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January 1, 2014

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RE: Energy Storage Report

Dear Senator Marty, Representative Hortman, Senator Tomassoni, Representative Atkins, Senator Brown, Representative Garofalo, Senator Ingebrigtsen and Representative Hoppe:

I am enclosing a report entitled, "*White Paper Analysis of Utility-Managed, On-Site Energy Storage in Minnesota*," prepared by Strategen Consulting for the Minnesota Department of Commerce, Division of Energy Resources. This report examines the potential for grid-connected electrical energy storage technology located in Minnesota, pursuant to Minnesota Laws 2013, Chapter 85, HF 729, Article 12, Section 5. The Commerce Department commends Strategen's approach in examining energy storage technology.

If you have any questions about the report, please contact me or my Deputy, Bill Grant at 651-539-1801 or bill.grant@state.mn.us.

All my best,

Mike Rothman

Mike Rothman
Commerce Commissioner

Enclosure

FINAL REPORT

White Paper Analysis of Utility-Managed, On-Site Energy Storage in Minnesota

Prepared by: Strategen Consulting

Prepared for:

Minnesota Department of Commerce,

Division of Energy Resources

DECEMBER 2013

COMM-20130722-69155

White Paper Analysis of Utility-Managed, On-Site Energy Storage in Minnesota

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ACKNOWLEDGEMENTS

MN Laws 2013, Chapter 85 HF 729, Article 12, Section 5 required the Department of Commerce to contract with an independent consultant to produce the enclosed report. This project was supported in part, or in whole, by a grant from the Minnesota Department of Commerce, Division of Energy Resources through utility assessments, which are funded by Minnesota ratepayers.

Prepared for: **Minnesota Department of Commerce, Division of Energy Resources,** Contract Number: 69155

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Table of Contents

List of Figures

List of Tables

1 Executive Summary

1.1 Overview

Pursuant to legislation passed in 2013[1], the Minnesota Department of Commerce (Commerce) contracted with Strategen and the Electric Power Research Institute (EPRI) to investigate the potential costs and benefits of grid-connected electrical energy storage technology located at the utility customer in the State of Minnesota. The investigation included standalone storage and storage integrated with solar PV, and it considered both residential and commercial customer sites. Four different general operational use cases for energy storage were identified and investigated, including:

1. Customer controlled for bill savings;
2. Utility controlled for distribution system benefits;
3. Utility controlled for distribution and market benefits; and
4. Shared customer and utility controlled for bill savings and market revenue.

The project team modeled each use case to calculate project lifetime costs and benefits, performed an analysis of key barriers to implementation, and provided recommendations to address key gaps to energy storage implementation. EPRI's role in this investigation was limited to modeling and objective technical support, and as such did not play a role in providing specific recommendations for regulatory or policy action.

1.1.1 Energy Storage Project Value Modeling

To determine the analysis inputs, the project team utilized publicly available reports in Minnesota as well as data provided by Xcel Energy and other Minnesota utilities. Where data gaps existed, they were estimated using information gathered during the California Public Utility Commission's (CPUC) Energy Storage Rulemaking proceeding in 2013, particularly those related to energy storage cost and performance.

Across the four use cases, approximately fifty different energy storage cases were modeled and simulated using the EPRI Energy Storage Valuation Tool (ESVT), spanning a range of input assumptions and benefit stream combinations. For each case, a benefit-to-cost (B/C) ratio was generated to show the direct, quantifiable fixed and variable costs and benefits, incorporating the time value of money, for the modeled project over its lifetime. A benefit to cost ratio less than one means that the real project costs exceeded benefits; in other words, net present value (NPV) was less than zero.

The resulting B/C ratios across these cases are summarized in Figure 1. The chart plots cover the range of benefit to cost values for each general use case.

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[1] Pursuant to legislation passed in 2013 (Value of On-Site Energy Storage: [MN Laws 2013, Chapter 85 HF 729](), Article 12, Section 5),[1] the Minnesota Department of Commerce was required to contract with a qualified contractor to produce a white paper analysis of the potential costs and benefits of installing utility-managed, grid-connected energy storage devices in residential and commercial buildings in Minnesota

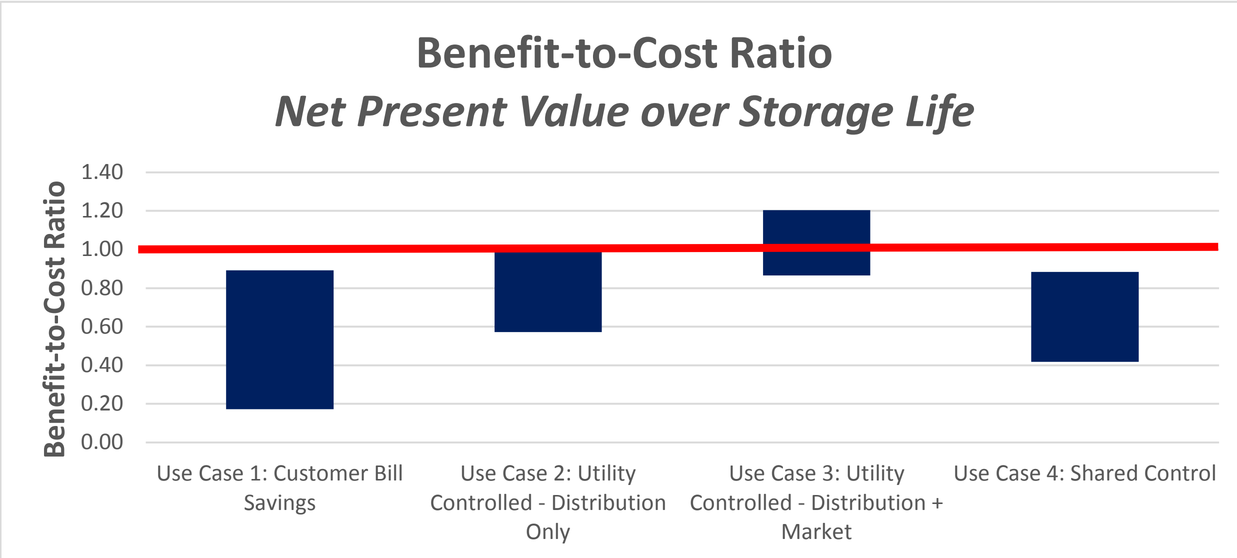

Figure 1: Summary of Customer-Sited Energy Storage Project Cost-Effectiveness in Minnesota

The majority of cases modeled returned B/C ratios less than one, particularly Use Case 1 (Customer Bill Saving) cases. However, Use Cases 3, which involved utility control and aggregated multiple benefit streams of energy storage, produced results which broke even or were positive over project lifetime. Additionally, Use Case 2 produced breakeven results under certain assumptions.

In addition to benefit-to-cost ratio, the breakeven capital cost of energy storage was calculated for model runs with a high benefit to cost ratio. The Breakeven Capital Cost is the maximum allowable storage upfront capital cost that would result in a breakeven result (B/C ratio > 1). Due to the importance of context for this metric, it is not summarized and only provided in the individual case results.

It should be noted that estimated energy storage assumptions utilized in this study originated from confidential energy storage developer input for cost and performance in 2015. Analysis results are sensitive to inputs for energy storage costs as well as assumptions for future-year grid service value. Energy storage costs are expected to decrease as more energy storage is installed worldwide. The benefits may also increase due to increased grid need for flexibility as wind and solar PV increase as a portion of overall power generated. Extrapolating these trends, the cost/benefit ratio of energy storage in the various cases modeled may continue to improve with time.

1.2 Key Conclusions

- Energy storage has the potential to provide multiple sources of value for customers and utilities. These values can come in the form of economic value and in terms of grid reliability. As such, the results are subject to change based upon federal and state tax policy changes, tariff changes, expansion the use of time-of-use (TOU) energy prices, or substantive changes in energy storage, renewable energy, or conventional energy resource prices.

- Utility controlled, customer-sited storage in Minnesota has the potential to provide benefits to the grid greater than the system's cost. Several different combinations of benefits were required to achieve benefit to cost ratios greater than one. While a number of different value streams were investigated, the value of each use case was primarily driven by the following grid services and incentives: 1) distribution upgrade deferral; 2) frequency regulation, 3) system capacity, and 4) Federal Investment Tax Credit (FITC) for solar and favorable accelerated depreciation schedules (MACRS).

  In order to achieve a benefit to cost greater than one, the modeling results showed the importance for the storage project to capture value from at least three of these four key benefits. Accessing the key benefits with a single storage resource requires a certain energy storage dispatch (i.e. charging and discharging) behavior and project structuring, as outlined below:

  - Distribution upgrade deferral benefits are dependent upon the need for an upgrade of a local distribution asset such as a substation or transformer and ability to defer it with storage, and thus are highly site and time-specific. The highest deferral values are associated with low load growth rates of (~1%/yr), which is consistent with the Minnesota average load growth rate.
  - Participation in frequency regulation requires bidding into the Midcontinent Independent System Operator (MISO) frequency regulation market. Capturing this benefit would require additional creation of MISO rules for customer-sited storage system market participation.
  - The system capacity benefit is based around supporting a utility's long-term Resource Adequacy requirements. Availability of this benefit is based on regional need at specific times. Additional tools and methods may be required to incorporate energy storage into the integrated resource planning (IRP) process that defines the need and potential solutions.
  - To capture the FITC and accelerated MACRS depreciation, the storage system must be linked to a solar PV system and receive 75% or more of its charging energy from solar. The utility must also be able to monetize the Investment Tax Credit and accelerated MACRS depreciation value, either directly or through a third-party ownership structure.

- Customer sited commercial and residential storage that relies upon customer tariffs were not able to achieve a benefit to cost greater than one. The customer tariffs evaluated do not provide sufficient price signals to customers to procure energy storage or operate it in optimal ways to benefit the electric system. Residential tariffs, due to lack of demand charges and lack of TOU pricing spreads, are most challenging for attaining cost-effective energy storage value propositions.

- Reliability (backup power) and voltage support service benefits of energy storage, while conceptually attractive, have not been found to be materially sufficient to significantly impact the cost-effectiveness of energy storage. However, these requirements and resulting benefits vary widely depending on customer need. Also, though the relative magnitude of power quality and reliability benefits may not be large, it could provide incentive for customers to allow utilities to site energy storage on their property.

- Certain storage benefits can vary by utility type. Rural cooperative utilities (co-ops) generally have more electric water heaters. Some cooperative utilities have load shapes with peaks in early morning during the winter, rather than the more typically observed hot summer afternoon. Energy storage should be modeled according to the benefits within a specific utility and to best suit each utility's characteristics.

1.3 Recommendations

Based upon the results of the study, we provide several recommendations for further actions by Commerce. These recommendations are intended to better understand energy storage integration, increase performance in Minnesota, and appropriately capture and compensate value provided by storage.

- Based upon the results, we recommend that utility controlled customer sited storage and distribution upgrade deferral be considered as a mitigation strategy in Minnesota's Renewable Energy Integration and Transmission Study (Docket No. E-999/CI-13-486).
- We recommend establishing planning procedures to support utilities in finding opportunities to install energy storage together with solar PV to defer high cost distribution upgrades. These procedures should allow utility controlled energy storage projects to be accepted and rate based if the cost-effectiveness exceeds that of the traditional infrastructure, and could be considered as part of CIP resource procurement.
- We recommend establishing energy storage pilot projects based around the key benefits identified in the study. Pilot projects will provide demonstrations of the value proposition of energy storage with valuable lessons learned and operational track record for future commercial consideration of energy storage as applied in the modeling.
- We recommend that utilities conduct financial due diligence to verify that they would be able to capture the Federal Investment Tax Credit for combined energy storage and solar PV projects. Likewise, it is important to validate that customer sited utility controlled systems would be able to provide frequency regulation to MISO.
- We would encourage MISO to establish clear processes for customer side and utility owned resources to participate in MISO markets.
- Utilities might consider rate structures and/or demand response programs that take into account the system value that might be provided by customer sited energy storage. If those rate structures were to change, customers might consider dual use for their Uninterruptible Power Supply (UPS).
- In order to provide the greatest benefit from customer-sited energy storage, utilities should define the control of these systems. Multiple options are possible for procurement, including rate-based recovery or third-party ownership. Incentives for energy storage could apply if the key benefits cannot be directly monetized, or if additional societal and/or system benefits could be shown to apply to energy storage assets.
- The study results indicate a potentially positive business case for standalone energy storage located at distribution substations in order to provide upgrade deferral and regulation value. We recommend additional due diligence for this case.

1.4 Scope Limitations

1) Energy storage encompasses a wide range of technologies and resource capabilities, with differing tradeoffs in cycle life, system life, efficiency, size, and other parameters. In order to maintain a reasonable scope for modeling, a generic fast responding battery was used for modeling. Several technologies are capable of providing the specifications modeled, including lithium ion batteries, advanced lead acid batteries, and sodium nickel chloride batteries. Technologies that could not be modeled due to time and resource constraints include:
    a. Flow batteries
    b. Flywheels
    c. Traditional lead acid batteries
    d. Modular compressed air energy storage (CAES)
2) Results of modeling are highly sensitive to the input assumptions used. The modeling performed was not exhaustive of all potential uses or scenarios for energy storage deployment.
3) Thermal energy storage was not modeled. A discussion of thermal energy storage follows the conclusions section. Electric hot water heaters are already utilized as a grid resource by rural co-ops, and new technologies may enhance their value to the grid.
4) The study did not model the magnitude or value associated with the cost of creating or mitigating GHGs.
5) The study was not able to take into account other indirect or societal benefits that might result from energy storage procurement, such as job creation, improved grid operations, etc.
6) The study did not investigate adding grid services to energy storage in an existing UPS case. Such a case – where an existing UPS system provides additional grid benefits – could be considered in future analyses.
7) The study did not include the potential secondary impacts of energy storage deployments to market prices. Competition by energy storage in certain markets, like frequency regulation, may result in price suppression from competition.

2 Introduction and Background

This report was prepared in response to a Minnesota Department of Commerce (Commerce) request for proposals to perform analysis of electrical energy storage managed by the electric utility and sited at the utility customer. Pursuant to legislation passed in 2013 (Value of On-Site Energy Storage: MN Laws 2013, Chapter 85 HF 729, Article 12, Section 5),[2] the Minnesota Department of Commerce was required to contract with a qualified contractor to produce a white paper analysis of the potential costs and benefits of installing utility-managed, grid-connected energy storage devices in residential and commercial buildings in Minnesota. The contract was awarded to Strategen Consulting, LLC[3] in partnership with the Electric Power Research Institute.[4] This effort follows the work of a similar study of the California market, *"Cost-Effectiveness of Energy Storage in California: Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007"*.[5]

The scope of work identified by the Minnesota Department of Commerce is as follows:

- Estimate the potential value of on-site energy storage devices as a load-management tool to reduce costs for individual customers and for the utility, including but not limited to reductions in energy, particularly peaking, costs, and capacity costs.
- Examine the interaction of energy storage devices with on-site solar photovoltaic devices.
- Analyze existing barriers to the installation of on-site energy storage devices by utilities, and examine strategies and identify potential economic incentives to overcome those barriers.

2.1 EPRI Involvement

EPRI participated in this effort as a contractor to Strategen Consulting. As an independent, not-for-profit, collaborative research organization, EPRI provides technically objective analysis to inform policy-makers, businesses, and the public. To conform with its mission and principles, EPRI does not advocate for policy, regulation, or use of technology. To support this white paper, EPRI provided technical support and analysis. However, EPRI did not make any policy recommendations related to the elimination of barriers for energy storage or creation of policies to support its adoption. All such recommendations should be attributed solely to Strategen Consulting.

2.2 Methodology

Strategen Consulting and EPRI have approached this analysis by leveraging and building upon prior analysis efforts performed in other geographies. Strategen is a business and governmental strategy

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[2] https://www.revisor.leg.state.mn.us/laws/?id=85&doctype=Chapter&year=2013&type=0
[3] www.strategen.com
[4] www.epri.com
[5] "Cost-Effectiveness of Energy Storage in California: Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007." EPRI, Palo Alto, CA: 2013. 3002001162. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001162

consulting firm focusing on clean energy markets and resource integration, particularly in the renewable energy and energy storage industries. EPRI is an independent, non-profit, collaborative research company with expertise across the electric power sector; EPRI has also developed an industry-leading Energy Storage Valuation Tool (ESVT) to model costs, benefits, and system impacts of energy storage resources. Strategen and EPRI have extensive experience in energy system modeling and market analysis, especially regarding energy storage. In the first half of 2013, Strategen and EPRI coordinated to perform a landmark energy storage value analysis in California for the California Public Utilities Commission (CPUC), which has been an integral contribution to the state's efforts to develop policy to cost-effectively integrate energy storage, including a recent CPUC decision to require California's investor owned utilities to procure 1.325 GW of energy storage by 2020.[6]

Strategen and EPRI addressed the requested white paper analysis by first analyzing Minnesota's current infrastructure, markets and policies impacting energy storage resources. EPRI's Energy Storage Valuation Tool 4.0 Beta (ESVT 4.0 Beta)[7] was used to model lifetime costs and benefits of storage in multiple scenarios, such as utility operation for local distribution benefits and customer reliability. The evaluation was then expanded to examine energy storage systems' interactions with solar PV equipment and generation, specifically tailored to PV generation profiles in Minnesota.[8] Finally, technical and business barriers were identified that may prevent different energy storage use cases from being installed or fully monetized. These barriers are addressed with multiple potential market and policy solutions to allow for accurate monetization of energy storage costs and benefits, with resulting appropriate integration of resources.

2.3 Summary of Analysis Methodology

2.3.1 Overview of Analysis Objective

The goal of this analysis is to provide information for the State of Minnesota to help it determine if it should take some action in the domain of on-site, utility-controlled energy storage. To make the decision to act, it must first be determined if there is value to taking action.

Currently, customer sited utility controlled energy storage technology has not been extensively deployed in Minnesota, aside from a small number of demonstrations. As a result, the Project Team decided to intentionally look across a broad range of possible control scenarios to identify and prioritize possible use cases for energy storage in Minnesota.

The key analytical research question is:

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[6] CPUC Decision D.13-10-040

[7] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001233 (At the writing of the report, ESVT 4.0 Beta is available for public beta testing. Final production version of ESVT 4.0 is expected to be released in 2014.)

[8] Strategen notes that commercial PV systems with tilt angles greater than 30 degrees would limit the number of panels that can fit on a roof, due to shading and spacing requirements, and require stronger wind protection. This would ultimately increase costs for limited increases in power production.

Does a customer sited energy storage scenario exist that is economical or nearly economical over the project lifetime from the customer or utility perspective, with installations in the next 1-3 year period?

If the answer is 'yes', what are some of the key factors that affect the cost-effectiveness in those cases?

The following narrative provides a step-by-step overview of the analysis methodology used to meet the research objective.

2.3.2 Literature Review

The first step of the analysis methodology was to review relevant literature and determine the sources of value for energy storage and key uses of the technology. The Project Team was intimately involved with major reference analyses earlier in 2013, which included the EPRI cost-effectiveness analysis for the California PUC Energy Storage proceeding, as well as the development and publication of the DOE / EPRI Electricity Storage Handbook. Based on this review, the Project Team determined that the energy storage grid services and a number of referenced input assumptions could be reapplied to Minnesota to leverage the work of prior stakeholder groups and reviews.

The list of literature reviewed is provided in the Information Sources section of the Appendix.

2.3.3 Data Collection

The second step of the methodology applied prior knowledge and customized the analysis to the State of Minnesota. To accomplish this, the Project Team began the process with a number of stakeholder interviews and discussions, including Department of Commerce staff, utility R&D and planning personnel (particularly at Xcel Energy), utility co-ops, and energy storage technology developers. The Project Team also reviewed a number of public reports, including the integrated resource planning documents.

Data collection was accomplished through a combination of publicly available sources, including Minnesota utility tariffs, integrated resource plans (IRP), and Midcontinent ISO (MISO) hourly market data. Xcel Energy also provided valuable data, including aggregated customer load profiles by category and distribution system load data. Data was synchronized as 8760 hour data for 2012, except for PV data, as described below.

Examples of data sources:

- Minnesota utility tariffs
    - The Project Team screened Xcel and rural co-op tariffs in Minnesota and looked for potential high value for energy storage from large on/off-peak retail energy price spreads and high demand charges.
- Customer load profiles
    - For tariffs where demand and time of use charges apply, multiple customer electrical usage load shapes were evaluated.
    - Xcel Energy provided averaged data that abides by their 15/15 rule, which averages at least 15 customers, where no customer exceeds 15% of the total load in the average.
- Utility distribution data
    - Xcel provided hourly load data from three (3) distribution feeders

- Market prices
    - The Project Team retrieved publicly available energy, frequency regulation, spinning reserve, and non-spinning reserve hourly prices for 2012 from the Midcontinent Independent System Operator (MISO)
- Reliability data and outage costs were referenced regionally for the north central United States in a 2009 report from Lawrence Berkeley National Laboratory[9]
- Financial information, such as state tax rate, was referenced from public sources and is cited when used in the report.
- Energy storage technology assumptions were adapted from the 2013 EPRI "Cost-Effectiveness of Energy Storage in California" report. These cost assumptions were developed jointly in 2013 by a broad set of stakeholders including California PUC Staff, utilities and industry. Where possible, the cost assumptions were confirmed in confidential meetings with leading energy storage providers.

The details of these assumptions are explained in each of the modeling runs below, including their source(s) and their application in the modeling runs.

2.3.4 Modeling

The investigators then chose four major usage scenarios to cover the breadth of possible energy storage control scenarios for customer sited energy storage systems:

1. Customer controlled for bill savings
2. Utility controlled for distribution system benefits
3. Utility controlled for distribution and market benefits
4. Shared customer and utility controlled for bill savings and market revenue

The EPRI Energy Storage Valuation Tool (ESVT) was then used to model a number of cases that were likely to generate above average lifetime cost-effectiveness results. An overview of the ESVT is further described in Chapter 4. The ESVT software models the quantifiable costs and benefits of an energy storage system over its lifetime, under a customizable set of assumptions.

In each case, scenario variations included standalone energy storage as well as energy storage combined with solar PV. Major scenario variations also included residential and commercial utility customer settings.

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[9] "Estimated Value of Service Reliability for Electric Utility Customers in the United States." LBNL, Berkeley, CA: 2009. LBNL-2132E. http://certs.lbl.gov/pdf/lbnl-2132e.pdf

2.3.5 Barriers Analysis

In parallel with the modeling activities, the Project Team conducted an analysis focused on barriers to storage installation, interconnection and/or compensation for value provided to the grid. For cases which achieved the highest cost-effectiveness results in the modeling tasks, key barriers to achieving full monetization of those values were evaluated. For each of the barriers identified, alternatives were proposed to improve the ability to monetize or interconnect energy storage to the grid, particularly focused on barriers likely to have the greatest limiting effect on storage adoption.

2.3.6 Conclusions and Recommendations

Based on the results of the value and barriers analysis, overall conclusions and recommendations for solutions and next actions were proposed by the investigators. Conclusions included an overview of the value of energy storage under specific use cases, applicability to different utility structures (investor-owned, municipal, cooperative), a review of barriers, and comments on the general potential for energy storage resources in Minnesota. The section recommendations include those on potential policies related to energy storage integration, valuation methodologies to encourage best-fit resource integration, and pricing schemes to recognize and compensate the full value of energy storage resources.

3 Overview of Minnesota Electric Grid

The Minnesota electric grid is operated by the Midcontinent Independent System Operator (MISO), which is responsible for moving electricity over large interstate areas. Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) are governed by the Federal Energy Regulatory Commission (FERC) and tasked with coordinating, controlling and monitoring the use of the electric transmission system by utilities, generators and marketers. MISO is one of nine ISO/RTOs operating in the United States.

3.1 Customers

The following pie charts are created using 2012 data from the US Energy Information Administration (EIA)[10]. The proportion of Minnesota utility customers in the residential, commercial, industrial, and transportation sectors are as follows:

[10] Source: EIA-861 Preliminary Survey Data for 2012, version last updated August 14, 2013

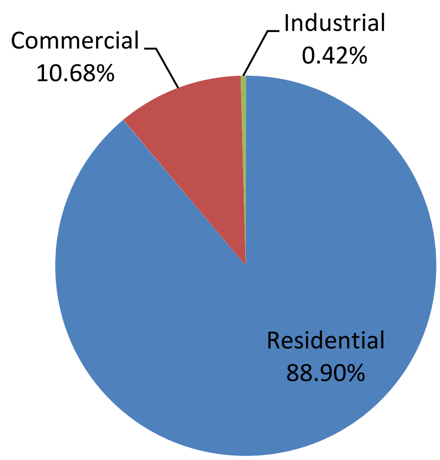

Figure 2: Proportion of Residential, Commercial, and Industrial Utility Customers

The proportion of electricity usage (MWh) by each sector is as follows:

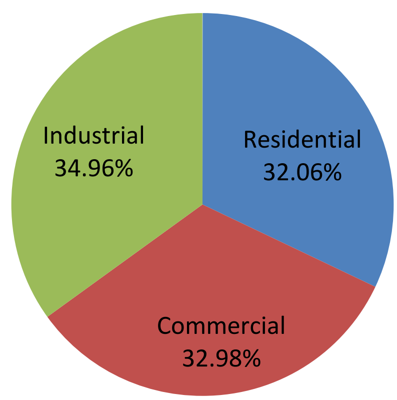

Figure 3: Proportion of Electricity Usage by Each Sector

The proportion of customers served by Investor Owned Utilities, municipal utilities, and cooperatives is as follows:

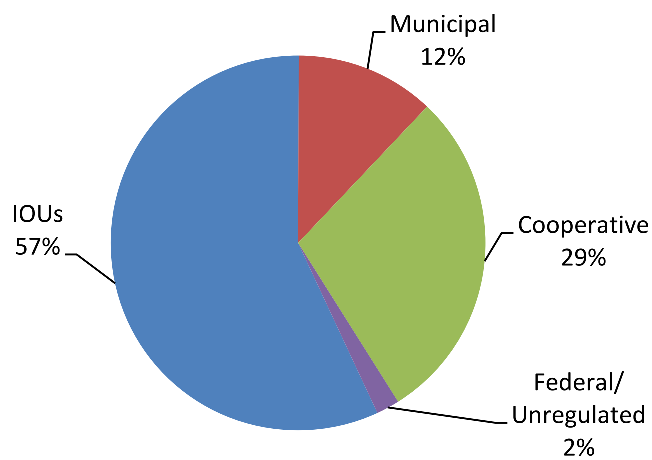

Figure 4: Proportion of IOUs, Municipal Utilities, and Cooperatives[11]

Of all the utilities in Minnesota, Northern States Power Company (NSP), a subsidiary of Xcel, serves approximately 47% of the state's utility customers.

3.2 Electric Utilities

Minnesota electric utilities fall under three categories, 1) cooperatives, 2) investor owned (IOUs), and 3) municipal. Of the three utility types, only investor owned utilities are subject to rate regulation from the Public Utility Commission. However, Minnesota statute 216B.026 allows cooperative members to elect to become subject to state rate regulation, of which only Dakota Electric has chosen to do so.

[11] EIA data varies slightly from the 2012 Minnesota Utility Data Book, with Co-op being 21%, Muni 14%, and IOU 65% (source: November 22nd, 2013 email from Lise Trudeau of MN Commerce to Strategen)

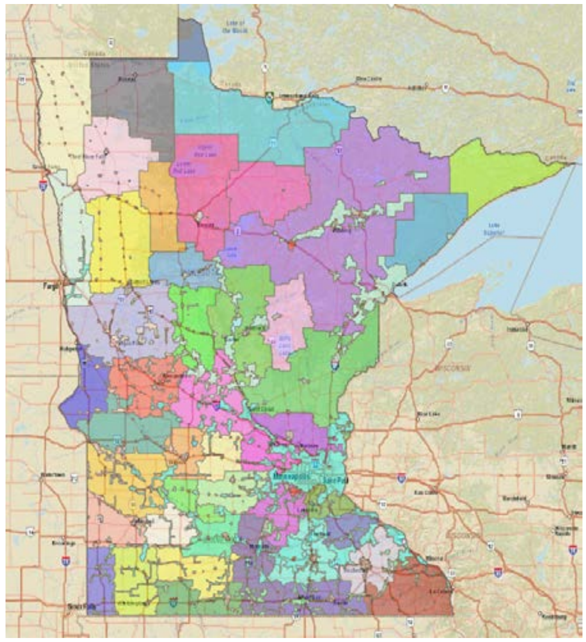

Figure 5: Electric Utility Service Areas[12]

3.2.1 Cooperatives

Cooperatives (also known as co-ops) provide generation, transmission, and distribution services. They are owned by their members and regulated by an elected board of directors. In Minnesota there are 45 distribution co-ops and six generation and transmission co-ops. In general, load curves for co-ops are steeper than for IOUs, and they are extensively shaping peak demand with demand-side management.[13]

3.2.2 Investor Owned Utilities

In Minnesota there are five IOUs:[14]

- Xcel Energy – Northern States Power Company
- Allete – Minnesota Power
- Alliant Energy – Interstate power
- Northwestern Wisconsin Electric
- Otter Tail Power Company

IOUs are regulated monopolies that receive oversight and direction from the Minnesota Public Utilities Commission and the Minnesota Department of Commerce (Commerce). IOU's are allowed to undertake

[12] Source: http://www.mngeo.state.mn.us/eusa/
[13] MN Commerce Lise Trudeau notes from utility meetings April 2012.
[14] In September 2013, Alliant announced plans to sell its Minnesota electric distribution business to Southern Minnesota Energy Cooperative (SMEC), a combined group of 12 neighboring electric cooperatives.

requests for offers given the resource mix that the PUC approves through orders in IRP's and resource acquisition dockets. IOUs likewise receive oversight on rates and resource cost recovery.

3.2.3 Municipal

Municipal utilities are governed and regulated by city councils or an appointed city utility commission. In Minnesota there are 125 municipal electric utilities. IOUs generally have the greatest percentage of residential customers as a proportion of total customers, while municipal utilities tend to have a greater percentage of residential customers than co-ops. Municipal utilities located near regional centers are seeing some load increases, while municipal utilities serving more rural areas have been experiencing decreasing loads.[13]

3.3 Current Energy Storage Projects in Minnesota

A multitude of energy storage systems, such as batteries, thermal energy storage programs, and other storage solutions have been installed or are in planning/development in Minnesota. At the time of this report's release, the US Department of Energy's international energy storage database contains detailed information for nine of these electrical energy storage installations in Minnesota, with more project data entries planned in the near future.[15]

3.4 Opportunities for Energy Storage Projects in Minnesota

The conclusions section will directly address findings for customer sited energy storage in Minnesota. In general, customer controlled storage has the greatest value for customers on utility tariffs with high demand charges and access to market benefits like frequency regulation. Customer-sited, utility controlled storage systems provide the greatest benefits for utilities that are able to monetize the following key benefits identified in the modeled cases:

- Distribution upgrade deferral: utilities that need to procure high cost distribution upgrades, particularly substation transformers, on feeders with low load growth will gain the greatest value from this storage capability.
- Regulation value: utilities must be capable of capturing the value of regulation capabilities provided by energy storage. The value and effect of market participation with storage will heavily depend upon the individual utility's overall MISO participation strategy.
- Capacity value: the value of capacity to a utility depends upon its need to procure local and/or system generation capacity at that time in its integrated resource planning (IRP) process.
- Tax Benefits including Federal Investment Tax Credit (FITC) and accelerated depreciation (MACRS): different utilities will have varying degrees to which they can capture the tax benefits identified in the study. For utilities that cannot capture the tax benefits directly, project structures incorporating a third-party may allow those utilities to capture a significant portion of the benefits.

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[15] http://www.energystorageexchange.org

4 Introduction to Energy Storage and Grid Benefits

Energy storage is a uniquely flexible type of asset in terms of the diverse range of benefits it can provide, locations where it may be sited, and the large number of potential technologies which may be suited to provide value to the grid. Fundamentally, energy storage shifts energy from one time period to another time period. However, the value of energy stored by a resource varies highly based upon the controllability and dispatch of that energy. Because the electric system operates on "just-in-time" delivery, generation and load must always be perfectly balanced to ensure high power quality and reliability to end customers. With large amounts of variable and uncertain wind and solar generation currently being deployed, guaranteeing this perfect balance is becoming an increasingly challenging issue. At very high penetrations of variable wind and solar generation, energy storage may be effective for soaking up excess energy at certain times and moving it to other times, enhancing reliability and providing economic benefits.

Figure 6 illustrates the many roles that energy storage can fill within the electric grid. Energy storage can provide large amounts of power and energy to the electric grid, as has been historically demonstrated by pumped hydropower facilities that can provide hundreds of megawatts or gigawatts of power for many hours. On the other end of the spectrum, off-grid battery systems have long been used to support electric service for small remote, residential buildings. The future may contain a spectrum of technologies, locations, and grid services, ranging from very large to very small energy storage systems capable of enhancing the reliability, economics, and environmental performance of the electric grid. A white paper analysis completed for the Minnesota Department of Commerce on September 30, 2013 identifies various types of energy storage resources of value to microgrids (including batteries, thermal energy storage, and vehicle-to-grid).[16] Given the potential for further microgrid development in Minnesota, energy storage is also likely to see expansion statewide.

[16] "Minnesota Microgrids: Barriers, Opportunities, and Pathways Toward Energy Assurance." Minnesota Department of Commerce: 2013. http://mn.gov/commerce/energy/images/MN-Microgrid-WP-FINAL-amended.pdf

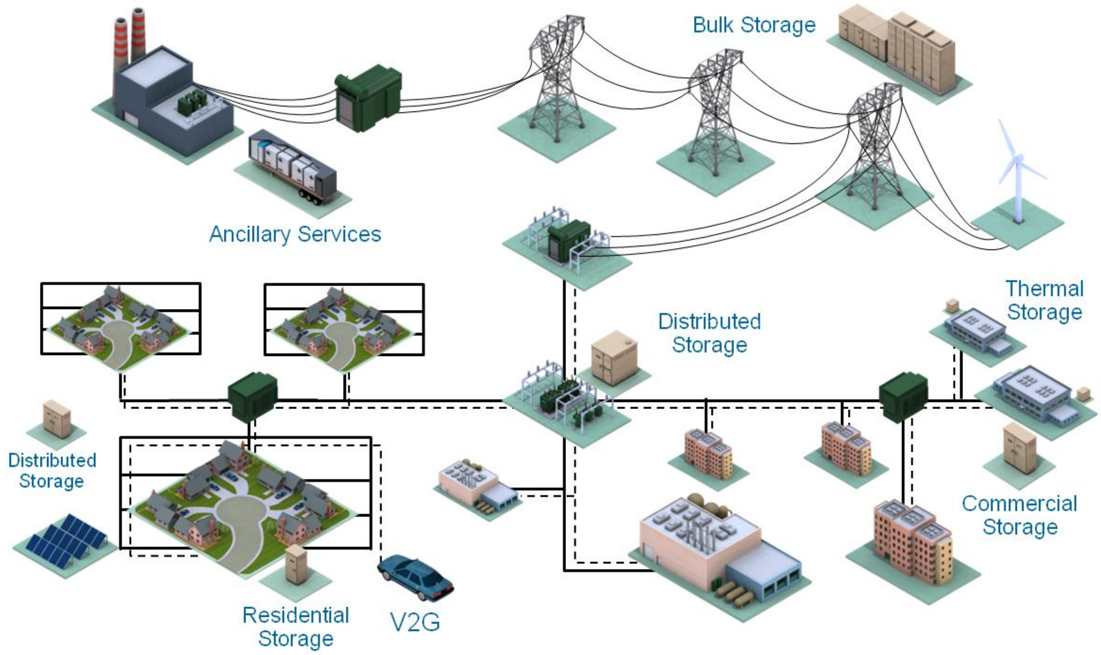

Figure 6: Overview of Energy Storage Roles on the Electric Grid (Source: EPRI)

In this analysis, we will focus primarily on electrical energy storage systems located at utility customer premises, both residential and commercial. Conceptually, an advantage of locating energy storage at the customer site is that it has the potential to provide economic and reliability value to all components of the electric system, including generation, transmission, distribution, and customer (load). Terminology and definitions for the grid services that energy storage could provide is not entirely uniform across the country, but the DOE/EPRI Handbook of 2013 provides the following list of energy storage grid services.

Bulk Energy Services
Electric Energy Time-Shift (Arbitrage)
Electric Supply Capacity
Ancillary Services
Regulation
Spinning, Non-Spinning and Supplemental Reserves
Voltage Support
Black Start
Other Related Uses

Transmission Infrastructure Services
Transmission Upgrade Deferral
Transmission Congestion Relief
Distribution Infrastructure Services
Distribution Upgrade Deferral
Voltage Support
Customer Energy Management Services
Power Quality
Power Reliability
Retail Electric Energy Time-Shift
Demand Charge Management

Figure 7: Grid Services of Energy Storage (Source: DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA)

The following paragraphs will provide a summary of the grid services that energy storage resources may be capable of providing.

4.1 Bulk Energy Services

"**Bulk Energy Services**" refers to the potential of energy storage to avoid costs associated with generation of electricity. More detailed explanations of these services is in Appendix 10.4.

Electric Energy Time-Shift (Arbitrage) refers to the ability of energy storage to charge (storage energy) when the cost of electricity is low, and discharge (release energy) when the cost of electricity is high. Electricity costs are typically low when demand is low at night and low cost baseload coal or low cost wind energy can supply the entire load. Conversely, electricity costs are typically high in the late afternoon on hot days when the most inefficient and rarely used gas turbines must be called upon to meet peak load conditions.

Electric Supply Capacity (or System Capacity) refers to a similar usage of energy storage as energy time-shift, but it refers to a different economic value. Where the arbitrage value comes from time-shifting the variable cost of electricity generation, the capacity value is an avoided fixed cost of generation. Historically, the decision to add new generation capacity (i.e. build power plants) has not been an economic one. Based on customer load growth forecasts, utilities create an integrated resource plan (IRP) which determines where and when new generators are needed. This new capacity need is defined by the peak load conditions. If energy storage can reliably provide capacity during peak system load conditions, it has the potential to avoid the fixed costs of new power plants, which are typically passed through to utilities and, by extension, customers as a fixed monthly or annual payment.

4.2 Ancillary Services

"**Ancillary Services**" are defined as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."[17] In other words, these services are all services to the high voltage transmission system that support the reliable delivery of power and energy.

Regulation (or Frequency Regulation) is an ancillary service that ensures the balance of electricity supply and demand at all times, particularly over time frames from seconds to minutes. When supply exceeds demand the electric grid frequency increases; when demand exceeds supply, grid frequency decreases. Sensitive equipment in the United States relies on grid frequency of 60 Hertz (60 cycles / second), with very low tolerance. Because energy storage can both charge and discharge power, it has

[17] U.S. Federal Energy Regulatory Commission 1995, Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities, Docket RM95-8-000, Washington, DC, March 29.

the potential to play a valuable role in managing grid frequency; furthermore, many energy storage technologies have been demonstrated to be faster and more accurate than other grid alternatives at correcting these frequency deviations. FERC Order 755 has stipulated that ISOs implement mechanisms to pay resources based upon their responsiveness to control signals. Under the new rules, energy storage resources with high speed ramping capabilities will receive greater regulation compensation than slower storage or conventional resources.

Spinning Reserves, Non-spinning Reserves, and Supplemental Reserves comprise another class of ancillary service referring to reserved excess generation capacity that is available to the electric system in the case of the worst contingency events. Spinning reserves are the fastest available reserve capacity, because the generators providing them are already “spinning”, but not fully loaded. Therefore, spinning reserves can begin responding immediately to a contingency event. Non-spinning reserves typically have minutes to respond to a contingency, and supplemental reserves are intended to replace spinning and non-spinning reserves after an hour. Because many energy storage technologies can be synchronized to grid frequency through their power electronics, energy storage could provide a service equivalent to spinning reserve while idle. Furthermore, an energy storage system that is charging energy may be capable to provide a magnitude of spinning reserve equivalent to the sum of its charging and discharging power. In other words, a storage system rated at 1 megawatt capacity could provide 2 megawatts of spinning reserve, if it moves from a state of 1 megawatt charging to 1 megawatt discharging. Energy storage would be equally capable of providing non-spinning or supplemental reserves, but these services are typically lower value than spinning reserve because they are easier for traditional generators to accomplish and have lower opportunity cost.

Voltage support is an ancillary service that is used to maintain transmission voltage within an acceptable range. With alternating current (ac) power, voltage and current are transmitted as sinusoidal waves. Maximum power is transmitted when voltage and current waveforms are synchronized. Certain electric loads, particularly inductive motors, have a tendency to cause voltage to move out of sync with current by consuming reactive, or imaginary, power (aka VARs). Due to advanced power electronics capabilities, energy storage has the capability to inject VARs and correct transmission voltages that are suboptimal or outside of acceptable bounds. Because a number of other devices are capable of providing voltage support at low cost, the value of this service for energy storage is typically considered to be low and has not received a deep level of attention.

Black start is a service typically provided by designated generators to restore the electric grid following a blackout. While this is conceptually a service that could be provided by energy storage, the exact specifications of a limited energy resource have not been well-defined, and it is typically considered to be a low value, incremental opportunity for energy storage.

4.3 Transmission Infrastructure Services

“Transmission Infrastructure Services” refer to the services, related to reliability and economics, to enable the electric transmission system to operate more optimally.

Transmission investment deferral is a service whereby a large capital investment in the transmission is avoided for a period of time. For example, if power transmitted from point A to point B exceeds the power rating of a transmission transformer or power line, it may require an upgrade to a higher rated piece of equipment. However, this upgrade could be triggered by peak loads which occur relatively infrequently, perhaps only a few hours per day and a few days per year. In such cases, a sufficient quantity of energy storage may be capable to charge during low load periods and discharge during high loads periods on the overloaded piece of transmission equipment and reduce load experienced on that equipment to offset load growth. By doing so, energy storage has the ability to defer an upgrade investment for some time, creating economic value equal to the *time value of money* for the size of the planned transmission upgrade investment for the deferral period.

Transmission congestion relief is a similar service to transmission investment deferral. However, the economic value associated with congestion relief does not necessarily tie directly to a planned transmission upgrade. In some regions, the wholesale price of energy is defined at different geographic locations, where the congestion associated with high loads results in a higher hourly energy price. This geographically-specific energy price is called a *locational marginal price (LMP)*. In practice, energy storage would behave very similarly to how it would perform energy time-shift (arbitrage) or transmission investment deferral (i.e. charging during low load periods and discharging during high load periods), but it would optimize its charge/discharge behavior based on an hourly price signal that is jointly defined by the wholesale market price of energy and the amount of location-specific congestion specific to its geographic location in the electric system.

4.4 Distribution Infrastructure Services

“Distribution infrastructure services” refer to services which support the physical infrastructure of the low voltage distribution system from the substation to the customer meter. These services support delivery of electric power with high reliability and lowest cost to the electric utility customer. The costs of the electric distribution system are typically regulated by a public utility commission (PUC) or similar entity which approves electric utility spending plans and offers them a regulated return on investment for managing the reliability of the system.

Distribution investment deferral is a service similar to the aforementioned transmission investment deferral, but specific to the low voltage distribution system. In this service, to relieve overloaded distribution lines or transformers, particularly high cost substation transformers, energy storage can charge during low load period and “peak shave” the highest load periods to avoid a high cost upgrade investment for years. Once again, the economic value associated with an upgrade deferral would be the time value of money for the cost of the upgrade for the achieved years of deferral, and the requirement of the storage may only be availability and performance for a relatively small number of days and hours associated with local maximum load events, which are overloading the asset in question.

Distribution voltage support refers to a service which maintains the power voltage within acceptable bounds, defined by ANSI standards (typically +/- 5% of nominal). For sensitive electric customer appliances and electronics, it is important that voltage is supplied within these limits. Typically, the service voltage drops as power moves to the end of the line, because customer computer and motor loads are consuming VARs, as explained in the “voltage support” service description. As a result, utilities typically install capacitor banks or voltage regulators, which boost voltage at the end of the line. However, the issues are becoming more complicated as, increasingly, solar photovoltaic (PV) systems are being installed, sometimes even reversing power flow altogether at certain times, and with significant variability. Energy storage, with power electronics capable of injecting and absorbing both real and reactive power at different rates, conceptually provides a balance for rooftop PV installations.

However, the state of research is still nascent in this area, so it is unclear how much value this service has and what the technical requirements are for energy storage to provide this service effectively.

4.5 Customer Energy Management Services

"Customer Energy Management Services" refer to the services that benefit an electric utility customer that result in lower utility bills or higher quality of electric service.

Power Quality describes a rather all-encompassing service by which the electric utility customer receives power which is clean and constant, without momentary interruptions in service. Some elements of power quality include consistent service voltage, low harmonics, and no disruptions in service. Some customers have very high requirements for reliability, due to sensitive equipment or electronics. A well-known example is data centers. Data centers regularly use energy storage in the form of an uninterruptible power supply (UPS), which converts grid electricity from ac-to-dc-to-ac and provide acceptably high power quality for the equipment. The value of this service is highly variable, depending on the consequences and alternatives available to the customer for solving specific power quality issues, but the ubiquity of UPS systems in data centers and critical loads is evidence of the importance of power quality for certain customers.

Reliability refers to the uptime of the electric grid. Outages can be caused by a number of different factors, including weather events and other unexpected contingencies, as well as unanticipated equipment failures. Because energy storage provides an inventory for electric energy, it may be able to help grid operators avoid some outages, or otherwise provide customers with backup power to ride through outages when they happen. Depending on the type of customer, their economic losses associated with outages, and the utility reliability characteristics at the customer location, economic value may be provided by an energy storage system to provide backup power. An energy storage system would need to have the appropriate capability to "island" its operation and serve the entire customer load, or a specified portion of the customer load.

Retail energy time-shift refers to a service of energy storage, where the energy storage serves to store energy by charging during periods where the retail price of electricity is low; then, it releases energy by discharging when the retail price of electricity is high. This situation is present when customers have a utility tariff with time-of-use (TOU) metering. This type of tariff is enabled by the deployment of automated metering infrastructure (AMI). The existence of TOU tariffs has existed for a long time in the commercial and industrial (C&I) electricity sector, but its emergence in the residential sector is relatively new. Residential customers often opt-in for these tariffs when they purchase rooftop solar PV or electric vehicles to increase bill savings.

Retail demand charge management refers to a service offered by energy storage, or other measures, to reduce the "demand charge" portion of a customer electric bill. A demand charge is a charge levied proportional to the peak customer instantaneous (15 minute average) demand each month. Without careful customer control, a customer could add a significant component to their electric bill as a result of a "peaky" load shape that causes them to pay a high monthly charge, with relatively lower average consumption. Energy storage can store energy during periods when the customer demand is low and discharge to shave off peak customer load periods, which in some cases could be infrequent and short duration. Typically the value of reducing demand charges exceeds the value of energy time-shifting, under current national tariff structures.

4.6 Summary of Grid Services for Energy Storage

The preceding section described widely accepted categories of energy storage services to electric grid. These services span the entire scope of electric service from generation to end customer. However, it should be noted that not all of these services have been demonstrated in commercial settings. Additionally, there are additional potential services to be provided by energy storage with the development of new markets or reliability metrics.

4.7 Societal Benefits

It should be noted that energy storage may provide benefits to society in addition to its value for grid services. These benefits may include:

Greenhouse Gas (GHG) and/or Pollution Reductions – Certain types of energy storage dispatch may result in reduced systemwide emissions. Cases where storage may reduce emissions include:

- **Offsetting inefficient regulation by non-renewable sources** - In cases where energy storage provides frequency regulation service to the grid, it may offset heat rate (efficiency) penalties of ramping by traditional generators, allowing the existing generator fleet to operate at a lower heat rate. Large quantities of grid storage may also reduce the number of cold starts for fossil generators, allowing for more efficient grid operations.
- **Increased capture of renewable over-generation -** In cases of high renewable penetration, energy storage may charge off excess renewable generation that would otherwise be spilled or curtailed and discharge that energy at times that offset the need for traditional generation.

Emissions reductions depend highly upon energy storage round trip efficiency, the system generator mix, and overall grid operations. These were not modeled as part of this study, but future system modeling could account for the potential emissions reductions of energy storage.

Job creation and/or technology leadership – Energy storage, as a rapidly developing industry, has the potential to create local jobs or establish technology leadership in Minnesota. The complex calculation required to determine long term benefits was not part of the scope of this study.

5 Energy Storage Use Cases

Due to the flexibility of operational modes and potential locations for siting, energy storage has the potential to provide many different combinations of the aforementioned services. The ability of a single energy storage system to provide these services can be assessed across multiple parameters, including 1) minimum required energy storage power (capacity) and energy (duration), 2) location requirements, 3) availability requirements, both frequency and duration, 4) flexibility and penalties of non-performance.

An energy storage use case describes a specific usage scenario for a single energy storage technology asset sited at a specific location and operated in a particular way to deliver a specific combination of grid services and benefits. The value of these services and benefits may be quantifiable to varying degrees through modeling and analysis, but not all will receive commensurate compensation under current policies.

Unlike the preceding list of individual energy storage services, which is fairly consistent and converging across the energy storage and electric industries, a comprehensive list of energy storage use cases has not yet been widely agreed upon. Due to the emerging nature of the energy storage industry, new, creative use cases are being identified. These new use cases are often targeted to the specific needs of a utility, customer, or new wholesale electricity market opportunities.

This paper will not attempt to cover the universe of use cases; however, a modified version of the table of use cases defined by the stakeholders of the California PUC energy storage proceeding is provided in the table below for reference.[18]

Table 1: Summary of CPUC-Defined Use Cases for Energy Storage

Transmission Connected	Bulk Peaker
	Ancillary Services Only
	On-Site Traditional Generation
	On-site VER
Distribution Connected	Distributed Peaker
	Distributed - Substation Level
	Distribution Upgrade Deferral
	Community Energy Storage
Customer Sited Distributed	Demand Side Permanent Load Shifting
	EV Charging
	Customer Bill Management
	Customer Bill Management + Ancillary Service Market Participation
	Emergency Backup Only
	Customer Sited Utility Controlled

The use cases that are highlighted in white are relevant to the cases defined in this study. However, for the purposes of this study, the use cases have been re-segmented to meet the goals identified in the scope. They are described in detail in the following sections, including examples, services provided, and monetizable value.

5.1 Introduction to Customer-Sited Energy Storage Use Cases

This white paper is particularly focused on use cases where the energy storage system is located on the utility customer's premises, either residential or commercial. Customer-sited energy storage could be

[18] California Storage Order Instituting Rulemaking R.10-12-007

interpreted as energy storage physically located at the customer site, and not necessarily on the customer-side of the meter. It can also include siting of energy storage at campus-level microgrids or small-scale residential-level microgrids. As such, these use cases may provide services to the customer, the utility, or both. For our purposes, it is assumed that customer operated storage is dispatched for greatest customer benefit, while utility operated storage is dispatched to provide the greatest benefit to the utility.

The conceptual advantage of a fleet of customer-sited storage is that, from a technical perspective, it provides flexibility to provide the maximum number of grid services, which are very location-specific. Additionally, energy delivered at the end-customer has the ability to avoid the line and transformer losses that occur with energy generated, transmitted, and distributed by a remote power plant. Power delivered from customer-sited energy storage during a system peak can simultaneously off-load T&D assets and generators, with the potential to provide multiple value streams to the owner with a simple operational objective. Additionally, due to the proximity to the customer, energy storage located at the customer site is best positioned to provide enhanced reliability and backup power during power outages.

The conceptual drawback of customer-sited storage is primarily scale of the individual storage resources. The fixed costs associated with installation and management of customer energy storage systems are typically spread over multiple small- to mid-size energy storage resources, especially as compared to the more concentrated fixed costs for larger, megawatt-scale systems. Additionally, certain grid services may require a minimum deployment of energy storage to achieve net economic benefit depending on the load characteristics and expected growth rate. For example, to defer a distribution substation upgrade may require a minimum of one megawatt and four hours of duration to achieve a meaningful deferral of capital expenditure. This solution could be installed at a single large commercial/industrial customer location – however, if this was to be accomplished by a fleet of residential, customer-sited energy storage systems, it could require at least 200 of such systems (assuming a 5kW, 4hr storage system). Furthermore, all of these systems would need to be located appropriately to provide support to the substation in need of upgrade, and the storage systems' operation would need to be managed and aggregated through secure communication and control. However, the benefit of a large number of distributed systems is that they can provide redundancy and potentially leverage economies of scale in manufacturing compared to larger, more customized units. Finally, it should be noted that locating energy storage next to a customer requires heightened sensitivity toward safety, as compared to remotely located energy storage systems in a secure, utility-controlled area.

5.1.1 Customer-Sited Use Cases Under Investigation

The analysis in this report will look at several variants of four general use cases for customer-site energy storage. The key distinction between the four use cases is the control of the storage system and the corresponding grid services under consideration. These four use cases include:

Customer –controlled

In this use case, storage systems will be located on customer site and controlled by customer to provide bill saving and demand charge reduction services. With the right configuration, such a storage system may also provide reliability benefits to the customer during outages. The impact of PV in conjunction with energy storage on the customer site is examined.

Utility controlled for distribution system services benefits

In this use case, a fleet of customer-sited storage systems located on the utility side of the meter can be operated by the utility to keep peak distribution load under a certain threshold for a given amount of time (usually 2-5 years) in order to defer infrastructure upgrade that would otherwise be triggered if load were to exceed the current infrastructure capacity. For the study, a fleet of resources was modeled to provide this deferral value.

Utility controlled for distribution and market benefits (bulk energy + ancillary services)

This use case builds upon the previous use case. Since distribution peak load is infrequent, a storage system solely dedicated to shave distribution peaks may be idle most of the time. Utilities can use those idling hours to bid energy into the bulk energy and ancillary service markets to improve the utilization rate of the storage system and offset its cost.

Shared customer / utility control

Customers and utilities can share the control of energy storage under an agreement. The customers will operate the storage system to achieve bill saving and reliability benefits, and allow the utility to control the system while the system is idling. Through aggregation of multiple customer sited storage systems, utilities can have a “virtual storage system” and use it as distributed capacity and bid into ancillary service markets.

5.1.2 Storage with and without an on-site photovoltaic (PV) solar system

Finally, each of the use cases contained a sub-case for standalone energy storage and a sub-case for energy storage co-located with on-site photovoltaic solar system.

5.1.3 Use Case/Service Table

The following analysis includes modeling and discussion of the four different use cases and considers the differences between commercial and residential customers as well as the potential impact of solar PV.

Table 2: Use Cases and Benefit Streams

Use Case	1		2		3		4	
Ownership	Customer		Utility		Utility		Customer	
Control	Customer		Utility		Utility		Customer + Utility	
Technology Combination	Storage Only	Storage + PV	Storage Only	Storage + PV	Storage Only	Storage + PV	Storage Only	Storage + PV
Customer TOU Energy	Modeling	Modeling					Modeling	Modeling
Customer Demand	Modeling	Modeling					Modeling	Modeling
Customer Reliability	Proof of Concept	Proof of Concept	Proof of Concept	Proof of Concept	Proof of Concept	Proof of Concept	Proof of Concept	Proof of Concept
Frequency Regulation					Modeling	Modeling	Proof of Concept	Proof of Concept
Spinning Reserve					Modeling	Modeling	Proof of Concept	Proof of Concept
Wholesale Energy			Modeling	Modeling	Modeling	Modeling	Proof of Concept	Proof of Concept
Capacity					Modeling	Modeling	Discussion Only	Discussion Only
Distribution Upgrade Deferral Due To Load Growth			Modeling	Modeling	Modeling	Modeling	Discussion Only	Discussion Only
Distribution Upgrade Deferral/Voltage Due to PV		Discussion Only		Discussion Only		Discussion Only		Discussion Only

Color Key: **Modeling:** ■ **Proof of Concept:** ■ **Discussion Only:** ■

5.1.4 Analysis Methodology for Customer-Sited Energy Storage Use Case Valuation

The quantitative value analysis for examining the customer-sited energy storage use cases leverages a software tool called the Energy Storage Valuation Tool (ESVT), developed by the Electric Power Research Institute.

The development of the ESVT software began in 2011 with the purpose of helping to determine which combinations of grid services, location, and technology make economic sense for supporting the electric system. The software was developed to be user-friendly, customizable, and transparent, with the intention of providing high comprehensiveness estimates of energy storage lifetime costs and benefits, while balancing this fidelity with a reasonable number of inputs and short enough runtimes to enable sufficient analysis scope to investigate sufficient breadth of analysis. The tool development sought to balance analysis breadth and depth to inform the decision-making of electric utilities and other stakeholders interested in the use of energy storage technologies.

5.1.4.1 How the Energy Storage Valuation Tool Works

The ESVT simulates energy storage operation for different energy storage use cases with compatible grid services, utilizing location-specific load, price, costs, owner financial characteristics, and storage technology cost and performance characteristics. The ESVT simulation engine prioritizes grid services that represent reliability-focused, long-term commitments over economic-focused short-term commitments for the energy storage system. For grid services that represent pure economic trade-offs, the ESVT optimizes the energy storage charging and discharging to maximize the net value generated by the energy storage system. ESVT has the capability to provide a number of detailed financial and technical outputs, including lifetime net present value analysis, detailed annual financial performance, and technical performance of the energy storage on an hourly basis. The inputs, model, and outputs of the ESVT are summarized in the Figure 8 below.

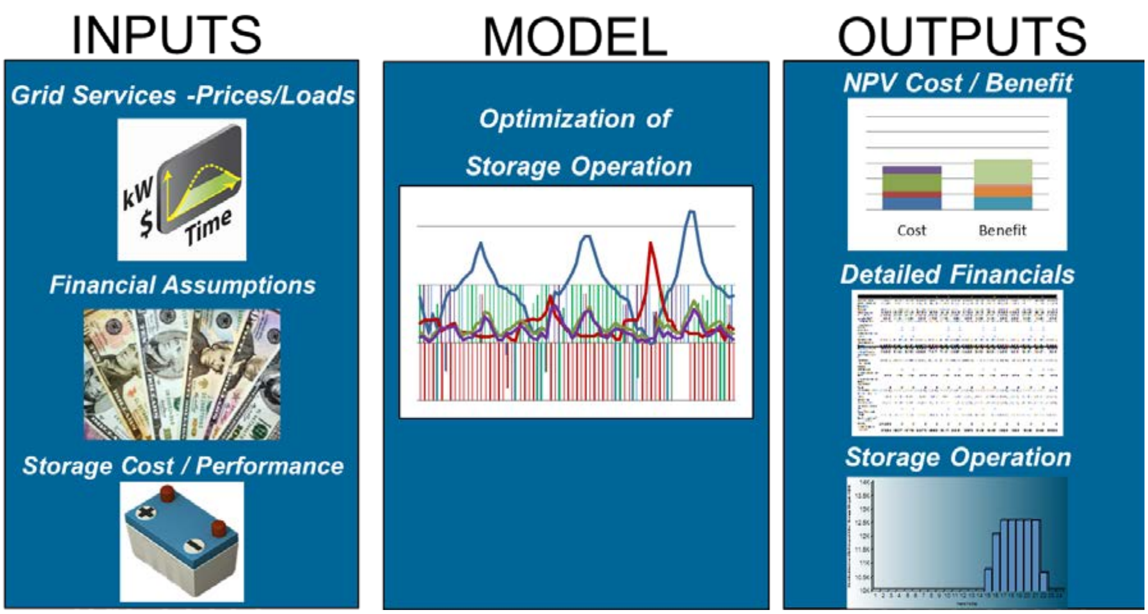

Figure 8: ESVT Inputs, Model, and Outputs

For this study, the primary output considered was the NPV cost/benefits ratio. For the outputs listed below, a benefit to cost ratio exceeding 1.0 indicates that the modeled benefits of energy storage exceed its costs over the lifetime of the installation, considering the time value of money and associated discounting of future year costs and benefits.

5.1.4.2 Limitations of ESVT model

As with an analysis model, there are limitations to using the ESVT. The most significant caveat of any model is that the quality of the input data strongly affects the quality of the results. Additionally, certain shortcuts and assumptions have been made to keep analysis set up and runtimes manageable. The ESVT simulation incorporates hourly prices and load streams for a single reference year, then it escalates certain values at user-defined rate. The energy storage operation is optimized based on perfect foresight and any indirect impacts that energy storage deployment would cause in the market, such as price suppression, are ignored. In other words, the lifetime cost-effectiveness results may be viewed as the ceiling of value with optimal operation and no increased competition, under the modeled assumptions. Granted, there may also be other market opportunities for energy storage that are not contemplated in this analysis, which could provide additional values above and beyond those modeled. Examples of such opportunities include: frequency response, flexible ramping service, flexible resource adequacy, and transmission n-1 contingency support. Outside societal benefits, such as emissions reductions, are also not calculated or included in the final outputs. The ESVT results should not be viewed as the final answer for the cost-effectiveness of energy storage, but it provides valuable insight for which use cases and scenarios have the potential to be "in the money" and which ones have significant gaps to overcome to achieve cost-effectiveness from a lifetime net present value perspective.

The ESVT went through a significant validation exercise toward its use as a customizable and transparent model when it was used to inform the California PUC's energy storage proceeding in over 30 different scenarios covering 3 distinct use cases.[5] This public report also provides significant more detailed information about the Energy Storage Valuation Tool and general analysis methodology for energy storage valuation.

5.2 Summary of Input Data Sources

Where possible, the approaches and input data utilized in the CPUC analysis have been leveraged and reapplied to the Minnesota analysis. For example, extensive information-gathering was performed by the California Energy Storage Alliance (CESA) to estimate the energy storage cost and performance assumptions of energy storage in 2015 and 2020 for the CPUC analysis, and those values have largely been adapted for this analysis.

However, significant updates in data gathering were required to customize this analysis to Minnesota. To inform the project team, a number of different data sources were utilized, including publicly available data, reports, and software tools, conversations with Minnesota utility personnel and corresponding data requests, and conversations with energy storage developers with current demonstrations and deployments in Minnesota. Significant data was provided by Xcel Energy, including aggregate customer load data, distribution load data, and costs associated with upgrade investment. Real utility and customer data significantly improves the fidelity of analysis. An overview of major input assumption categories and the source of this data is provided in the table below.

Note that detailed input assumptions can be found *in Appendix 10.1: Links to Modeling Input & Output Files.*

Table 3: Summary Overview of Analysis Input Sources

Grid Services	Assumption	Source/Value
	End Customer Load Profiles	Xcel Energy
	End Customer Tariffs	Xcel Energy and Connexus
	Distribution Level Load Profiles (feeder and substation circuit	Xcel Energy & Various Municipal and Co-Ops

	data)	
	Capacity Value	Modified California-specific data from the California Energy Commission (CEC) Cost of Generation modeling and Xcel Energy's resource balance year of 2018
	Distribution Upgrade Deferral Value	From Xcel for certain cases and from 90th Percentile Data from FERC where applicable[19]
	Historic Wholesale Market Value	MISO 2012 data escalated at 3% per year, with sensitivities conducted around FERC 755 frequency regulation market pay-for-performance
	PV Production	PVWatts simulation data for various tilt angles and azimuth orientations
Financial Assumptions	**Assumption**	**Source/Value**
	Discount Rate Ranges (Depending on Ownership Structure)	Debt: 5-6% Equity: 11-12%
	Project Start Year	2015
	Project Life	20 years
	Taxes	Federal Income Tax: 35% MN State Income Tax: 9.8% MN Property Tax: 3.87%
	Debt to Equity Ratios	50% Debt 50% Equity
	Depreciation Schedules	7yr MACRS for standalone storage 5yr MACRS for storage integrated with PV

[19] 90th Percentile Estimated Installed Cost = $225/kW installed in 2004 dollars and at 2% p.a. inflation, in 2013 dollars: $225*(1+2%)^(2013-2004) = $269/kW installed; Figure 5. PG&E T&D Distribution Marginal Costs. SANDIA REPORT (SAND2009-4070 Printed June 2009: Electric Utility Transmission and Distribution Upgrade Deferral Benefits from Modular Electricity Storage, A Study for the DOE Energy Storage Systems Program

	Federal Investment Tax Credit	30% for storage integrated with PV
Energy Storage Technology Cost/Performance	**Assumption**	**Source/Value**
	Technology Choice	Chemical storage, modeled after off-the-shelf lithium-ion solutions
	Initial Investment Pricing	4-hour Duration System: $2,000/kW 2-Hour Duration System: $1,200/kW
	Future Cost of Cell Replacements	$250/kWh (assumes 2% cost reduction over time) Replacement assumed in year 10, unless otherwise noted
	AC to AC Roundtrip Efficiency	83%

5.3 Energy Storage Technology Discussion

5.3.1 Energy Storage Technology Classes

Energy storage encompasses a wide range of technologies and resource capabilities, with differing tradeoffs in cycle life, system life, efficiency, size, and other parameters.

Table 4: Energy Storage Technology Classes

Technology Class	Examples
Chemical Storage	Batteries
Mechanical Storage	Flywheels, Modular Compressed Air
Bulk Mechanical Storage	Large scale Compressed Air
Thermal Storage	Ice, Molten Salt, Hot Water
Bulk Gravitational Storage	Pumped Hydropower, Gravel

5.3.2 Technologies Modeled

In order to maintain a reasonable scope for modeling, specifications corresponding to a generic fast responding battery were used. Several technologies are capable of providing services within the parameters modeled, including:

- Lithium ion batteries
- Advanced lead acid batteries
- Sodium nickel chloride batteries

5.3.3 Potential Customer Sited Technologies Not Modeled

Other technologies have the potential to suit customer sited applications, but would require adjustment to the inputs. Technologies that could not be modeled due to time and resource constraints include:

- Flow batteries
- Flywheels
- Traditional lead acid batteries
- Modular compressed air energy storage (CAES)

The fact that these technologies were not modeled should not prevent consideration for grid deployment. Many provide cycle life, calendar life, and/or cost advantages relative to the generic battery specifications used in the study. During energy storage procurement, it is recommended to select a technology in the context of an actual project value proposition, with due consideration for project timeframes, financing, resource benefits, and procurement requirements.

5.4 Use Case #1: Customer Controlled Energy Storage for Bill Savings

The primary value driver of customer-sited, customer controlled energy storage systems comes from reducing peak demand to lower customers' electricity bills, mostly through demand charge reduction, with some benefit potential from time of use (TOU) energy charge shifting from peak to off-peak. A secondary benefit may be improved customer reliability during a grid outage event, but the system needs to be configured to safely provide behind the meter power. When integrated with on-site solar according to IRS rules, a customer sited storage system may additionally be eligible for the 30% Federal Investment Tax Credit (FITC) and accelerated five year MACRS depreciation for renewable energy systems.

5.4.1 Use Case Modeling Approach

To evaluate customer peak demand reduction in ESVT, Strategen and EPRI utilized actual 8760 hourly commercial customer load profiles[20] and tariff data unique to Minnesota in a variety of combinations. Unique, individual residential 8760 hourly load profile data was not available, so aggregate data scaled down to a representative residential customer load size was utilized for the residential modeling with corresponding residential tariff data.

For reliability valuation, ESVT utilized regional outage statistics and corresponding outage cost data from a 2009 report from Lawrence Berkeley National Laboratory (LBNL-2132E).[9]

For storage plus PV scenarios, limited customer-specific data was available for customer-sited PV systems (partially because of confidentiality considerations), so PV generation data was simulated for

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[20] While actual customer load data was utilized for the study, it was processed by the utilities to anonymize the data prior to release.

Minnesota installations using PVWatts[21] and then netted out of the customer load profile data described above for the scenarios for modeling in ESVT.

Pairing the above load and tariff data with storage cost and performance data, the benefit-to-cost ratios for each scenario were calculating using ESVT's prioritization and optimization algorithm as described below. Using the benefit-to-cost ratio results of these various combinations of load and tariff, the most promising scenarios were selected for appropriate sensitivity analysis.

5.4.2 ESVT Prioritization & Optimization

To model the operation of a customer-sited and controlled energy storage system used primarily for customer bill savings in the ESVT, the model takes a heuristic approach. It first optimizes the energy storage charging and discharging behavior to minimizing the demand charges, which are assessed by the peak power rate over the course of a month. It accomplishes this by looking ahead in the month and identifying the lowest peak load target that can be accomplished by the energy storage. Next, if the customer also has a time-of-use energy rate, the energy storage will be charged and discharged to take advantage of time-shifting (arbitrage) opportunities. In the experience of the investigators, demand charge savings typically represent the largest bill saving opportunities for electric energy storage. For enhanced reliability value of energy storage, the ESVT has the capability to reserve a certain amount of energy at all times in case of outage. However, this power reservation is typically not economic, so cases were modeled to calculate the value of incidental reliability by hour; that is to say, if there is an outage and the energy storage system is empty, the system would not provide any backup power during those hours. If the system has partial or full charge, it provides varying levels of reliability value. The figure below represents the hierarchy of services modeled for Use Case 1 in ESVT.

[21] PVWATTS multiplies the nameplate DC power rating by an overall DC to AC derate factor to determine the AC power rating under standard test conditions (STC) of specified PV system characteristics and solar irradiance.

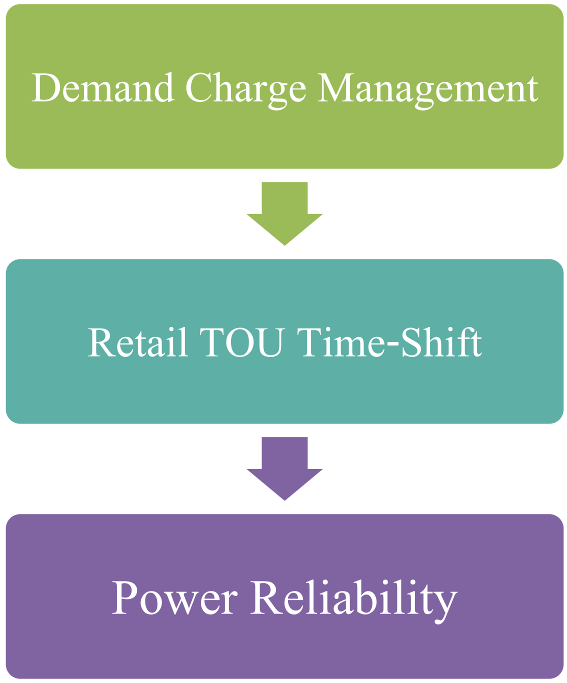

Figure 9: Use Case 1 Model Prioritization

When simulating energy storage operation for this use case, ESVT follows the prioritization map above. When the storage system is operated to provide both demand charge reduction and TOU time-shift, it is dispatched to reduce the overall demand charge first, and maximize TOU time-shift savings within the constraints of demand charge management. In cases where the system is also operated to enhance power reliability, this service has the highest priority over the other two customer bill saving services. Because of the uncertain nature of power outage events, a storage systems needs to be ready whenever the outage hits, or it would lose its reliability value.

5.4.3 Summary of Standalone Storage Scenarios & Modeling Results

The table below lays out the analysis scenarios calculated in ESVT for this use case—highlighting the combinations of load and tariff modeled and their corresponding benefit-to-cost ratio results. Not all combinations of key assumptions were modeled in the sensitivity analysis due to applicability and the resource and time constraints of this study. Because of very low subscribership to the optional residential TOU tariffs (343 customers for Xcel energy as of December 2012)[22] and the relatively small benefit potential the TOU tariff structures, only a limited number of runs were conducted for the residential scenario.

[22] "2012 Annual Report: Smart Grid." Xcel Energy. Docket No. E999/CI-08-948 before the Minnesota Public Utilities Commission. April 1, 2013.
https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7bFC232A99-7FEF-4518-92BB-D3A4BF69FE1E%7d&documentTitle=20134-85231-01

Table 5: Use Case 1 Standalone Storage Scenarios and Modeling Results

Customer Class	Customer Load	Tariff	Additional Sensitivity Considerations	Benefit-to-Cost Ratio
Commercial	Big Box Retail	Xcel GS (S)		0.54
	Big Box Retail	Xcel GS-TOU (S)		0.49
	School	Xcel GS (S)		0.56
	School	Xcel GS (S)	Tax Benefits Excluded	0.17
	School	Xcel GS-TOU (S)		0.54
	University	Xcel GS-TOU (S)		0.66
	University	Xcel GS-TOU (S)	Reliability Benefit Included	0.68
	Hospital	Xcel GS-TOU (S)		0.58
	University	Connexus General Commercial		0.63
Residential	No Electric Space Heating	Xcel Residential – TOU		0.31
	Electric Space Heating	Xcel Residential – TOU		0.30

5.4.4 Summary of Storage with PV Scenarios & Modeling Results

From the various combinations of load profiles and tariffs modeled and preference towards highlighting the most promising combination of load and tariff, the University load with Xcel General Service-TOU with reliability benefits was selected to model the impact of combining storage with PV. For the storage with PV scenarios, the Federal Income Tax Credit (FITC) and other tax considerations were found to be a primary driver of value and illustrated in the specific storage with PV scenarios and resulting benefit-to-cost ratios listed in the table below:

Table 6: Use Case 1 Storage with PV Scenarios and Modeling Results

Base Load & Tariff Combination	PV System Assumptions	FITC & Tax Considerations	Benefit-to-Cost Ratio[23]
University Load Xcel GS-TOU (S)	800 kWp 20deg fixed tilt 180deg azimuth	FITC: N/A Depreciation: 7yr MACRS Other Tax Benefits: Included	0.66
		FITC: 30% Depreciation: 5yr MACRS Other Tax Benefits: Included	0.88
		FITC: 30% Depreciation: 5yr MACRS Other Tax Benefits: Excluded	0.55

Without the FITC, pairing PV with storage in the modeled use case has negligible impact to energy storage value in this use case. However, FITC eligible projects, where the storage is integrated and operated with the PV system to meet IRS requirements, would be expected to have significantly more attractive benefit-to-cost ratios. In addition to the FITC, eligible storage projects can benefit from 5-year instead of 7-year MACRS depreciation schedules.

5.4.5 Detailed Scenario Assumptions & Modeling Results

Due to the large number of cases modeled, the investigators chose to highlight a case with more favorable results to discuss the detailed inputs and outputs of the analysis. (Full input and output results for this use case are included in the Appendix). Again, with preference towards highlighting the most promising combination, the University load with Xcel General Service-TOU with reliability benefits was selected to illustrate the detailed assumptions and results of a particular scenario. Below are detailed financial inputs, customer site data, and technology cost/performance considerations. Detailed input assumptions for each scenario can be found in the appendix documents.

[23] A benefit to cost ratio exceeding 1.0 indicates that the modeled benefits of energy storage exceed its costs over the lifetime of the installation, considering the time value of money and associated discounting of future year costs and benefits.

Table 7: Use Case 1 Financial Inputs and Customer Site Data

Category	Assumption	Value
Financial Inputs	Financial Model	Discounted Project Cash Flows
	Discount Rate	11.47%
	Inflation Rate	2%
	Fed Taxes	35%
	State Taxes	9.80%
Customer Site Data	Customer Type	Commercial (university)
	Tariff	Xcel GS-TOU (S)
	Tariff Escalation Rate	4%
	Peak Load (kW)	3012.18
	Average Load (kW)	1365.47
	Load Factor	45%

Table 8: Use Case 1 Technology Cost/Performance Data

		Battery
Technology Cost / Performance	Nameplate Capacity (MW)	0.5
	Nameplate Duration (hr)	4
	Capital Cost ($/kWh) -Start Yr Nominal	500
	Capital Cost ($/kW) - Start Yr Nominal	2000
	Project Life (yr)	20
	Roundtrip Efficiency	83%
	Variable O&M ($/kWh)	0.25
	Fixed O&M ($/kW-yr)	15
	Replacement Cost ($/kWh)	250

For the scenario assumptions listed above, the net present value of the lifetime benefits and costs are illustrated in the table below with a companion cost to benefit comparison chart. Detailed results for each scenario can be found in the appendix documents.

Table 9: Use Case 1 Net Present Value

Net Present Value Over Project Life		
	Cost	**Benefit**
Capital Expenditure (Equity)	212,534	0
Financing Costs (Debt)	117,508	0
Operating Costs	33,140	0
Taxes (Refund or Paid)	0	111,525
Power Reliability	0	13,454
Retail TOU Energy Time-Shift	0	10,281
Retail Demand Charge Management	0	112,358
Total	363,182	247,618
B/C ratio		**0.68**

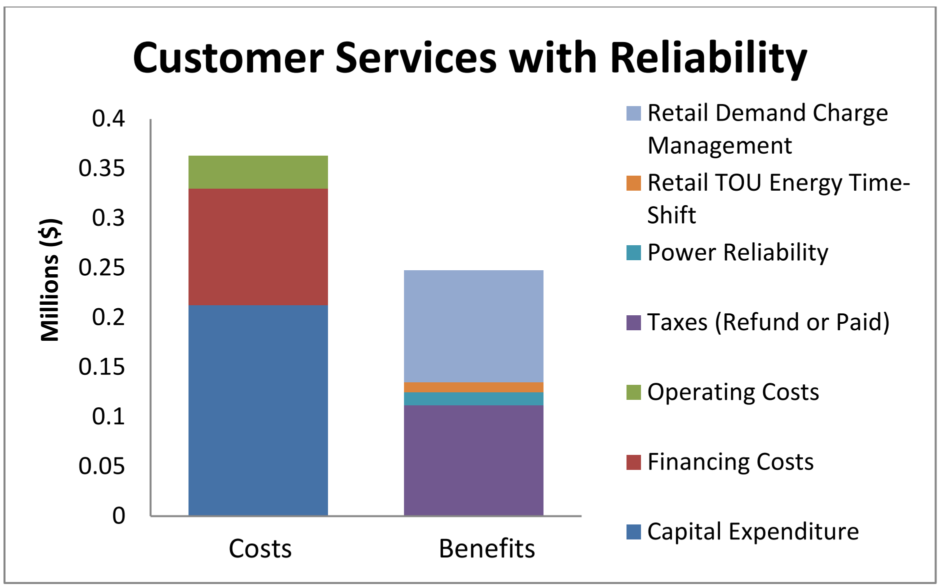

Figure 10: Use Case 1 Benefits and Costs (Customer Services with Reliability)

5.4.6 Sensitivities Considered

Several input sensitivities were considered and modeled. Given the preference towards evaluating the most promising combination of load and tariff, sensitivities focused on the highlighted scenario for use case 1. These sensitivities include the following:

- Tax treatment (include or exclude tax benefits in model) to show the significance of tax benefits for this use case
- Storage system ability (or inability) to perform reliability functions during a grid outage
- Storage with PV scenarios also included key sensitivity runs to evaluate the value of FITC eligibility and tax treatment

5.4.7 Use Case Conclusions & Key Limitations

In general, the customer-sited, customer-controlled use case proved to be a difficult value proposition in Minnesota, considering the combinations of loads and tariffs available for the study. The primary driver behind these low benefit-to-cost ratio results was relatively low customer demand charge rates in the tariffs, which ranged from approximately $8-$12/kW per month for most commercial customers. Demand charges of $15-$20/kW per month are typically required to provide sufficient value to justify a bill management storage device at current prices.

The economics for energy storage in residential scenarios are significantly worse than for commercial customers due to a lack of demand charges in the residential tariffs. This is a ubiquitous issue across the U.S. for this storage use case in the residential sector. Residential tariffs are typically designed to shield end customers from complexity and high risks; as such, the implementation of residential demand charges is part of a much larger strategy of grid cost distribution.

A key limitation of this analysis is that it was based around aggregated customer load shapes, which could flatten demand spikes of the individual source customers. Customers with very peaky loads could have higher bill saving potential than those modeled. Additionally, there are certain customers with very high power quality and reliability needs that have already invested in energy storage for uninterruptible power supply (UPS). It is difficult to model these customers' specific economics, but their investment is proof that the value provided by UPS energy storage systems is significant to warrant purchase. It is further possible that these customers have considered bill savings potential in their UPS investments, either through existing opt-in for retail TOU rate tariffs structures or potential future participation therein.

5.5 Use Case #2: Utility-Controlled for Distribution System Benefits

This utility-controlled use case differs significantly from the previously described customer controlled cases. While the storage system itself is sited similarly to the customer-controlled system at the point of customer load, it is located on the utility side of the meter, with the utility having full control of its operation. Additionally, this use case assumes multiple storage units are placed along a particular distribution circuit at multiple end-customer sites and that they have the necessary equipment and software to communicate in a network with the utility. In such a configuration, the following potential benefits may be captured:

- Distribution investment deferral
- Customer reliability and power quality improvement

5.5.1 Use Case Modeling Approach

The anchor benefit for this use case is distribution investment deferral to delay a major upgrade to the distribution infrastructure. Typically, this would involve delaying the construction of a new substation transformer, which can be an expensive capital outlay driven by a small number of hours where the existing asset would be overloaded. To calculate the value of deferral, Strategen and EPRI collected various actual distribution circuit-level 8760 hourly load profiles in Minnesota for representative loads as well as growth rates and upgrade costs for these circuits. Distribution upgrade costs are highly site-specific, and in practice should be considered on a case-by-case basis. Where upgrade costs were unknown, statistical cost data for 90th percentile upgrade costs were utilized.[24]

For the storage with PV scenarios, no high-penetration PV distribution circuits were uncovered in this study's request for information. Therefore, PV generation data was simulated for Minnesota installations using PVWatts[21], producing a blended generation profile of various tilt angles and orientations that would represent a typical situation on a distribution circuit containing several customer-sited PV systems. The simulated PV generation profiles were then netted out of the customer load profile data described above for the scenarios for modeling in ESVT.

Discussion of Reliability: The value of energy storage for providing backup power to customers is also considered. The costs associated with electric service outages are highly customer-specific, but a significant study was done by LBNL to estimate the costs of outages by duration, customer segment, and U.S. region.[9] The ESVT uses this information as well as the probability of outages for different frequency (SAIFI) and duration (SAIDI). If energy storage located at the customer premise is configured to operate in "islanded mode" during a grid outage, it may allow customers to ride through service outages for a period of time, which is determined by the amount of energy stored at the time of outage and the customer load.

The value of energy storage reliability is calculated as Value = (probability of outage)*(outage duration avoided by storage at current state-of-charge)*(cost of outage).

Costs of outage are based on LBNL numbers for North Central U.S.

Discussion of Voltage Support: In this use case, the energy storage system may also have the ability to provide voltage support to the local distribution system; however, this service is not explicitly modeled in this analysis, due to relatively low value and still undefined requirements. Currently, voltage is controlled using 3 phase capacitor banks, which are very low cost, designed primarily to boost voltage at the end of distribution lines to remain within ANSI standards and to reduce distribution losses. Energy storage could provide this service through the injection of real power (watts) or reactive power (VARs), which may provide incremental benefit. However, if large amounts of solar PV are interconnected to the utility distribution system, the potential for reverse power flow (during periods of low load) or rapid fluctuations (due to cloud effects) may require a more dynamic, bidirectional response of real and reactive power to support the power quality of electric utility customers. There is some trade-off between real and reactive power and the capability of energy storage to provide both simultaneously. If the voltage support service is required at different times than other services, there may be no conflict in availability. Alternatively, if voltage support service is required at the same time as a deferral or other service, the energy storage power conversion system could be overbuilt at additional cost so that the energy storage system could simultaneously provide real and reactive power. For example, a power

[24] 90th Percentile Estimated Installed Cost, SANDIA REPORT, SAND2009-4070, Unlimited Release Printed June 2009 Electric Utility Transmission and Distribution Upgrade Deferral Benefits from Modular Electricity Storage, A Study for the DOE Energy Storage Systems Program, Eyer/Corey

conversion system of 1.44 kilowatts or greater can simultaneously provide 1 kilowatt of real power and 1 kVAR of reactive power.[25]

Pairing the above load and upgrade deferral data with storage cost and performance data, the benefit-to-cost ratios for each scenario was calculating using ESVT's prioritization & optimization algorithm as described below. Using the benefit-to-cost ratio results of these various combinations of load and deferral values, the most promising scenarios were selected for appropriate sensitivity analysis.

5.5.2 ESVT Prioritization & Optimization

Figure 11 illustrates the modeled prioritization and co-optimization used by the EPRI Energy Storage Valuation Tool to model this use case. Grid service priority is displayed visually with higher priority modeled services above lower priority modeled services.

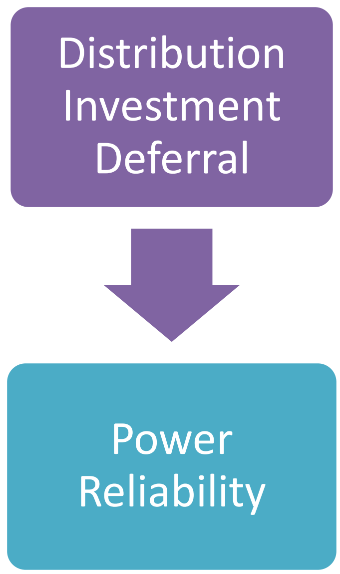

Figure 11: Use Case 2 Model Prioritization

The ESVT models this use case as two quantifiable grid services for energy storage: distribution investment deferral and power reliability. The modeling of the distribution deferral dispatches energy storage to offset any load growth on the marginally overloaded transformer (or other asset) to defer the need for an upgrade for a few years. The simulation holds this operation as top priority for the storage system, because the utility may otherwise sacrifice reliability due to thermal overload.

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[25] For information about real and reactive power, please see: Allaboutcircuits.com, Volume II – AC: Power Factor: True, Reactive, and Apparent power, http://www.allaboutcircuits.com/vol_2/chpt_11/2.html

After the energy storage successfully "shaves" the load growth for the maximum number of years, depending on load shape, growth rate, and storage system size), the additional value of energy storage to provide customer reliability (backup power) is then calculated per hour, taking into account energy storage system size, state of charge, and the value of reliability, as explained in the preceding section. It should also be noted that this use case could also be modeled to prioritize customer reliability by reserving a certain amount of energy in the storage system; however, due to the comparably low value of energy storage as a standby reliability resource, that typically has not be a valuable service for energy storage.

5.5.3 Summary of Standalone Storage Scenarios & Modeling Results

Several cases were modeled to investigate the value of providing distribution and reliability services. Variables investigated include the load growth rate, size of the distribution investment, and load characteristics of three different feeder loads, including a residential feeder, a commercial feeder, and a mixed residential and commercial feeder. Not all combinations of key assumptions were modeled in the sensitivity analysis due to applicability and the resource and time constraints of this study.

5.5.3.1 Value Drivers

Load growth rate drives the duration of the deferral, increasing the project value. The cost of the distribution investment is also a clear value driver. The case with low load growth rate and high upgrade costs yielded a benefit to cost ratio approaching 1. The table below lays out three of the analysis scenarios calculated in ESVT for this use case—highlighting the combinations of load and upgrade deferral assumptions as well as their corresponding benefit-to-cost ratio results.

Table 10: Use Case 2 Standalone Storage Scenarios & Modeling Results

Scenario	Load Growth	Upgrade Cost	Benefit-to-Cost Ratio
Commercial - 13.8kV	1%	\$176-384/kW (Xcel Provided)	1.01
Commercial - 13.8kV	2%	\$269/kW (90th percentile)	0.83
Commercial - 13.8kV	1%	\$269/kWh (90th percentile)	0.97

5.5.4 Summary of Storage with PV Scenarios & Modeling Results

The 13.8kV commercial feeder was selected to model the impact of combining storage with PV.

Solar PV has a few potential impacts on the usage and impact of energy storage for providing distribution and reliability services. These include 1) net load shape, 2) voltage control and protection, and 3) incorporation of solar PV financial incentives.

First, when considering the potential for a distribution investment deferral, the load shape is important. If the highest load days of the year have very long, flat peaks of 6-10 hours, this could be a costly energy storage investment, depending on the underlying technology. However, with a large penetration of PV, the midday and early afternoon solar PV production has the potential to make peak durations shorter, or potential split them into two smaller and more manageable peak periods.

The second consideration is voltage control and protection, though this case is not explicitly modeled. As solar PV penetration increases there is more potential for rapid voltage swings for customers, particularly during the morning and evening ramps and due to the minute-to-minute effects of cloud cover. Some of these issues can be addressed with “smart inverter” technology, which can curtail PV production or change power factor to support voltage. Another potential issue of PV is reverse power flow. If PV penetrations are high enough and local load low enough, it is possible that power flow could be reversed at the substation transformer. This can be an uncomfortable situation for utilities, because their protection schemes were developed in anticipation of unidirectional power flow. There is concern of equipment being damaged or potential safety risks, but these issues are currently inconclusive and under investigation.

A final consideration for energy storage value in this use case with solar PV is the potential to consider federal tax incentives that support the adoption of solar PV, which may extend to the storage asset. These include the potential to consider a 30% federal investment tax credit (FITC) on the capital cost of the energy storage and the potential to be eligible for a faster Modified Accelerated Cost Recovery System (MACRS) capital depreciation schedule, which results in additional federal tax benefits. To achieve these values, energy storage must be closely tied with and directly store at least 75% of its energy from a solar PV system. This particular requirement was currently infeasible to model in the ESVT model, but the modeled cases below show the financial impact of the federal solar PV incentives assuming the storage system can provide the identical services as previously modeled, without any additional operational requirements to earn the FITC and 5 year MACRS depreciation. It may not be unreasonable to assume this in this particular case, because the requirement to charge with solar may be accomplished with a morning charge period, followed by the release of energy in the afternoon. Depending on local load characteristics, peak load periods often occur in the summer from 2-6pm, which should not interfere with the storage ability to charge from solar PV during the morning hours.

Table 11: Use Case 2 Storage with PV Scenarios & Modeling Results

Base Load & Tariff Combination	PV System Assumptions	FITC & Tax Considerations	Benefit-to-Cost Ratio
Commercial - 13.8kV with Reliability Benefits	800 kWp DC 10-30deg fixed tilt 150-210deg azimuth	FITC: N/A Depreciation: 7yr MACRS Other Tax Benefits: Included	0.824
		FITC: 30% Depreciation: 5yr MACRS Other Tax Benefits: Included	0.977

Table 12: Use Case 2 Financial Inputs and Customer Site Data

Category	Assumption	Value
Financial Inputs	Financial Model	Discounted Project Cash Flows
	Discount Rate	11.47%
	Inflation Rate	2%
	Fed Taxes	35%
	State Taxes	9.80%
Distribution	Base Year Reference	2012
	Distribution Load Peak (MW)	13.8
	Distribution Load Growth Rate	2%

Table 13: Use Case 2 Technology Cost/Performance Data

		Battery (Utility Sited)
Technology Cost / Performance	Nameplate Capacity (MW)	1
	Nameplate Duration (hr)	4
	Capital Cost ($/kWh) -Start Yr Nominal	500
	Capital Cost ($/kW) - Start Yr Nominal	2000
	Project Life (yr)	20
	Roundtrip Efficiency	83%
	Variable O&M ($/kWh)	0.25
	Fixed O&M ($/kW-yr)	15
	Replacement Cost ($/kWh)	250

In this case, the energy storage was modeled as one large energy storage system of 1 megawatt and 4 hours of energy duration. However, the customer-sited storage system contemplated in this use case may not typically be this large. Depending on the customer load type, the scale of customer-sited energy storage systems may range from less than 5kW for residential customers to hundreds of kW or more for commercial customers. In cases with smaller systems, a number of energy storage devices could be controlled in aggregate to meet the name grid services modeled. However, it should be noted that aggregation of many energy storage systems could result in higher costs, and that these potential impacts have not been modeled in this analysis.

For the scenario assumptions listed above, the net present value of the lifetime benefits and costs are illustrated in table below with a companion cost to benefit comparison chart. Detailed results for each scenario can be found in the appendix documents.

Table 14: Use Case 2 Net Present Value

Net Present Value Over Project Life		
	Cost ($)	**Benefit ($)**
Capital Expenditure	1,491,428	0
Financing Costs	803,588	0
Operating Costs	605,845	0
Taxes (Refund or Paid)	0	513,526
Electricity Sales	0	896,060
Distribution Investment Deferral	0	979,608
Totals	2,900,860	2,389,193
Benefit to Cost Ratio		**0.82**

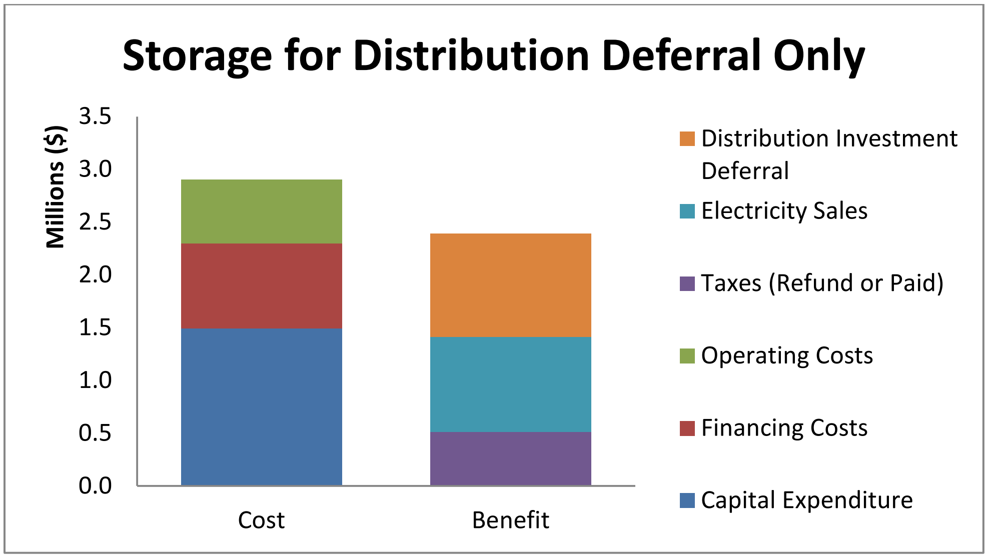

Figure 12: Use Case 2 Benefits and Costs (Distribution Deferral Only)

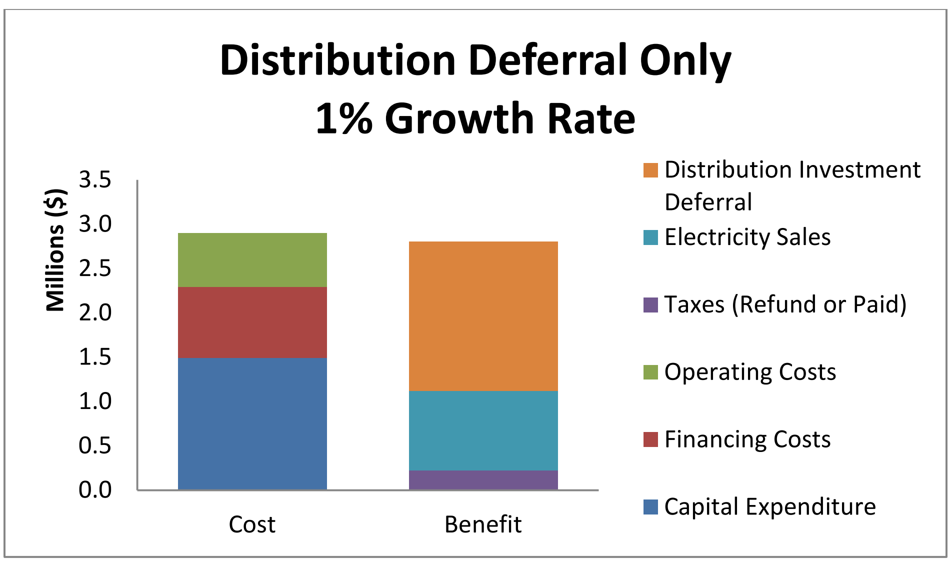

Figure 13: Use Case 2 Benefits and Costs (Distribution Deferral Only 1% Growth Rate)

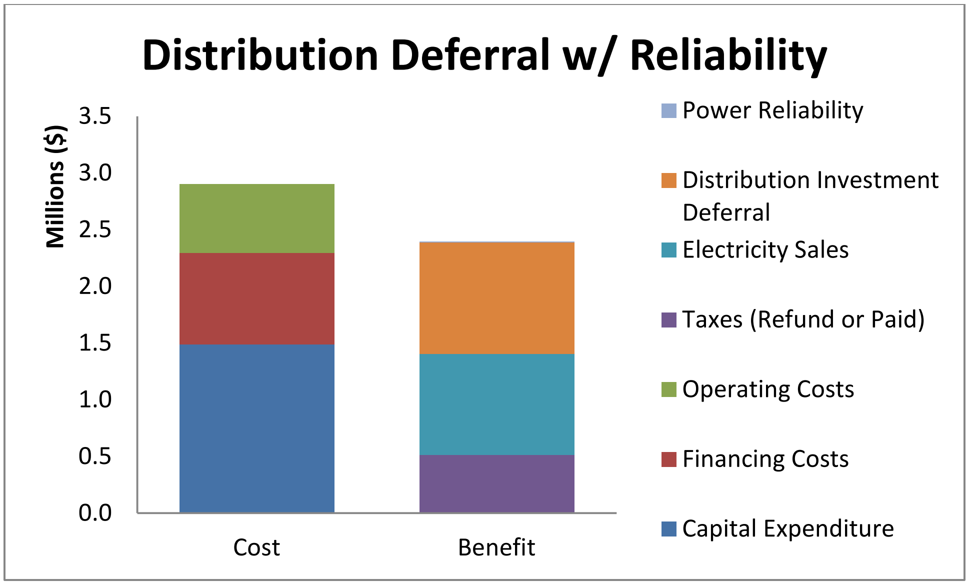

Figure 14: Use Case 2 Benefits and Costs (Distribution Deferral w/ Reliability)

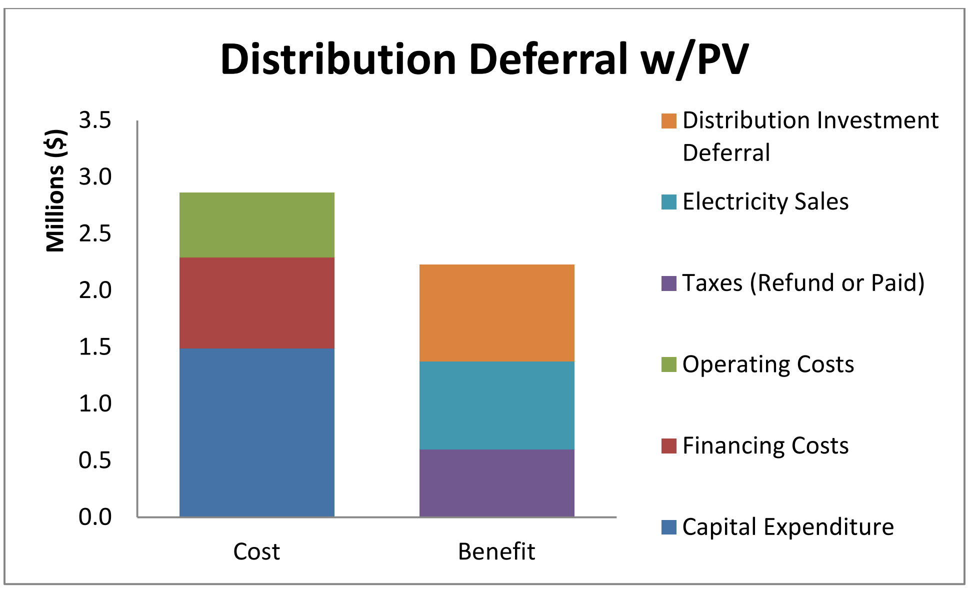

Figure 15: Use Case 2 Benefits and Costs (Distribution Deferral w/ PV)

5.5.5 Use Case Conclusions & Key Limitations

5.5.5.1 Conclusions

1. Deferral of major distribution upgrades can be a high value service for energy storage. However, it is highly site-specific. Substation transformers can represent large and under-utilized asset upgrades. Deferring theses lumpy capital outlays has the potential to save ratepayer money

equivalent to the time value of money for that investment. Slow load growth rate conditions, as are currently present in Minnesota, provide better economic cases than faster load growth rate, because a small energy storage system has potential to accomplish a longer deferral.

2. In this use case, energy storage may also provide additional distribution level services, such as voltage support and increased reliability, in case of local outage. However, in general these appear to be relatively low value in comparison to the cost of energy storage systems, and they appear to be an incremental value opportunity, rather than the primarily service to justify energy storage investment.
3. The distribution feeder configurations (commercial, residential, and mixed) had negligible impact on cost-effectiveness.
4. Though solar PV has the potential to change the "net" load shape significantly and affect the duration of investment deferrals, modeled cases did not show any difference in investment deferral length with the feeder load shapes provided by Minnesota utilities.
5. The significantly higher value of cases with solar PV is driven primarily by the potential to incorporate a federal investment tax credit (FITC) to offset the cost of the energy storage investment.

5.5.5.2 Key Limitations

1. A small number of cases were investigated for the distributed capacity use case, and the supporting data for the 3 distribution feeder loads were limited to 3 somewhat representative load curves provided by Xcel Energy. In reality, there are many variations of distribution load shapes and distribution upgrades planned.
2. This case looked at only one type of distribution transformer upgrade triggered by a thermal overload with expected slow load growth rate. Other types of upgrades may be driven by other types of conditions, including but not limited to 'N-1 Contingency' risk mitigation measures. These other types of upgrades were not modeled or substantially investigated in this analysis.
3. Solar PV and load were considered deterministically in the ESVT model with perfect foresight. Real life conditions are stochastic and the quality of load and PV output forecasting should be considered. Understanding the required controls and forecasting schemes for energy storage were not considered in this study.

5.6 Use Case #3: Utility-Controlled (Distribution + Market)

This use case is nearly identical to the second case, with the addition of MISO wholesale market participation and System Capacity value. It assumes the storage units have the necessary equipment, metering, and software to communicate in a network with the utility and MISO. With this configuration, the following potential benefits were modeled:

- Distribution investment deferral
- System capacity (resource adequacy) – Refer to appendix for value calculations
- Market services
    - Energy

- Ancillary services
    - Frequency regulation
    - Spinning reserve
    - Non-spinning reserve
- Customer reliability and power quality

5.6.1 Use Case #3 Modeling Approach

As in use case #2, the primary benefit for use case #3 is distribution investment deferral for circuit load growth. To calculate the value of a deferral, Strategen and EPRI collected various actual distribution circuit-level 8760 hourly load profiles in Minnesota for various representative loads as well as growth rates and upgrade costs for these circuits. Since the cost of site-specific distribution upgrades can vary widely and were not available initially, a 90th percentile referenced cost estimate for upgrades were modeled to investigate the cost-effectiveness of cases more likely to be attractive.[24] Later in the analysis effort, actual cost and upgrade information was provided by Xcel Energy to support the analysis, so this is provided as a sensitivity case. The following descriptions of Use Case #3 grid services modeled is adapted from the EPRI report "Cost Effectiveness of Energy Storage in California."

Grid Services Modeled

Below is a short description of each grid service modeled in Use Case #3.

Distribution investment deferral is modeled as the requirement for energy storage to offset the load growth on a distribution asset which would cause thermal overload and require the upgrade of the asset. The value of this service is modeled as the time value of money for the investment required for the conventional upgrade

System capacity is modeled as the requirement for energy storage to avoid or defer building a new generation asset. This is estimated as the difference between the conventional generation fixed cost and net revenues, a metric known as net Cost of New Entry (CONE). This value for energy storage is derated proportional to the number of peak hours when it is unavailable to provide its discharge capacity. This is further described in the Appendix.

MISO market revenues are modeled in ESVT as a co-optimization of multiple market services, including energy time-shift (arbitrage), frequency regulation, spinning reserve, and non-spinning reserve.

Energy time-shift (arbitrage) value is modeled as the difference in the value of selling stored electricity minus the cost of lower price electricity that was stored, and accounting for the roundtrip losses of the energy storage system.

Frequency regulation is modeled in MISO as a combined up and down market, where the energy storage must follow second-by-second signals to balance system-wide electricity supply and demand. This service is compensated based on capacity (MW) and the storage system must purchase and sell energy within each hour that it performs this service. The ESVT does not model intra-hour operation of the storage, except by providing an estimate of the energy throughput within each hour. Due to computing resource constraints, this study did not explicitly model cycling of the energy storage system, which may cause wear and tear on energy storage systems.

Spinning and non-spinning reserve are modeled as a contingency reserve service, so ESVT awards this capacity-based service value to energy storage, as long as it has at least one hour of energy stored to respond if called in a contingency scenario. A charging energy storage system may earn up to two times its capacity if it meets the one hour requirement. During charging, a storage system can respond in two parts: removing its load from charging and then providing its discharge capacity.

For the storage with PV scenarios and for reliability valuation, the approach matched the Use Case #2.

Pairing the above load and upgrade deferral data with storage cost and performance data, the benefit-to-cost ratio for each scenario was calculated using ESVT's prioritization and optimization algorithm as described below. Using the benefit-to-cost ratio results of these various combinations of load and deferral values, the most promising scenarios were selected for appropriate sensitivity analysis.

5.6.2 ESVT Prioritization & Optimization

Figure 16 illustrates the modeled prioritization and co-optimization used by the EPRI Energy Storage Valuation Tool to model this use case. Grid service priority is displayed visually with higher priority modeled services above lower priority modeled services. Services shown next to each other are at equivalent priority and are optimized economically in the simulation.

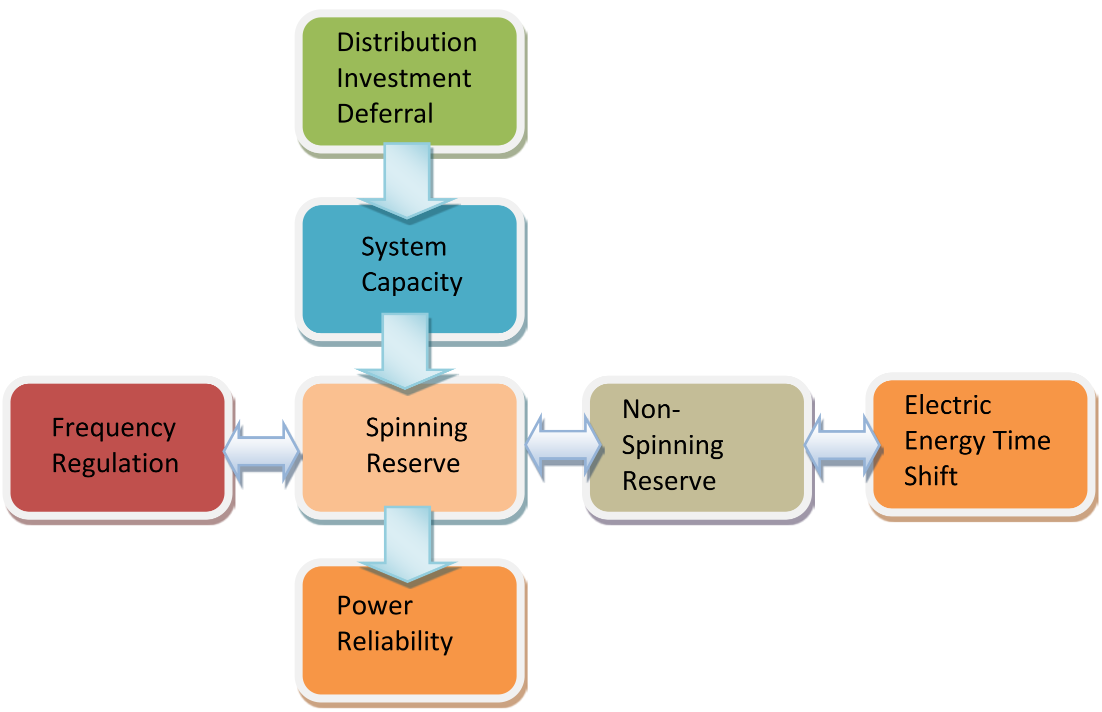

Figure 16: Use Case 3 Model Prioritization

In this use case, the highest priority service is distribution investment deferral, because this is a multi-year commitment to defer the investment. The investment deferral period would end as soon as the storage fails to keep the peak load under the initial threshold; in other words, when load growth on the asset exceeds the ability of energy storage to continue to sufficiently shave the peak. Once the storage system has fulfilled the commitment for distribution investment deferral, the remaining capacity is first dedicated to providing system capacity, which is typically a yearly or monthly commitment for the storage system to discharge during system peak times. To account for the penalty of non-conformance due to other commitments or insufficient energy duration, the benefit value ESVT assigns to system capacity is derated based on how well the storage system has met its system capacity commitment. Ancillary services (frequency regulation and reserves) and energy time-shift services are a co-optimized dispatch to maximize profitability for each day using the remaining, uncommitted storage capacity. Finally, any remaining energy availability is considered for additional, incidental reliability value, but this does not affect the dispatch of the energy storage.

5.6.3 Summary of Standalone Storage Scenarios & Modeling Results

The table below lays out the analysis scenarios calculated in ESVT for this use case—highlighting the combinations of load and upgrade deferral assumptions as well as their corresponding benefit-to-cost ratio results. Not all combinations of key assumptions were modeled in the sensitivity analysis due to applicability and the resource and time constraints of this study.

Table 15: Use Case 3 Standalone Storage Scenarios & Modeling Results

Distribution Circuit Load Type	Additional Sensitivity Considerations	Benefit-to-Cost Ratio
Commercial - 13.8kV		0.9991
Commercial - 13.8kV	Reliability Benefit Included	1.0025
Residential - 13.8kV		0.95
Commercial and Residential - 13.8kV		0.92

5.6.4 Summary of Storage with PV Scenarios & Modeling Results

From the various combinations of load profiles and upgrade deferral assumptions the 13.8kV commercial feeder was selected to model the impact of combining storage with PV.

As described in Use Case #2 (Section 4.4.4.), Solar PV has a few potential impacts on the usage and impact of energy storage for providing distribution and reliability services. These include 1) net load shape, 2) voltage control and protection, and 3) incorporation of solar PV financial incentives.

Beyond what has been described in Use Case #2, there are some additional issues to consider with Use Case 3. The key distinction is that Use Case 3 considers the impact of solar PV on the bulk electricity system and the potential for storage to play a role. Additional impacts could include 1) the variability caused by solar PV could make the demand for MISO balancing reserves, especially frequency regulation and spinning reserve, could increase; 2) the peak "net load" periods caused by large amounts of solar PV could change and peak capacity needs may shift.

The system impacts of PV were not modeled, because effects on system load shape and ancillary service prices are dependent on market penetration. To date, solar PV penetration in Minnesota and the Midwest has been very low. However, if this changes, the potential system impacts of PV on market prices and resource adequacy / capacity needs should be considered.

Table 16: Use Case 3 Storage with PV Scenarios & Modeling Results

Base Load & Tariff Combination	PV System Assumptions	FITC & Tax Considerations	Benefit-to-Cost Ratio
Commercial - 13.8kV with Reliability Benefits	800 kWp 10-30deg fixed tilt 150-210deg azimuth	FITC: N/A Depreciation: 7yr MACRS Other Tax Benefits: Included	0.96
		FITC: 30% Depreciation: 5yr MACRS Other Tax Benefits: Included	1.15

5.6.5 Detailed Scenario Assumptions & Modeling Results

The 13.8kV commercial feeder was again selected to illustrate the detailed assumptions and results of adding the consideration of solar PV. Below are the detailed financial inputs, feeder data, and technology cost/performance considerations. Detailed input assumptions for each scenario can be found in the appendix documents.

Table 17: Use Case 3 Financial Inputs and Customer Site Data

Category	Assumption	Value
Financial Inputs	Financial Model	Discounted Project Cash Flows
	Discount Rate	11.47%
	Inflation Rate	2%
	Fed Taxes	35%
	State Taxes	9.80%
System / Market	Base Year Reference	2012
	Real Fuel Escalation Rate	2%
	Energy & A/S Escalation Rate	3%
	Yr 1 capacity value ($/kW-yr)	$40
	Net CONE value ($/kW-yr)	$141
	Resource Balance Year	2018
	Mean RT Energy Price ($/MWh)	31.03
	Mean DA Energy Price ($/MWh)	32.01
	Mean Reg Price ($/MW-hr)	9.81
	Mean Spin price ($/MW-hr)	3.38
	Mean Non-Spin price ($/MW-hr)	1.45
Distribution	Distribution Load Peak (MW)	13.8
	Distribution Load Growth Rate	2%

Table 18: Use Case 3 Technology Cost/Performance Data

		Battery (Utility Sited)
Technology Cost / Performance	Nameplate Capacity (MW)	1
	Nameplate Duration (hr)	4
	Capital Cost ($/kWh) -Start Yr Nominal	500
	Capital Cost ($/kW) - Start Yr Nominal	2000
	Project Life (yr)	20
	Roundtrip Efficiency	83%
	Variable O&M ($/kWh)	0.25
	Fixed O&M ($/kW-yr)	15
	Replacement Cost ($/kWh)	250

In this case, the energy storage was modeled as one large energy storage system of 1 megawatt and 4 hours of energy duration. However, the customer-sited storage system contemplated in this use case may not typically be this large. Depending on the customer load type, the scale of customer-sited energy storage systems may range from less than 5kW for residential customers to hundreds of kW or more for commercial customers. In cases with smaller systems, a number of energy storage devices could be controlled in aggregate to meet the name grid services modeled. However, it should be noted that aggregation of many energy storage systems could result in higher costs, and that these potential impacts have not been modeled in this analysis.

For the scenario assumptions listed above, the net present value of the lifetime benefits and costs are illustrated in table below with a companion cost to benefit comparison chart. Detailed results for each scenario can be found in the appendix documents.

In addition to the financial results of this scenario, the energy storage dispatch details are identified in the table and figure below.

Table 19: Use Case 3 Net Present Value

Net Present Value Over Project Life		
	Cost	**Benefit**
Capital Expenditure (Equity)	1,491,428	0
Financing Costs (Debt)	803,588	0
Operating Costs	526,226	0
Taxes (Refund or Paid)	0	147,596
Electricity Sales	0	441,520
Distribution Investment Deferral	0	979,608
System Capacity	0	825,712
Frequency Regulation	0	382,780
Synchronous Reserve	0	34,773
Non-Synchronous Reserve	0	0
Power Reliability	0	16,184
Total	2,821,241	2,828,173
Benefit to Cost Ratio		**1.00**

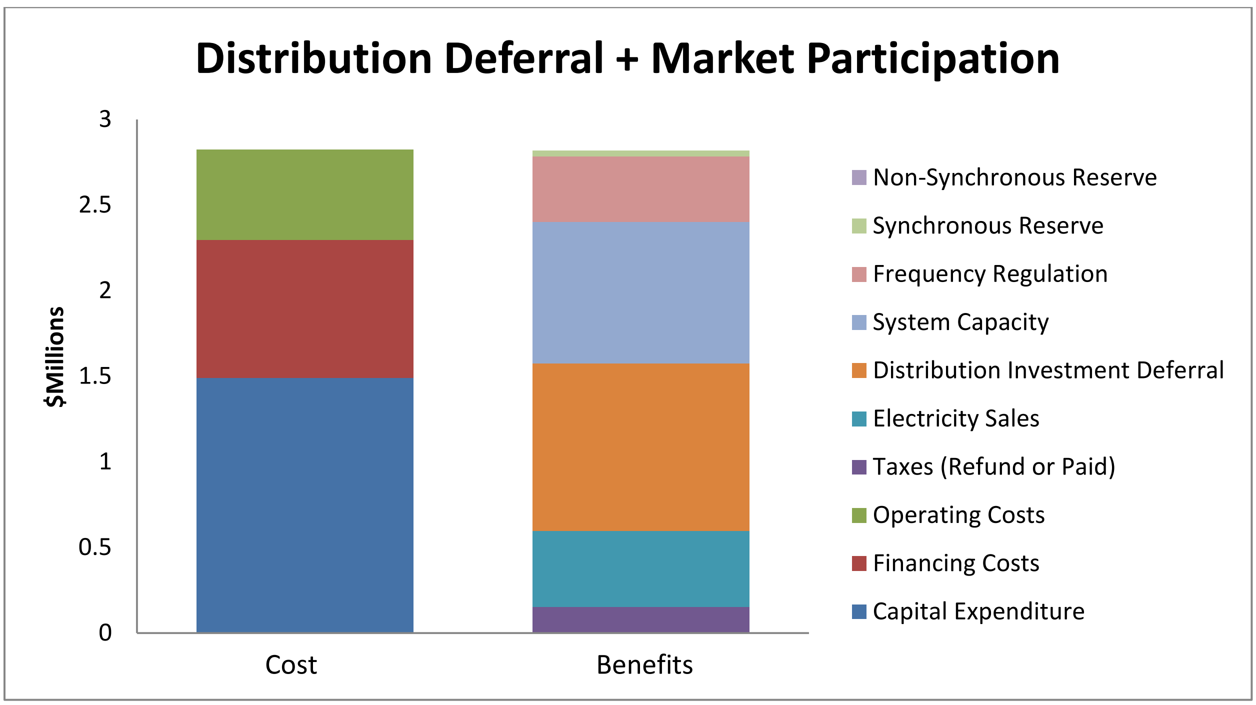

Figure 17: Use Case 3 Benefits and Costs (Distribution Deferral + Market Participation)

5.6.6 Use Case Conclusions & Key Limitations

Conclusions

Use Case #3, distributed peaker with market benefits, is an illustration of energy storage accomplishing several services for different stakeholders. As a result, it is not surprising that the modeled results were better than prior use cases.

In some of the cases investigated, the inputs utilized produced breakeven or somewhat positive project cost-effectiveness results. As in Use Case #2, the value of distribution deferral was important to the over value of the use cases, with additional value coming from the system capacity (avoided combustion turbine build) value, and the value of frequency regulation.

In the cases considering solar PV, the value for energy storage has the potential to be higher. As in the prior cases, the potential to capture a federal ITC for co-deployed solar PV and energy storage provides substantial value to the storage use case. Additionally, though not modeled, the solar PV also has the potential to increase the value of ancillary services that improve operator flexibility to respond to variability, including frequency regulation and spinning reserve.

Key Limitations

A small number of cases were modeled for this use case and the economics under different input assumptions can vary materially. As a result, economics of energy storage are best investigated on a case-by-case basis. Distribution level services are especially sensitive and dependent on location.

Value of system capacity and market services are less site-dependent, but future prices and values are uncertain and dependent on a number of factors, particularly future wind and solar market penetration, the cost of natural gas, and approaches taken by utilities and MISO to improve the way the grid is operated.

Once again, modeled solar PV, load, and market prices were considered deterministically in the ESVT model with perfect foresight dispatch. Real life conditions are uncertain (stochastic) and the quality of load, price, and PV output forecasting should be considered. Understanding the required controls and forecasting schemes for energy storage were not considered in this study.

Practical operational challenges that may result from aggregating energy storage systems and performing multiple services, such as coordination and data communication latency, were not considered in the modeling of this use case.

Dynamic and sub-hourly behavior of the energy storage was not considered in the modeling. Additional costs and benefits may be present, beyond what was considered in the modeling of energy storage.

5.7 Use Case #4: Shared Control (Customer Bill Savings + Aggregated Market Services)

Use Case #4 is a hybrid of Use Case #1 and #3. The assumption is that a customer purchases and primarily operates an energy storage system for its own bill savings, but then shares its operation to perform ancillary services during hours when it is unutilized for bill saving activity like demand charge management. The underlying assumption is that the customer, with facilitation from a third-party aggregator, offers its unutilized availability to provide ancillary services to the MISO market to earn additional value. A similar business model has been observed in California with the facilitation of a third-party energy service company (ESCO), or the energy storage vendor themselves.

Grid Services Modeled

Below is a short description of each grid service modeled in Use Case #4.

Retail demand charge management, as described in Use Case #1, is the usage of energy storage to reduce the instantaneous peak demand for each month and minimize the associated demand charge.

Frequency regulation is modeled in MISO as a combined up and down market, where the energy storage must follow second-by-second signals to balance system-wide electricity supply and demand. This service is compensated based on capacity (MW) and the storage system must purchase and sell energy within each hour that it performs this service. The ESVT does not model intrahour operation of the storage, except by providing an estimate of the energy throughput within each hour. Due to computing resource constraints, this study did not explicitly model cycling of the energy storage system, which may cause wear and tear on energy storage systems.

Spinning and non-spinning reserve are modeled as a contingency reserve service, so ESVT with award this capacity-based service value to energy storage, as long as it has at least one hour of energy stored to respond if called in a contingency scenario. A charging energy storage system, may earn up to two times its capacity if it meets the one hour requirement. During charging, a storage system can respond it two parts: removing its load from charging and then providing its discharge capacity.

ESVT Prioritization and Optimization

The figure below illustrates the priority of grid services as modeled in Use Case #4, using the Energy Storage Valuation Tool, where higher grid services have higher priority and services at the same level are co-optimized for maximum storage profitability.

Because the energy storage in this use case is owned and primarily operated by the customer, the demand charge management service has highest priority. After the energy storage maximizes its demand charge savings, it then considers other opportunities to earn incremental revenue with MISO market ancillary services. Finally, as described in previous use cases, additional reliability value for backup power is estimated with the remaining energy storage charge.

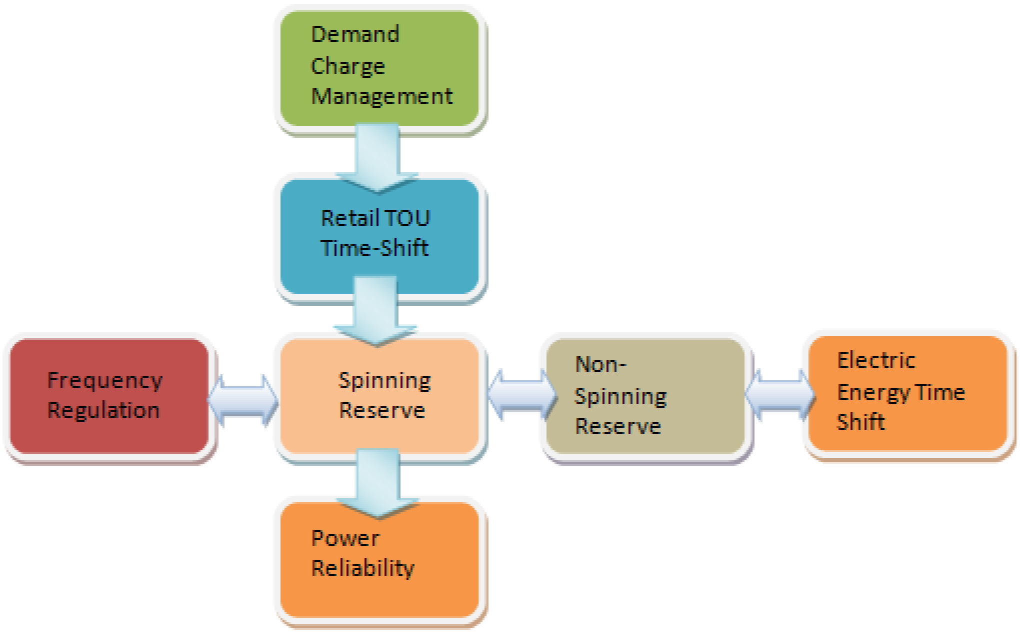

Figure 18: Use Case 4 Model Prioritization

Integrated modeling of this use case was not readily available in the current model structures of ESVT. As a result, the investigators ran this analysis in two separate simulations. First, a customer bill savings optimization was performed. Then a second simulation was run to optimize market services, with a constraint that the energy storage was unavailable for operation during the hours in the prior simulation where the storage was operating for the customer bill saving services. Finally, the results of the two simulations were merged together into a combined result.

5.7.1 Summary of Standalone Storage Scenarios & Modeling Results

The table below lays out the analysis scenarios calculated in ESVT for this use case—highlighting the combinations of load and upgrade deferral assumptions as well as their corresponding benefit-to-cost ratio results. Not all combinations of key assumptions were modeled in the sensitivity analysis due to applicability and the resource and time constraints of this study.

Table 20: Use Case 4 Standalone Storage Scenarios & Modeling Results

Distribution Circuit Load Type	Additional Sensitivity Considerations	Benefit-to-Cost Ratio
Run 12.X	done w/ capacity value	0.88
Run 12.X (No Capacity)	done w/o capacity value	0.43
Run 12.X (No Capacity) (2x P4P)	done w/ capacity value	0.65
Run 12.X (No Capacity) (2)	done w/o capacity value and 7yr + 14yr replacement schedule	0.42

6 Barriers Analysis

6.1 Introduction

Energy storage resources may encounter barriers to deployment, which can either limit or entirely prevent their optimal installation. The barriers can result from a number of reasons, ranging from lack of identified system need to insufficient compensation that limits cost recovery. Barriers vary for each of the four use cases outlined in this paper; they may even vary across specific technologies and applications.

This section outlines a spectrum of barriers for each of the four identified use cases. For each use case and related barrier, we identify the barrier itself, how it limits resource deployment, and potential policy or analytical remedies to enable deployment of cost-effective storage resources. Some barriers are relevant only for specific use cases, and each barrier is manifested differently for each use case (though some use cases share barrier characteristics). The identified barriers follow:

System need represents cases where a lack of identified system capacity needs can limit the deployment of energy storage. The barrier could come in the form of real system needs, potentially remedied by energy storage resources that have not been fully identified. The barrier could also be displayed when procurement stakeholders do not consider energy storage as a potential solution to an already-identified system need.

Cohesive regulatory framework represents the lack of a well-coordinated regulatory framework, which hinders consistent valuation and integration processes for energy storage resources. This generally entails a lack of coordination and consistency across stakeholders (regulatory agencies and system operators); it may also entail inconsistent policies within one stakeholder. Because storage can function at different times as load, generation, a transmission asset, and/or a distribution asset, it can be difficult to capture the value provided across those regulatory silos.

Evolving markets and related mechanisms can create uncertainty in costs and revenues for energy storage resources. Markets may also be developing in a way that will not compensate energy storage for its services to enable cost recovery. Storage services provided to day-ahead and/or real-time markets can have uncertain long term valuations. All of the above situations can make system operators or other stakeholders particular project investors wary of evaluating, financing, or installing energy storage resources.

Resource Adequacy (RA) value: Most forms of energy storage differ from traditional generators in a variety of ways:

- Energy storage does not have the startup limitations of traditional generating resources; startups typically require very little warning and resources can be started, stopped, and charged numerous times in a day or year without penalty.
- Energy storage also typically offers a wide flexible range, covering both the charge and discharge range of the resource. This full charge and discharge range can have value in services like load following and regulation.
- Most forms of energy storage also offer a much faster ramp rate than a typical generator; many can ramp to full capacity in a fraction of a second.
- Energy storage typically does have a use limitation in the form of the total energy contained in the energy storage device.

Because storage differs from traditional generating resources, accounting for the RA value for energy storage in Minnesota and elsewhere is unclear. The lack of RA clarity limits the ability of utilities to evaluate energy storage benefits, and reduces the incentive for utilities to install such resources. RA proceedings should model and clarify the value of various forms of energy storage based upon their characteristics and the resulting benefits to the grid.

Cost-effectiveness analysis: a lack of accurate and/or consistent cost-effectiveness analyses approaches will create difficulty with regards to integrating and reducing rate recovery risk of optimal amounts of storage resources. Questions about the accuracy of valuation methodologies will often lead to overly conservative consideration of storage resources. It is also possible that many of the benefits provided by storage will be undervalued or simply not included in cost-effectiveness analyses.

Cost recovery policies: insufficient revenues for energy storage resources will limit cost recovery and related resource deployment. A lack of cost recovery policies can result from incorrect or nonexistent compensation for services or system benefits provided by energy storage.

Cost transparency & price signals: decisions regarding resource deployment rely on accurate cost estimates for installation and operation, as well as consistent price signals in response to services provided. If stakeholders do not have clarity on either costs or revenues, there will be difficulties deploying optimal amounts and mixes of storage resources.

Commercial operating experience: commercial operating experience provides stakeholders insight into installation and operation of storage resources. A lack of local operating experience leads to uncertainty or hesitancy with resource deployment and may also lead to less cost-effective operation of such resources, with related impacts on future deployment.

Interconnection processes: energy storage resources must be able to effectively and consistently connect the grid in order to become operational. Interconnection processes designed around large traditional generating resources or retail customers may not allow storage devices to provide their full range of benefits:

- Interconnecting small storage resources may be cost prohibitive;
- Aggregated distributed storage resources may not be able to be counted and/or studied as combined systems;
- Interconnection rules may not allow storage resources to provide market services as well as retail services, despite the fact that these services can be clearly delineated in the operation of the storage resource.

Accessing of Federal Investment Tax Credits (FITC) and accelerated MACRS depreciation by utilities: the rules governing FITC and MACRS depreciation benefit capture for storage systems combined with on-site PV systems is unclear. The eligibility of storage resources to capture these benefits is dependent upon the specific system configuration and charging behavior. In addition, utilities need to be positioned to take advantage of these benefits, either directly or through a third-party ownership arrangement.

Customer sited MISO market participation: the rules for MISO market participation by customer-sited systems may require additional clarification. As has been shown in PJM and NYISO territories, customer sited systems can provide market services to the grid. However, allowing for market participation in practice can be complex and may require new rules to allow distributed resources to participate.

6.2 Barriers, Impacts, and Policy Solutions

Below, we outline the barriers, their impacts, and potential policy solutions for each barrier in each use case. Policy solutions are presented in the abstract; if stakeholders choose to pursue them, such policies should be carefully crafted to ensure the beneficial integration of storage resources.

6.2.1 Use Case #1 (Customer-Sited, Customer Controlled Energy Storage)

Barriers to use case #1 appear in many categories, including cost-effectiveness analysis, cost recovery policies, cost transparency and price signals, commercial operating experience, and interconnection processes. Current methods of cost-effectiveness evaluation do not fully consider all of the benefits that energy storage provides, and there are not consistently-used evaluation methods; this reduces the relative value of energy storage compared to other resources and sends incorrect signals to potential customer-owners. These storage resources do not receive tax or other incentives similar to certain preferred resources (i.e. customer-cited solar), are not fully compensated for the grid benefits they provide, and do not receive appropriate price signals given current rate structures. This reduces the financial viability of installing and operating energy storage resources. A lack of commercial operating experience limits utility willingness to integrate energy storage, and also makes customer operation more difficult. Finally, existing interconnection rules for behind the meter systems can be complex, and are not currently designed to accommodate behind the meter storage systems.

Stakeholders can overcome these barriers by providing customer-operators financial structures (appropriate pricing schemes and/or incentives) that accurately reflect the cost and value of storage resources, send accurate price signals to operators, and enable cost-effective operation: for example, instituting time-of-use electricity rates with two-way smart meters. These pricing schemes could be further improved through efforts at improving the comprehensiveness and accuracy of resource costs and benefits. Regulators could improve the ease of resource integration by instituting transparent and consistent interconnection processes. Finally, funding for pilot projects could improve operational experience with related benefits.

6.2.2 Use Case #2 (Utility-Controlled, Distribution-Only Use Cases)

Barriers to use case #2 relate to a lack of accurately identified local and system needs that storage could address and/or consideration of energy storage as a potential solution to these local and system-level needs. Similarly to use case #1, there are barriers related to cost-effectiveness analysis, cost recovery policies, cost transparency & price signals, commercial operating experience, and interconnection processes. When energy storage is not fully considered for system planning, it is discounted and/or excluded from actual integration, with related consequences. This includes both short- and long-term planning processes: for example, the frequently immediate need for distribution upgrades, which generally requires difficult and costly action to maintain system reliability, could be mitigated with well-planned additions of storage resources providing distribution upgrade deferral. The other barriers have impacts similar to those mentioned in use case #1 above.

Solutions to these barriers include many of those mentioned in use case #1, as well as clarification of eligibility for meeting RA criteria and of actual RA value for utility-operated storage resources. Collection and monitoring of distribution circuit data could also be used to anticipate locations where energy storage can be of value before the need for distribution upgrades becomes critical, with overloads already occurring.   Finally, interconnection processes and cost-effectiveness analysis will need specific solutions for this use case, given the system benefits it provides and the size and location of storage resources. Finally, energy storage resources could be officially recognized as a resource that viably meets evolving system needs, which could increase cost-effective resource integration.

6.2.3 Use Case #3 (Utility-Controlled, Distribution + Market)

Barriers to use case #3 are essentially the same as those to use case #2, as well as those related to providing ancillary services and system capacity. Resources providing wholesale services are hampered by an uncoordinated or incomplete regulatory framework given overlapping jurisdictions between utilities and MISO; this also extends to overlapping jurisdictions for interconnection processes. Because energy storage is traditionally not considered eligible for Resource Adequacy (RA) value, there is a lack of clarity around its eligibility for RA value, and therefore lack of clarity/certainty on RA as a potential revenue stream for energy storage. These resources are further constrained by evolving markets (including uncertainty about future market dynamics) for the types of ancillary services that energy storage can provide (i.e. frequency regulation from distributed resources). There is also a lack of commercial operating experience of distributed storage providing ancillary services. As with use case #2, many barriers result in difficult market entry, incomplete or inaccurate valuation, and an inability to capture all value streams.

Potential remedies include those mentioned in use case #2, as well as increasing collaboration between agencies for consistent valuation, policies, and coordinated regulatory proceedings. Wholesale energy & ancillary services markets could be developed with energy storage in mind, creating revenue streams for distributed ancillary services. As with use cases #1 and #2, improving valuation methods for use case #3 resources could lead to more cost-effective resource integration and provide guidance for developing policies, rates, and tariffs.

6.2.4 Use Case #4 (Shared Control, Customer Bill Savings + Aggregated Market Services)

Barriers to use case #4 are similar to those for use case #1, as well as those resulting from a lack of consistent identified system need, evolving markets and market entry for aggregated resources, and a lack of both commercial operating experience and accommodating interconnection processes for aggregated resources providing ancillary services. Finally, there is limited precedent for sharing asset control between customers/third-party developers and utilities for behind the meter resources, resulting in immature contracting mechanisms and related control technologies and communications protocols. These extra barriers reduce the impetus to install these resources, reduce opportunities for market participation and related cost recovery, and make interconnecting and operating resources difficult.

Resolutions to the barriers encountered in use case #4 are the same as those in use case #1. Stakeholders can overcome the additional barriers in use case #4 by focusing on aggregated energy storage integration. This includes accurately identifying system needs and considering aggregated energy storage as a solution to such needs, modifying and clarifying policies for aggregated resources providing ancillary services, expanding the operational knowledge base for aggregated resources, modifying interconnection rules for aggregated resources, and establishing pilot projects for shared control/use of behind-the-meter storage assets.

6.3 Barriers Summary

Each of the barriers applies to each use case differently, and some use cases do not experience certain barriers at all. In general, Case #3, which aggregates the greatest number of benefits, has the most applicable barriers. Case #1, as a customer controlled system, is much easier to deploy. The modeling indicates that reducing barriers is key to obtaining the highest benefit to cost.

The following table shows which category of barriers impact each use case. More detailed descriptions of each barrier, its impacts, and potential solutions to overcome those impacts can be found in appendix A.

Table 21: Use Cases and Applicable Barriers

Use Case	Use Case #1: Customer-sited, customer controlled energy storage	Use Case #2: Utility-controlled, distribution-only use case	Use Case #3: Utility-controlled (Distribution + Market)	Use Case #4: Shared control (Customer bill savings + aggregated market services)
System need				
Cohesive regulatory framework				
Evolving markets				
RA value				
Cost-effectiveness analysis				
Cost recovery policies				
Cost transparency & price signals				
Commercial operating experience				
Interconnection processes				
Tax Benefit for PV-connected systems				
MISO Participation				

Barrier Intensity: **Low:** **Medium:** **High:**

7 Incentive Program Discussion

Incentive programs may be designed to capture the benefits of an energy storage system that cannot be directly compensated.[26] For instance, there may be environmental benefits to using an energy storage system that are valuable to both the customer and society as a whole. These benefits are difficult to quantify, and can be significant, but may not be monetized in the overall storage system economics.[27] Other benefits might accrue to the system or grid overall, but the rules may not be in place to allow

[26] This section, "Incentive Program Discussion", partially adopted from the CPUC's *Statewide Joint IOU Study of Permanent Load Shifting* from December, 2010 prepared by E3 and Strategen.
[27] This analysis does not attempt to quantify the value of societal benefits from energy storage.

access to them by the system owner. Incentive programs provide a way to close the gap between the system cost and system benefits, ultimately reducing the payback time and making the business case for energy storage more attractive. Incentive programs may also provide a useful means to encourage early adopters of a new technology solution to take action, lowering prices in the medium term to a level sufficient to allow for adoption without incentives.

7.1 Incentive Program Design

Distributed storage may have value streams that cannot be directly monetized by the end user. Incentives may align current costs & benefits.

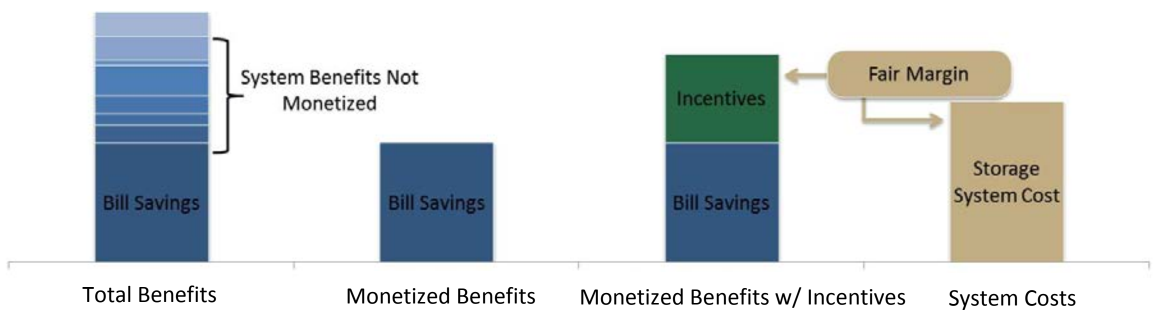

Figure 19: Impact of Incentives on Benefits and Costs

Market transformational incentives for grid storage, such as the California Self Generation Incentive Program "SGIP", can help enable the vision for future clean energy supply.[28]

Incentive programs typically fall into two categories, performance-based ($/kWh), and capacity-based ($/kW). The following sections will discuss the unique characteristics of these two incentive types and important considerations for each.

7.2 Performance Based Incentives

Performance based incentives can be accomplished in multiple ways:

The first mechanism for a performance based incentive is to use the retail rate itself as the 'performance based incentive'. Savings can be generated from the shifting and timing of energy consumption, given the time-of-use rate structure and related demand charges.

Another approach to performance based incentives would be to pay a $/kWh incentive (in addition to bill savings) for energy consumption shifted from on peak to off peak time.

[28] For more information about the SGIP, please see: http://www.cpuc.ca.gov/PUC/energy/DistGen/sgip/

A third approach would be to incentivize a system based upon its operation during specified hours. This type of incentive could make sense when the storage resource is providing services like Frequency Regulation or Capacity, which can provide value to the grid in excess of the kWh dispatched.

7.3 Capacity-Based Incentives

Capacity-based incentives can be paid up-front, based on the size of the storage system. One option is to create incentive levels that are broken out into tiers based on a range of system sizes. Rates can also be designed to decline on an annual basis. This helps to encourage early participation in the program. Payments are typically made upon project completion and verification.

7.4 SGIP Program Example

The California Public Utility Commission's Self-Generation Incentive Program (SGIP) provides incentives to support existing, new, and emerging distributed energy resources located on the customer's side of the utility meter. Under SGIP, a total of 544 projects have been completed for a capacity of 252MW. It is one of the longest-running (founded 2001) and most successful distributed generation incentive programs in the country.

Table 22: Current SGIP Incentive Levels (2013)

TECHNOLOGY TYPE	INCENTIVE ($/W)
Renewable and Waste Heat Capture	
Wind Turbine	$1.19
Waste Heat to Power	$1.19
Pressure Reduction Turbine	$1.19
Non-Renewable Conventional CHP	
Internal Combustion Engine – CHP	$0.48
Micro-turbine – CHP	$0.48
Gas Turbine – CHP	$0.48
Emerging technologies	
Advanced Energy Storage	$1.80
Biogas Adder	$1.80
Fuel Cell – CHP or Electric Only	$2.03

7.5 Important Considerations

The following sections discuss a variety of important considerations when designing an incentive system.

7.5.1 Incentive Recipient

An important consideration when designing an incentive program is identifying who the target recipient will be. In this study, multiple use-cases are considered, including: customer owned and controlled, utility owned and controlled, and joint customer/utility controlled. However, only the customer owned used case would be eligible for incentives because incentive programs primarily benefit the ratepayer.

7.5.2 Incentive Levels Based on Expected Payback

Technology specific incentive levels based on expected payback may have a number of limitations. The diversity in technologies and use-cases, as well as variations in the cost of design, labor, and materials could make it difficult to confidently establish an accurate installation cost. This is further complicated when multiple systems must be integrated together. Additionally, technology specific incentives could lead to “boom and bust” cycles of energy storage system installation resulting from incentive levels set too high or too low. Lastly, technology specific incentives could lead to favoritism of a specific technology type, abandoning the principle of technology neutrality.

7.5.3 Retail Rate Design

Retail rate structures can dictate the opportune time to charge or discharge a storage system. Existing rate structures for residential customers include TOU rates, but do not include demand charges. Furthermore, existing rate structures do not have a ‘super off-peak’ rate that would provide lower energy costs for increased energy usage in the middle of the night.

A variety of options for modifications to the existing rate structure are available. A separate energy storage rate could be created for qualifying projects that meet set performance standards. TOU rates and demand charges could be included. A ‘super off-peak’ rate could also be provided to encourage charging during very low cost periods, such as during the middle of the night. Existing customer TOU rates could be “grand-fathered” into the program for when specific conditions occur that jeopardize the economics of the energy storage system. However, this option poses challenges when it comes time to update the rate in the future.

7.5.4 Ratepayer Neutral Incentive Levels

A future consideration could be to model ratepayer neutral incentive levels. In other words, these incentive programs would be provided without a cross-subsidy from non-participating ratepayers, while still being substantial enough to attract a reasonable level of participation in the program. The balance of these two factors is an important part of overall program design, and highly dependent on Minnesota goals/objectives for energy storage.

Incentive payments can be distributed in a variety of ways, including: as installments throughout the project lifetime, an upfront lump-sum, or as performance-based incentives. If the incentive is performance-based or paid out over time it is critical that the time value of money be taken into consideration in program design.

8 Thermal Energy Storage

The preceding analysis was limited specifically to electric energy storage technologies. However, thermal energy storage is another technology option, which may have the capability to provide many of the same services to the electric grid. A primary purpose of thermal storage is to provide management of building load shape for utility or customer value, without causing occupant discomfort. Because there are pilots of grid-connected thermal energy storage technology currently in progress within the state of Minnesota, it bears recognition and discussion as part of this paper. However, detailed analysis of thermal energy storage technology is not included in this white paper report.

8.1 What is Thermal Energy Storage?

Thermal Energy Storage (TES) refers to a class of technologies that converts electrical to thermal energy and stores thermal energy to provide space heating, space cooling or water heating at another appropriate time. In this discussion, we will focus on technologies where the energy originates as electric energy. Technologies that fit into this category include electric water heaters, heat pump water heaters, storage space heaters and ice or chilled water storage. TES is often cost effective as it is integrated with building systems, and can provide customer side benefits other than just load shifting. In contrast to electrical storage, thermal energy storage is usually incorporated through customer economics (similar to energy efficiency measures), based on reduction in utility peak demand charges. The customer economics makes it an easier sell as customer sited storage. However, it also has limitations on its use, the two key ones being that usage is constrained by building cooling, heating or water heating need, and second, there cannot be electricity sent back into the grid (unless other forms of electrical storage are also present). Another form of thermal storage, not discussed in depth here, is building passive storage. This technology uses building control systems to modulate indoor temperatures within limits of customer comfort to store thermal energy in the building shell. The advantage is it costs next to nothing in buildings with good control system capability, but the disadvantage is that it can be easily modified.

Examples of TES based programs for Grid Benefit:

1. Usage of electric hot waters for renewable integration: Many utilities either have pilots, large scale deployments, or are evaluating electric water heaters with storage for supporting grid needs. In Minnesota, Great River Energy has approximately 100,000 storage electric water heaters under utility control.[29] Other regions with marked interest in water heater storage include the Pacific Northwest and Hawaii.
2. The Southern California Public Power Authority (SCPPA) has a $53 million effort to install thousands of packaged ice storage systems for small and medium commercial buildings. The goal here is to relieve distribution system constraints as well as reduce on-peak power purchases.
3. The California Public Utilities Commission (CPUC) has a $20 million (annual) utility program, called Permanent Load Shift (PLS) to incentivize thermal storage systems. This program ran as a pilot from 2008 to 2012 and was recently ratified as a program in May 2013. The primary target is to relieve summer on-peak congestion, and the qualifying technologies include all “cool”

[29] Great River Energy, Comment on the Energy Efficiency and Renewable Energy Office (EERE) Proposed Rule: 2012-06-13 Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Energy Conservation Standards for Residential Water Heaters; Request for information; July 12, 2012 http://www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0022-0041

storage technologies that do not negatively impact overall air-conditioning efficiency. It applies to large chilled water systems for large commercial and institutional buildings, and ice storage for medium and small commercial buildings that can work with both chiller systems and packaged rooftop units.

8.2 Electric Resistance Water Heater

8.2.1 How it Works

An electric hot water heater works by converting electric energy into heat using a heating element. In a standard hot water heater, a target temperature is set by the user of hot water based on desires of safety and comfort. However, advanced electric hot water heaters have been designed, through multiple approaches, to decouple the user-desired hot water temperature from the maximum temperature within the tank. As a result, water temperatures of up to 200 F can be stored, but supplied at 140 F or less (normal hot water temperature), providing flexibility to the water heater on timing of absorbing electrical energy from the grid.

8.2.2 Value to Customers and Electric Utilities

These advanced electric hot water heaters may provide multiple services to the electric grid without causing consumer discomfort, including taking advantage of low electricity prices, reducing demand charges, local "peak shaving" (resulting in upgrade investment deferrals), and improved resource adequacy (capacity) by providing demand response. The key difference between electric hot water heaters and electric energy storage is that the hot water heater's primary objective is to provide hot water for consumption. Electric energy storage can store and release energy to the grid based solely on reliability and economic considerations. Hot water heaters only store energy; release of the energy occurs through the consumption of hot water, which is entirely decoupled from the objectives of the electric system. As a result, hot water heater resource availability is constrained by customer behavior. Despite these constraints, electric water heater may already exist at customer sites, so the grid services, constrained as they may be, has the advantage of being provided by an appliance which has already been purchased for the purpose of hot water production. As a result, even a modest benefit to the grid may justify the relatively small incremental investment to upgrade a standard electric water heater to a grid-interactive hot water heater, during regular customer replacement.

8.2.3 Heat Pump Water Heaters

Heat Pump water heaters have emerged as a high energy efficiency option in the last 5 years. Compared to electric water heaters they are twice as efficient or more. Heat pump water heaters operate using the Carnot cycle, absorbing heat from the outdoors and rejecting it to water using a refrigeration cycle using a compressor. However, since the compressor draws power of 1.5 kW or less (compared to 4.5 kW for electric water heater), their capability to absorb large amounts of electrical energy could be limited. At present, most heat pump water heaters carry an electrical resistance element (for rapid heating), which if controlled separately can be used to ramp up similar to electric water heaters. EPRI is currently conducting research on how to enable heat pump water heaters for grid management similar to electric water heaters. Utilities interested in this technology include the Northwest and California utilities, as HPWH present a combination of substantial energy efficiency savings along with grid management capabilities.

8.3 Ice and Chilled Water Storage

8.3.1 How it Works

Ice and chilled water thermal energy storage technologies are primarily used to reduce demand charges to the customer and secondarily can improve the efficiency of air conditioning in buildings. These technologies work by creating ice or chilled water at night when outdoor ambient temperatures are cooler and electricity is lower cost. Then, when building air conditioning systems are needed, the ice or chilled water cools the building air, using heat exchangers. This has the dual benefit of allowing customers to use lower cost nighttime electricity, downsizing the overall installed air conditioning system (if the ice/chilled water storage is included in the HVAC planning process), and increase the overall efficiency of air conditioning due to thermodynamic efficiency using cooler nighttime air (depends on technology). The roundtrip efficiency (energy shifted/energy used) of these systems ranges usually between 90 and 110%, depending on the type of technology and efficiency of the air conditioning system.

8.3.2 Value to Customers and Utilities

For the electric grid, there is a benefit of this technology's tendency to reduce peak load events, both locally and system-wide, because peak load events are often driven by summer peak air conditioning demand. Ice and chilled water storage has been demonstrated to provided reduced customer demand charges and time-of-use energy savings. Many large buildings incorporate cool thermal storage as it can either reduce first cost of the air conditioning system or provide a very quick payback. Since all air conditioning systems are sized for the peak summer day, thermal storage can reduce the size of air conditioning systems by providing supplemental cooling capacity. Thermal storage could also reduce the temperature of the supply air to the building space, which means less air flow is required to provide the same amount of cooling, resulting in smaller ducts and fans, which also reduces cost. Thousands of cool storage systems have been installed; many have a successful operating history of over 3 decades. On the utility side, TES can be used to defer distribution upgrades, defer generation upgrades for resource adequacy (system capacity), and reduce T&D energy losses. As with hot water heaters, cold storage does not provide electricity back to the grid and its use is inherently limited by the demand for building cooling. Additionally, the investment in cold storage can once again be modest, especially if its implementation is planned and optimized during the design phase for HVAC projects, because of its capability to provide capital savings elsewhere in the overall design.

8.4 Thermal Energy Storage Technical Considerations

8.4.1 Efficiency

Thermal energy storage in form of hot water or ice converts electricity into thermal energy. A thermal reservoir is used to store this energy which is either above or below the ambient temperature. In case of batteries or pumped hydro for example, the electric energy is converted into chemical energy or potential energy which can be converted back to electric energy when required. There are losses involved in this conversion, but the losses are within reasonable limits. In electric thermal storage, the ability to convert thermal energy back to electric energy is lost. From a thermodynamics standpoint, heat is low grade energy. All available thermal energy cannot be converted into work (electricity) without rejecting some of the thermal energy to the sink (atmosphere). For example an internal combustion engine in a car has to reject heat to the atmosphere through the radiator and the exhaust gases. Only a part of the chemical energy (gasoline) we put into the car gets converted into useful work.

8.4.2 Up Time

Uptime is the time the electric water heater can actually be used as a peak load shifting or demand response device. Unlike other storage devices like batteries and flywheels, the up time for the electric water heater is the time when it is charging. Once the smart electric water heater is fully charged that particular smart electric water heater ceases to be a resource any more. Since the discharge rate is dependent on the water draw the electric water heater cannot be discharged by remote signals. If the water draw is low, the smart electric water heater will have a relatively low up time. For an electric water heater with a significantly higher water draw the up time will be high. Understanding the discharge pattern of a fleet of smart electric water heaters is necessary to optimize the combined up time. Heavy users of hot water or occasional high use of hot water must be incorporated in the control strategies so that the charge time and hence the up time can be adjusted.

8.5 Geographic Considerations for TES

As with electric energy storage, the application of thermal energy storage is not ubiquitous and may be subject to certain geographic constraints. When considering the applicability of grid-interactive electric hot water heaters, it is important to recognize that a key reason for deploying electric hot water heaters is a lack of natural gas service, since heating water with natural gas is typically more cost-effective than heating water with electric resistance. As a result, the initial geographic focus for advanced electric hot water storage is limited primarily to rural areas without natural gas service, which can be estimated as the difference between households in Minnesota and the number of residential natural gas customers, estimated at 610,000.[30] It should also be noted that electric heat pump water heaters are another competitive technology in the creation of hot water. Electric heat pump water heaters are significantly more efficient than electric resistance water heaters, but they have the drawback of offering less additional value to the grid through demand response and balancing.[31]

When considering ice and chilled water storage applicability, it is also important to consider the climate of Minnesota. Cooling load is limited in residential and small commercial buildings, but large commercial buildings operate in cooling for large portions of the year. Hence some of the technologies such as packaged ice storage systems may be more cost-effective and likely to be adopted in warmer regions.

8.6 Regulatory Considerations

Federal regulation of hot water heaters (10CFR 430.32) requires electric water heaters above 55 gallon storage to have an energy factor (EF) of defined by the following equation –

EF = 2.057− (0.00113 × Rated Storage Volume in gallons).

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[30] E-mail from Kelly Murphy at Steffes Corporation. November 25, 2013.
[31] Research is ongoing at EPRI to provide balancing through variable speed compressors that can ramp, as well as using the electric strip heat element contained in these HPWH.

This requirement will push storage type electric resistance water heaters out of the market on April 16, 2015. Utility programs designed for peak load shifting (off-peak water heating) will be adversely impacted due to amended energy standards beginning on April 16, 2015 (banning of resistance water heaters with storage cap of > 55 gallons). DOE is actively working with various utilities, manufacturers, environmental advocacy groups and other interested parties to find a solution to this problem. At this point a waiver process for larger water heaters is proposed but the terms seem to be too burdensome for utilities and manufacturers as well.

A potential legislative approach has been proposed with which all the stakeholders agree. An amendment to the 'Energy Savings and Industrial Competitiveness Act of 2013' that was introduced in the Senate in July 2013 has been proposed. The amendment proposes adding standards for Grid Enabled Water Heaters which are greater than 75 gallons and are used in Demand Response / Thermal Energy Storage type applications.

A parallel effort, an administrative solution with DOE is also being pursued in case the legislative proposal meets roadblocks.

8.7 EPRI Research and Planned ESVT Modeling Enhancements

As of the writing of this report, the EPRI Energy Storage Valuation Tool has some capability to model thermal energy storage systems, particularly the operation and value of ice-based thermal energy storage systems. However, these capabilities were deemed insufficient to perform high fidelity modeling of Minnesota use cases at this time. Development of features to effectively address modeling of thermal energy storage with the ESVT is underway and expected for completion in 2014.

EPRI is also conducting research into combining different types of storage in buildings, to determine the optimally cost effective combinations of storage technologies for customer sites. This research is initially targeted at the Southern California area, but can be extended to other areas. The analysis aims to use building models to determine load shapes using combinations of temperature set point control, hot water control, cool thermal storage and battery storage. ESVT will be used iteratively with building models to determine optimal dispatch strategies to maximize utility value. The results of the research will be available in Fall 2014.

9 Conclusions and Recommendations

This section summarizes the major conclusions and recommendations for entire analysis performed for the Minnesota Department of Commerce.

9.1 Modeling Findings

1) Energy storage is capable of providing multiple sources of value for customers and utilities. These values can come in the form of economic value and in terms of grid reliability. Utility-operated energy storage modeled cases returned significantly higher direct, quantifiable value than customer-operated energy storage cases. The customer tariffs evaluated do not provide sufficient price signals to customers to procure energy storage or operate it to optimally benefit

the electric system. Residential tariffs, because they typically lack demand charges or high time of use (TOU) pricing differentials, return the lowest value for energy storage. Key customer benefits include:

a. **Demand Charges** – The majority of energy storage benefit for customers is derived from overall reduction in a customer's demand. Demand charges of $15 - $20/kW per month are generally needed to provide sufficient value to the customer to compensate for the cost of the energy storage system.
b. **Time of Use (TOU) Energy Charges** – This benefit accrues from buying energy at a low price and selling at a higher price. Modeling showed that this benefit was not significant. In many residential tariffs, there is not TOU energy charge on the bill, so this benefit cannot be realized.
c. **Federal Investment Tax Credit** – This tax credit can be applied to an energy storage system that obtains 75% or more of its charging energy from an integrated photovoltaic solar system. It requires that the system be co-located with on-site solar. Commercial end customers may be better positioned to take advantage this benefit than utilities.
d. **Accelerated MACRS depreciation** - Like the FITC, this benefit only applies to storage systems co-located with solar PV. Such systems can be depreciated over 5 years instead of 7, resulting in tax avoidance and time value of money benefits to the storage owner.
e. It is worth noting that demand response activities could provide additional value to customer operated systems, where load is reduced in response to a utility need for system capacity. This value was not quantified in the model.
f. Additionally, the value of customer backup power (enhanced reliability) could be obtained if energy storage has the capability to operate as an uninterruptible power supply. While the value of this service generally appears to be low, there are certain instances and customers where this value could be significantly higher, particularly with critical loads, such as hospitals and data centers. Appropriate configuration for the energy storage and the load are required to provide this functionality.

2) The value of utility controlled, customer sited systems relied upon four key benefits, each with their own specific requirements and value. Based upon the modeling, a system must be able to capture at least three of these benefits in order to achieve a benefit to cost ratio greater than one.

   a. **Distribution upgrade deferral** – energy storage can provide significant benefit by deferring distribution upgrades. It should be noted that this benefit is highly location specific, as it relies upon storage sited and sized to defer the upgrading of distribution equipment on a feeder. The value of upgrade deferral depends greatly upon two key factors:

      i. The cost to upgrade a distribution transformer and/or substation. These costs range widely. The cost used in the modeling was $269/kW, which is based upon the Energy Storage Guide by Sandia.[24] This cost was somewhat higher than costs received by Xcel in the late stages of analysis, which included a range of 125 to 156/kW.[32] Because upgrade deferral would be performed at the highest value sites first, the value used may still be reasonable for an above average upgrade cost in Minnesota.

ii. Load growth drives certain distribution upgrade needs and deferral value. Low load growth allows for longer deferral or smaller energy storage system for equivalent deferral, and thus a higher value for a storage resource providing deferral. Load growth of 1% provided a much longer deferral length than load growth of 2%, increasing the value of this benefit.

Based upon the modeling, the most cost effective storage assets are more likely to be located at sites requiring upgrades in the near term, with high upgrade costs and low expected load growth.

b. **Frequency Regulation** - Participation in frequency regulation requires bidding into the Midcontinent Independent System Operator (MISO) frequency regulation market. Market participation could have significant value, but capturing this benefit would require additional creation of MISO rules for customer-sited storage systems to participate in the market. MISO market participation, particularly participation in the Regulation market, provides significant additional value to the storage system in the modeled scenarios. The value of the Regulation market pricing is uncertain due to several factors:
   i. The market is a day-ahead market. As such, it is subject to variability by time of day, month, year, and long term energy pricing and renewable penetration.
   ii. The value of fast responding, accurate storage due to the recently implemented FERC Order 755 (pay for performance) is difficult to predict. Scenarios were run with multiple multipliers as proxies for the eventual impact of FERC Order 755. Higher multipliers of 1.5-2X in the modeled cases resulted in the greatest cost/benefit ratio for the storage system.

c. **System Capacity (Resource Adequacy)** - The system capacity benefit is based around supporting a utility's long-term Resource Adequacy requirements. Availability of this benefit is based on regional need at specific times. Additional tools and methods may be required to incorporate energy storage into the integrated resource planning (IRP) process that defines the need and potential solutions.

d. **Federal Investment Tax Credit (FITC)** - As in the customer operated scenario, the addition of solar PV to the system provides significant economic value in the form of the FITC, which has the potential to provide a 30% tax credit to storage systems which are

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[32] Nov 13 E-mail from Xcel, summarizing Xcel distribution plan for Belle Plain substation.

combined with solar and which gain 75% of their charging energy from the PV system. With utility operated systems, it may be a challenge to capture the FITC. This is discussed in additional detail in the Barriers and Conclusions sections. Aside from the economic benefits provided by the FITC, co-locating energy storage with PV may provide tangible operational benefits to system operations; understanding these impacts and benefits of energy storage would require an expanded modeling effort. It would require using production cost models to understand bulk impacts, which incorporate fleet generation and power flow analysis, and distribution analysis tools, which measure power flow and voltage impacts from substation to customer.

9.2 Scope Limitations

8) Energy storage encompasses a wide range of technologies and resource capabilities, with differing tradeoffs in cycle life, system life, efficiency, size, and other parameters. In order to maintain a reasonable scope for modeling, a generic fast responding battery was used for modeling. Several technologies are capable of providing the specifications modeled, including lithium ion batteries, advanced lead acid batteries, and sodium nickel chloride batteries. Technologies that could not be modeled due to time and resource constraints include:
    a. Flow batteries
    b. Flywheels
    c. Traditional lead acid batteries
    d. Modular compressed air energy storage (CAES)
9) Per the project specification, only customer sited applications of energy storage were considered. Storage may also be sited in the community, at distribution or transmission substation, co-located with renewable or fossil generation, and a number of other potential sites, with different combinations of services to consider.
10) As noted in the model findings, some important energy storage benefits are highly site specific. Site specific values were derived from public sources; additional values were supplied by Xcel Energy to support the analysis. It is important to note that different sites with different upgrade costs would result in different benefit to cost ratios, which could differ significantly from those modeled.
11) For customer controlled storage, the model results apply only to the specific customer tariffs modeled. However, other currently tariffs were excluded from modeling on the basis that they did not have time-of-use (TOU) rates or were otherwise clearly unattractive for energy storage.
12) The energy storage costs used were based upon public cost effectiveness modeling assumptions conducted by the California Public Utilities Commission in early 2013. Benefit to cost ratios will vary depending upon storage resource costs. These costs will be subject to market prices at the time of procurement and may decrease over time with increased manufacturing volume.
13) The modeling was based around a project start date assumption of 2015.
14) Thermal energy storage was not modeled. A discussion of thermal energy storage follows the conclusions section.
15) The study did not model the magnitude or value associated with the cost of creating or mitigating GHGs.
16) The study was not able to take into account other societal benefits that might result from energy storage procurement, such as job creation, improved grid operations, etc.

17) The study did not address a high-reliability Uninterruptible Power Supply (UPS) case. Such a case – where a UPS system provides grid benefits – could be worth future consideration.
18) The study did not include the potential impact to the entire system of a customer sited storage deployment. This could be represented by a production cost savings. Benefit to the customer other than what was represented by their rate structure and the market benefits were not considered.
19) The value of reliability varies widely by energy storage customer and is difficult to quantify. Additionally, the duration of backup power that an energy storage resource could provide to the end customer varies by the state of charge of the resource. Because of this, the value of backup reliability to end customers was not included in the study.

9.2.1 Electric Vehicles

As the electric vehicle (EV) market grows, utilities are beginning to consider the impacts of these vehicles on the grid.

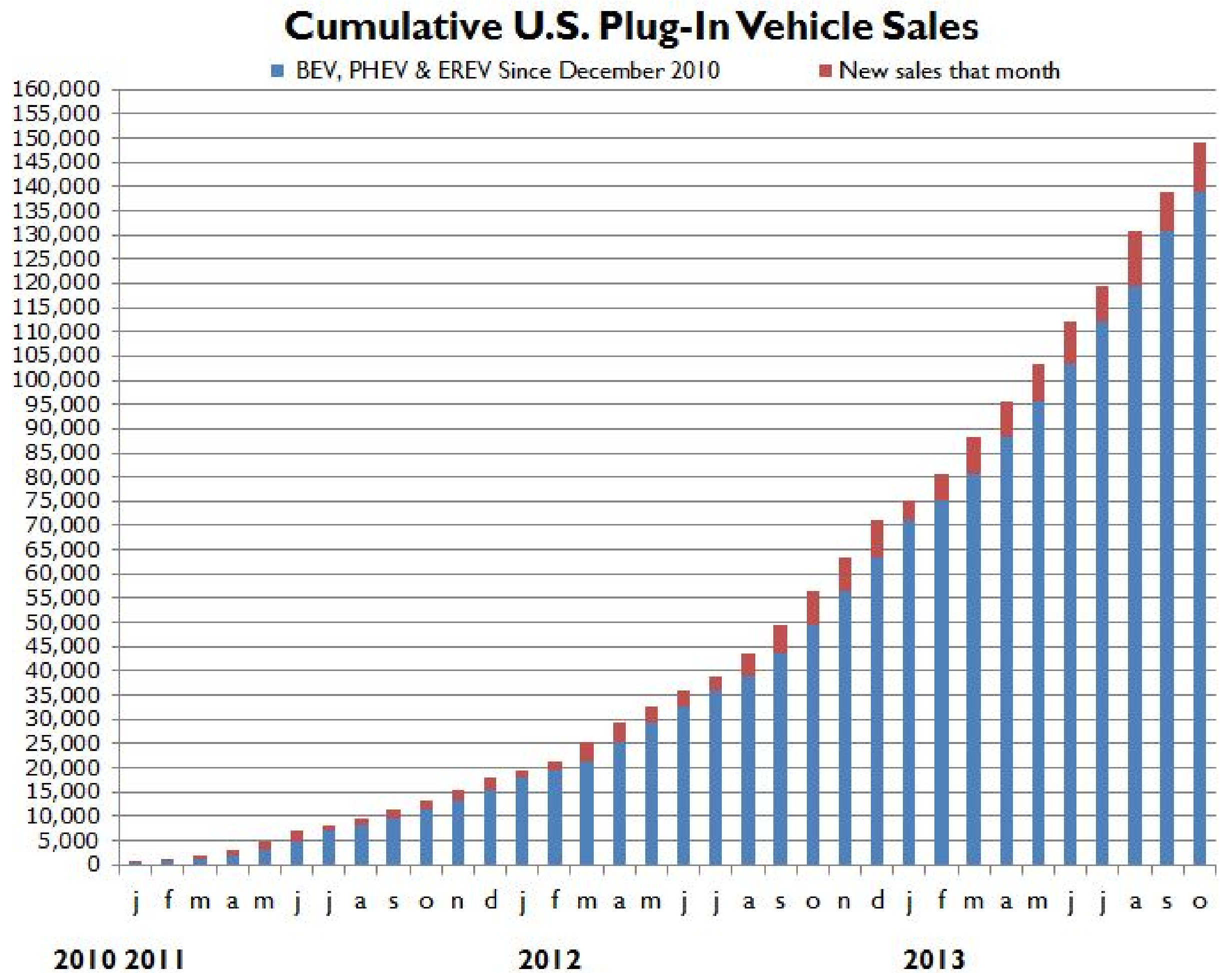

Figure 20: Cumulative U.S. Plug-in Vehicle Sales[33]

EVs, which represent both a significant source of new load and potentially a significant source of new supply, can provide a variety of grid services, the market value of which is just beginning to be defined. According to the 2013 Minnesota Microgrid Report, EV smart charging could enable participation in demand response markets, with early adopters likely being large campus microgrids.[16] Evaluation of electric vehicles is excluded from the scope of this analysis, but is worthwhile to consider for future studies, in particular for EV charging impacts to net system load and peak demand.

9.3 Key Barriers

There are three overarching areas where barriers for energy storage adoption are manifested: Planning, Deployment & Interconnection, and Monetization.

1) Grid Planning

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[33] Sales figures sourced from HybridCars.com with additional input from Electric Drive Transportation Association

a. Utilities need a way to start looking for opportunities for energy storage integration, as distribution utilities have not yet incorporated storage into their planning processes. Tools and methods need to be developed to enable them to do so.
b. For T&D upgrade deferral: In order to identify sites where deferral would have a high value, it is critical to have monitoring of distribution upgrades. Existing utility practices may involve waiting until the system has a failure before upgrading the distribution assets. In these cases, additional storage may be required to defer the substation upgrade on an already overloaded transformer.
c. Utilities may be able to ratepayer benefit by owning and operate customer sited energy storage systems. There is precedent for this with energy storage in the Southern California Public Power Authority project that deployed thermal storage air conditioning units on commercial rooftops. On the solar side, Southern California Edison created a deal with commercial building owner ProLogis to own and operate solar on commercial rooftops.
d. Access to capital: Building an energy storage track record of performance is critical to increasing confidence in the technology, to enable more widespread financing of energy storage, which spurs development and lowers the cost of capital. Due to unique factors including climate, market needs, and grid topology, it is important to gain this experience to be gained regionally.

2) Deployment & Interconnection
   a. Utilities and regulators could work with storage stakeholders to use existing system standards and define product eligibility requirements for both deployment and interconnection.
   b. For customer-operated resources:
      i. It is important for customers to know whether they have the ability to interconnect their installed storage assets. This applies at multiple levels, including general grid interconnection and interconnection into specific markets (i.e. wholesale energy markets). System operators should clarify and improve the ability of customer-owned resources to interconnect at multiple levels.
         1. System operators should expand and clarify eligibility for retail interconnection with local distribution utilities. In this case, certain aspects of liability may need to be addressed between storage system owners and their respective utility.
         2. Regulations and interconnection procedures should also be clarified regarding wholesale interconnection with MISO markets. Specifically, the regulations should address whether customers have to pay retail or wholesale electricity prices when performing frequency regulation and other market services. Additionally, telemetry requirements for energy storage should be well defined.
   c. For utility-owned resources:

        i. Utilities will need to manage liability associated with utility-owned storage systems sited on customer locations.

3) Monetization of energy storage benefits: Through interconnection and market participation, storage system owners and operators may not be able to monetize all of the benefit streams that their storage systems provide. This can include greater system benefits (i.e. distribution upgrade deferral) as well as market services.
    a. For customers, the monetizable benefits streams and potential solutions include:
        i. Demand response: demand response charges should be clarified and appropriately applied to customer-owned and customer-operated energy storage systems. Well-outlined demand response charges will give customers price signals needed to provide appropriate demand response services.
        ii. System capacity value and peak load reduction: storage resources that feed energy to the grid should be able to monetize the capacity that they provide. This is most easily done through sufficient price signals for providing energy, such as TOU rate structures. These systems can also provide resource adequacy and flexible capacity benefits. Utilities and other system operators should establish methods to evaluate the RA and flexible capacity values of storage resources and compensate them accordingly.
        iii. Distribution support/deferral: customer sited resources that provide distribution support and/or distribution upgrade deferral should be able to monetize the benefit of that service. Utilities can appropriately value the distribution services provided and compensate customers accordingly (i.e. through a direct payment or a reduction in interconnection costs).
    b. For utility-owned resources, monetizable benefit streams and potential solutions include:
        i. Local and system capacity value: Most energy storage systems can provide several unique advantages when it comes to resource adequacy and flexible capacity benefits. These benefits include the ability to ramp much more quickly than traditional resources, the ability to regulate across the entire charge and discharge range of the resource, the ability to add controllable load to the grid in times of local renewable over-generation, and the ability to be distributed into areas where local capacity is most needed. The valuation and counting methods for RA and capacity do not currently account for these benefits, and may require additional development in order to appropriately account for the capacity value that energy storage can provide to the grid.
        ii. Distribution support/deferral: This compensation can be similar to that identified in (a.iii.) above for customer-owned resources.
        iii. Ancillary services: A method should be developed to allow access to MISO markets for a reliability asset or aggregated assets that provide ancillary services, and fairly compensate the asset's contribution without double-dipping benefits.

iv. Federal ITC for Solar: currently energy storage resources may receive a Federal Investment Tax Credit (ITC) for Solar if they are directly coupled with solar and at least 75% of the energy used to charge the energy storage device comes from the solar resource. However, it is difficult for utilities to get this credit because there is a lack of clear IRS guidance regarding ITC applicability to energy storage (to date, all energy storage resources coupled with renewable energy systems have obtained the ITC for Solar via a private letter ruling). There should be increased clarity regarding ITC eligibility for energy storage paired with renewable generation, including necessary steps for applying for and receiving the Federal ITC for Solar.

v. Ability to access accelerated (5 year instead of 7 year) MACRS depreciation benefits due to storage coupled with solar.

9.4 Key Recommendations

1) Establish goals with respect to energy storage that will build understanding and a track record of performance through the following means:
    a. Multi-stakeholder policy development. This has been successfully accomplished in California through AB 2514 and the subsequent Energy Storage Rulemaking, which drove a multi-stakeholder process that developed a framework for energy storage use cases, cost effectiveness and procurement through 2020.
    b. Storage specific rulemaking. Importantly, progress on energy storage will be fastest if the relevant regulatory bodies 'focus' on energy storage via a specific ongoing rulemaking or other stakeholder process. Many existing regulatory processes can include storage (eg. Demand response, distributed generation, renewable energy etc.), but because storage is not their primary focus per se, limited progress will be made. Further, it is important to have a regulatory 'home' for energy storage to ensure and coordinate progress in all other relevant concurrent proceedings. In California, for example, that has been the successful role and purpose of the Energy Storage Rulemaking at the CPUC.
    c. Commercial demonstration and deployment of energy storage for both utility owned and customer owned systems. Such demonstration projects will provide the necessary experience and begin to familiarize utility interconnection engineers and planners with energy storage. This has been successfully accomplished in California, for example, through the Self Generation Incentive Program (SGIP), the Permanent Load Shifting Program (PLS), and various public interest energy research and utility RD&D funded programs.
2) Establish clear interconnection policies including very low or no interconnection fees for energy storage for the following customer sited behind the meter energy storage use cases
    a. Standalone energy storage

b. Coupled with net energy metered eligible generator, such as solar and used for demand charge reduction – in such cases, the same NEM interconnection privileges should apply to the energy storage device as an integral component of the combined system so long as the energy storage system does not backfeed non-renewable energy into the grid.
c. Either (a) or (b), above, plus the ability to participate in MISO markets. In this use case, energy storage systems should be allowed the opportunity to charge at wholesale rates for energy services delivered into MISO markets.
d. It is important to note that there is a class of 'non export' energy storage systems that are solely used for load modification or emergency backup. Such energy storage systems should either not require interconnection (as they function more closely to an appliance) or they should be significantly fast tracked for interconnection approval.

3) Since high value energy storage opportunities are very time and location-specific, integrate consideration of energy storage into integrated resource planning (IRP) and distribution planning processes to facilitate consideration of energy storage and reduce risk of rate recovery for load serving entities.
    a. Define the requirements and accounting rules for duration-limited energy resources to be counted toward system resource adequacy and avoided T&D costs. Consider establishing requirements and accounting rules for flexible capacity in addition to standard capacity, a resource that will likely become increasingly more important with increased penetration of variable energy resources such as wind and solar and electric vehicle charging.
    b. Prerequisites to successful integration of energy storage into IRP and distribution planning processes include:
        i. Create/endorse commercial planning models that are capable of accurately modeling storage in the planning / operational contexts;
        ii. Create/endorse easy-to-use tools and processes for utility planning engineers to easily identify possible opportunities.
        iii. Create an acceptable cost effectiveness methodology and approach that can be consistently used across all load serving entities. Monitor progress to this effect in the California PUC processes, where the first major deployment of grid-based storage at all interconnection points is expected to occur in 2014-2015.
4) Invest in market transformation education and training. The electric power system has been operated and planned consistently for the last hundred years or so. Incorporating a new flexible asset class such as energy storage will require significant education among a broad stakeholder set. This education can focus on commercially available technologies, use cases, or cost-effectiveness, for example. Targeted stakeholders could include:
    a. Key policy makers/legislators
    b. Key regulatory agencies: energy, water, air quality, environment
    c. Utilities, utility planners, engineers, interconnection engineers
    d. Local permitting authorities
    e. Ratepayer advocates

f. Environmental advocates
g. Adjacent industry stakeholders such as vehicles, renewable energy, energy efficiency, demand response
h. Energy Storage industry stakeholders

5) Discuss how utilities might be able to take advantage of tax advantages of any available tax credits or accelerated depreciation schedules (MACRS).
6) Address barriers related to MISO market participation for customer-sited storage facilities.

10 Appendix

10.1 Link to Modeling Input & Output Files

10.1.1 Input Templates

[*Please see separate XLS workbook*]

10.1.2 Output Templates

[*Please see separate XLS workbook*]

10.2 Complete Barriers Tables

10.2.1 Use Case 1: Customer-Sited, Customer Controlled Energy Storage

	What is the barrier?	How is it a barrier?	What are the potential resolutions?
(a) system need			
(b) cohesive regulatory framework			
(c) evolving markets			
(d) RA value			
(e) cost-effectiveness analysis	The current methods of cost-effectiveness evaluation do not consider all of the benefits that energy storage provides. For example, option value is a benefit not typically considered in current models, where resources that are quickly deployable can provide viable alternatives to long lead-time assets. Such resources could have a value for optionality, where there is reduced risk by deploying a resource closer to the time that it is need. Additionally, expectations that storage costs will drop rapidly results in waiting for a future technology instead of committing to an accurate and comprehensive cost-	The relative value of energy storage compared to other resources may not be fully captured in valuation methods. This also results in the incorrect communication of the value of storage technologies to potential customer-owners, which will lead them to install sub-optimal amounts of energy storage.	Using industry tools and methodologies, future studies could be done for a variety of use cases that identify the benefits of energy storage and explain how they could be captured in a cost-effective manner. Any use cases that demonstrate cost-effectiveness under existing conditions and pricing systems could be highlighted.

	effectiveness analysis of existing systems.		
(f) cost recovery policies	Currently there are no incentive programs (state or federal) targeted specifically to energy storage technologies. Tax credits and other incentives impacting conventional behind-the-meter renewables (e.g. rooftop solar) do not apply to energy storage unless it is directly paired with renewables, and energy storage has no equivalent financial incentives.	Utility customers, whose procurement and installation of energy storage could greatly benefit grid operations, often do not have the financial wherewithal to install energy storage without grants or other financial assistance. Even with the financial wherewithal for initial capital funding (either through capital reserves or financing), customers will not receive a return on investment without appropriate cost recovery mechanisms.	State and federal policies could be developed specifically for energy storage technologies without the need for pairing with generation from renewable resources. These policies could offer similar tax and financing benefits to those currently offered to renewable energy technologies.
	Many of the system benefits provided by energy storage can be realized by utilities and ratepayers, and customer-owned energy storage resources are not financially compensated for those grid benefits (i.e. through time-of-use electricity rates or compensation for distribution upgrade deferral benefits).	A lack of incentive programs and appropriate cost-benefit recovery policies eliminates participation from a large number of potential customer-owners.	Policies could be created or market redesign could occur to fairly value the benefits that energy storage provides to utilities and compensate energy storage owners/operators for those benefits.
	Time of use rate structures are not widely deployed, which eliminates time-shifting financial incentives of energy storage. Smart meters, which are necessary for measuring time-specific energy use,	The absence of time-of-use rate structures and smart grid monitoring eliminates the primary revenue stream of energy storage (purchasing energy at low prices and offsetting purchases or selling	Smart meters could be deployed and time-of-use electricity rates could be instituted, possibly with customers able to feed energy into the grid at time-of-use rates.

	are not widely deployed.	energy at higher prices).	
(g) cost transparency & price signals	For some utility customers, demand or time-of-use (TOU) charges may be insufficient (or non-existent) to incentivize the use of energy storage technologies.	Low or non-existent demand and TOU charges decrease cost-effectiveness by increasing the payback time for energy storage systems. In other words, this negatively impacts how long it will take for the up-front capital cost of the system to be offset by the energy and demand savings provided to the customer by the energy storage system.	Demand and TOU charges could be adjusted to more accurately reflect the cost/value to the system of energy storage resources.
(h) commercial operating experience	Customers and utilities in Minnesota do not have significant experience with energy storage. Additionally, some newer technologies cannot offer the same warranty and performance guarantees as incumbent technologies.	The lack of operating experience in Minnesota limits utility willingness to integrate energy storage.	Additional sources of funding could be developed to create pilot projects that help new technologies build a record of operating experience. Pilot and demonstration projects could also help to prove the cost-effectiveness of different uses and technologies. Successful energy storage operation case studies could be identified, to share lessons learned and promote utility adoption. .
(i) interconnection processes	The interconnection rules for behind-the-meter systems can be complex and expensive. There are potentially	The conflicting and complex interconnection processes can create uncertainty and confusion for potential	Interconnection rules and requirements for aggregated systems could be revised, and an interconnection fast track

	conflicts or excessive restrictions regarding resources paired with renewables, especially those that use multiple meters.	energy storage owners. Some interconnection requirements may eliminate the possibility of cost-effective integration of energy storage. This ultimately discourages market participation and use of energy storage technologies.	could be created for certain types of storage systems, particularly systems that are paired with renewables.
	Laws in Minnesota state that anyone with a solar panel can connect to the grid if the panels are less than 40 kW. The same rules do not apply to energy storage.	Insufficient flexibility (for example, as compared to residential solar panels) inherently makes interconnection more complicated or potentially impossible.	Similar rules as those for solar systems could be applied to energy storage systems under 40 kW, to allow for easy interconnection of residential energy storage.

10.2.2 Use Case 2: Utility-Controlled, Distribution-Only Use Cases

	What is the barrier?	How is it a barrier?	What are the potential resolutions?
(a) system need	Utilization of individual and aggregated energy storage is not viewed as a viable opportunity for providing ancillary services and meeting other system needs, i.e. those presented by gradually increasing wind generation.	By not being considered as a resource that can meet increasing system needs, energy storage is not appropriately prioritized and integrated. For example, energy storage could effectively respond to excess wind generation that could result in negative market energy prices, yet this is not officially recognized.	Energy storage resources could be officially recognized as a resource that viably meets evolving system needs.
	A lack of data collection and forecasting of distribution upgrade deferral leads to urgent upgrade needs. This	Energy storage resources can be used effectively for distribution upgrade deferral, but require planning and certain lead-	Distribution circuit data could be regularly collected and monitored to anticipate locations where energy storage can

	favors quickly-installed resources over those requiring planning and longer lead-times.	times to be installed for that purpose. Without forecasting, critical system constraints and overloads create urgent distribution upgrade needs, which makes energy storage an unfavorable solution.	be of value for solving distribution system needs. Effective monitoring can provide this information before the need for distribution upgrades becomes critical with overloads already occurring.
(b) cohesive regulatory framework			
(c) evolving markets			
(d) RA value	There is a lack of clarity around how energy storage is valued toward utility resource adequacy (system capacity) requirements. It is possible that energy storage will simply not count towards RA requirements, as policies have not been developed to accommodate it.	Utilities will not be able to leverage RA benefits through the installation of energy storage. This takes away a potential incentive for procuring energy storage, and an avoided cost of new fossil generation.	Clarify policies around energy storage eligibility for meeting RA criteria. If no policies exist, create policies outlining RA value of energy storage, demand response, and other limited energy resources..
(e) cost-effectiveness analysis	A comprehensive and consistent cost-benefit analysis framework, that takes into account all of the services provided by energy storage resources, has not yet been adopted in Minnesota. Some of the benefits provided by energy storage are difficult to monetize. Rate structures required for some benefits are still not developed. This makes creating an accurate	Utilities that are interested to procure energy storage are unclear about the lifecycle costs and benefits of those resources, and are thus wary of procuring energy storage. This is especially true if existing cost-effectiveness analysis doesn't take into account the full range of benefits provided by energy storage.	Work could be done with grid modeling experts to lay out possible uses of energy storage resources, as well as the full range of costs and benefits of storage. These results could be applied to Minnesota's electric grid, with utilities allowed to utilize conclusions for justification for storage resource procurement.

	analysis more difficult.		
(f) cost recovery policies	Cost recovery and cost allocation mechanisms for energy storage devices are still undefined. There is a lack of clarity around potential monetized benefits provided by energy storage resources (i.e. value of achieved distribution upgrade deferral)	Absent clear rate policy toward cost recovery, IOUs are hesitant to make investments in energy storage. Lack of recognition as a resource class that provides monetized benefits hinders energy storage from receiving financial benefits. This also creates a precedent that may be difficult to overcome in other policies.	Cost recovery policies that apply to energy storage at this level could be identified. Rate structures that appropriately compensate the spectrum of services provided by energy storage resources could be established. Other grid benefits, i.e. distribution upgrade deferral, could be modeled and quantified, with that quantified value attributed to the storage resource.
(g) cost transparency & price signals	Full costs of energy storage resources, integration, and operation are unclear or unknown. Costs going forward, as technology evolves, are unknown. The full spectrum of benefits & services provided by energy storage have not been monetized.	Unknown resource and integration costs make utilities hesitant. First, utilities are wary of high costs. Second, they are not made aware of potentially advantageous costs. Third, uncertainty makes grid planning difficult. Because of this, utilities may be more likely to stick with status quo solutions, which have more certainty.	Cost-benefit characteristics of energy storage could be fully identified and monetized, possibly through working with modeling experts. Ongoing & future market changes could be identified.
(h) commercial operating experience	There is limited operating experience by utilities in Minnesota. Few devices have been deployed in pilot application outside labs. Track record of deployed devices in the field is very limited. In addition, other applications have been in	Utilities are hesitant to begin using a technology class that they have little experience with. A lack of experience by other utilities means that utilities cannot reach out and learn easily. It is often perceived as safer to stick with the status	In-state pilot projects could be developed to increase utility experience. Energy storage deployment could be gradually increased. Minnesota utilities could connect with others with more

	operation for many decades, but it is unknown at this point how much of the existing experience can be transferable to operating new devices.	quo or less complex alternatives.	experience.
(i) interconnection processes	Interconnection rules for energy storage at the transmission or distribution levels are either unclear or not yet established. Hardware and operational standards are not clear. Overlapping jurisdictions between MISO and utilities requires coordination that must be well-managed (i.e transmission interconnection requests are handled by Xcel, while energy flows through MISO jurisdiction). Overlapping jurisdictions can be difficult to navigate.	Lack of clarity around interconnection requirements delays resource integration and can increase start-up costs. Concerns about integration difficulties, costs, and timelines dissuade utilities from procuring energy storage. Projects may be deemed ineligible because of non-accommodating interconnection processes.	Existing interconnection processes impacting energy storage, including requirements, jurisdictions, and coordination between agencies and utilities, could be identified. Interconnection processes could be appropriately shaped to accommodate energy storage.

10.2.3 Use Case 3: Utility-Controlled (Distribution + Market)

	What is the barrier?	How is it a barrier?	What are the potential resolutions?
(a) system need	**See 2a**		
(b) cohesive regulatory framework	Coordinated rules and proceedings have not been established to comprehensively shape grid development. This especially impacts larger-	The market does not have sufficient direction for identifying best energy storage uses and adding resources accordingly. Resources providing	Procurement and regulatory proceedings could be coordinated in a way that fully accounts for flexible resources such as

	scale and centrally operated resources.	multiple services) may be used sub-optimally, with related negative impacts on cost effectiveness and resource adoption.	energy storage. Methodologies to incorporate energy storage resources into applicable proceedings could be developed, including through accurate valuation of energy storage resources.
(c) evolving markets	Energy and ancillary service markets are evolving due to load shape changes and a changing generation mix. Due to increasing variable and uncertain wind power deployment, needs for flexible operating reserves such as frequency regulation and spinning reserve are increasing. Pricing schemes for such reserves are changing to meet grid needs.	Regulators are still learning how to best identify grid needs and procure related services. This "learning by doing" may take some time before a vibrant market evolves for energy storage.	Existing and upcoming grid needs could be identified, with grid products designed accordingly to meet grid needs. Connect technology providers to grid operators to better understand the capabilities of energy storage to meet their needs in practices, and to work towards beneficial resource development and integration.
(d) RA value		**See 2d**	
(e) cost-effectiveness analysis		**See 2e**	
(f) cost recovery policies		**See 2f**	
(g) cost transparency & price signals	Full costs of energy storage resources, integration, and operation are unclear or unknown. Costs going forward, as technology evolves, are unknown. The full spectrum of benefits & services provided by energy storage have not	Unknown resource and integration costs make utilities hesitant. First, utilities are wary of high costs. Second, they are not made aware of potentially advantageous costs. Third, uncertainty makes grid planning difficult. Because of this,	Cost-benefit characteristics of energy storage could be fully identified and monetized, possibly through working with modeling experts. Ongoing & future market changes could

	been monetized. Many of these unclear price signals are in wholesale energy markets, which are operated by MISO.	utilities may be more likely to stick with status quo solutions, which have more certainty.	be identified.
(h) commercial operating experience	**See 2h**		
(i) interconnection processes	**See 2i**		

10.2.4 Use Case 4: Shared Control (Customer Bill Savings + Aggregated Market Services)

	What is the barrier?	**How is it a barrier?**	**What are the potential resolutions?**
(a) system need	Utilization of aggregated customer-operated energy storage is not viewed as a viable opportunity for providing ancillary services and meeting other system needs, i.e. those presented by gradually increasing wind generation.	By not being considered as a resource that can meet increasing system needs, energy storage is not appropriately prioritized and integrated. For example, customer aggregated energy storage could effectively respond to excess wind generation that could result in negative market energy prices, yet this is not officially recognized.	Energy storage resources could be officially recognized as a resource that viably meets evolving system needs.
(b) cohesive regulatory framework			
(c) evolving markets	The future ancillary services products are not yet defined. Behind the meter and demand-side A/S participation has	It is difficult to build a business case on undeveloped market products and specify system requirements to meet these undefined	Regulation energy management for sub 1-hour resources, updated market models to allow selling ancillary services during charging (i.e. creating

	also not been clearly defined.	rules.	regulation up & regulation down markets, either instead of or in addition to existing regulation markets), and flexible ramping products could be implemented. These could all be implemented for customer-operated, behind-the-meter resources.
(d) RA value			
(e) cost-effectiveness analysis	**See 1e**		
(f) cost recovery policies	**See 1f**		
	Minnesota Statute sec. 216B states that an entity must directly serve at least 25 customers to be considered a utility. This also disqualifies entities that feed services into the larger grid from being considered as a utility.	Because energy storage resource operators are not considered utilities, they are not eligible for many of the benefits and cost recovery methods afforded to utilities (i.e realizing the full benefits afforded to the grid by resources, and the ability to rate base such resources for cost recovery). This impacts the financial viability of many energy storage projects.	Energy storage resources and operators could be incorporated into policies and statutes in a manner that recognizes the services they provide and gives them some sort of identity (utility, generator, etc.) with according accommodations and benefits.
(g) cost transparency & price signals	**See 1g**		
(h) commercial operating experience	**See 1h**		
(i) interconnection processes	**See 1i**		

10.3 Explanation of System Capacity and Derivation of Cost of New Entry (CONE) Value

Below are excerpts from the EPRI report to the California PUC:

Cost-Effectiveness of Energy Storage in California: Application of the Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007. EPRI, Palo Alto, CA: 2013. 3002001162.

"What Is System Capacity Value?

Across the United States, it is common for new combustion turbines to be insufficiently profitable in providing energy ancillary services to recover their capital costs at a sufficient rate of return. However, it is often required for resource adequacy reasons for new capacity resources to be built. This difference between net present value of cost and benefit is often referred to as "missing money."

In California, requirement for additional capacity is identified several years in advance through the Long Term Procurement Proceedings (LTPP) at the CPUC. These proceedings direct investor owned utilities to procure additional capacity resources in a specific timeframe, to support increasing load or generator retirements. As a result of this directive and the insufficient inherent profitability for the generators, utilities may need to provide new generators with a yearly capacity payment to make up for "missing money." To approximate the resulting capacity value required to cause a newly built generator to break even and meet required rate of return, a metric often referred to as Cost of New Entry (CONE) is generated.

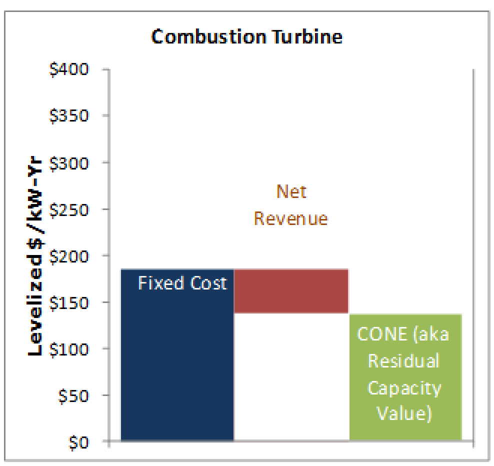

Figure B 1

Illustration of Cost of New Entry (CONE)

Other resources that can provide system capacity include renewable generation, demand response, etc. Energy storage can also provide system capacity but is not currently compensated for because of lack of market mechanism.

Resource Balance Year: Short-Term and Long-Term Capacity Value

It should be noted that currently California has available generation capacity exceeding demand. As a result, there is no system-wide requirement to build new generation for additional capacity (with the exception of some transmission constrained load pockets). The year when California is roughly expected to require additional generation is 2020, an assumption provided by the CPUC technical staff and core stakeholder group. In the years preceding 2020, it is expected that capacity values would be lower. Therefore, for ESVT runs that begin in 2015, a starting capacity value was estimated by fitting an exponential curve from current year capacity value to the resource balance year.

CONE Calculation

CONE is derived in the Energy Storage Valuation Tool by simulating the operation of a combustion turbine (defined by the CPUC technical staff as LM6000 w/ SPRINT). See Table B 1. The ESVT calculates the annual capacity payment required for the combustion turbine to earn its required return on investment.

Table B 1

LM6000 SPRINT Inputs

CT Input	
System Name	LM6000/SPRINT
Plant life	20
Optimal Efficiency (Heat Rate)	9387
Overnight CapEX	$1619/kW
Variable O&M	$4.1685
Fixed O&M	$17.40
Minimum Operating Level	40.0%
Temperature Derate	105%

Because the CONE value is dependent on generator performance and cost characteristics, as well as the prevailing CAISO market prices, it is necessary to generate a unique CONE for any change in these assumptions. Due to transmission and distribution losses between generation and load, capacity value may be greater for energy storage or distributed generation located at the distribution substation or at the customer. It was roughly estimated in this analysis that due to avoided transmission losses, the substation-sited storage earned an enhanced capacity value by five percent (5%).

The seven (7) CONE scenarios observed, the ESVT runs utilizing them, and the resulting CONE value are summarized in Table B 2.

Table B 2

CONE Value Summary Table by Analysis Run

CONE #	CONE	Run	Notes
1	161	run1	Use Case 1: Base Case
7	165	run1 2010	Use Case 1 Sensitivity: 2010 Ref Year
7	165	run1 2010P4P	Use Case 1 Sensitivity: 2010 Ref Year with P4P regulation prices
2	152	run1 LMS100	Use Case 1:CONE derived with LMS100
6	50	run1 lowCONE	Use Case 1 Sensitivity: low CONE
1	161	run1a	Use Case 1 Sensitivity: 2 Replacements
1	161	run1b	Use Case 1 Sensitivity: No regulation services
1	161	run1c	Use Case 1: higher CapEX assumption
1	161	run1d	Use Case 1: higher variable O&M assumption
1	161	run1e	Use Case 1 Sensitivity: 3 Replacements
1	161	run2	Use Case 1 Sensitivity: 2X Regulation Price
1	161	run3	Use Case 1 Sensitivity: 3 Hour Duration
1	161	run4	Use Case 1 Sensitivity: 4 Hour Duration
3	174.7	run10	Use Case 1 Sensitivity: Market Scenario 1
4	167.7	run11	Use Case 1 Sensitivity: Market Scenario 2
3	174.7	run12	Use Case 1 Sensitivity: Market Scenario 3
4	167.7	run13	Use Case 1 Sensitivity: Market Scenario 4
1	161	run16	Use Case 1 Sensitivity: Flow Battery
1	161	run16a	Use Case 1 Sensitivity: Flow Battery (high variable O&M)
1	161	run17	Use Case 1 Sensitivity: Pumped Hydro
1	161	run18	Use Case 1 Sensitivity: CAES
N/A	N/A	run19	Use Case 2: Ancillary Service Only
1	161	run20	Use Case 1 Sensitivity: Project Start Year 2015
1	161	run21	Use Case 1 Sensitivity: Project Start Year 2015 with P4P regulation prices
5	169.05	run22	Use Case 3: Base Case
5	169.05	run22no reg	Use Case 3 Sensitivity: No regulation
5	169.05	run22b	Use Case 3 Sensitivity: 2 Hour Duration
5	169.05	run23	Use Case 3 Sensitivity: 2X P4P regulation prices
5	169.05	run24	Use Case 3 Sensitivity: High Load Growth Rate
5	169.05	run26	Use Case 3 Sensitivity: Flow Battery
5	169.05	run35	Use Case 3 Sensitivity: Project Start Year 2020

Alternative Methods of Determining CONE Value

The calculation of CONE value is under the assumption that a "new entry" would be necessary in the resource balance year. In another situation, when growth in renewable generation offsets load growth, it may be possible to use mothballed generators to serve as reserve capacity for occasional usage during peak times. In this case, rather than basing capacity value on recovering fixed investment in new generator, it may be based more on a much lower fixed O&M value of keeping those generators on. Alternatively, in the situation where there are enough demand response to provide capacity value in 2020, this will significantly lower demand for generators to provide capacity, thus reducing CONE. To capture part of the uncertainties about CONE value, a case with a "low CONE" escalated from the 2011 system capacity value was done as sensitivity.

Validation of ESVT-Derived CONE

Previously, in the draft results of the analysis provided at the March 25, 2013, public workshop at the CPUC, results were based upon an externally derived CONE value from the "E3 DER Avoided Cost Calculator." At the time, the ESVT was not able to generate CONE for a CT with sufficient fidelity. The disadvantage of using the externally derived CONE was inflexibility to generate new CONE values based on different market scenarios and turbine technologies. The CONE value used in the draft results was $155/kW-yr, compared with $161/kW-yr for the ESVT-derived CONE value for the base case. The difference between the two is only 3-4%, well within the margin of error expected for this type of analysis. The investigators found it important to capture the impact of market scenario changes on the CONE value and maintain the key relationship between generator capital costs, market benefits, and CONE.

Capacity Derate

At this stage, the capacity value for a conventional generator has been determined for every run in the analysis. However, when the capacity value for energy storage is being estimated, the limited duration of the resource should be accounted for, when attempting to compare storage side-by-side in its ability to provide capacity service equivalent to a CT. The ESVT model estimates this impact through a derating of the CT capacity value (based on CONE). This derating is accomplished by multiplying the capacity value by [(# of capacity hours available) / (# of total capacity hours)]. This method is not accepted by PUC's to estimate capacity value for limited energy resources, but it serves to estimate impact and capture a relationship between storage duration and capacity value. Capacity value of limited duration resources may be an important area of research looking forward."

10.4 Glossary of Terms

AB 2514: California Assembly Bill 2514 requires the CPUC to determine by October 1, 2013 energy storage procurement targets for 2015 and 2020 for investor owned utilities. Additionally, the bill requires the governing boards of publicly owned utilities to determine by October 1, 2014 energy storage procurement targets for 2016 and 2021.

Ancillary Services (AS): Regulation, Spinning Reserve, Non-Spinning Reserve, Voltage Support and Black Start together with such other interconnected operation services as the MISO may develop in cooperation with market participants to support the transmission of energy from generation resources to loads while maintaining reliable operation of the MISO controlled grid in accordance with Midwest Reliability Organization (MRO) standards and good utility practice.

Automatic Generation Control (AGC): Generation equipment that automatically responds to signals from the ISO's EMS control in real time to control the power output of electric generators within a prescribed area in response to a change in system frequency, tie-line loading, or the relation of these to each other, so as to maintain the target system frequency and/or the established interchange with other areas within the predetermined limits.

Balancing Authority (BA): The responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports Interconnection frequency in real time. (NERC)

Balancing Authority Area (BAA): The area governed by the local balancing authority.

Base Load: The minimum amount of electric power delivered or required over a given period at a constant rate. (NERC)

Black Start: The procedure by which a generating unit self-starts without an external source of electricity thereby restoring a source of power to the balancing authority area following system or local area blackouts.

California Independent System Operator (CAISO): CAISO is the Independent System Operator for the state of California. Its jurisdiction is limited to California. (See "Independent System Operator")

California Public Utilities Commission (CPUC): The CPUC is the regulatory body responsible for regulating privately owned electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies in California. Five commissioners each serve staggered six-year terms as the governing body of the agency. Commissioners are appointed by the governor and must be confirmed by the California State Senate.

California Energy Storage Alliance (CESA): The California Energy Storage Alliance, "CESA", is a broad coalition committed to expanding the role of energy storage to promote the growth of renewable energy and a more affordable, clean, and reliable electric power system. CESA's members are a diverse mix of energy storage technology manufacturers, renewable energy component manufacturers, developers and systems integrators. CESA was founded in 2008 by Janice Lin, Managing Partner, Strategen Consulting LLC, and Don Liddell, Principal of Douglass & Liddell.

Day Ahead Market: Also known as the Integrated Forward Market, the Day Ahead Market co-optimizes energy and ancillary services (AS) to assure a feasible, secure, and least cost operating plan for the next day.

Demand: The rate at which electric energy is delivered to or by a system or part of a system, generally expressed in kilowatts or megawatts, at a given instant or averaged over any designated interval of time; or, the rate at which energy is being used by the customer. (NERC)

Demand-Side Management: The term for all activities or programs undertaken by Load-Serving Entity or its customers (NERC)

Federal Energy Regulatory Commission (FERC):[34] The Federal agency with jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, oil pipeline rates, and gas pipeline certification. FERC is an independent regulatory agency within the Department of Energy and is the successor to the Federal Power Commission.

Federal Investment Tax Credit (FITC): A 30% tax credit on the capital cost of solar generation. Energy storage resources that receive 75% of their charging or greater from paired solar resources are eligible for the FITC.

Frequency Regulation: The ability of a Balancing Authority to help the Interconnection maintain Scheduled Frequency. This assistance can include both turbine governor response and Automatic Generation Control. (NERC)

Independent System Operator (ISO):[35] An independent, federally regulated entity established to coordinate regional transmission in a non-discriminatory manner and ensure the safety and reliability of the electric system.

Interchange Authority: The responsible entity that authorizes implementation of valid and balanced Interchange Schedules between Balancing Authority Areas, and ensures communication of Interchange information for reliability assessment purposes. (NERC)

Interconnection: When capitalized, any one of the three major electric system networks in North America: Eastern, Western, and ERCOT. (NERC)

Investor Owned Utilities (IOUs): In Minnesota, the Investor Owned Utilities are Xcel Energy, Allete – Minnesota Power, Alliant Energy – Interstate Power, Northwestern Wisconsin Electric, and Otter Tail Power Company. These are differentiated from other utility types such as Municipal Utilities (MUNIs) and Cooperative Utilities (COOPs). IOUs are regulated by the Minnesota Public Utilities Commission.

Load: An end-use device (NERC)

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34 EIA Glossary

35 EIA Glossary

Locational Marginal Price: The marginal cost ($/MWh) of serving the next increment of Demand at that Pnode consistent with existing transmission facility Constraints and the performance characteristics of resources.

Midcontinent Independent System Operator (MISO): MISO is the Independent System Operator for several Midwestern states and for Manitoba, Canada. Its territory fully encompasses some states, and includes limited portions of others. Minnesota's electric grid falls under the jurisdiction of MISO. (See "Independent System Operator")

Non-Spinning Reserve: The portion of generating capacity that is capable of being synchronized and ramping to a specified load in ten minutes (or load that is capable of being interrupted in ten minutes) and that is capable of running (or being interrupted).

North American Electric Reliability Corporation (NERC):[36] A nonprofit corporation formed in 2006 as the successor to the North American Electric Reliability Council established to develop and maintain mandatory reliability standards for the bulk electric system, with the fundamental goal of maintaining and improving the reliability of that system. NERC consists of regional reliability entities covering the interconnected power regions of the contiguous United States, Canada, and Mexico.

Off-Peak: Those hours or other periods defined by NAESB business practices, contract, agreements, or guides as periods of lower electrical demand. (NERC)

On-Peak: Those hours or other periods defined by NAESB business practices, contract, agreements, or guides as periods of higher electrical demand. (NERC)

Operating Reserve: That capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages and local area protection. It consists of spinning and non-spinning reserve. (NERC)

Peak Demand: The highest hourly integrated Net Energy For Load within a Balancing Authority Area occurring within a given period (e.g., day, month, season, or year); or, the highest instantaneous demand within the Balancing Authority Area. (NERC)

Publicly Owned Utilities (POUs): Municipal and Cooperative utilities owned by the public, in contrast with investor owned utilities (IOUs).

Reactive Power: results when the voltage and current are out of phase and is measured in volt-amperes reactive (VAR).

Regulation Down: Regulation reserve provided by a resource that can decrease its actual operating level in response to a direct electronic (AGC) signal from the MISO to maintain standard frequency in accordance with established reliability criteria.

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36 EIA Glossary

Regulation Service: The process whereby one Balancing Authority contracts to provide corrective response to all or a portion of the ACE of another Balancing Authority. The Balancing Authority providing the response assumes the obligation of meeting all applicable control criteria as specified by NERC for itself and the Balancing Authority for which it is providing the Regulation Service. (NERC)

Regulation Up: Regulation provided by a resource that can increase its actual operating level in response to a direct electronic (AGC) signal from the MISO to maintain standard frequency in accordance with established reliability criteria.

Remote Intelligent Gateway (RIG): The ISO requires direct telemetry of participating generators and load by installing a remote intelligent gateway (RIG) for generating units providing regulation energy or a data processing gateway (DPG) or other ISO-approved technology for resources providing non-regulation ancillary services or supplemental energy.

Resource Adequacy: The ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements. The Resource Adequacy program in MN is administered by the MISO.

Spinning Reserve: The portion of unloaded synchronized generating capacity that is immediately responsive to system frequency and is capable of being fully loaded in ten minutes.

Transmission: An interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric systems. (NERC)

Voltage Support: Services provided by generating units or other equipment such as shunt capacitors, static VAR compensators, or synchronous condensers that are required to maintain established grid voltage criteria. This service is required under normal or system emergency conditions.

10.4.1 Detailed Grid Service Modeling Definitions in ESVT

10.4.1.1 Distribution Investment Deferral

Definition

Distribution investment deferral is the use of storage to shave transformer peak load to delay a bulky investment on the substation for a few years. Transformer peak is defined as the highest load hour in base, or reference year load on the substation. The investment is deferred for as long as the storage is able to keep annual peak under the base year load peak or a defined threshold percent of base year load peak. It is possible to start deferring the investment a few years after the storage system is installed by making the "Load Target" a number above 100%.

Storage Dispatch

To provide this service, the storage system is discharged to bring the peak load under the load target. Load target is defined as a percentage of the base year peak load. Based on perfect foresight, the storage system charges to full capacity before the anticipated peak load. Distribution investment deferral has the higher priority over system and ancillary services because once the storage system fails to keep the load under the load target, the investment must be made. The longer the storage system can keep the load under the load target, the more money will be saved.

Benefit Calculation

The benefit value is calculated as the net present value (NPV) of the time value of money for the investment size deferral by the energy storage.

10.4.1.2 System Electric Supply Capacity

Definition

System electric supply capacity is the use of energy storage in place of a combustion turbine (CT) to provide the system with peak generation capacity during peak hours. Storage systems that can successfully fulfill the service requirements are compensated with the system capacity value, which is equal to the Cost of New Entry (CONE) in the resource balance year, which is derived with ESVT. The resource balance year is defined as the year when the integrated resource plan calls for additional generation.

Under user defined ESVT assumptions, the storage system must have a minimum duration of 4 hours to qualify for this service. Shorter duration systems have their discharge capacity reduced to meet the minimum requirement for the service. Capacity hours per month are defined as the top 20 load hours each month. Capacity value of the energy storage system is derated proportional to the number of hours when it is unavailable to meet peak load hours, due primarily to availability limitations for a limited duration energy storage resource. For example, a 4 hour storage system cannot fully meet a 6 hour peak, so ESVT would assign 2/3 of the capacity value to that storage system in the simulation.

System capacity value calculation is further described in the Appendix.

Dispatch Decision

The dispatch for system electric supply capacity has higher priority than other AS services but a lower priority than distribution investment deferral. The storage system is charged before capacity hours to ensure that it has enough energy at the beginning of capacity hour, and it discharges at full qualifying capacity during capacity hour.

Benefit Calculation

*System Electric Supply Capacity Benefit = Capacity Payment ($/kW-yr) * Storage Qualifying Capacity *Capacity Derate*

10.4.1.3 Electric Energy Time Shift

Definition

Electric Energy Time Shift is the use of storage to buy energy during low-price hours and sell during high-price hours.

Dispatch Decision

Electric Energy Time Shift has lower priority than System Electric Supply Capacity and Distribution Investment Deferral. After the storage system dispatches to fulfill the requirement for these two services, the remaining capacity is optimized between electric time shift and AS services. In a 24-hour window, the dispatch is optimized to "buy low and sell high."

Benefit Calculation

Electric Energy Time-Shift (Arbitrage) benefit = (Energy sales) – (Energy Cost) / (Roundtrip efficiency) – (Variable O&M)

1. Electricity Sales ($) = Hourly Discharge * Hourly Energy Prices. Discharge is the same every year, but the energy price escalates every year based on inflation and gas price escalation rate.
2. Energy Cost ($) = Hourly Discharge * Hourly Energy Prices. Charge is the same every year, but the energy price escalates every year based on inflation and gas price escalation rate.
3. Roundtrip Efficiency (%) = The roundtrip efficiency is defined as the total energy out divided by energy in, including losses in the power electronics, balance of plants, battery, and control equipment. Parasitic losses are assumed to be included in this metric for this analysis, but the user may separately define "housekeeping power" to decouple hourly parasitic losses from roundtrip efficiency.
4. Variable O&M = Hourly Discharge (kWh) * Variable O&M Cost.

10.4.1.4 Regulation Service

Definition

Regulation Service (or Frequency Regulation) is the use of storage to follow the Balancing Authority's (BA) Automatic Generation Control (AGC) signal to balance short-duration (seconds to minutes) imbalances to maintain the grid's fundamental system frequency (60 Hz in the U.S.).

Market Bidding and Dispatch

Regulation service has lower priority than system electric supply capacity. To provide this service, the storage system must have at least 15 minutes of capacity available. Its dispatch is on the same priority level and co-optimized with other ancillary services and electric energy time-shift to maximize market profit. The MISO analysis is done for MISO electricity markets, which has a combined regulation up and regulation down. Both storage system charging (load) and discharging (generation) may participate in Regulation in the ESVT simulation.

Also, due to intensity of calculation, this analysis did not take into account intra-hour (4 sec) dispatch in this case. Resulting hourly dispatch is calculated from regulation market bids by multiplying an intra-hour energy throughput factor for the combined regulation up and down signal.

Benefit Calculation

Storage bids its available capacity (MW) into a combined Regulation up and down market. Storage is compensated based on hourly regulation market prices for following a dispatch signal. It also earns value based on day-ahead energy prices for energy discharged and is charged for energy that it consumes. The ability to bid regulation is based on the full difference between discharge and charge capacity.

Regulation Benefit = Regulation Market Revenue + Electricity Sales Revenue – Regulation Charging Cost – Variable O&M Cost

10.4.1.5 Synchronous (Spinning) Reserve

Definition

Synchronous reserve (spinning) is generation capacity that is already operating and synchronized to the system that can increase or decrease generation within 10 minutes. Synchronous reserves are procured by the ISO on an hour by hour basis in a competitive market. Energy storage may be capable of bidding in the synchronous reserve market to supply synchronous reserves.

Market Bidding and Dispatch

Synchronous reserve is on the same hierarchy level as other market services. Its bidding and dispatch is co-optimized with other day-ahead market services, including energy and ancillary services. Synchronous reserve does not dispatch, but the storage system must contain at least one hour of energy to qualify, in case it is called, due to a system contingency event. Both the storage system's charge and discharge capacity may be bid into this service. For example, idle storage with greater than one hour of energy may bid its rated capacity, and storage charging at full rated capacity may bid two times (2x) its rated capacity, because the storage can stop charging and begin discharging. Therefore, a 1MW storage system may bid 2MW of synchronous reserve.

Benefit Calculation

*Synchronous Reserve Benefit = Synchronous Reserve Bid*Synchronous Reserve Price*

10.4.1.6 Non-Synchronous (Non-spinning) Reserve

Definition

Non-synchronous (Non-spinning) reserve is an ancillary services product that consists of off-line generation that can be ramped up to capacity and synchronized to the grid in less than 10 minutes when responding to an event.

Market Bidding and Dispatch

The storage system must reserve at least one hour of duration and the storage capacity (MW) bid when it agrees to provide this reserve. The storage system may not be discharging at full capacity or otherwise obligated to possibly discharge during hours when it is providing this reserve. However, in these cases, probability to dispatch is zero

Benefit Calculation

*Non-Synchronous Reserve Benefit = Non-Synchronous Reserve Bid*Synchronous Reserve Price*

10.4.1.7 Reliability

Definition

Reliability in this context refers to the value of energy storage as a source of islanded backup power for customers. This value is defined by cost of outage for different customer segment

Market Bidding, Dispatch, and Benefit Calculation

This service has no dispatch and is calculated an as incidental value, based on the remaining energy duration in the battery each hour, the cost of grid outage, and probability of an outage

Benefit Calculation

The storage system bids capacity into non-synchronous reserve markets and is paid based on hourly market clearing prices for its availability. The storage system attempts to maintain a full charge so that it can offer its full discharge capacity in all hours. If a system is discharged (based on a small probability of non-synchronous reserves being called), it also receives the energy price during the hour of discharge, which is represented by electricity sales in the NPV benefit table.

*Non-Synchronous Reserve Benefit = Non-Synchronous Reserve Bid *Non-Synchronous Reserve Price*

10.4.2 Information Sources

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