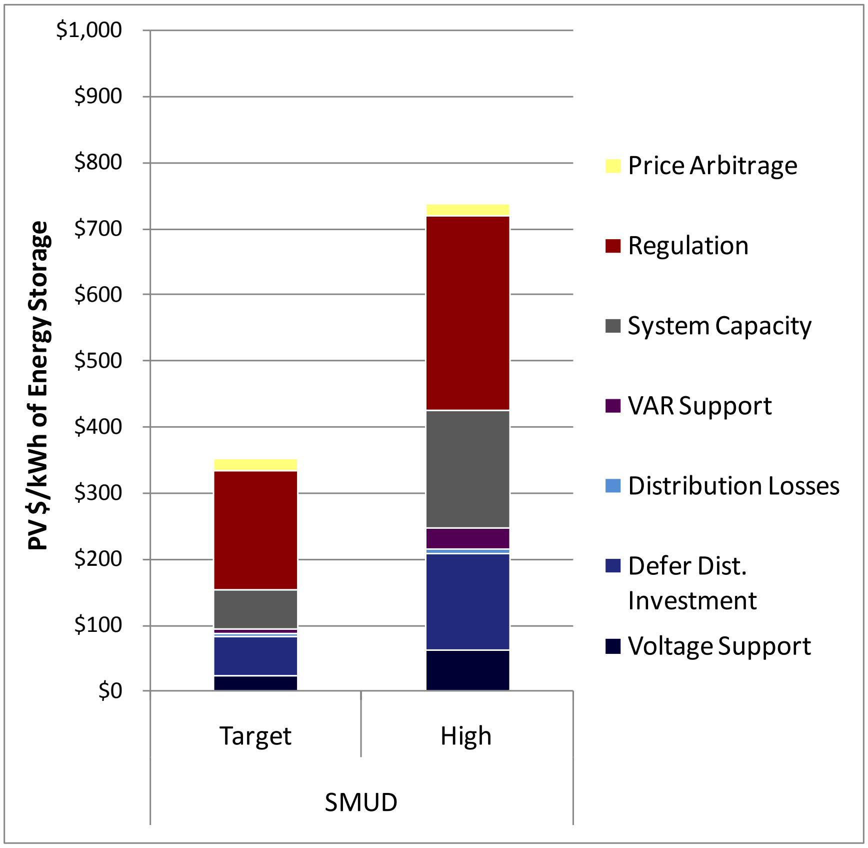

Figure 5-21
3rd Party Aggregated Energy Mgmt. – 2 Hr – CPP – Regulation – TRC Perspective

Section 6: Conclusions

High Value Applications

For utility applications of energy storage located in the SMUD system, this analysis finds regulation and system capacity to be the benefits that drive high values. More research is therefore needed regarding how best to create battery communication tools that allow batteries to pursue these benefits while simultaneously providing other benefits. The importance of these two benefits does not change with location; the highest value utility-owned battery applications both at the substation and as distributed systems (DESS) involve accruing regulation and system capacity benefits. The analysis also finds that reliability benefits could be large given assumptions about SMUD outage statistics and customer value of service information. Still, even in cases with a high reliability benefit, other benefits such as regulation and system capacity must be targeted simultaneously in order to accrue high application present values. The value of distribution investment deferral from storage is potentially large, but appears limited for SMUD given the current conditions and practices of the SMUD distribution system.

On the customer side of the meter, applications focused on bill reduction provide potentially large benefits for customers, particularly if SMUD enacts a CPP rate or other higher TOU rates. In addition, the customer applications focused on reliability needs may already be economic for customers with very high value of service, but these high values are unlikely to be widespread.

Locational Value of Storage

By defining storage applications with specific locations on the distribution grid, this study aims to provide insight into the locational value of energy storage. The analysis shows that storage located at the substation has the potential for the greatest benefit to the utility in the near-term. Substation storage requires less need for aggregation of many smaller units to capture benefits. The reason substation storage is most valuable is that it can accrue the high value benefits of regulation, system capacity and T&D investment deferral. Figure 6-1 shows the highest value scenario for a substation storage application accruing these three high value benefits. The T&D benefit shown could be even higher if the storage is transportable and is able to defer multiple T&D investments over its lifetime.

Distributed utility storage located on the feeder could also be coordinated to pursue the benefits of regulation and capacity. If it is not economic to aggregate

DESS systems for participation in AS markets, the value is lower than the substation location. Distributed storage located at the feeder would provide a different value for T&D investment deferral. Distributed storage is unlikely to be able be transportable and integrated in distribution planning such that it can accrue deferral benefit values for multiple years of deferral. On the other hand, distributed storage may be a good way to provide relief to overloaded underground cables that have a high probability of failure during peak load days. This report did not have access to engineering reports regarding how much storage would be needed to "unload" an underground cable in practice.

The system capacity, regulation, and T&D benefits from distributed storage look the same as or lower than substation storage; the report looked at the benefit of customer reliability from distributed storage. Customer reliability benefit values are based on the SMUD system for 2008. SMUD 2008 values lead to higher customer reliability benefits than average for SMUD, as 2008 was an unusually bad outage year. Still, even with 2008 outage statistics, a battery focused on customer reliability benefits does not accrue benefits as high as the benefits of capacity and T&D deferral accrued at the substation level.

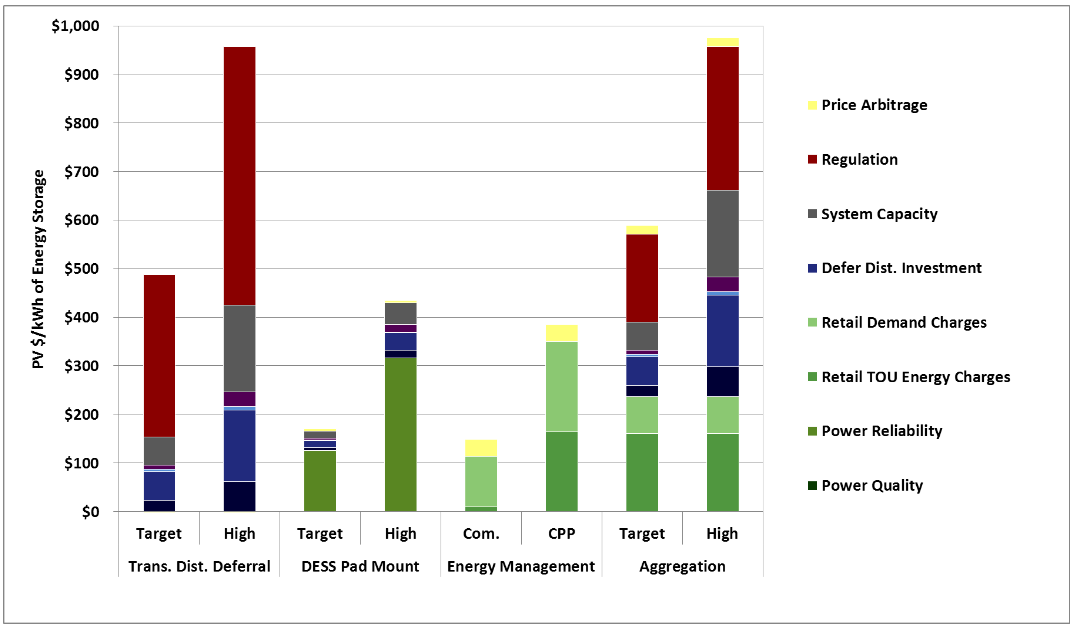

Figure 6-1
Comparison of Locational Difference in Storage Applications

A behind the meter storage device could have retail bill impact benefits for customers, but these benefits are lower than the benefits for utility operated storage. A CPP rate in SMUD could potentially increase the benefits of storage, but not enough such that customer side of the meter storage is more valuable than utility side of the meter storage. Higher benefit values are only achieved through aggregation of customer or third party owned storage such that it can provide grid benefits of regulation and capacity.

Aggregation of customer sited systems, however, has the potential to combine the retail rate savings seen by the customer with the higher value system and distribution benefits for the utility. The retail rate reduction is a benefit for the customer but a loss of revenue for the utility. Because the revenue lost in retail rates usually outweighs the actual benefits to the utility, it is generally not in the utility's interest to encourage customer sited applications that will result in lost revenue.

Nevertheless, if battery systems will be installed by customers for their own benefit in any case, it could benefit the utility to take advantage of those systems. Combining customer and utility benefits through aggregation provides the highest present value benefits of any of the applications modeled in this report. Customer side of the meter applications can provide high value under the assumption that there is a third party aggregator able to operate the battery customer energy management while simultaneously negotiating with the utility to provide utility benefits. This is particularly true if regulation revenue can be earned through aggregation.

Areas of Future Study

In general, for the applications examined by this report, energy storage lifecycle costs will need to fall to approximately $500/kWh or below in order to make batteries cost-effective. While most battery costs today are higher than $500/kWh, researchers at EPRI anticipate that production costs of Li-ion could be reduced significantly in the near future due to the scale of global production of Li-ion batteries for electric vehicles. Although future cost reductions are uncertain, SMUD may want to study their potential effects. For example, SMUD may wish to study how to extract system benefits from customer applications that may be installed by customers and operated to optimize customer benefits. In addition, SMUD may wish to study how best to integrate a transportable substation battery system into distribution investment planning such that one battery would be able to defer multiple projects over a 10-15 year lifetime. Finally, the current analysis does not find high value benefits from local renewable smoothing/integration at this time, but the application merits further attention given future local renewables goals.

Program:

Energy Storage

1023591

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com