Energy Research and Development Division
FINAL PROJECT REPORT

SACRAMENTO MUNICIPAL UTILITY DISTRICT –

PHOTOVOLTAIC AND SMART GRID PILOT AT ANATOLIA

Prepared for: California Energy Commission
Prepared by: Sacramento Municipal Utility District

MARCH 2015

CEC-500-2015-047

PREPARED BY:

Primary Author(s):
Mark Rawson
Ed Sanchez

Sacramento Municipal Utility District
6201 S Street
Sacramento, CA 95819-4630
Phone: 916-732-557

Contract Number: PIR-10-004

Prepared for:

California Energy Commission

Michael Sokol
Contract Manager

Mark Rawson
Ed Sanchez
Project Managers

Aleecia Gutierrez
Office Manager
Energy Generation Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Energy, under Award Number DE-EE0002066, and the California Energy Commission.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Intergration
- Transportation

Sacramento Municipal Utility District – Photovoltaic and Smart Grid Pilot at Anatolia Final Project Report is the final report for the PV and Smart Grid Pilot at Anatolia,project contract number PIR-10-004 conducted by Sacramento Municipal Utility District. The information from this project contributes to Energy Research and Development Division's Energy Systems Integration and Renewable Integration Programs.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Sacramento Municipal Utility District (SMUD) received funding from the U.S. Department of Energy's (DOE) High Penetration Solar Deployment contract for a pilot demonstration project. In this project, SMUD tested advanced lithium ion storage at both customer and distribution transformer locations in the Anatolia III Solar Smart Homes community in Rancho Cordova, California. The team installed high-resolution monitoring equipment throughout the neighborhood electrical system, from the substation to individual homes. The project aimed to help utilities resolve the challenges of intermittency and reliability associated with high solar photovoltaic (PV) penetration. It also assessed the benefits of distributed energy storage for utilities with growing peak demand.

The project demonstrated successful load-shifting of residential demand and smoothing of PV system output at the residential and transformer-level, as well as utility control of PV inverters via smart meters. Customers oversubscribed to the dynamic pricing program, which helped them manage their bills using PV and energy storage. SMUD quantified the benefits of energy storage at $88/kW to $215/kW for customer-sited and $67/kW to $176/kW for transformer-sited distributed energy storage. The project also considered several utility business models based on the result that energy storage combined with smart meters can be used to successfully mitigate the issues of reverse power flow, voltage violations, and power quality associated with high penetrations of solar PV.

Keywords: California Energy Commission, energy storage, high penetration solar, Li ion, distributed generation

Please use the following citation for this report:

Rawson, Mark; Eddie Sanchez. Sacramento Municipal Utility District. 2014 ***Sacramento Municipal Utility District – Photovoltaic and Smart Grid Pilot at Anatolia.*** California Energy Commission. Publication number: CEC-500-2015-047.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ..... **i**

PREFACE ..... **ii**

ABSTRACT ..... **iii**

TABLE OF CONTENTS ..... **iv**

LIST OF FIGURES ..... **v**

LIST OF TABLES ..... **vi**

EXECUTIVE SUMMARY **1**

Introduction 1

Project Purpose 1

Project Results 2

Project Benefits 3

CHAPTER 1: Introduction **4**

CHAPTER 2: Performance Objectives and Deliverables **5**

Chapter 3: Key Findings **11**

3.1 Strategic Objective 1 11

3.2 Strategic Objective 2 14

3.3 Strategic Objective 3 27

3.4 Strategic Objective 4 30

Chapter 4: Value of PV and Energy Storage **34**

4.1 Framework 34

4.2 Configurations Analyzed 35

4.3 Applications 35

4.3.1 Configuration 1 – CES 36

4.4. Benefits 37

4.4.1 Common Data Sources 37

4.5 Summary 44

Chapter 5: Strategic Implications for SMUD **45**

5.1 Integrating Energy Storage 45
5.1.1 New Business Models Using Distributed Storage 45
5.2 Managing High Penetrations of PV 59
5.2.1 Leveraging Smart Meter Network 60
Chapter 6: Lessons Learned 70
6.1 Billing 70
6.2 Customer Interaction 70
6.2.1 Customer Experience 70
6.3 Monitoring and Communications 71
6.4 Integration 72
6.4.1 Storage Devices 72
6.5 Data Management and Analysis 73
Chapter 7: Recommendations for Further Study 75
APPENDIX A: Final Testing Results A-1
APPENDIX B: Focus Group Results B-1
Appendix C: Business Model Analysis C-1
Appendix D: Interim Report .....

LIST OF FIGURES

Figure 1: Samples of Energy Storage reducing Peak Load 14
Figure 2: Hour of Each Transformer's Daily Peak Load - June 2012 16
Figure 3: Hour of Each Transformer's Daily Peak Load - July 2012 16
Figure 4: Hour of Each Transformer's Daily Peak Load - August 2012 17
Figure 5: Hour of Each Transformer's Daily Peak Load - September 2012 17
Figure 6: Peak Load Distributions at Substation and Neighborhood Level 18
Figure 7: Load and PV Profiles for May 18 2013 19
Figure 8: Total Energy Supplied and Consumed by Anatolia Neighborhood on a Daily Basis 19
Figure 9: May 18th 2013 load Profile with Hypothetical 1 MWh Storage 20

Figure 10: Solar resource power spectral density for clear and cloudy days in early April 23

Figure 11: Power spectra of feeder real power flow on clear and cloudy days in early April..... 24

Figure 12: Power spectra of transformer 8K5 secondary voltage on clear and cloudy days 25

Figure 13: Scatter plot of LTC tap changes as a function of resource variability 26

Figure 14: Average Daily Load Shape for Customers with PV and Energy Storage (Treatment Group) versus Customers with only PV (Control Group). 30

Figure 15: Comparison of Representativeness between the Treatment Group and the Control Group 31

Figure 16: Description of How the ESCT Works 34

Figure 17: SMUD's Capacity Price Forecast 38

Figure 18: SMUD's Carbon Price Forecast 38

Figure 19: Benefits of Configuration One, Broken Out by Application 41

Figure 20: Results of Configuration Two, Broken Out by Application 42

Figure 21: Results of Configuration 3, Broken Out by Application 44

Figure 22: Comparison of Value by Configuration 44

Figure 23: Impact of Scenarios on Value of Configuration One – Community Energy Storage Owned by SMUD 56

Figure 24: Impact of Scenarios on Configuration Two – Residential Energy Storage Owned by SMUD 56

LIST OF TABLES

Table 1: Map of Performance Objectives 5

Table 2: Schedule of Deliverables 6

Table 3: Summary Statistics of Smoothed and Unsmoothed Transformer Load Ramp Rates – CES 12

Table 4: Summary Statistics of Smoothed and Unsmoothed Customer Load Ramp Rates – RES12

Table 5: Asset Management Impacts of Location 21

Table 6: Additional PV Inverter Control Functions Contained in SEP 2.0 28

Table 7:. Statistical Results Comparing Behavioral Differences Between Customers with PV and Energy Storage (Treatment Group) and Customers with Only PV (Control Group) 32

Table 8: Configurations Analyzed for Benefits 35

Table 9: Summary of Distributed Energy Storage and PV Business Model Variables 46

Table 10: Pros and Cons of Possible Locations for Distributed Energy Storage (ES) and PV 48

Table 11: Pros and Cons of Different Ownership Structures 49

Table 12: Pros and Cons of Interconnection Options 50

Table 13: Pros and Cons of Financing Options 51

Table 14: Pros and Cons of Different Levels Of Utility Control 52

Table 15: Pros and Cons of Different Compensations Schemes 53

Table 16: Availability Analysis of RES and CES Unites 57

Table 17: Binning Analysis of Availability 58

Table 18: Mapping of Tested Energy Storage Functionality Against Potential High Penetration PV Issues 60

Table 19: Network centric view of applications required communications throughout SMUD's service territory 63

Table 20: Distributed Solar Penetration Estimates 64

Table 21: Estimated Number of Communication End Points for Residential PV 65

Table 22: Comparison of SSN AMI Network and Customer Broadband for Inverter Control 65

EXECUTIVE SUMMARY

Introduction

Under DE-FOA-0000085 High Penetration Solar Deployment, the U. S. Department of Energy funded agreements with SMUD and Navigant Consulting, SunPower, GridPoint, the National Renewable Energy Laboratory, and the California Energy Commission for this pilot demonstration project. Funding was $5,962,409. The Energy Commission provided cost share of $500,000 for the project.

SMUD tested advanced lithium ion storage at both customer and distribution transformer locations in the Anatolia III Solar Smart Homes community in Rancho Cordova, Sacramento County, in the southeast portion of SMUD's service area.

One of the first integrated PV and energy storage projects in the United States, the Anatolia venture accomplished many firsts:

- A residential energy storage appliance received UL certification.
- A customer-sited, grid-connected energy storage appliance was permitted and installed.
- Load was shifted and smoothed at a residential scale.
- High-resolution monitoring equipment was installed throughout the electrical system of a neighborhood, from the substation to individual homes.

Project Purpose

The project aimed to help resolve three challenges for utilities:

- The intermittency of photovoltaic (PV) generation.
- The impacts on reliability of large penetrations of PV.
- Growing utility system peak load.

Specific objectives were to:

- Demonstrate residential- and transformer-level load-shifting of residential demand 3,566 times.
- Demonstrate residential- and transformer-level load-smoothing 2,051 times.
- Demonstrate utility control of a PV inverter via a smart meter.
- Set up dynamic pricing for customers with PV and energy storage.
- Develop and use a communication system for utility control of distributed energy storage.
- Define and assess the benefits of distributed energy storage to SMUD and its customers.

- Assess the strategic implications of this project for SMUD, with an eye toward developing new programs and managing high penetrations of distributed PV.

Project Results

- The research team learned some valuable things from this study.
- Distributed energy storage can help manage high penetrations of PV – The research team demonstrated energy storage functions that could control voltage, manage reverse power flow (reducing ramping), and shift load.
- Some SMUD customers interested in managing their energy costs and energy storage can facilitate the use of energy storage – SMUD's residential energy storage offering was oversubscribed, indicating a strong interest. In a focus group, participants said they valued highly the idea of managing their energy costs with energy storage.
- Distributed energy storage can add value for SMUD and its customers – The research team quantified benefits of $88/kilowatt (kW) to $215/kW for customer-sited and $67/kW to $176/kW for transformer-sited distributed energy storage.
- The impact of PV on the feeder was low – Even though almost all the 300 homes in the neighborhood had solar PV, the research team did not find issues at the substation or feeder level. The research team thinks this was due partly to large loads up the feeder from the neighborhood that absorb excess power and partly to SMUD's distribution design standards.
- Distributed energy storage can help reduce residential and transformer-level peak loads – The research team studied timing of peak loads and dispatched energy storage to reduce peak levels.
- A smart meter can be used to control a PV inverter, and most of the necessary protocols are in place to facilitate this – After demonstrating this capability in the lab, the research team conducted a gap analysis between functionalities SMUD wanted and existing protocol. The team found no gaps.
- The project has strategic implications for SMUD, other utilities, and the PV and energy-storage industries in business and resource planning, technology deployment, and asset management. These implications include:
    - At this point, no dominant business models have emerged and the industry is open for new ideas. The research team demonstrated two business models for using distributed PV and energy storage and it brainstormed several dozen more, each with different pros and cons for SMUD, its customers, and the industry.
    - Energy storage can be used to manage high penetrations of PV and mitigate potential issues such as reverse power flow, voltage control violations, power

quality issues, increased wear and tear on utility equipment, and systemwide power supply issues.

- Smart meters are another tool utilities can use to manage high penetrations of PV. The necessary equipment and protocols exist, and the next step is to determine how to integrate the functionality with utility programs and what level of utility control is required.
- Time-of-use rates for the residential customers who hosted energy storage systems did not cause a significant change in energy usage patterns. However, the rates we used were not optimized for PV and energy storage. Opportunities exist for utilities to develop new structures.

Project Benefits

Using what the research team has learned, it has developed suggestions for further study. First, now that researchers have demonstrated utility control of a PV inverter in a lab setting, the next step would be real-world deployment in a residential neighborhood. Second, more configurations of energy storage should be tested, including customer control, backup power capabilities, four-quadrant control of voltage and power factor, automated back-feed prevention, and new smoothing algorithms. Finally, develop more effective smoothing algorithms and autonomous storage controls, and aggregation software for utility control of fleets of energy storage devices.

The results of this research project set the stage for California utilities to optimize the deployment of distributed energy storage, and provide valuable lessons learned for when that does occur. California has numerous goals for energy storage, and studies such as this are important in helping utility customers realize the most benefits while achieving these goals.

CHAPTER 1: Introduction

The U. S. Department of Energy under DE-FOA-0000085 High Penetration Solar Deployment funded the Sacramento Municipal Utility District (SMUD) along with its project partners Navigant Consulting, SunPower, GridPoint, and the National Renewable Energy Laboratory to implement the Anatolia PV and Storage Demonstration Pilot for a total Project cost of $5,962,409 Cost share of $500,000 was also provided by the California Energy Commission.

- SMUD demonstrated advanced lithium ion storage at customer and distribution transformer locations in the Anatolia III Solar Smart Homes Community located in the southeast portion of SMUD's service territory in the city of Rancho Cordova, CA.
- The overarching goals of this demonstration were to:
    - Firm intermittency of PV generation
    - Mitigate reliability impacts of large penetrations of PV
    - Reduce utility system peak load

The grant was also used to conduct research on the value of energy storage sited on a customer residence and as a distribution asset. These funds allowed the design, integration, testing and application of energy storage appliances in a community with a high concentration of PV homes, homes that are of similar vintage, and at the end of a distribution circuit.

The combination of these characteristic made this a unique environment to validate the benefits of this technology for both the home owner and utilities. The technology was operated by SMUD to investigate the use of energy storage for renewable energy firming and load shifting along with assessing the impact of dynamic prices and critical peak prices over the course of the study. These funds supported high resolution telemetry at the homeowner's residence, at the transformer and substation along with metrological data to assess the impact of this technology on grid operations.

SMUD used the grant funds to procure fifteen Residential Energy Storage (RES) appliances and three Community Energy Storage (CES) appliances. The grant funds supported the design, integration, testing, siting and installation, and de-commissioning of these energy storage devices. The funds were also used for customer recruitment and support over the course of the demonstration. The funds were also used to support the system integration and development of a home energy portal and the data analysis that was conducted by the National Renewable Energy Laboratory and Navigant Consulting.

CHAPTER 2:
Performance Objectives and Deliverables

The project team set performance objectives and deliverables in the proposal and DOE SOPO. Each objective and deliverable was reviewed for completion and per Table 1 and Table 2. All objectives were met and deliverables provided.

Table 1: Map of Performance Objectives

Objectives	Complete?	Discussion
Add energy storage as either RES (connected behind the meter) or CES (connected to distribution transformers).	Yes	15 RES and 3 CES units were installed.
Install communications so that the energy storage can be monitored and controlled by SMUD.	Yes	Communications was done via the customer's broadband connection for the RES units and via a cellular modem for the CES units.
Install a Utility portal that will allow SMUD to monitor PV output, energy storage, and customer loads, as well as coordinate the resources at a system aggregate level, or more granularly at the substation, feeder, or individual residence level.	Yes	The project team implemented a Utility portal that allowed us to view real time data and control energy storage devices by unit, transformer, fleet and feeder.
Deploy a Customer portal that will allow consumers to monitor their energy usage, PV output, and energy storage in real-time. In addition, consumers will receive energy conservation tips and other educational tools to help them change their energy use patterns.	Yes	The project team implemented the Customer portal and was able to send energy conservation related messages.
Determine pricing signals that will change the energy usage behaviors of customers.	Yes	The RES customer group was put on a Time-of-Use rate during the study.
Determine if customers who have PV and energy storage manage their energy usage differently when compared to those who do not.	Yes	The project team found no difference between groups. The project team suspects this is because customers were not given control of the units.
Control a PV/energy storage inverter with a smart meter from SMUD's AMI deployment.	Yes	The project team partnered with EPRI to conduct lab demonstrations of controlling an inverter with a smart meter.
Develop a functional specification for a smart meter/inverter interface that would enable management of distributed PV/storage system with AMI.	Yes	The specification was developed as part of task 4.06.

Objectives	Complete?	Discussion
Help to build a strategy for integrating energy storage and PV that can be replicated throughout SMUD's service territory and the utility industry as a whole.	Yes	The project team discusses this in section 5.
Simulate the lower bandwidth communications of the AMI wireless mesh network to determine the limitations it could present in terms of data capacity and latency; and implement a prototype interface between a smart meter and PV inverter to demonstrate the simulated communications channel.	Yes	The project team partnered with EPRI to conduct lab demonstrations of controlling an inverter with a smart meter.

Table 2: Schedule of Deliverables

Task #	Deliverable	Complete?	When?	Documentation
1.01	Kick-off Meeting Agenda	Yes	6/14/2010	High Level Agenda for Kick OffV3.xls
1.01	Kick-off Meeting PowerPoint Presentation	Yes	6/18/2010	2010-06-17 HPS Kick off meetng.pdf, SMUD-DOE Kickoff Meeting – Technology Installation and Integration 20100611.pptx, SMUD metering_NREL-jbank.pdf, SunPower-SMUD-DOE Home Storage Demo Program Charter (as presented 6-18-2010).pdf
1.01	Kick-off Meeting minutes	Yes	6/21/2010	2010-06-21 HPS Kick Off Notes_v3.docx
1.02	CPR meeting, meeting record and recommendation for continuing project	Yes	11/8/2012	DOE CPR Nov 8 2012.pptx, 2012-11-01 CPR Meeting V12.pdf, CPR Meeting Summary.pptx
1.03	Final Meeting Agenda	TBD	TBD	This is still being scheduled with DOE
1.03	Final Meeting PowerPoint Presentation	TBD	TBD	This is still being scheduled with DOE
1.03	Written documentation of final meeting agreements and all pertinent information, for final meeting	TBD	TBD	This is still being scheduled with DOE

Task #	Deliverable	Complete?	When?	Documentation
1.03	Schedule for completing closeout activities	Yes	7/31/2013	Closeout Schedule.docx
1.04	Monthly progress reports	Yes	Multiple	Multiple
1.05	Final report	Yes	9/30/2013	2013-09-30 Final Report.docx
1.06	Meeting Agenda - DOE program review	Yes	DOE Peer Review 5/26/201, High Penetration Solar Forum 3/1/2011, SunShot Grand Challenge Summit 6/13/2012, High Penetration Solar Forum 2/13/2013	Refer to workshop proceedings on SunShot Initiative homepage.
1.06	Meeting presentations - DOE program review	Yes	5/26/210, 3/1/2011, 6/13/2012, 2/13/2013	Prm2010_smud.pdf, highpenformum1-14_rawson_smud.pdf, 2012-06-07 SunShot Poster.pdf, 2012-02-13 SMUD High Pen Pres.pptx
1.06	Meeting Minutes - DOE program review	Yes	5/26/210, 3/1/2011, 6/13/2012, 2/13/2013	Refer to workshop proceedings on SunShot Initiative homepage.
1.07	Sub-agreements	Yes	Multiple	Multiple
1.08	Internal Technical Workshop - Meeting Agenda	Yes	12/2/2010	2010-12-10 Internal Meeting.pptx
1.08	Internal Technical Workshop - Presentations	Yes	12/13/2010	2010-12-10 Internal Meeting.pptx
1.08	Internal Technical Workshop - Meeting Minutes	Yes	12/16/2010	2010-12-13 Meeting Notes.docx

Task #	Deliverable	Complete?	When?	Documentation
1.09	Final results workshop - meeting agenda	Yes	8/28/2013	Final Results Workshop – Morning.pdf, Final Results Workshop – Afternoon.pdf
1.09	Final Results workshop - Meeting Presentations	Yes	8/28/2013	Final Results Workshop – Morning.pdf, Final Results Workshop – Afternoon.pdf
1.09	Final Results Workshop - Meeting Minutes	Yes	8/28/2013	Sent via email to SMUD team
2.01	Hardware specifications documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.01	Pre-Installation unit certification reports for all field deployable units	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.01	Post-Installation unit diagnostic reports for all field deployed units	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	Software specifications documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	Interface specification documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	An operational utility portal	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	An operational consumer portal	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.03	Data packet specification document	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
2.03	Defined data packets	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
3.01	Data for Analysis	Yes	N/A	Data hosted by NREL at https://pfs.nrel.gov and http://www.nrel.gov/midc/smud_anatolia/

Task #	Deliverable	Complete?	When?	Documentation
3.02	Determinations of impact of PV/energy storage on feeders	Yes	12/30/2013	2013-12-30 Final Report.docx
3.02	Data for subsequent analysis	Yes	N/A	Data hosted by NREL at https://pfs.nrel.gov and http://www.nrel.gov/midc/smud_anatolia/
4.01	A summary report on the framework for assessing PV/storage benefits for the project	Yes	11/30/2010	PV-Storage Benefits Framework – Final – 11-30-2010
4.02	A testing and monitoring plan that covers each of the operating scenarios.	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
4.03	Pricing models for each of the three customer groups	Yes	5/30/2012	Rates were implemented with customers in Q2 2012
4.03	Pricing model implementation plan	Yes	5/30/2012	Rates were implemented with customers in Q2 2012
4.04	Advanced Pricing Workshop - Agenda	Yes	6/27/2011	Advanced Pricing Workshop – 06-27.pptx
4.04	Advanced Pricing Workshop - Presentations	Yes	6/27/2011	Advanced Pricing Workshop – 06-27.pptx
4.04	Advanced Pricing Workshop - Meeting Minutes	Yes	7/26/2011	Meeting Minutes – Advanced Pricing Workshop – 07-26-2011.pptx
4.05	Report outlining output of data analysis	Yes	12/27/2012, 2/14/2013, 3/25/2013	2013-2-19 Q2 Data Report – Final.docx, 2013-2-19 Q3 Data Report – Final.docx, 2013-3-25 Data Report – Final.docx
4.06	Straw man functional specification for PV/smart meter interface	Yes	7/19/2013	2013-07-19 Functional Spec.docx

Task #	Deliverable	Complete?	When?	Documentation
4.07	Recommended updates for strategies	Yes	12/30/2013	2013-12-30 Final Report.docx
4.08	Summary report on business model options and potential value tradeoffs	Yes	12/30/2013	2013-12-30 Final Report.docx
N/A	CPR Report	Yes	7/20/2012	Final CPR 20 Jul 2012.pdf

Chapter 3:
Key Findings

The project team structured the project around a set of strategic objectives and key research questions to focus the testing and analysis. This section reviews each question and the insights gained from the work.

3.1 Strategic Objective 1

Understand how the integration of energy storage could enhance the value of distributed PV resources within the community

Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity?

The answer to this question is yes, the location does change the ability to manage variations in load and PV capacity.

The algorithms implemented in this demonstration smooth and dampen variations, rather than firm the PV production into a set load shape. Consequently for the remainder of this report, the term smoothing will be used instead of firming.

While the RES and CES units employ the same smoothing algorithm – a moving average based algorithm that tries to dampen changes in power – the CES units see load (and thus volatility) aggregated from 5 to 15 houses. This means that spikes in load or rapid changes in PV output from one house are added to load from many houses and result in a relatively lower change at the transformer level. Thus, the CES unit is responding to relatively smaller changes in load and has an easier time responding by charging or discharging as needed.

Evidence of this can be seen in the impact of the smoothing algorithm, Table 3 and Table 4 compare ramp rates with and without the smoothing algorithm applied in the CES and RES, respectively[1] . Table 3 shows that with the CES the smoothing algorithm reduced the mean and medium ramp rates at the transformer. In contrast, Table 4 shows the smoothing algorithm with the RES actually increased mean and median ramping[2]

[1] For more information on the analysis that went into these tables, refer to the Q4 2012 Data Analysis Report

[2] It is suspected that this is because the algorithm drives an immediate charge in response to a discharge or vice versa and that this effect is more pronounced in the RES units because of the higher spikes

Table 3: Summary Statistics of Smoothed and Unsmoothed Transformer Load Ramp Rates – CES

Statistic Parameter	Unsmoothed Load	Smoothed Load
Mean Ramp Rate (W/s)	55.9	50.6
Median Ramp Rate (W/s)	23.8	13.7
Standard Deviation of Ramp Rate (W/s)	74.9	78.8
Number of Data Points	99,250	

Table 4: Summary Statistics of Smoothed and Unsmoothed Customer Load Ramp Rates – RES

Statistic Parameter	Unsmoothed Load	Smoothed Load
Mean Ramp Rate (W/s)	13.3	19.6
Median Ramp Rate (W/s)	2.6	4.4
Standard Deviation of Ramp Rate (W/s)	50.5	60.3
Number of Data Points	147,431	

How much storage is necessary to accomplish the desired PV and load firming effects?

The answer to this question depends on the definition of firming. Per the discussion above, smoothing was tested in the project. With the smoothing algorithm deployed, the CES units discharged an average of 5.5 kWh/day on high solar variability days[3] and the RES units discharged an average of 1.9 kWh/day[4] . These values are lower than the unit's energy storage capacity – 34 kWh for the CES units and 7.7 kWh for the RES units. However, the smoothing algorithm used was only effective in smoothing ramps greater than 2.5 minutes in length4. Thus, a faster acting algorithm might require more energy storage capacity.

If defining firming as the ability to turn PV into a firm, reliable resource, the requirements are higher. The exact amount depends on the utility's use of energy storage to firm PV.

[3] Refer to the Q2 2012 Data Analysis Report for the definition of high solar variability days.

[4] Refer to the Q1 2013 Data Analysis Report for detail on how these numbers were calculated.

If the intent was to firm PV output on any day of the year and in any weather conditions, an energy capacity of 6.2 to 6.8 kWh per kWp(DC) would be required to completely back up a PV system. This number was calculated from looking at the highest output for any PV system over the course of year and normalizing by capacity [5] The average PV system size is 2 kW in the Anatolia neighborhood, so this would require a 12.4 to 13.6 kWh energy storage system.

If a utility had day ahead solar forecasting capabilities detailed enough to predict typical weather patterns (e.g. sunny, fully over cast, partly cloudy, etc.), the utility would know storage would not be required on clear days and could plan ahead for low PV output on fully over cast days. The energy storage equipment would be designed to firm PV output on partly cloudy days. The maximum amount of storage required to firm PV output on intermittent days would be ~2.5 kWh per kWp (DC) of PV capacity or 5 kWh for a 2 kW PV system in Anatolia. This amount is less than half of the amount required (6.2 to 6.8 kWh per kWp (DC)) if the storage is sized to back up PV in any conditions.

Can an integrated PV/energy storage system provide service reliability benefits for customers?

Service reliability can be thought of in two ways:

- Reducing the impact of outages by providing back up power.
- Reducing voltage fluctuations.

In terms of mitigating outages, the answer is yes, but current interconnection standards prevent this. IEEE 1547 governs the interconnection of distributed energy resources and mandates that inverters trip offline in the event of a grid outage. The primary driver of this is to ensure that a grid connected distributed energy resource is not producing energy and energizing lines when utility repair crews are active. IEEE 1547 is currently being updated and this might change in the future. In theory, an automatic transfer switch could be designed into a PV/energy storage system to remove the system from the grid in the event of an outage. However, this would require the addition of equipment and controls software to manage loads, PV generation and battery charging that are not common now and that were not tested in the study.

For reducing voltage fluctuations, the answer is likely yes if volt/var control was enabled. However, (a) the penetration of PV on this feeder isn't high enough to actually see voltage issues (as confirmed in NREL's 2009 study of the neighborhood[6]) and (b) this functionality was not designed into the demonstration units. A recommendation for further study from this report is to test this functionality as part of a demonstration.

---

[5] Refer to the Q4 2012 Data Analysis Report for more information on this analysis

[6] The 2009 report is entitled Impact of SolarSmart Subdivisions on SMUD's Distribution System, July 2009, NREL/TP-550-46093

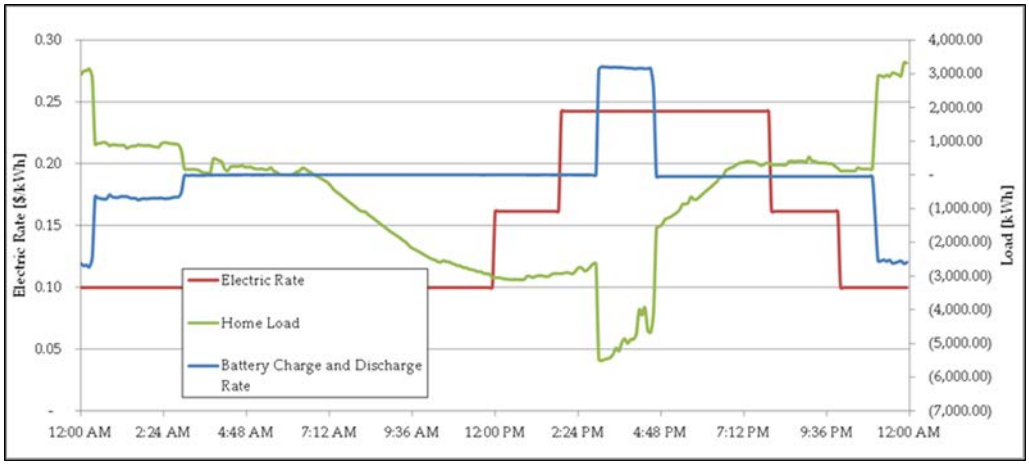
3.2 Strategic Objective 2

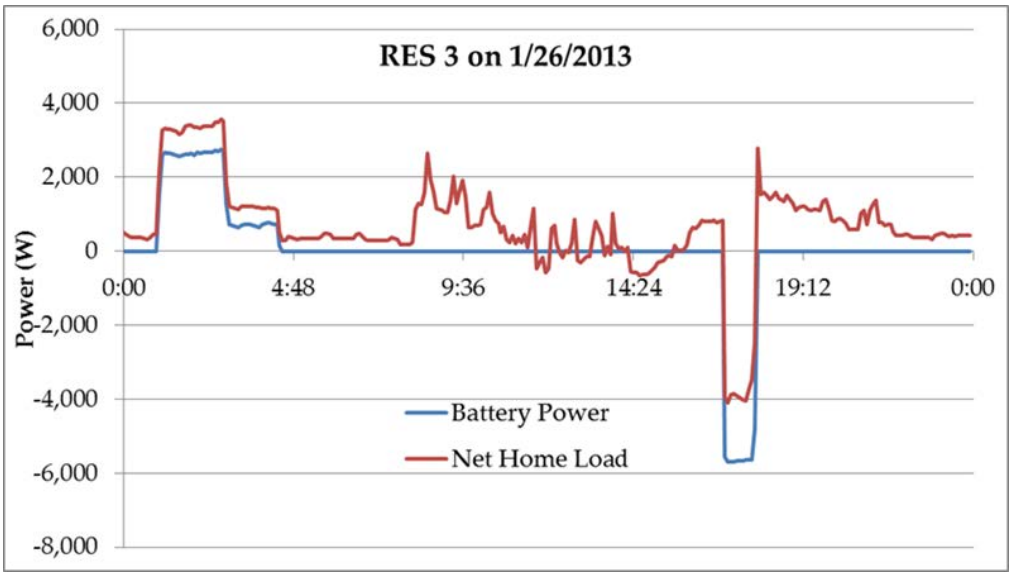
Determine if the addition of energy storage could add value for the utility

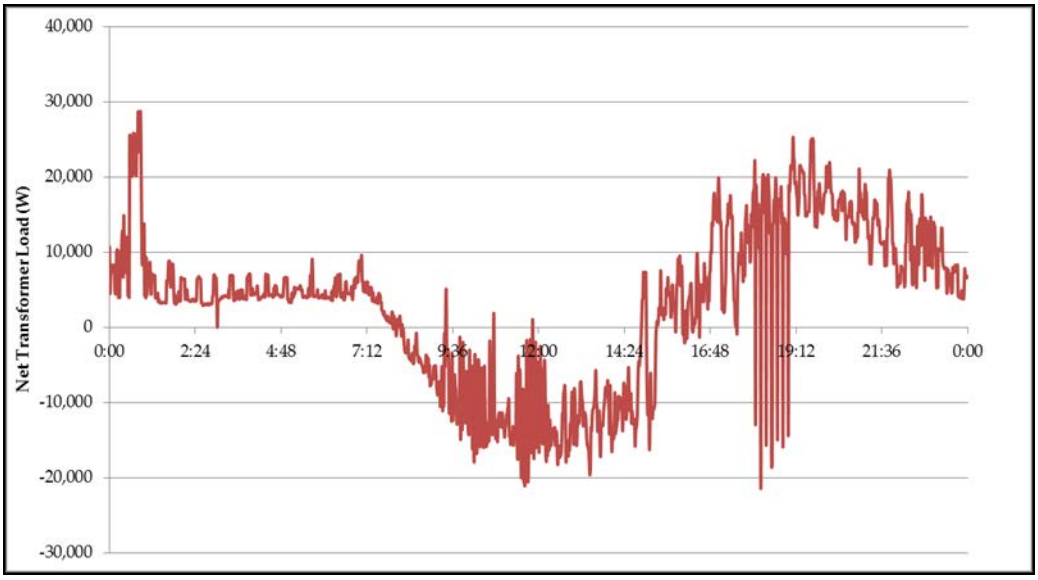
Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM?

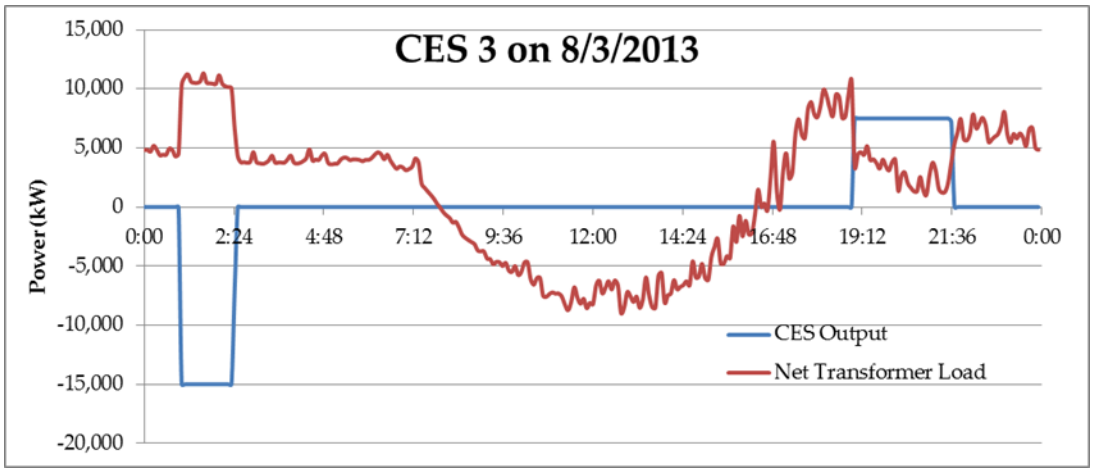
Yes, SMUD proved many times that energy storage in both the RES and CES configuration can reduce peak loads. SMUD ran load shifting 2,847 times with for the RES units and 719 times for the CES units and sample plots from actual tests are shown below.

Figure 1: Samples of Energy Storage reducing Peak Load









However, one key finding of the study was that the neighborhood summer peak in Solar Smart communities is later than SMUD's summer system peak of 4 to 7 PM. The figure's below show the time of transformer peaks in the neighborhood – by month – against the system peak period. As a result, using energy storage to reduce peak during SMUD's system peak might not result in peak reduction in the neighborhood's peak.

Figure 2: Hour of Each Transformer's Daily Peak Load - June 2012

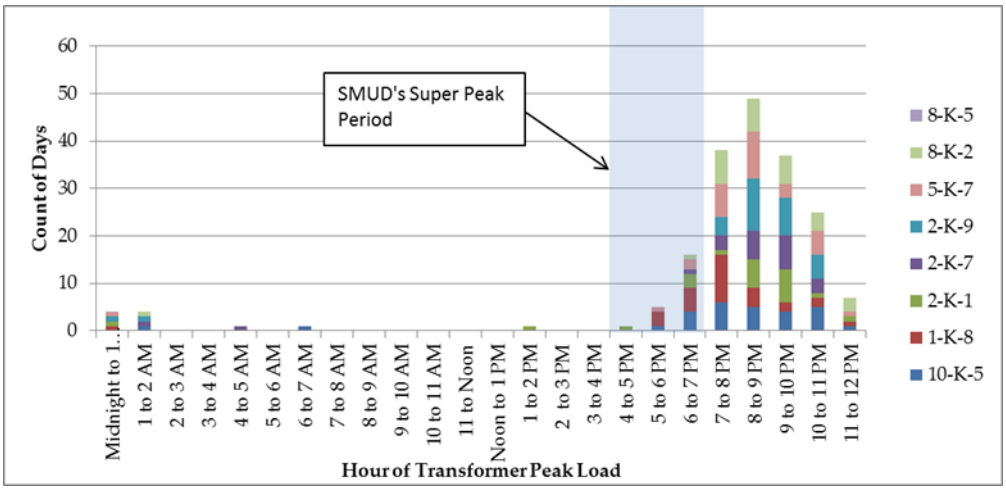


Figure 3: Hour of Each Transformer's Daily Peak Load - July 2012

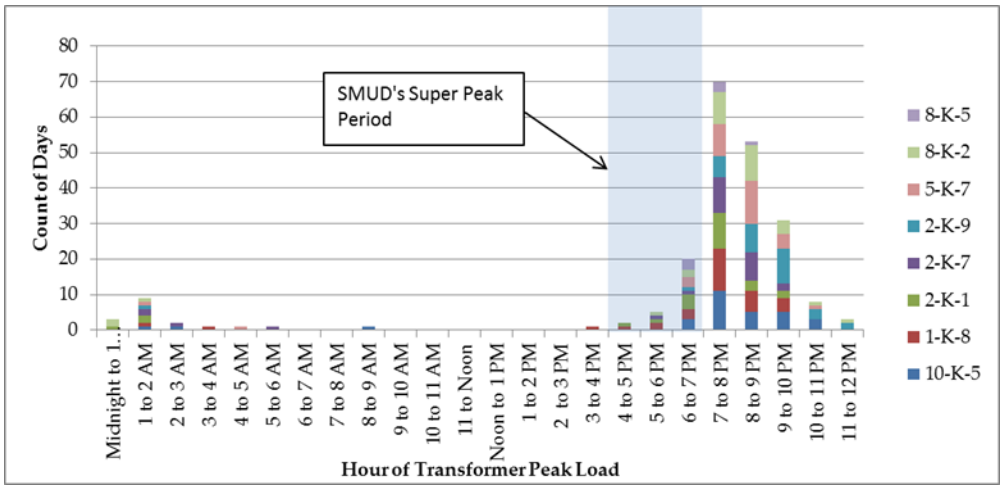


Figure 4: Hour of Each Transformer's Daily Peak Load - August 2012

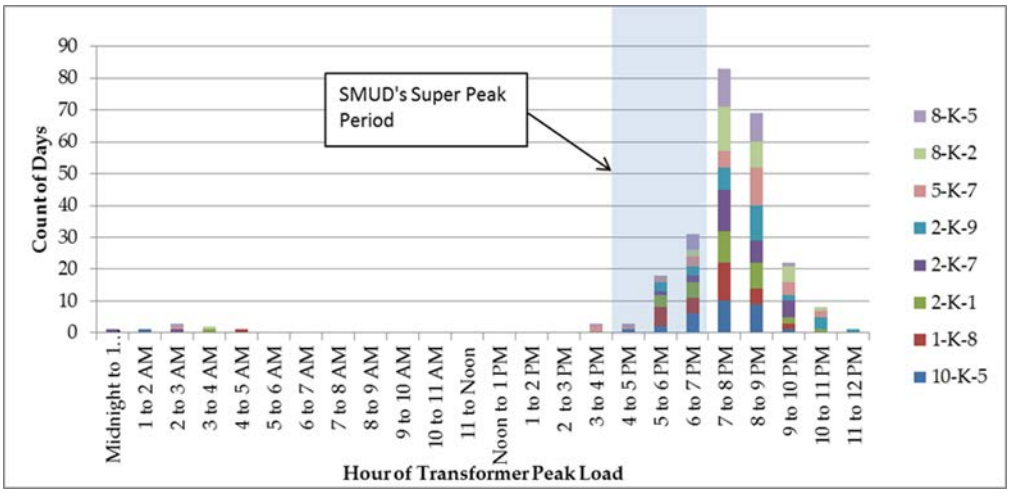
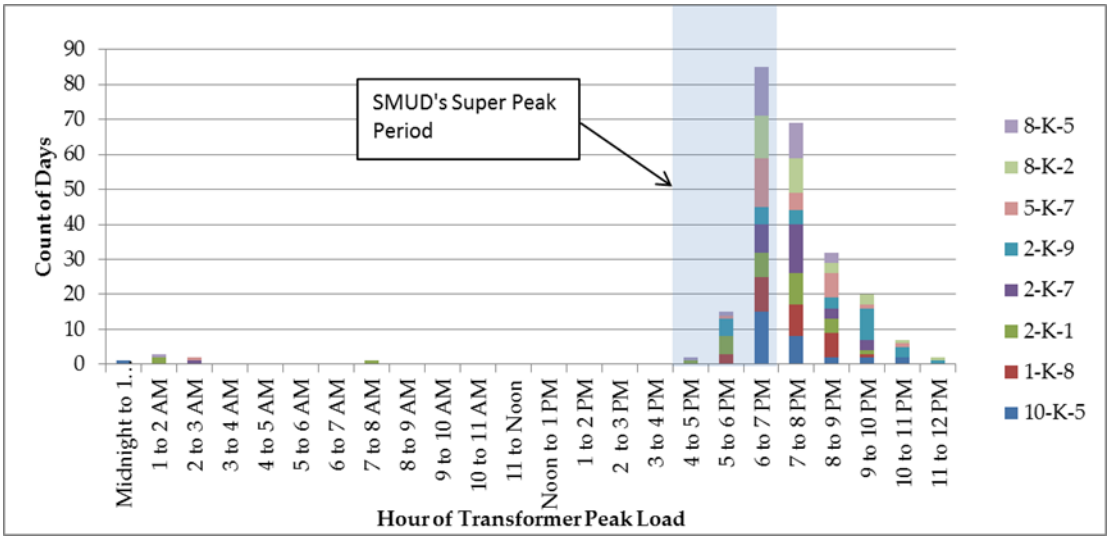


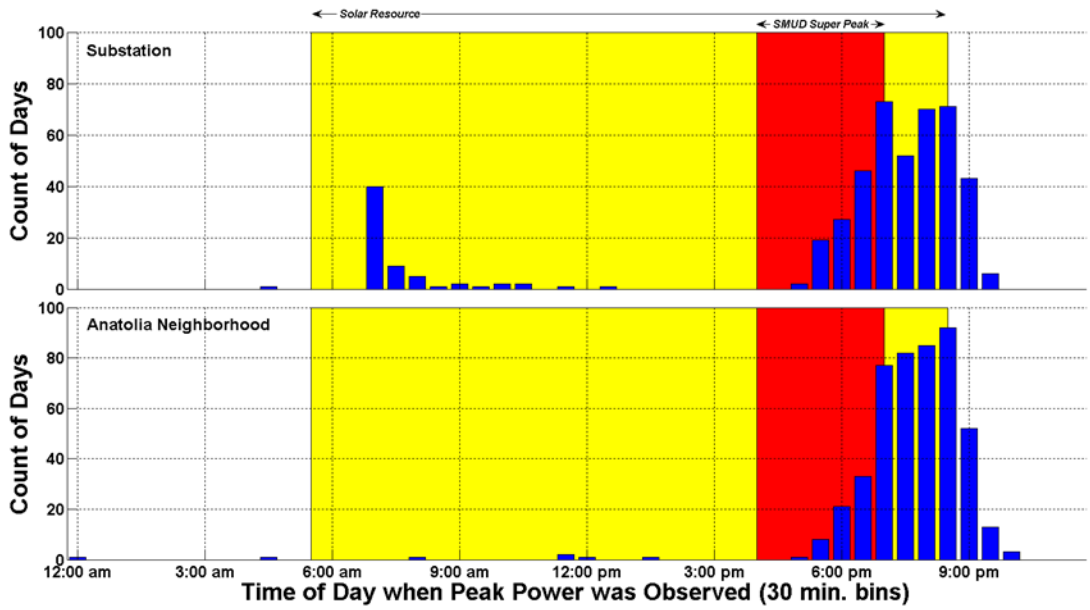
Figure 5: Hour of Each Transformer's Daily Peak Load - September 2012



The project team also looked at the feeder level for information on timing of peaks. The distributions of the peak load occurrences at the neighborhood and feeder levels are given in Figure 6. Source data for these graphics are drawn from over a year of SMUD's SCADA Data. The upper plot gives the distribution over time of when the substation experienced its peak load value. Here the time points are binned into half hour periods on the horizontal axis and the count is given on the vertical. The lower plot presents the same results for the Anatolia Neighborhood. Additionally, the PV production region is blocked out in yellow while SMUD's Super Peak Period is given in red.

In Figure 6, the majority of the observed peak loads occur after the Super Peak region. Once again demonstrating that the loads in this area in general do not coincide with SMUD's Super Peak period. The majority of the peak load periods also occur at the tail end of the daylight hours when very little power is being generated by the PV in the neighborhood indicating that the PV in the Anatolia neighborhood is not significantly shifting the peak load time. At the substation level where the installed PV capacity represents a smaller percentage of the total load a similar trend is seen with the PV having little effect in shifting the load.

Figure 6: Peak Load Distributions at Substation and Neighborhood Level

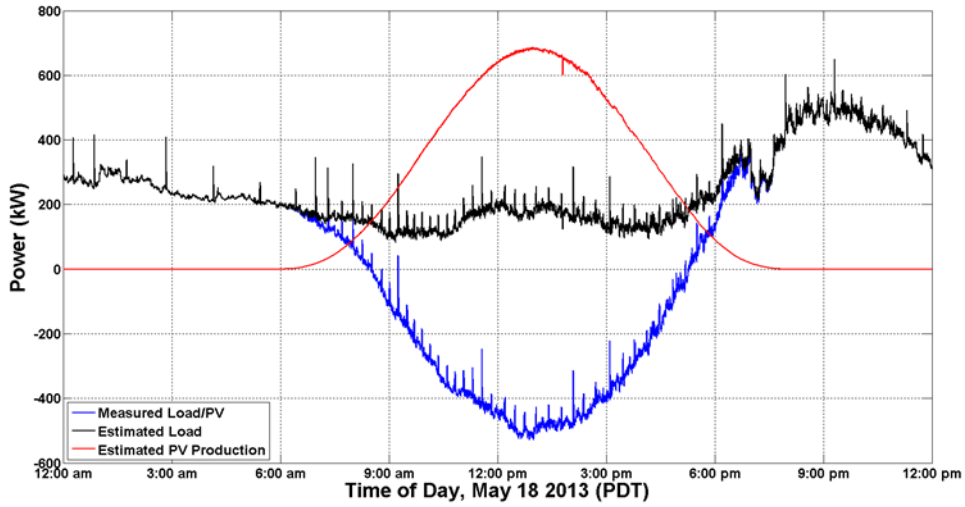


In order to better demonstrate how the PV in the Anatolia Neighborhood is affecting the afternoon peak load a specific example is presented in Figure 7. May 18, 2013 was a particularly clear day with a very clean irradiance profile with a high amount of total solar energy available due to the proximity to the Summer solstice. Additionally, the load is relatively light as it occurs in the spring before a lot of air conditioning load becomes prevalent. The high PV output and lower load conditions provides a worst case example for the PV being able to affect the load peak time.

In Figure 7, the blue trace is the measured load at the neighborhood level, it demonstrates the typical midday trough due to the PV generation and a clear load peak in the evening at about 9 pm. This peak load time is slightly later than normal but not atypical in the measured data. The red trace is the estimated total daily PV power output; it was constructed from the irradiance measurement using a few scaling factors to account for the installed capacity, panel tilts, and orientations. This estimate represents a best guess and is not perfectly accurate due the variance in house orientation, tilt angle and the geographic diversity of the irradiance. The black trace gives the estimated load as derived by adding the PV production to the measured load flow. Here the peaks of the estimated load and the measured power flow line up exactly indicating that the PV is having no effect on either reducing the peak or shifting it for this day. This is as

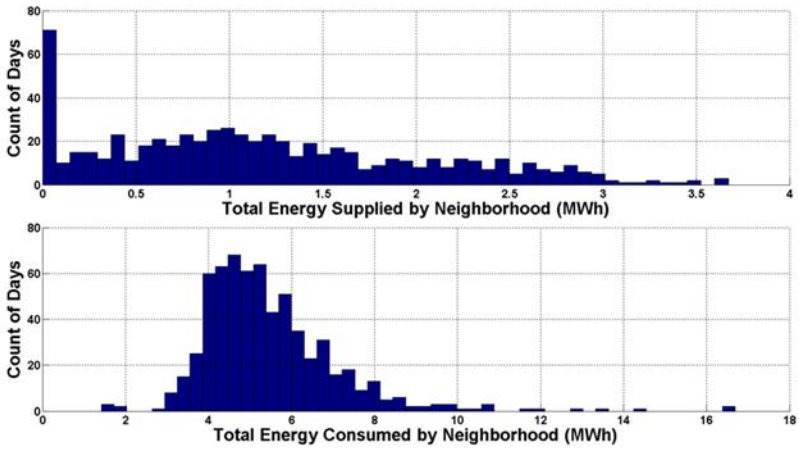
expected because the peak is occurring nearly two hours after sunset when the PV has stopped producing power. Several other days were considered in this fashion with similar results.

Figure 7: Load and PV Profiles for May 18 2013



In order to estimate the amount of energy storage needed to perform peak shaving in the Anatolia Neighborhood, the feeder level power flow measurements were used to establish how much energy was being consumed and exported on a daily basis. The power measurements during midday when the PV was producing and the neighborhood was a net supplier were integrated to establish how much energy was feeding to the substation on a daily basis. Additionally the power measurements from periods when the Neighborhood was a net consumer were integrated separately. These integrals were performed on each of the 642 daily profiles available in the feeder level data set. Histograms of these results are given in Figure 8, the top plot is the total energy supplied during the period while the neighborhood is a net exporter and the bottom plot is total energy consumed while the neighborhood is a net importer.

Figure 8: Total Energy Supplied and Consumed by Anatolia Neighborhood on a Daily Basis



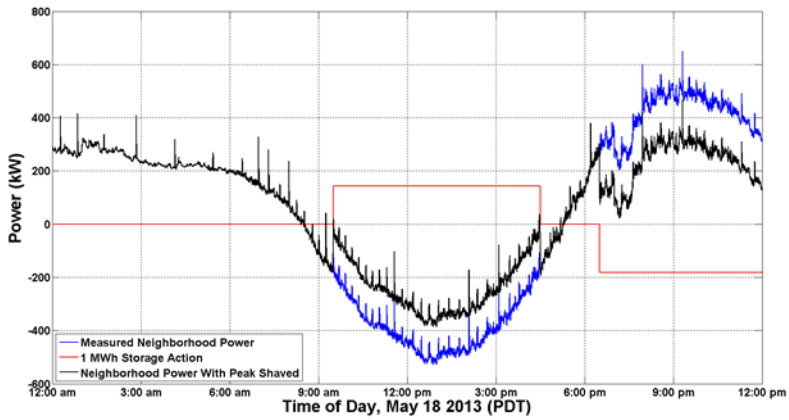
The amount of energy supplied by the neighborhood is quite variable ranging from 0 up to 3.7 MWh per day with the average at 1.2 MWh. During the 642 days analyzed, 22 of them demonstrate no periods of reverse power flow with the neighborhood acting as a net consumer the entire day. The majority of these 22 days occurred in the winter months when the solar resource was at a minimum.

The daily energy consumption for the neighborhood resulted in a much more tightly packed distribution with total daily consumption ranging from 1.4 MWh to 16.7 MWh with the majority of days densely packed around the average of 5.5 MWh. Once again these numbers represent the total energy consumption when the neighborhood was a net consumer, generally during the non-daylight hours. Across the entire data set only one day, June 5th, 2012, was found in which the neighborhood was a net supplier for the entire day, producing 300 kWh, for all other days in the data set the total energy consumed exceeded the total supplied. However, there were several other days observed which were very close with total daily consumption of less than 250 kWh.

Based on the results of this analysis, in order to provide benefits for peak shaving at the neighborhood level, total energy storage sized in the range of 500 kWh to 1 MWh would be able to capture most of the exported energy on average and be able to fully discharge during the peak period without exceeding the load.

The project team then simulated the impact of this. The May 18th load profile from Figure 7 was adjusted to include a hypothetical 1 MWh energy storage device implementing peak shaving to demonstrate this effect. Here an ideal energy storage device is implemented without accounting for any efficiency losses. The storage is charging during the daylight hours while the neighborhood is exporting power and discharging in the late afternoon and evening while the neighborhood load is peaking as indicated by the red trace of Figure 9. The blue trace is the original measurement data and the black trace adds the energy storage action to it. Both the solar peak (midday trough) and the load peak in the evening are reduced, reducing both the excess power that the utility must sink and the power that it must supply during peak hours.

Figure 9: May 18th 2013 load Profile with Hypothetical 1 MWh Storage



The Anatolia neighborhood is still currently under development with full build out of the homes expected to reach three times what is currently built in the area. Given that these new homes would have similar design and construction this would have the effect of increasing the power flows by a factor of three over what was measured over the course of this project. Previous studies by NREL have shown that this full build out poses minimal operational impacts to the utility but the increased power flows would need to be included for any energy storage sizing. Based on measurement data, the Anatolia Neighborhood peak load only represents about 10% of the peak load at the substation and thus is having minimal impact on the demand seen there and the Anatolia PV never produced enough power to cause the substation to back feed over the span of data collection for this project. As the neighborhood builds out, it is unlikely this will change as it would still represent a small portion of the total load supplied by the substation.

Does the location of energy storage significantly affect the ability of the utility to manage the resource?

Yes, the location of a distributed energy storage system affects the ability of the utility to manage the resource in two areas: Asset Management and Operations.

In regards to Asset Management, the two locations tested – utility sited at a transformer and customer sited in a residential home – have pros and cons. The table below maps them out. One key observation from the table is that from an Asset Management perspective, both configurations have pros and cons and neither is better than the other.

Table 5: Asset Management Impacts of Location

	CES (Utility sited)	**RES (Customer sited)**
Pros	• Asset is utility sited and does not require any customer contact beyond installation • Asset does not impact customer bill easing billing and avoiding cost of battery round trip inefficiencies • Asset can be sized to service multiple homes • Home owner liability and risk is reduced	• Unit can be housed in customer's garage and sheltered from elements • Unit can aide in lowing customer bills depending on rate structure and dispatch schedule of batteries • Can be configured to reduce outages and provide a UPS source (NA in this project)
Cons	• Distribution crew is required for all maintenance activities • Unit is installed outside and exposed to elements	• Equipment trouble shooting requires schedule coordination with homeowner • Customer bears impact of system inefficiency and might complain about higher bills • Increased risk and liability issues

In terms of Operations, SMUD tried different solutions for each configuration and the findings are as follows:

- SMUD used the customer's broadband connection to control the RES units. SMUD encountered several issues with this solution. The first was electromagnetic interference (EMI) between the storage device and broadband cabling. This required time consuming trouble shooting and repair. The second was the broadband connection was found to be intermittent in this neighborhood. When communication with the devices was lost, it interrupted the data feeds. Thus, using customer's broadband is not recommended going forward. In the future, SMUD could leverage its AMI/HAN infrastructure that has been deployed or its direct load control infrastructure (DRMS) to operate customer sited energy storage systems, but this would require broadband or WiFi.
- For the transformer sited CES units, SMUD used cellular modems for operating the units. This was also not a highly reliable solution because outages with the local cellular service would cause communications and monitoring interruptions. If SMUD were to scale up a deployment of this configuration, they'd likely use their secondary Silver Springs network deployed for distribution automation purposes or their fiber optic SCADA system.

To conclude, each configuration would likely use a different operating system if rolled out at a larger scale.

How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?

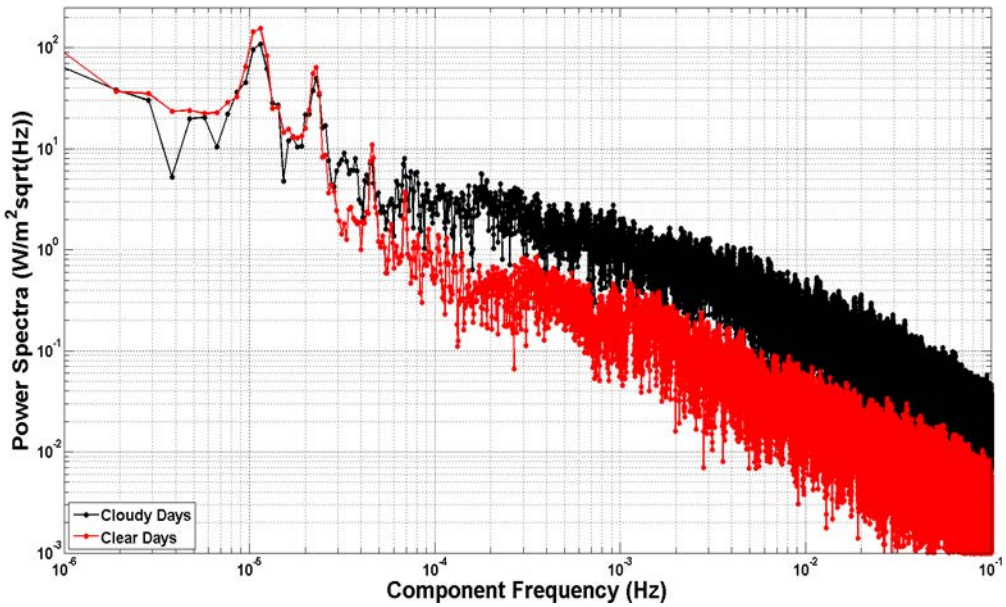
Power Spectral Density Plots have been previously used to assess the variable nature of loads and the solar resources in the Anatolia community[7] Fourier analysis is used to transform the time series measurement data into the frequency spectra. The total power of each frequency component is then easily attained and variable features in the measurements can then be seen as spikes in power at the corresponding frequency. Here this analysis technique is used to observe the nature of solar resource variability and how that affects the total feeder power flow.

Since the PV is installed on the customer rooftop level, both the distribution transformer and SCADA power measurements include the PV generation and the load netted together. In order to assess the impacts of solar resource variability, cloudy and clear days are compared. Here data sets from early April are used to limit the influence of variable load effects most commonly seen in the summer and because the spring months generally demonstrate the most variability in the solar resource.

[7] J. Bank and B. Mather, "Analysis of the Impacts of Distribution Connected PV Using High-Speed Datasets", IEEE Green Technologies Conference. April 4-5 2013, Denver CO p. 153-159

Seven clear days and seven cloudy days from between April 1st and April 18th 2013 were selected for analysis. One second global horizontal irradiance measurements from the north side of the neighborhood were compiled and the resulting power spectra were computed for this data. Figure 10 presents these results, with the clear days plotted in red and the cloudy days in black.

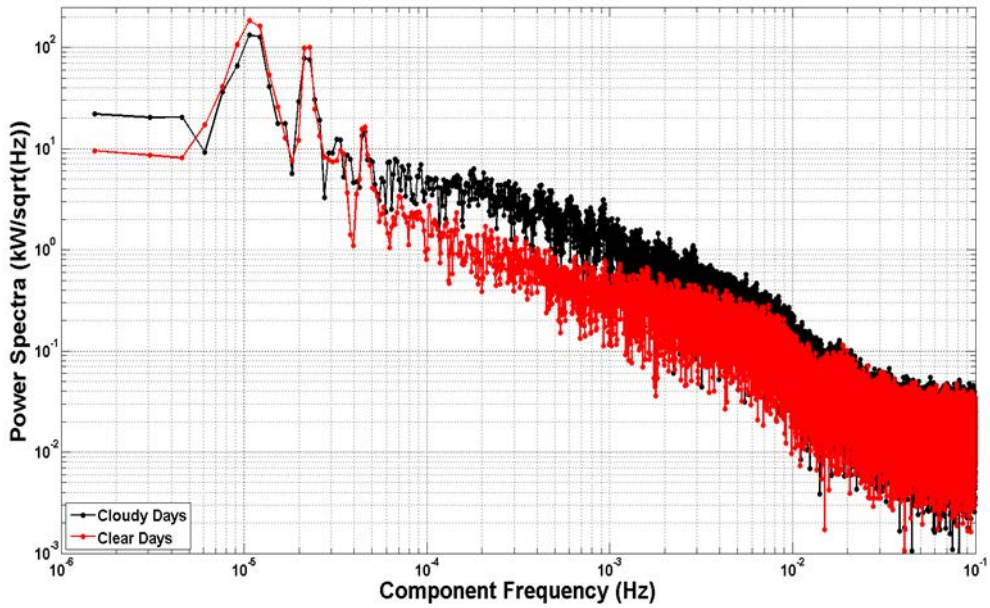
Figure 10: Solar resource power spectral density for clear and cloudy days in early April



The 24, 12 and 6 hour components of the daily solar profile are prevalent on the left hand side of the plot in both trends and contain most of the power in the signal. To the right of these points the two spectra become markedly different though. The cloudy days demonstrate significantly higher power throughout the 2.7 hour (f ≈10-4 Hz) to 10 sec (f ≈10-1 Hz) band. This indicates significantly higher resource variability on the cloudy and overcast days as expected. Neither spectrum has any prominent spikes in this region though, indicating the random, aperiodic nature of the cloud passage through this area.

The effect of the PV variability can be seen at the neighborhood level through the feeder level SCADA measurements. In Figure 11 the spectra of the feeder real power measurements is plotted in black for the cloudy days and in red for the clear days. The cloudy days demonstrate more power in the 2.7 hour (f ≈10-4 Hz) to 20 sec (f ≈5*10-2 Hz) band than the clear days do.

Figure 11: Power spectra of feeder real power flow on clear and cloudy days in early April

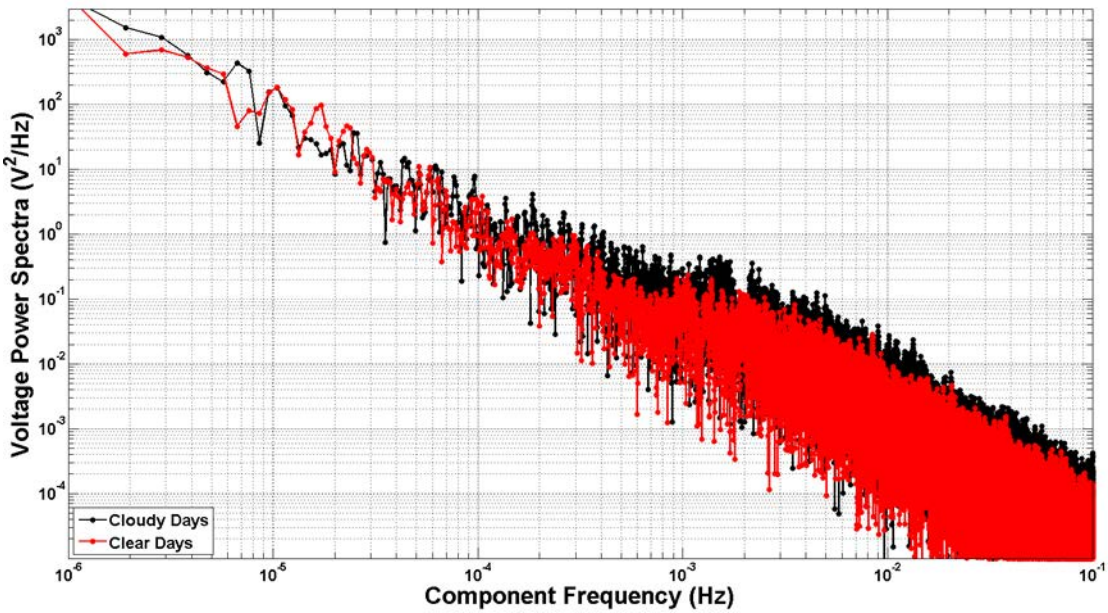


Given the small area covered by this neighborhood, less than half a square mile, the irradiance throughout should be highly correlated and non-diverse. With all the PV panels experiencing very similar solar resource, the variability in irradiance should be well correlated with the variability in total power of the neighborhood. Up to a point this is seen in Figure 10 and Figure 11, while the clear (low PV variability) and cloudy (high PV variability) days show drastic difference between the irradiances in Figure 10, these differences are still present in Figure 11 but are not as pronounced.

While the available resource is non-diverse across the neighborhood several other factors are at play which can serve to limit the variability of the PV seen at the system level. The solar panels throughout the area are all roof mounted on the homes and thus do not all have the same orientation, with most ranging from south-east facing to south-west. This diversity in PV panel orientation serves to lessen the impacts of non-diverse global horizontal irradiance as each panel is receiving slightly different incident irradiance. Additionally the load in the neighborhood is being netted against the PV generation before the measurement point and thus PV makes up a smaller percentage of the total signal power, reducing its prominence in the spectra of Figure 11. Despite these smoothing effects the utility is seeing increased variability in power flows at the feeder level as a result of the variability in the solar resource.

The voltages for this April clear and cloudy day data set demonstrate some increased variability but not as pronounced as that of the power flow. The power spectral density plot for the secondary voltage at transformer 8K5 is given in Figure 12.

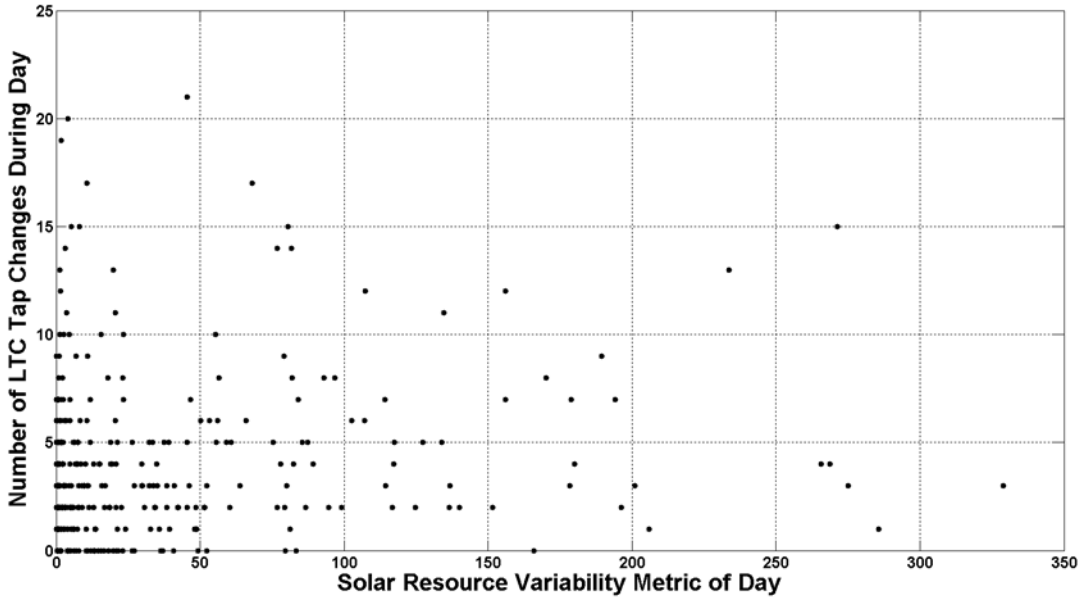
Figure 12: Power spectra of transformer 8K5 secondary voltage on clear and cloudy days



Once again the power spectra for the cloudy days are plotted in black and the clear days are plotted in red. Here the cloudy days demonstrate slightly more variability across the spectra but not nearly as prominent as the differences seen in Figure 10 and Figure 11. In fact, this particular transformer showed the largest differences between clear and cloudy data sets with most of the other metered transformers (total of twelve) seeing nearly identical power spectra for clear and cloudy days. Thus for this circuit, the variability in solar resource is having little effect on the variability in customer voltage. Additionally, the voltages measured at the feeder level showed no appreciable differences in variability. This is most likely because the PV penetration is relatively low (about 18%), the PV is close to the substation and the circuit has been designed with the Anatolia Solar community in mind.

Another effect the variable nature of the solar resource can have is to introduce increased activity of voltage regulation equipment on the circuit. If the solar resource variability is influencing the circuit voltage the switched capacitor banks and load tap changers (LTC) can see an increase in number of operations as they try to regulate the voltages on the circuit in response to passing clouds and other transients. Increased number of operations can shorten their lifespan, thus high penetrations of PV have the potential to reduce the useable life of voltage regulation equipment. To investigate this interaction, the number of LTC tap changes during the daylight hours for each day between June, 7 2012 and June, 30 2013 was compared against the relative variability of the solar resource for that day. These results are presented in the scatter plot of Figure 13.

Figure 13: Scatter plot of LTC tap changes as a function of resource variability



In Figure 13, the independent axis corresponds to the relative solar resource variability, computed by taking the variance of the point to point one second changes for the irradiance data collected at the north side of the Anatolia neighborhood; higher numbers here indicate increased variability in the irradiance. The dependant axis corresponds to the number of tap changes on the substation transformer during the daylight hours. Each point in the scatter plot corresponds to one day in the source data set. If the PV was having an influence on the LTC, highly variable days would result in more tap changes producing a strong positive correlation. Figure 13 does not indicate this strong correlation, reinforcing the previous point that the voltages on this circuit are relatively immune to fluctuations in the solar resource for a variety of reasons.

3.3 Strategic Objective 3

Determine how to leverage SMUD's AMI investment to manage a distributed PV/energy storage resource

Can a smart meter be used to monitor and control a PV system, and to what extent?

During the study, SMUD proved this was possible via a desk top demonstration[8]. SMUD partnered with the Electric Power Research Institute (EPRI) and conducted testing at EPRI and SMUD labs. SMUD leveraged the Smart Energy Protocol (SEP) version 1.1 communications protocol to test the following functions:

- Setting – On/Off
- Control – Output Level
- Control – Cancel Event
- Read – Current Output Level
- Read – Historical Output

When SMUD started this project, SEP 1.1 was the most up to date protocol available and SMUD tested all available functions for PV inverters. Subsequently, SEP 2.0 has been released and contains the additional functions shown in Table 6. SMUD conducted a gap analysis between what monitoring and control functionality SMUD would like and what was available in SEP 2.0 and did not find any gaps. Thus, a smart meter could be used to monitor and control a PV system in every aspect required by SMUD.

[8] Refer to the task 4.06 deliverable for full documentation of the testing that was run and the results.

Table 6: Additional PV Inverter Control Functions Contained in SEP 2.0

Read Voltage
VARs
Power Factor
Current Settings
Event Duration
Event Success
Inverter Fault and Last Gasp Codes
Control Voltage
VARS
Power Factor
Setting Automated Control Mode

What are the practical challenges associated with using AMI for managing PV?

As discussed above, SMUD tested and proved the use of a smart meter to control a PV inverter. Before rolling out this functionality in a real world setting or across the service territory, SMUD needs to consider the following practical challenges:

- Several functions could compete for AMI network bandwidth – SMUD is considering many different uses of its AMI network such as DR control, communications, and electric vehicle charging management and monitoring that will be competing for bandwidth. SMUD conducted a preliminary assessment of the impact of using the network for controlling PV systems. The impact was small, but needs to be assessed against all the other potential uses.
- Deciding on a level of utility control – SMUD found that all the technology and protocols exist to meet SMUD desired functionality of a PV smart meter interface. However, many of these functions could be done by the inverter autonomously. The California Public Utilities Commission and California Energy Commission have an open proceeding on this, but SMUD needs to decide its preferred path forward.
- Developing a roll out schedule considering PV industry dynamics – The PV industry is changing rapidly and deploying new technologies and business models that could change how SMUD controls inverters. SMUD needs to regularly track these changes and assess their impact on control of inverters.

What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be developed?

When SMUD was awarded this project in late 2009, very little work had been done by industry stakeholders in this area (e.g. equipment vendors, utilities, standards making organizations, etc.). In the four years since then, several efforts have begun to define technical requirements for advanced inverters and their integration with utility communication systems. These efforts include:

- Smart Energy Protocol (SEP) 2.0 – this is a technical requirements document developed by the ZigBee Alliance that defines a protocol for communication between a smart meter and a PV inverter
- SunSpec Alliance – A working group of PV industry stakeholders has created open information standards to help facilitate interoperability between different vendor's PV components. As part of this, they created a standard for advanced inverters.
- CEC/CPUC Candidate DER Capabilities Working Group– In an effort to update California's Rule 21 Distributed Energy Resource interconnection standard, the California Public Utilities Commission (CPUC) and California Energy Commission (CEC) started a working group to define mandatory requirements for PV inverters interconnecting in California. Their work is ongoing, but some mandatory requirements included automated volt/var control, ability to change real power output based upon utility signals and a low voltage/frequency ride through capability.
- Inverter Manufacturers – Several European countries have been using advanced inverters for several years and vendors are now offering these in the US.
- OpenADR – The OpenADR protocol has been developed in the past decade to serve as a flexible, open protocol for Automated Demand Response (ADR). However, it has several functions that could be leveraged for utility control of inverters.

As a result of all this work, the project team believes that the required codes, standards and reference designs are already in place.

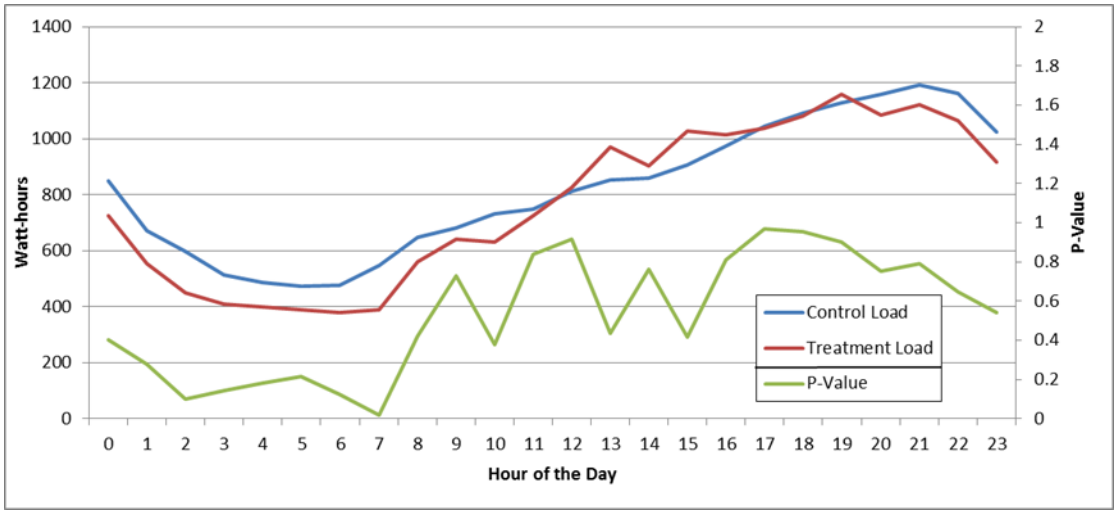
3.4 Strategic Objective 4

Determine if capacity firming and advanced pricing signals will influence the energy usage behaviors of customers

Do the customers who have capacity firming capability (energy storage) behave differently than those who do not?

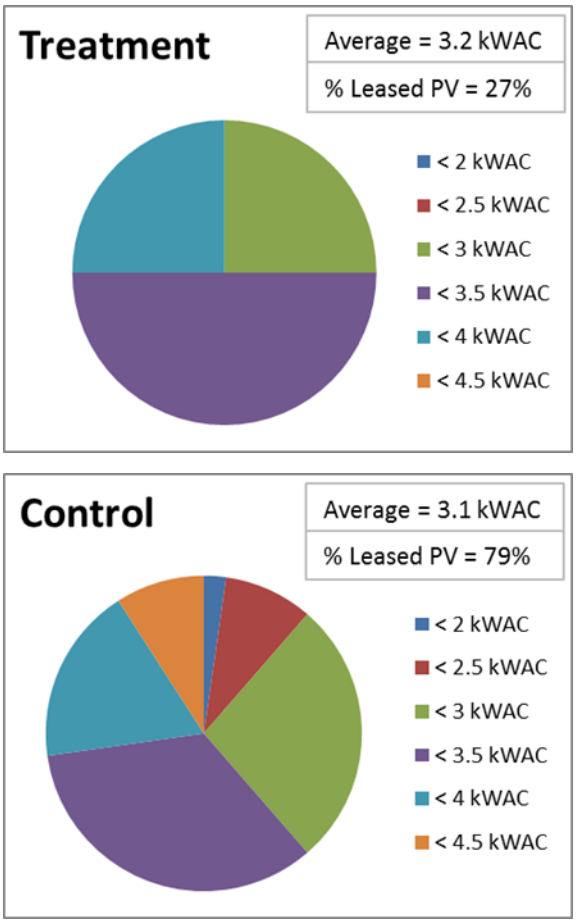
Customers with PV and energy storage do not use more total daily energy or draw more peak demand than customers with only PV. Figure 14 shows some minor deviations, but this is likely due to the small sample size of the treatment group (i.e. the RES customers).

Figure 14: Average Daily Load Shape for Customers with PV and Energy Storage (Treatment Group) versus Customers with only PV (Control Group).



Before comparing meter data between the two groups, Navigant looked into whether the control group is representative of the treatment group. Navigant compared the average PV capacity per home, the proportion of customers leasing their PV, and the distribution of PV capacities (Figure 15). The average PV capacity and the distribution of PV capacities are similar between the two groups.

Figure 15: Comparison of Representativeness between the Treatment Group and the Control Group



Navigant also verified the quality of meter data before reviewing any results. The analysis team ultimately removed ~4% of the data as having possibly erroneous meter reads and/or data gaps. Navigant also limited the data to May 1st through May 9th, and May16th through June 1st in order to avoid days in which the units were in smoothing and would likely display erratic loads.

To compare the meter data between the two groups, Navigant tested the average daily energy consumption, the average daily peak demand, and the hourly difference between the two groups. The energy load at 7 am is the only significant difference, although the demand at 2 am is almost significant because this is when the RES units were charged.

Table 7:. Statistical Results Comparing Behavioral Differences Between Customers with PV and Energy Storage (Treatment Group) and Customers with Only PV (Control Group)

Statistical Test	Treatment Group Average	Control Group Average	P-Value
Average Daily Energy Consumption	18.5 kW	19.6 kW	0.86
Average Peak Demand	1,506 W	1,535 W	0.90
Average Load at 7am	391 W	547 W	0.06

Given the limited number of sites and the short time-period of interest, the project team cannot confidently propose that this trend will continue, or that this trend has occurred during other time periods or trials. However, the findings fit with the expectations based upon customer feedback received.

Do the customers with the RES behave differently than those with CES?

The original intent was to recruit residential customers on CES connected transformers to be part of the study by agreeing to have higher resolution monitoring and installing a customer portal. SMUD was not successful in this because of lack of interest, even with monetary incentives. SMUD used a very thorough approach of direct mailing, email and phone calls, and only recruited two customers to participate.

Given this lack of interest, SMUD can make the assumption that customers connected to a transformer with energy storage would not be aware (or interested) in its presence and likely would not change their behavior because of its presence. The comparisons from the previous question are then valid for this group of customers as well.

How does energy storage impact the customer's ability/desire to respond to pricing signals?

The intent was to (a) allow customers control of their energy storage units and (b) implement a Critical Peak Price (CPP) rate of $0.75/kWh for 12 hours a year to test customer response to pricing signals. However, SMUS was unable to implement these for the following reasons:

- SMUD did not allow for customer control of the RES units because the RES appliance interface and GridPoint software required extensive development and the schedule did not permit additional modifications. Further, SMUD did not feel comfortable giving customers control of brand new technology.
- SMUD Customer and Rates department did not want to place such a small number of customers on a special rate because of the large effort required in doing so and that SMUD was in the midst of a customer pricing study in which customers had already been placed on this rate.

As a result, SMUD did not test the customer's response to real time pricing signals.

However, SMUD did switch the RES customers from a tiered rate structure to a time of use rate structure that included an off-peak, on-peak and super-peak rate structure. The off-peak rate was ~$0.10/kWh and $0.25/kWh during super-peak. A billing analysis of before and after the rate was implemented found little change in RES customer energy usage during peak times. This suggests that (a) the super-peak rate was not high enough to elicit a response and (b) since the customers could not control the units, they did not respond to changes in rates. This finding was confirmed by a post-demonstration survey of the RES participants in which eight out of nine survey participants said the time of use rate had little to no impact on the way they used energy.

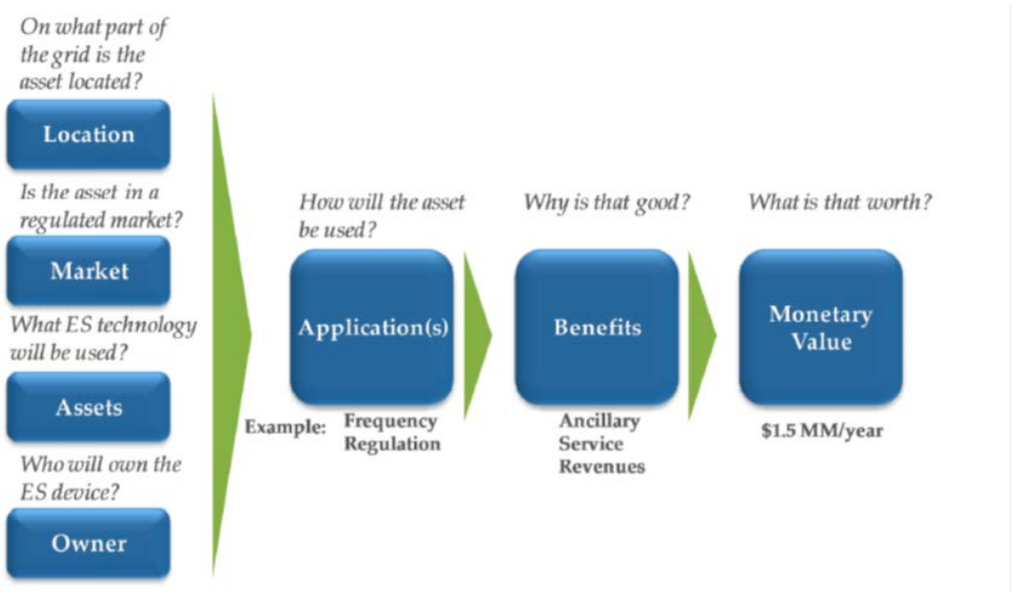
Chapter 4:
Value of PV and Energy Storage

4.1 Framework

In order to assess the business implications of this technology for SMUD and other interested parties, Navigant calculated the value of the distributed energy storage configurations deployed. Navigant also looked at value accruing to both the utility and its customers. Navigant used the Energy Storage Computational Tool (ESCT) that Navigant developed for the DOE's Office of Electricity[9] to calculate the benefits of different energy storage technologies and applications.

The ESCT characterizes energy storage projects by identifying key characteristics of the deployment (i.e. by identifying the location, type of market, owner and type of energy storage asset deployed) and by identifying how that deployment will be used (i.e. the applications it will it be used for). Different applications will lead to various benefits whose monetary value can be quantified using sets of equations and appropriate inputs. Figure 16 depicts the overall methodology that the tool employs to determine the monetary value of an energy storage deployment. The final set of benefits are brought into net present value terms and normalized by power capacity, resulting in $/kW metrics.

Figure 16: Description of How the ESCT Works



[9] More information about the ESCT is available at http://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_computational_tool

4.2 Configurations Analyzed

The first four characteristics that must be defined in the ESCT are location, market, assets and owner. The project team confined the analysis to what was deployed and looked at the three configurations shown in Table 8. The two locations chosen – on the distribution system and at an end user – match the CES and RES locations, respectively. SMUD is in effect a regulated utility, so Navigant used a regulated market. For assets, Navigant used the exact configurations tested. Configurations 1 and 2 match the CES and RES deployments, respectively. SMUD technically did not test configuration 3, but had planned to at the beginning of this study, so Navigant analyzed it.

Table 8: Configurations Analyzed for Benefits

Configuration #	1	2	3
Location	Distribution System	End User	End User
Market	Regulated	Regulated	Regulated
Assets	30 kW/34 kWh Li-Ion Systems	5 kW/7.7 kWh Li-Ion Systems	5 kW/7.7 kWh Li-Ion Systems
Owner	Utility	Utility	End User

Navigant also used data measured and calculated during the study to inform the benefits analysis. This included:

Round Trip Efficiency- In the quarterly data analysis reports, SMUD had been tracking the RES and CES round trip efficiencies. The RES unit efficiencies have been between 80% and 90%, varying strongly with weather. The CES unit efficiencies have been in the mid to upper 80%.

Equipment Lifetime – Since this was only a 1.5 year demonstration, SMUD did not have enough time to observe how the energy storage cells age. Thus, SMUD worked with the equipment vendors to develop estimates of system lifetimes and arrived at 15 years. Note that this might require cell replacement to reach 15 years. However, given that Navigant performed a net present value analysis of the benefits and are using discounted cash flows, the financial difference between at 10 and 15 year life is small.

4.3 Applications

The ESCT framework contains eighteen different applications for energy storage, but Navigant focused on those relevant to SMUD and the configurations SMUD tested. SMUD did not look at applications related to ancillary services because the focus of the study was on functionality that could help integrate high penetrations of DG PV on a feeder and ancillary services are grid level functions.

4.3.1 Configuration 1 – CES

The first configuration represents the CES units tested, but scaled up in number to represent a realistic deployment. The community studied currently has 33 transformers, so Navigant assumed full deployment of CES units across three communities similar to the one studied. Thus, Navigant simulated 100 CES units. Navigant looked at the following applications individually and bundled together:

Electric Energy Time Shift - The Electric Energy Time-shift application involves storing electricity when the price of electricity is low and discharging that electricity when the price of electricity is high. SMUD demonstrated this capability many times during the study and also demonstrated the ability to flexibly schedule the units throughout the year to respond to seasonal changes in power prices, weather, and sunset timings.

Voltage Support - The Voltage Support application involves using energy storage assets to provide distributed or centralized voltage support. Storage is well suited for this application because it is quick to respond, can be sited where it is needed, and can effectively provide voltage support during contingency conditions. Voltage support could be provided by dispatching real or reactive power. In the study, SMUD did not test the unit's reactive power capabilities, but did demonstrate load smoothing with real power dispatch. This could have the effect of improving voltage in the event of severe PV ramping events.

Distribution Upgrade Deferral - Upgrade deferral is the process by which utilities delay the need to replace or enhance equipment within the grid, usually by using a power source or load management to reduce the peak load served by the equipment to below the equipment's rated power. The Distribution Upgrade Deferral application involves installing energy storage in order to delay distribution system upgrades. The value of this application is derived from the fact that storage can be used to provide enough incremental capacity to defer the need for a large 'lumpy' investment in distribution equipment.

4.3.1.1 Configuration 2 – RES

The second configuration represents the RES units SMUD tested – customer sited systems with utility control. Navigant scaled up the number of units to represent a wide scale deployment by SMUD. The Anatolia neighborhood currently has approximately 300 homes and Navigant assumed one third had an RES unit to arrive at 100 units in one neighborhood. Navigant then looked at three neighborhoods having this level of deployment. Given that the units are owned by the utility, the same applications apply as configuration one. The differences in value will be a function of the performance characteristics of the units and the amount of storage relative to the local electrical system.

Configuration 3 – RES with Customer Ownership

The final configuration is one that SMUD considered testing but ultimately did not pursue because of schedule and budget constraints – customer control of customer sited energy storage systems. Again, Navigant looked at a larger scale deployment – 100 homes in a neighborhood similar to Anatolia. For applications, Navigant focused on things customers would likely do with their units – control their energy bills and enhance power quality. Since SMUD's

residential customers (and a majority of residential customers in the US) do not have demand charges, Navigant focused on energy charges.

Time of Use Energy Cost Management - For the Time-of-use (TOU) Energy Cost Management application, energy end users (utility customers) would use energy storage devices to reduce their overall costs for electricity. They would accomplish this by charging the storage during off-peak periods when the electric energy price is low, then discharge the energy during times when on-peak Time of Use (TOU) energy prices apply. SMUD demonstrated this many times during the study by operating the energy storage as a customer would. The 15 RES customers were put on a TOU rate as part of this study and SMUD charged the units during off peak hours and discharge them during Super Peak hours.

Electric Power Reliability - The Electric Service Reliability application involves using energy storage to ensure highly reliable electric service. In the event of a short or extended service disruption, the energy storage can be used to provide power to critical loads. SMUD did not test this function during the demonstration because current grid interconnection rules (IEEE 1547) require distributed generation to trip offline in the event of an outage. However, SMUD received several participant questions about this and has discussed the concept with energy storage equipment vendors, so Navigant analyzed its benefits.

4.4. Benefits

As discussed above, Navigant modeled the benefits of the energy storage configurations SMUD actually deployed. To inform the analysis, Navigant made extensive use of monitored data from the project and forecasts from various departments within SMUD. The following sections describe data Navigant used for the calculations and the resulting benefits.

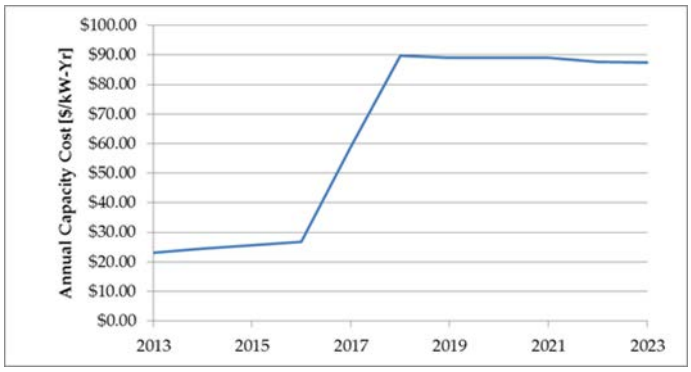
4.4.1 Common Data Sources

For the analysis, SMUD used data from other planning efforts. Key data includes:

Power Prices: Navigant used hourly price forecasts for the next 15 years as modeled by SMUD's Resource Planning And Pricing Department. In the months outside of super-peak (October through May), the difference between on-peak and off-peak was low – typically $10/MWh. In the super-peak months, it averages $16/MWh, but gets as high as $56/MWh. These relatively low differentials are driven by low natural gas prices that are expected to persist in the near future.

Capacity Prices: SMUD Resource Planning and Pricing Department also provided their capacity price forecasts, shown in Figure 17. Prices are very low now because California has an excess supply of capacity. While they are expected to rise in 2018 because of the need for new capacity, $90/kW-Yr is lower than many other parts of the country.

Figure 17: SMUD's Capacity Price Forecast

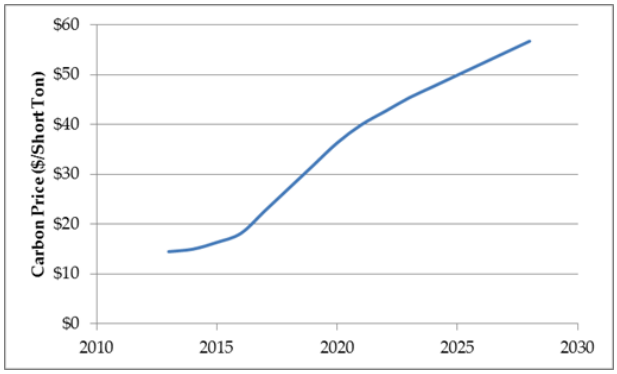


Deferred Distribution Costs – In 2011, SMUD had a study commissioned to look at various options for different types of energy storage[10]. As part of this study, SMUD distribution engineers looked at feeder needed upgrades and estimated what the required costs and how much energy storage could defer them. SMUD arrived at a likely value of $100/kW-Yr for three years and an upper value of $158/kW-Yr for five years. Refer to the full report for details of the calculations.

Voltage Control Costs – Also as part of 2011 study, SMUD estimated the value of voltage support to be $3/kVAR with an upper value of $8/kVAR. This was based upon the cost of shunt capacitors – the most common technology currently providing voltage support.

Emission Price Forecasts – SMUD's Resource Planning And Pricing Department provided the carbon price forecast shown in Figure 18. It is based upon internal SMUD estimates that account for resource mix, policies and other external variables. Navigant focused on carbon exclusively as SMUD's fossil fleet is entirely natural gas fired, so NOx and SOx emissions are relatively low or negligible

Figure 18: SMUD's Carbon Price Forecast



[10] Benefits Analysis of Energy Storage: Case Study with the Sacramento Utility Management District, 2011, EPRI report 1023591

Distribution System Characteristics – For all of the calculations of impacts to the distribution system, Navigant used data on the neighborhood where SMUD did actual testing. Key characteristics were:

- Approximately two miles of distribution line between substation and neighborhood transformers;
- Peak load of 1.3 MVA based upon the feeder monitoring;
- Voltage of 12.47 kVA; and
- Impedance of 0.245+j0.208 ohms/mile based upon equipment data from SMUD.

Financial Inputs – In order to calculate the net present value of benefits, Navigant used SMUD's current cost of capital – 6.17% as a proxy for the discount rate and a generic 2% assumption for inflation.

Configuration 1 – CES

For this configuration, Navigant analyzed three applications: Electric Energy Time-Shift, Voltage Control and Distribution Upgrade Deferral. These applications result in several different benefit streams and Navigant calculated each benefit as follows:

Reduced Electricity Cost – the calculation Navigant used is: Total Energy Discharged for Energy Time-Shift (MWh) x [Avg. Variable Peak Generation Cost ($/MWh) – Avg. Variable Off-Peak Generation Cost ($/MWh) /Energy Storage Efficiency (%)] and the source for each variable is :

- Total Energy Discharged for Energy Time Shift – Navigant looked at hourly pricing data and weather patterns and assumed the energy storage units would be used to shift energy from mid-May to mid-October. This comes to 152 days per year. Based upon SMUD's super peak period (4 to 7 PM), Navigant assumed a three hour discharge. Navigant also looked at hourly prices and assumed the units would be charged at night whenever prices were lowest, over a three hour period. Using operating parameters from the study, Navigant assumed the units are charged to 90% State of Charge (SOC) and discharged to 20% SOC. This equates to 23.8kWh of discharge for one unit or 2.38 MWh for the 100 unit fleet.
- Variable Generation Costs – As discussed above, SMUD's Resource Planning And Pricing Department provided hourly power price data. Navigant calculated the average price differential between peak and off-peak prices from mid-May to mid-October and used those.
- ES Efficiency – Navigant used the value of round trip efficiency discussed above based upon measurements from the equipment

Deferred Generation Capacity – This benefit assumes a utility can monetize capacity savings either through lower capacity payments or offsetting construction of a new peaking facility. Given the size of the configuration relative to a typical peaking plant, Navigant are assuming

the former. The calculation Navigant used is Capacity Price ($/kW-Year) ÷ 8760 hours/year x 1000kW/MW x Peak Reduction (MW) x Number of Hours of Peak Reduction (Hours) and the following data sources:

- Capacity Price – Navigant used the data discussed above on capacity price forecasts.
- Peak Reduction – The assumed 100 units have a total discharge capacity of 2.38 MWh and spreading that out over three hours comes to a peak reduction of 0.79 MW.
- Number of Hours of Peak Reduction – Navigant assumed that the discharge for Electric Energy Time Shift is during peak hours, so the total hours is 152 days times three hours per day = 459 hours.

Reduced Electricity Losses – The benefit captures the fact that SMUD is shifting usage to off peak periods and reducing peak load on the feeder. Since losses are proportional to the square of the current, reducing peak load on circuits will result in fewer overall losses. The equation for this calculation is complex and involves several parts. Please refer to the ESCT user's guide[11] for a full description, but Navigant used the measured neighborhood peak load and impedance data from SMUD to calculate the value of this benefit.

Improved Power Quality – This benefit captures the impact of the Voltage Support Application discussed in 4.3.1. The value is calculate by multiplying the energy storage systems reactive power capacity times the capital cost of conventional voltage support discussed in 4.4.1. Note that Navigant assumed the energy storage units could provide Voltage Support either via reactive or real power capabilities. If using real power capabilities (the unit's smoothing function), that would take away from storage capacity used for Electric Energy Time Shift. To assess the magnitude of this, Navigant looked at the average energy storage discharge on high solar volatility days when the units were in smoothing mode (this is discussed above in section 3). Navigant took this average discharge by day and multiplied by the number of high volatility days observed from mid-May to mid-October (the period Navigant is assuming for Electric Energy Time Shift) and subtracted that from the annual discharge from Electric Energy Time Shift. This came to 8 MWh/year less of Electric Energy Time Shift.

Deferred Distribution Investments – The benefit only accrues during the years the investment is deferred and is calculated by:

Benefit = Distribution Capacity Deferred (kVA) x Capital Cost of Deferred Distribution Capacity ($/kVA)

---

[11] The user's guide is available at http://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_computational_tool

For the capacity deferred, Navigant used the output of the 100 energy storage units during Electric Energy Time Shift - .79 MW – and used a simplifying assumption of a power factor of one. Navigant used the distribution capital cost assumptions discussed in 4.4.1.

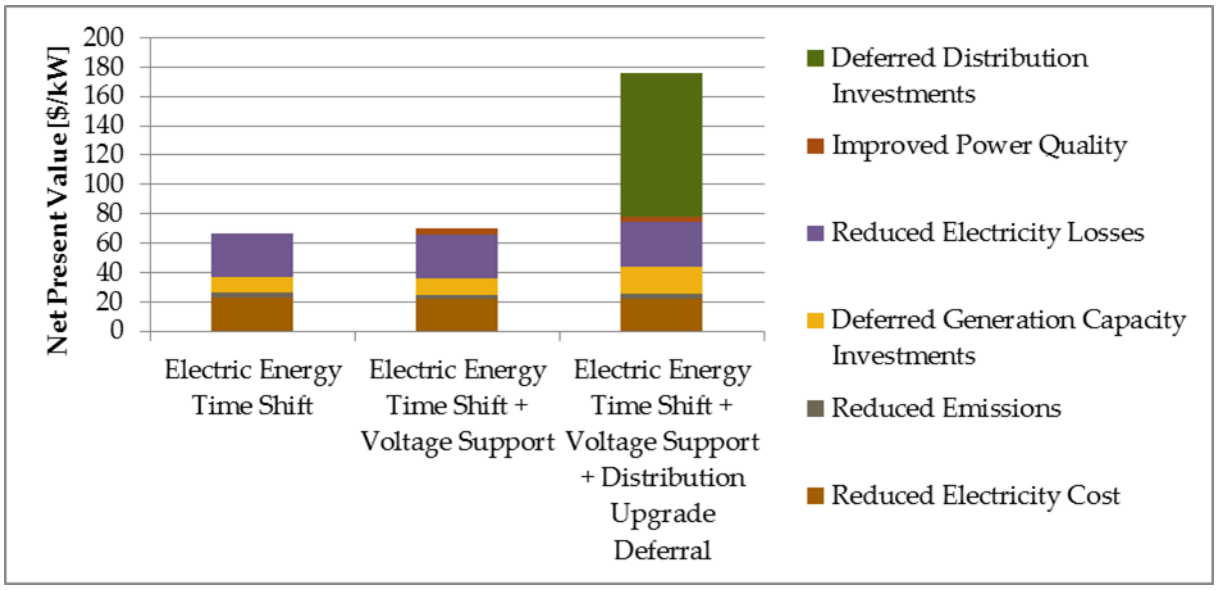
Reduced Emissions – This benefit captures emissions savings by shifting generation from peaking plants to baseload plants that have presumably lower emissions. This is certainly the case in SMUD's service territory as they do not have any baseload coal resources. The calculation is:

Benefit = Energy Discharged for Energy Time-Shift (MWh) x [Emissions Factor for Generation on the Margin (tons/MWh) – Emissions Factor for Base Generation (tons/MWh)/ Storage System Round-trip Efficiency (%)] x Value of Emissions ($/ton)

SMUD's Resource Planning And Pricing Department provided emissions factors for their on peak and off peak fossil resources and Navigant used the emissions forecast discussed in 4.4.1 above to calculate the value.

Figure 19 shows the resulting value of each of these benefits. It shows the cumulative impact by adding in benefits. The biggest benefit is Deferred Distribution Benefits when using the energy storage for Distribution Upgrade Deferral. SMUD's 2011 value study cited that most of SMUD's distribution system is well built and will likely not need upgrading in the near and mid-term. Thus, the most representative near term value of configuration one is $70/kW-Year.

Figure 19: Benefits of Configuration One, Broken Out by Application



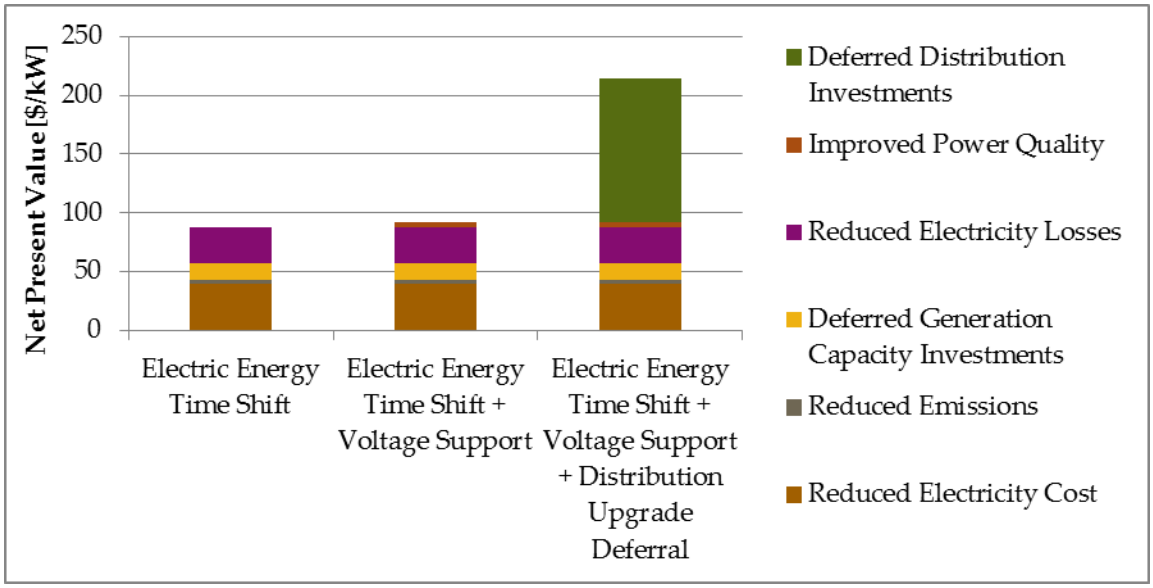
Configuration 2 – RES

The applications and benefits for this configuration are the same as configuration one because the utility still owns the asset and would operate them in the same manner. The difference lies is the actual equipment used and the location of deployment. The differences are as follows:

- Navigant simulated 300 units RES units in three neighborhoods instead of 100 CES units spread over three neighborhoods. Using the actual unit size (7.7 kWh capacity) and discharging from 90% to 20% SOC, this comes to a 1.62 MWh/day discharge capability all in one neighborhood.
- Navigant also analyzed a three hour discharge for this configuration, which comes to .54 MW peak.

The results are shown in Figure 20, by application. The results are very similar to configuration one except the magnitude is higher. Some of this is because of normalization by a smaller total system size and some of it is due to more energy storage being installed in one neighborhood. Again, Deferred Distribution Investments is the largest value, but will not likely be applicable to most high penetration solar neighborhoods.

Figure 20: Results of Configuration Two, Broken Out by Application



Configuration 3 – RES with Customer Ownership

For this configuration, Navigant analyzed two applications: Time-of-Use Energy Cost Management and Electric Service Reliability. As discussed above, SMUD did not demonstrate Electric Service Reliability but several customers asked about the capability and the project team understands that equipment vendors might be developing products with the capability. Note that this is the first configuration in which some of the benefits directly accrue to the customer whereas the benefits of configuration one and two only apply to SMUD.

These applications result in several different benefit streams and Navigant calculated each benefit as follows:

Reduced Electricity Costs – As discussed in 4.3.3, the primary benefit for customers owning the energy storage is shifting from high rates to low rates on a time of use rate. In this case, Navigant used the actual rate the RES customers were on - ~$.25/kWh on Super Peak from 4 to 7

PM, ~$.16/kWh on Peak, and ~$.09/kWh off Peak for June through September. Navigant assumed the customers would charge at night and discharge for three hours during Super Peak. The exact calculation is: Benefit = Total Energy Discharged for TOU Energy x [On-Peak Retail Price of Electricity ($/MWh) – Off-Peak Retail Price of Electricity ($/MWh) /Storage System Round-trip Efficiency (%)]. With the capacities of the storage systems, the total discharge per year for one customer would be 0.46 MWh.

Reduced Electricity Losses, Deferred Generation Capacity Investments, Deferred Distribution Investments, and Reduced Emissions – This benefit is calculated in the same manner as discussed in 4.4.2 except that Navigant used 100 RES systems in one neighborhood instead of 100 CES units across three neighborhoods.

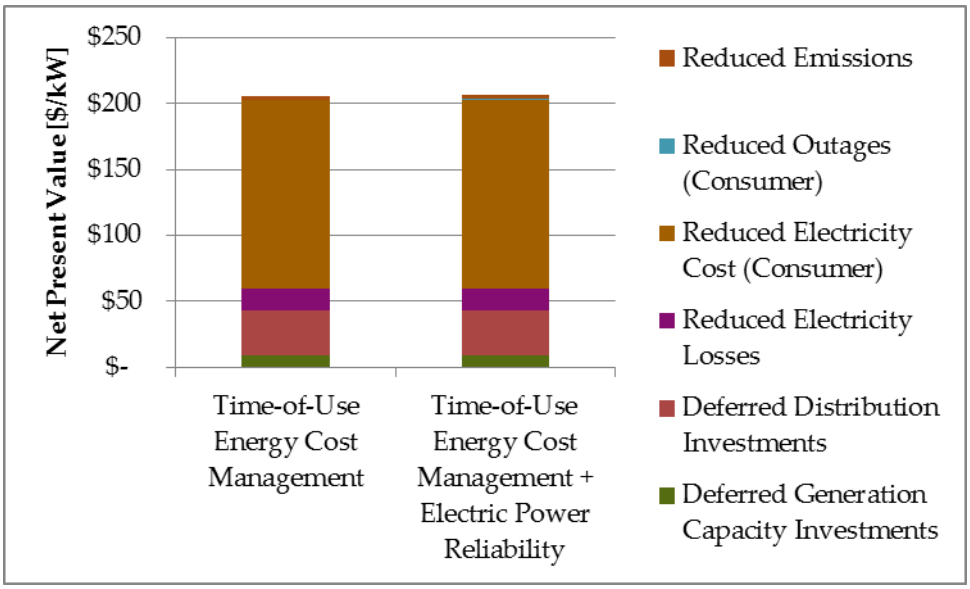
Reduced Customer Outages – As discussed in SMUD's previous study of the value of PV10 , assessing the value customer's place on being able to service critical loads during an outage is difficult. The best information available for residential customers is from a 2009 Lawrence Berkeley National Laboratory (LBNL) study[12]. The LBNL report surveyed many other studies that asked residential customers about their willingness to pay for a service that provided power during utility outages. From this, the LBNL team developed values for different regions of the country and different outage lengths. Please refer to the full report for more detail, but the values ranged from $1.4 to $6.9/kW.

Assessing the value per event is the first part of the calculation. The second piece is calculating an assumed number of events per year. SMUD publishes its SAIDI and SAIFI statistics online and Navigant used those to develop CAIDI statistics for several different years. Using this data, the calculation is: Benefit = Duration of Power Quality Events Per Year (hours) x Average Un-Served Load (kW) x Value of Service ($/kWh). Navigant ran this calculation using different levels of CAIDI, un-served load and Value of Service that Navigant found.

Figure 21 shows that the largest benefit accrues to the customer and is related to electricity costs savings. The value of reduced outages is very small. This is due to (a) SMUD has a very reliable grid and has fewer outages than many other utilities and (b) the value of service numbers reported are currently low. However, the most recent of these studies was done several years ago and Navigant suspects that as residential customers rely more and more on electronic devices (e.g. tablets, computers, smart phones, etc.), the reported values will go up. Also, if customers were to compare the value to the cost of a portable generator, the value could be several thousands of dollars.

[12] Sullivan Et. Al. Estimated Value of Service Reliability for Electric Utility Customers in the United States, June 2009, LBNL-2132E

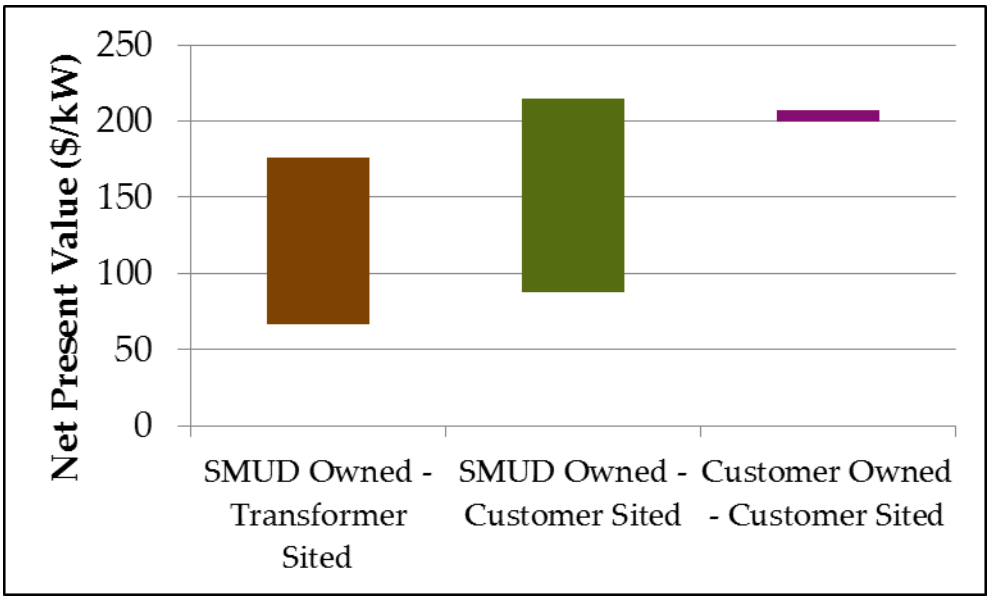
Figure 21: Results of Configuration 3, Broken Out by Application



4.5 Summary

Figure 22 compares the value of each configuration. Configuration 2 – SMUD owned but customer sited – has the highest value, but recall most of the value is in deferring distribution upgrades and that is not likely to be applicable in most circumstances in the near term for SMUD. In the next section – strategic implications for SMUD – Navigant examined how value might change under different scenarios of energy prices, capacity prices, etc.

Figure 22: Comparison of Value by Configuration



Chapter 5:
Strategic Implications for SMUD

This section assesses the implications of this project on how SMUD views and manage distributed energy storage in high penetration PV applications. The project's implications for how SMUD may integrate energy storage are discussed first and then how SMUD can use storage to manage high penetrations of distributed PV is discussed.

5.1 Integrating Energy Storage

5.1.1 New Business Models Using Distributed Storage

Before developing programs and incentives for distributed energy storage, SMUD must select a business model or models to adopt. As part of the project Navigant tried two models – discussed below – but many more are possible. To date, the energy storage industry has not decided on a common solution, so the intent of this section is to develop a comprehensive list of possible options and discuss the pros and cons of each.

Business Model Elements

Business models to deploy distributed energy storage and PV can take many forms. To compare different ideas, Navigant looked at several different variables, discussed below and summarized in Table 9.

- Location – The energy storage could be located at the customer or SMUD's property. SMUD tried both during the project.
- Owner – During the project, SMUD only demonstrated SMUD ownership, but the customer or a third party could own the system. All three ownership options have been proven out in the distributed PV space.
- Interconnection – An energy storage system could be connected to the PV system or directly to the grid. In the project, the PV systems were already installed, so SMUD did not have the option to connect to PV and storage together as an integrated system.
- Financing – Beyond the system owner buying the equipment up front, SMUD could participate in financing to help support the industry. SMUD could provide a loan for ustomers or third parties to buy the equipment and to support the technology, the loans could be at subsidized rates. SMUD could also lease the equipment at market or subsidized rates.
- Utility Control – The project was constrained to 100% utility control, but equipment vendors are selling products for 100% customer control as well. A third option could be primarily customer control with occasional control by the utility. This would be similar to air conditioning demand response programs in which a customer controls their air conditioner most of the year, but the utility can either cycle the unit or reduce the temperature set point if needed for an agreed upon compensation.

Compensation – SMUD could chose to provide compensation to customers or third party system owners to: support a high potential technology that is not yet cost effective, incent certain usage behaviors, or incent customers to install certain monitoring or control equipment. This could be done through an upfront incentive, payment for specific services (such as VAR support) or a fixed, re-occurring payment that does not vary by usage. All three of these options have parallels in other industries and have been demonstrated commercially.

Table 9: Summary of Distributed Energy Storage and PV Business Model Variables

Business Model Variables					
Location	**Owner**	**Interconnection**	**Financing**	**Utility Control**	**Compensation**
Customer	Utility	Direct to Grid	SMUD Provides Loan	SMUD 100% Controls Asset	Upfront Incentives
Non-Customer	Customer	Direct to PV	SMUD Leases to Customer	Owner 100% Controls Asset	Regular Fixed Payments
	Third Party		SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
			Customer Owns		Upfront + Payment by Service
			Third Party Owns		

Next, Navigant brainstormed all possible combinations of these variables. During this process, Navigant made several assumptions:

- Customer ownership with 100% utility control doesn't seem likely as the customer would not be engaged. SMUD received feedback from study participants that they did not get a lot of value out of energy storage when they cannot control it.
- If SMUD is leasing or providing a loan for customer's to own energy storage, they are doing so at a subsidized rate and will not also provide upfront incentives. However, they might provide performance based incentives for customers to use the energy storage in a certain way.
- For customer sited systems which SMUD owned, SMUD would want control at least some of the time.

While these assumptions did reduce the number of potential business models, the list of possible models is large at 54 possible business models. A full summary is contained in Appendix C and shows all possible variations of the variables listed in Table 9.

Comparison of Business Models

After developing a comprehensive list of business models for distributed energy storage and PV, Navigant looked at the pros and cons of each model to three stakeholder groups: SMUD, SMUD's customers, and companies involved in PV and energy storage. Navigant broadly defines the last stakeholder group as Third Party and it includes equipment vendors, system integrators, installation contractors and financial entities involved in distributed energy storage and PV.

Each of these stakeholder groups is important to SMUD and SMUD's strategic directives direct it to consider each one in the development of new programs. The tables below look at the pros and cons of each business model variable on each of these groups and Appendix C contains a detailed description of the pros and cons of each business model.

SMUD is currently developing a business case for a solar and storage program. The pros and cons developed in this report will inform the models selected.

Table 10: Pros and Cons of Possible Locations for Distributed Energy Storage (ES) and PV

	SMUD		Customer		Third Party	
Location	Pros	Cons	Pros	Cons	Pros	Cons
Customer	Opens up possibility of customer ownership and this enables more business models	Accessing/repairing equipment will require coordination with customer	Customer can own and control ES to manage energy costs; Customer can feel involved in program	ES equipment operation and maintenance can impact customer; ES equipment could take up space in customer's home; Customer bears safety risk	Third Party has the opportunity to develop direct customer relationships and possibly sell other services	Third Party has to recruit customers to host ES and this could require lots of overhead
Non-Customer	Accessing equipment does not required coordination with customer; If SMUD owns, asset can be moved to maximize value	Does not provide a way to engage customers	Customer not impacted by day to day operations and no customer liability risk for safety issues	ES could be located next to transformer on customer's property; Customer might not feel involved in program	Third Party could install more ES per site; likely lower recruitment costs	No customer interaction to sell other services

Table 11: Pros and Cons of Different Ownership Structures

	SMUD		Customer		Third Party	
Owner	Pros	Cons	Pros	Cons	Pros	Cons
SMUD	SMUD can control equipment; Easy for SMUD to monetize benefits	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer does not need to maintain for finance equipment	Customer does not feel involved and might not be able to control energy costs	Does not require third party to develop ownership and financing models and this may be difficult in a relatively new industry	No involvement in business model beyond equipment manufacture and installation
Custom er	SMUD customers feel engaged in program; SMUD does not need to maintain equipment	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; Monitoring and control equipment and systems could be required	Customer can control ES to capture benefits and manage energy costs	Customer responsibl e for maintenan ce and bears safety liability; Customer might need to finance	Does not require third party to develop ownership and financing models and this may be difficult in a relatively new industry	No involvement in business model beyond equipment manufacture and installation
Third Party	Industry feels engaged in programs; SMUD does not need to maintain equipment	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; Monitoring and control equipment and systems could be required	Customer not responsible for maintenanc e; Financing not required	Customer does not feel involved and might not be able to control energy costs	Allows for industry participation beyond just manufacture and installation; Third party can control as needed to earn revenue	In the near term, financing might be difficult to obtain for relatively new industry

Table 12: Pros and Cons of Interconnection Options

	SMUD		Customer		Third Party	
Interconnection	**Pros**	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Direct to Grid	Direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	Extra equipment or software might be needed to monitor PV system output	ES performance and maintenance not tied to PV system	Customer cannot use ES to store PV system output for later usage; Two inverters might be required and this would be more expensive	ES performance and maintenance not tied to PV system	Two inverters might be required and this would be more expensive
Direct to PV	Likely easier to monitor PV system output	Grid support functions might be more difficult	Customer can use ES to store PV output and dispatch during times of high demand or high electricity costs	Might not be able to earn incentives or payment for grid support functions	PV and ES could be sold as a bundled product with only one inverter	Might not be able to earn incentives or payment for grid support functions

Table 13: Pros and Cons of Financing Options

	SMUD		Customer		Third Party	
Financing	**Pros**	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
SMUD Provides Loan	SMUD could specify required monitoring, communications and control equipment in order to get a loan	SMUD needs to develop a loan program, which might be a new business area	No upfront costs for ownership	Customer has to take on debt	N/A	N/A
SMUD Leases to customer	SMUD could specify required monitoring, communications and control equipment in order to get a lease	SMUD needs to develop a lease program, which might be a new business area	No upfront costs for ownership	Lease could be viewed as a lien against a home	N/A	N/A
SMUD Owns	SMUD can control the equipment	SMUD must rate base all the equipment and program costs	No upfront costs for ownership	Customer might not be able to control operation	No upfront costs for ownership	Third Party might not be able to control
Customer Owns	SMUD does not take on the equipment costs, but could still get benefits	SMUD might not be able to specify required equipment or operation	Customer can manage as desired	Potentially large upfront costs	N/A	Third Party might not be involved
Third Party Owns	SMUD does not take on the equipment costs, but could still get benefits	SMUD might not be able to specify required equipment or operation	No upfront costs for ownership	Customer might not be able to control operation	Third party can control operation	Third Party must obtain financing

Table 14: Pros and Cons of Different Levels Of Utility Control

	SMUD		Customer		Third Party	
Utility Control	**Pros**	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
SMUD 100% Controls Asset	SMUD retains control of asset	SMUD does not support third party involvement in operation	Hassle free for customer	Customer cannot manage energy costs	N/A	Third Party cannot operate to maximize their revenue
Owner 100% Controls Asset	SMUD does not need to set up and pay for communications and control systems	SMUD cannot control the ES equipment and it might not be used in a way that benefits SMUD	Customer can manage energy costs	SMUD might not be able to access or control the equipment to help with troubleshooting or control the equipment to provide reliability benefits	Third Party can operate to maximize revenue	N/A
Owner Mostly Controls Asset, with Occasional Utility Control	SMUD would be able to control if needed and specify communications and control equipment	SMUD cannot control the ES equipment all the time and operate it to fully benefit SMUD	Customer can manage energy costs but SMUD can access the equipment to help with troubleshooting or control the equipment to provide reliability benefits	Customer cannot control all the time	Third Party can operate to maximize revenue	Third Party cannot control all the time

Table 15: Pros and Cons of Different Compensations Schemes

	SMUD		Customer		Third Party	
Compensation	**Pros**	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Upfront incentives	Simple to implement and does not require monitoring equipment or verification processes	ES might not be used as efficiently as possible	Reduces first cost and no ongoing monitoring required to get performance based incentives	Customer not incented to use system efficiently to manage energy costs	Reduces first cost and no ongoing monitoring required to get performance based incentives	Third Party not incented to use system efficiently to maximize revenue
Regular Fixed Payments	Simple to implement and does not require monitoring equipment or verification processes	ES might not be used as efficiently as possible	Simple program and no ongoing monitoring required to get performance based incentives	Potentially high first costs; Customer not incented to use system efficiently to manage energy costs	Regular payments provide stable revenue stream	Third Party not incented to use system efficiently to maximize revenue; potentially high first costs
Payment by Service	SMUD can design compensation schemes to ensure ES is used effectively and benefits SMUD	Monitoring and communication equipment required to verify performance; Overhead costs required to operate and maintain and program	Customer can operate ES to maximize return on investment and manage energy costs	Potentially high first costs	Third Party can operate ES to maximize revenue	Potentially high first costs
Upfront + Payment by Service	SMUD can design compensation schemes to ensure ES is used effectively and benefits	Monitoring and communication equipment required to verify performance;	Reduces first cost and customer can operate ES to maximize return on investment	N/A	Reduces first cost and Third Party can operate ES to maximize revenue	N/A

	SMUD	Overhead costs required to operate and maintain and program	and manage costs			

5.1.1.1 Technology Readiness

SMUD considers many factors when assessing a technology's readiness for inclusion in programs or a wider deployment. This section discusses what was learned from this project in the context of what factors SMUD uses to assess a technology.

- **Fit with Strategic Directives** – Distributed energy storage and PV can help SMUD with the following strategic directives:
  - Empower customers with solutions and options that increase energy efficiency, protect the environment, reduce global warming, and lower the cost to serve its region. (Strategic Directive 1-B)
  - SMUD's rates shall be designed to balance and achieve the following goals
    - Meeting customer energy requirements (Strategic Directive 4)
    - Maintain a high level of customer relations (Strategic Directive 5)
  - Be an environmental leader through community engagement, continuous improvement in pollution prevention, carbon reduction, energy efficiency and conservation (Strategic Directive 7)
  - Meet greenhouse gas reduction goals by 2050 (Strategic Directive 9)
  - Integrate emerging technologies into SMUD's customer offerings (Strategic Directive 18)
- **Benefit to Customers** – This technology can benefit SMUD's customers in several ways:
  - Electric Power Reliability – SMUD did not test the backup power capability of the energy storage units. However, if a product was offered in the future that complied with all relevant regulations, distributed energy storage could be used to provide higher electric reliability to SMUD's customers.
  - Ability to Manage Energy Costs – Distributed energy storage coupled with PV would give customers another tool to manage their energy costs.

They could charge the unit during times of low cost and discharge during times of high cost.

- o Overall Rate Reduction – If SMUD can deploy distributed energy storage and capture all the benefits, the value would eventually be passed onto SMUD customers through lower rates.

- **Cost Effectiveness** – As discussed above, the benefits range from a Net Present Value $60 to $200/kW of unit capacity. Contrasting this against current installed costs of several thousands of $/kW suggest they are not cost effective right now. However, future developments could change and likely improve the cost effectiveness of distributed energy storage systems.

- **System Cost Declines**

  The units used in the project cost several thousand dollars per kW. These costs are in line with current distributed energy storage prices reported by EPRI study[13] . The report showed residential scale Li-Ion systems at between $7,500/kW and $13,000/kW and community scale Li-Ion systems at between $1,800/kW and $5,500/kW.

  However, the equipment SMUD purchased represented some of the first units from manufacturers, so the costs are not representative of high volume manufacturing prices. Further, recent press releases and statements by battery manufactures indicate goals of cell prices dropping 50% by 2020 because of innovation and scale up. Thus, distributed energy storage prices will likely decline going forward.

- **Power Market Conditions**

As discussed in 4.4.1, a combination of low natural gas prices and abundant supply of capacity in California are creating low market prices for energy and capacity. For the value analysis above, SMUD used most likely projections that foresee these conditions persisting. Future unforeseen jumps in natural gas prices or limiting of capacity supply capacity would significantly change power market conditions and distributed energy

storage would have more value. Likewise, higher emissions costs would increase the value of distributed energy storage. Figure 23 and Figure 24 below show the impacts of two future scenarios:

A. Capacity prices rise to the upper end of those shown in Figure 17, carbon prices trade at the high end shown in Figure 18 and power prices double their current levels.

---

[13] *Energy Storage System Costs, 2011 Update*, EPRI, February 2012

B. Capacity prices rise to current levels in other parts of the country (PJM-ISO is currently at ~$160/kw-Year), carbon prices trade at the high end shown in Figure 18 and power prices triple their current levels.

Scenario A drives up value by ~35% and Scenario B increases value ~90%. These two scenarios illustrate that while distributed energy storage is not cost effective for SMUD now, it may be in the future under certain changes in power market prices.

Figure 23: Impact of Scenarios on Value of Configuration One – Community Energy Storage Owned by SMUD

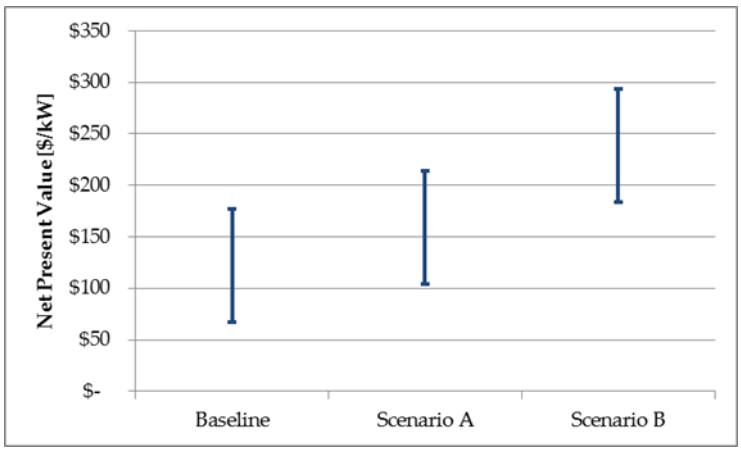
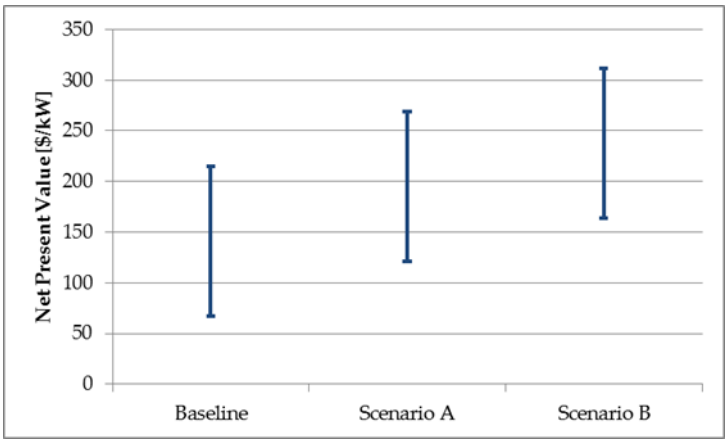


Figure 24: Impact of Scenarios on Configuration Two – Residential Energy Storage Owned by SMUD



The project team did not look at the impact of unforeseen changes in rate structures on configuration three because they vary much slower than power market prices and SMUD's rate structure is undergoing changes (as discussed below in section 5.2.3).

- Reliability – Table 16 contains an availability analysis of the test units throughout the test period and Table 17 shows a binning analysis of this data.

Table 16: Availability Analysis of RES and CES Unites

	Availability						
Unit	Q2 2012	Q3 2012	Q4 2012	Q1 2013	Q2 2013	Q3 2013	Totals
RES1	88%	100%	97%	100%	100%	100%	82%
RES2	88%	64%	88%	100%	100%	44%	93%
RES3	89%	100%	98%	48%	0%	100%	66%
RES4	20%	0%	90%	100%	100%	100%	69%
RES5	89%	37%	88%	100%	100%	100%	84%
RES6	85%	14%	0%	34%	14%	100%	42%
RES7	35%	100%	15%	23%	100%	44%	61%
RES8	87%	100%	99%	100%	100%	44%	95%
RES9	86%	100%	100%	97%	100%	100%	93%
RES10	89%	100%	95%	100%	24%	100%	75%
RES11	34%	47%	0%	34%	0%	100%	35%
RES12	89%	100%	99%	93%	100%	44%	94%
RES13	85%	100%	100%	66%	11%	100%	64%
RES14	7%	100%	100%	32%	98%	44%	57%
RES15	88%	100%	93%	87%	91%	97%	87%
CES 1	100%	74%	100%	50%	45%	100%	80%
CES 2	100%	100%	80%	59%	71%	20%	73%
CES 3	75%	74%	71%	59%	87%	100%	76%

Four of the units had availability over 90%. The other units had low availability for a variety of reasons:

- Component failures;
- Firmware upgrades; and
- Delayed maintenance and troubleshooting because of difficulty coordinating a visit with a site owner or scheduling the right staff from the project team.

In addition, SMUD was very cautious in operating the units and immediately shut them down if a customer experienced any issues. In one instance, SMUD shut down the entire fleet when there was a safety concern with one unit.

Table 17: Binning Analysis of Availability

Total Availability Over Test Period	Count of Units
>90%	4
80% to 90%	4
70% to 80%	3
60% to 70%	4
<60%	3

- Technical Risk – Through the demonstration project, SMUD obtained a good understanding of what the technical risks are with distributed energy storage and PV and how to manage them. See the lessons learned section of this study for a longer discussion of the issues encountered.
- Controls and Integration with Utility Systems – The unit and fleet level controls were designed specifically for the project and met the needs of this demonstration project. Before integration into SMUD's operating systems, the unit and fleet level controls would have to go through more optimization and testing to meet SMUD's needs.
- Market Risk – Market risk is a broad category that includes sub-categories like customer acceptance, viability of business models, matureness of supply chain, presence of trained installation work force and codes/standards to facilitate installation. While a detailed assessment of each of these items is outside the scope of work, SMUD demonstrated and learned several things during this project that can help SMUD assess the market risk.
    - Customer Acceptance – Potential business models for deploying distributed energy storage with PV could include customer sited energy storage. During the project, SMUD received lots of interest from Anatolia residents in hosting an energy storage system. This suggests that customer acceptance could be high with the right business model.

- Viability of Business Models – Section 5.1.1 contains a longer discussion of potential business models for distributed energy storage with PV and suggests that no winning business models have developed yet. However, we demonstrated two business models in the project – utility owned, sited and operated, and utility owned, utility operated and customer sited. This suggests that some business models are possible.
- Matureness of Supply Chain – The project partners SilentPower and PowerHub are offering commercial products, as are other vendors. This suggests that a supply chained has developed to support some level of an industry.
- Presence of Trained Installation Workforce – The project team was able to work with local electrical contractors to install the equipment and they did not require any extra training beyond what the technology partners offered in directions. This should not be a barrier to broader adoption.

- Codes/Standards – For safety, SMUD required certification of the RES units to UL 1741, which means a safety certification is in place. The project team then worked with the city of Rancho Cordova to obtain building permits for installation. They did not have an existing process in place and it is suspected most cities do not. The creation of a template or sample building permitting process for distributed energy storage would help support the industry.

Observations – The technologies SMUD deployed functioned as expected and met all the demonstration project objectives. The project team has identified some areas for further work – cost, reliability and controls and integration - prior to a large scale roll out.

5.2 Managing High Penetrations of PV

High penetrations of distributed PV on a feeder or across a utility's service territory can potentially impact utility operations and require equipment upgrades. Potential issues include:

- Voltage control violations
- Power quality issues (e.g. flicker)
- Reverse power flow
- Increase wear and tear on utility equipment (such as cap banks and LTC's)
- Real and reactive power imbalances
- Frequency issues if a utility cannot "see" large MW's of behind the meter PV
- System wide power supply due to daily morning and evening ramping of PV

The potential impact of high penetration varies significantly and is influenced by feeder design, location of the PV, magnitude of PV installations, load, existing equipment and solar resource variability. While the Anatolia neighborhood has a high penetration of PV (almost 100% of homes have PV), the feeder that serves the neighborhood has several large loads closer to the

substation. This effectively reduces the relative penetration of PV. As a result of this and SMUD's standard methods for designing distribution networks, we have not seen any of the issues above[14].

However, the project team demonstrated many functionalities of energy storage that could mitigate the issues if they arise in neighborhoods similar to Anatolia or any other neighborhood. Table 18 shows how these functionalities could help. Thus, while SMUD might not have high penetration PV problems now, SMUD demonstrated several uses of energy storage for mitigation

Table 18: Mapping of Tested Energy Storage Functionality Against Potential High Penetration PV Issues

Tested Functionality	Issue Addressed	Mitigation
Perform Smoothing of Combined PV and Load	Voltage control issues; Increased wear and tear on utility equipment; power quality issues	Energy storage could be added to a community with a high penetration of PV and put in smoothing mode to balance out fluctuations in PV output that can cause these issues
Shifting Load	Reverse power flow; System wide power supply because of ramping	Energy storage could be deployed to charge or discharge to mitigate these issues
Charging or Discharging on Utility Command	Reverse Power Flow	If energy storage were deployed in a community that experienced reverse power flow, SMUD could charge the energy storage to absorb the excess PV production

5.2.1 Leveraging Smart Meter Network

SMUD demonstrated the ability to control a PV inverter via a smart meter and then examined the practical challenges associated with using Advanced Metering Infrastructure (AMI) for managing PV. SMUD first looked at other competing uses for AMI network bandwidth. SMUD then looked at scenarios for PV penetration against the size of SMUD's AMI network. Next, SMUD compared AMI with customer broadband as a means for control. Finally, SMUD looked at some emerging trends that could impact utility control of inverters.

[14] Impact of SolarSmart Subdivisions on SMUD's Distribution System, July 2009, NREL/TP-550-46093

5.2.1.1 Overview of Potential Field and Customer Applications

To put residential PV based communications in the context of the overall uses (current and potential) of the AMI network, it is useful review the many possible applications that may need to leverage the AMI network. A variety of network based applications are likely to require communications throughout the service territory. To understand how PV related applications fit into the picture, it is useful to look at the spectrum of applications that are likely to require communications.

Applications vary in their communications requirements, focus and criticality to SMUD, but they will overlap geographically. Many future applications will be considered field communications, and have more traditionally been handled by Distribution Operations in utilities. Others are customer focused or at least require two way communications to the customer AMI meter. All these applications can potentially share network resources—and costs,--to make them individually more cost effective.

The overlap, interactions and priorities of the various applications will need to be reviewed, and some of them need to be understood better before network sharing can safely and effectively be achieved. Some network sharing is already being done with the AMI network (see Table 19 below under Meter Focused in the Application Focus Area column), and these applications will vie for use of the network.

SMUD's Smart Grid Vision, Strategy and Roadmap, Phase 1, enumerates many network based applications that are currently being piloted, and others that are envisioned for the future. SMUD has a strategy of using at least 3 distinct SMUD controlled field networks for different applications (AMI, Distribution Automation, Substation Automation—note that portions of the these networks use 3rd party carrier circuits, but the networks are still effectively defined and controlled by SMUD for cyber security reasons). SMUD also uses customer provided broadband for some applications (e.g., OpenADR pilot and some Home Area Network (HAN) communications pilots).

Table 19 below shows a partial listing of these various applications, and which of the three networks they are likely to be targeted for. Note that there will likely be Distribution Automation (DA) applications that will need to leverage AMI network, so there is not necessarily a clean functional division to these networks.

This type of analysis, with more detail about the specific network traffic characteristics of each application, can be used in planning and design of future network expansion, or at some point in the future, a wholesale upgrade of network infrastructure. For purposes here, it is assumed that the current Silver Springs Network (SSN) infrastructure will be in place at least through 2020, and that it can be upgraded to accommodate the most important applications for SMUD. One key thing to note is that the Infrastructure Management category (see Utility Area column in Table 19) can come to place a significant burden on network bandwidth, even if only periodically. One type of activity is likely to require firmware updates to enable different functions, which can require a significant amount of network bandwidth, and can impact operational and customer communications if not managed well.

Looking at the spectrum of applications and traffic requirements is one key to effective strategic network planning. Note that the green shaded areas indicate applications that are focused on PV functions, including monitoring and managing residential customer sited PV, but also the potential periodic updates (e.g., for protocol updates or compatibility) as well as for DA centric applications such as voltage stabilization and VAR support. SSN indicates that it should not be a problem from a bandwidth perspective supporting residential PV communications via ZigBee and SEP 2.0[15]. However, this support needs to be considered in the context of other applications that are likely to vie for use of AMI network and the specific timing of each.

[15] Mentioned in conversation with Obadiah Bartholomy, 9-4-13.

Table 19: Network centric view of applications required communications throughout SMUD's service territory

Network	Utility Area	Application Focus Area	Application	Notes
AMI Network: SSN Network 900MHz mesh with AT&T cellular backhaul	**Customer Centric Applications (Primarily Residential)**	Meter focused	Meter data (interval) for billing	These applications are the primary focus of AMI. These are meter-centric applications, and successful execution is necessary for the AMI business case.
			Automated connect/disconnect	
			Meter event notifications (e.g., tamper)	
			Advanced meter data (load research, etc.)	
			Other operational data...	
		HAN focused (DR and EE)	DLC programs (Smart tstat, load switches)	These are focused on HAN communications and leveraging the HAN for DR, EE, and customer commuications
			Smart Appliances	
			Pricing programs	
			Other...	
		PV focused	Monitoring status to provide customer information	These are focused on PV monitoring, management, and being able to provide information to customers
			Remote control/monitoring functions	
			Seasonal and conditionalpolicy management	
		Storage focused	Load shifting, energy storage	Storage monitoring/management and customer communications
			Other...	
		EV focused	Smart Charging (storage, etc.)	EV monitoring/management and customer communications
			Other...	
	Infra-structure Management	Daily/ Continuous	Daily: meter event notifications (network connectivity)	Network, HAN, PV, EV, Storage telemetry and monitoring that is needed on a daily basis
			Network infrastructure status monitoring	
			Status monitoring for apps (HAN, PV, Storage, EV)	
		Periodic (e.g., Firmware Updates)	Meters (900MHz module, Zigbee module, metering chip?) e.g., SEP 1.1 to 2.0 migration.	Periodic maintenance that requires network bandwidth: firmware updates to various network attached functions (e.g., upgrade from SEP 1.1 to 2.0 and beyond)
			Network (wireless access points)	
			HAN (zigbee modules for all HAN equipment, PCTs, smart appliances, etc.)	
			PV (smart inverter control chips)	
			Storage (storage control chips)	
			EV (smart charging control chips)	
	DA Centric Applications	CVR support	End-of Line voltage	Distribution automation functions which leverage information available via the AMI network (e.g., EoL voltage)
		OMS support	Outage detection (last gasp)	
		Power Quality	Inverter control for AC voltage stabilization and dynamic VAR Support (remote vs. local automation): PV and Storage	
DA Network: field radios to SONET backhaul	**Distribution Operations Centric Applications**	Reliability	VVO/CVR/FLISR-- wireless communication network	These are DA functions that leverage field commuications totally independent of the AMI network: these typically use the DA SCADA network infrastructure.
		Efficiency	CVR/VVO	
		Power Quality	Cap bank control and VAR support	
		Equip. health	Monitoring for condition based maintenance	
		etc.	Many other potential applications	
SA Network: frame relay over SONET to sub-stations	**Substation Operations Centric Applications**	Switching, manage-ment, security, safety, etc.	Numerous	These are substation automation functions that require high speed communications and often high bandwidth (e.g., IP security camera) to and from substations.

If a large number of these applications plan to use the AMI network (e.g., say several DR programs, including HAN communications to smart devices, etc. as well as some storage monitoring applications as well as PV applications), then the analysis should look at all the applications together and make the determination. Table 19 shows a list of possible applications for the AMI network—and the DA and Substation Automation (SA) networks—based on a review of some material made available by SMUD.

Residential Solar: Initial Network Scale Characterization

Given the context above, SMUD drilled down one level deeper and started to characterize the possible breadth of PV communications by looking at an estimated number of PV endpoints in the future.

Based on initial information on expected solar penetration from SMUD, Navigant has developed the following table of rough estimates of solar penetration for two future time periods. The total numbers were provided by SMUD, and the residential / C&I breakout was reverse engineered from the data in Table 21.

Table 20: Distributed Solar Penetration Estimates

	2020	2030
	MW	MW
Residential	51	250
C&I	299	1,450
Total	**350**	**1,700**

Green indicates initial information provided by SMUD

The MW penetration estimates in Table 20 were used to project the possible number of residential distributed PV endpoints (rooftops) in the same two time periods (see Table 21 below). Three different cases are shown. The Expected case was derived from a potential estimate provided by SMUD of 50K residential rooftops by 2030, with a speculated average capacity of 5kW. Given 51MW of approximate PV, that leads to almost 10,300 rooftops in 2020. To get the high and low estimates, a 40% variation in MW deployed was used, as well as a 20% variance in the average size of a residential PV installation. This yields a high estimate of 18K residential PV rooftops in 2020 that might need to be managed via a network—in this case using the AMI network. This is a lot of rooftops, but only 3% of the 600K AMI metering end-points in 2020.

Note that the percentage of existing AMI column assumes the full population of AMI meters to be 600K AMI meters deployed throughout the service territory.

Table 21: Estimated Number of Communication End Points for Residential PV

		2020			2030			
	kW/ House	# roof-tops	MW	% existing AMI	#roof-tops	MW	% existing AMI	Pena-tration Est.
High Est.	4	18,015	72	3.0%	87,500	350	15%	140%
Expected	**5**	**10,294**	**51**	1.7%	**50,000**	**250**	8%	**100%**
Low Est.	6	5,147	31	0.9%	25,000	150	4%	60%

The 3% of AMI endpoints requiring additional information does not seem that it should be difficult for the existing AMI network infrastructure to handle. However, the characteristics of the required communication are somewhat undetermined at this point, and fundamental questions such as how much intelligence is used locally at the PV installation to make automated decisions, versus how much communication to a central location is required, will drive requirements for bandwidth, latency and other required network characteristics.

Comparison of 900MHz Mesh AMI Network and Consumer Broadband

The section above shows that the impact to SMUD's AMI network would likely be small. However, control via AMI is not SMUD's only option for controlling PV inverters. In this project, SMUD demonstrated control of energy storage appliances via the customer's broadband connection and broadband provides an alternate communication pathway. To start the analysis of different options, Navigant started with a comparison between the basic attributes of the 900MHz wireless mesh infrastructure (Silver Spring Networks infrastructure) and customer broadband for use in communication to smart inverters.

Table 22: Comparison of SSN AMI Network and Customer Broadband for Inverter Control

Comparison Area	900MHz Mesh Utility AMI Network	Customer Broadband
Bandwidth	Varies by deployment architecture, but is likely asymmetric with *download* (to the home) being faster than *upload*.	Varies by location and service offering, and is typically asymmetric with *download* (to the home) being faster than *upload*. Typical download bandwidths range from 5Mbps to 40Mbps, and upload speeds range from 256Kbps to 10Mbps.
Latency	Varies by deployment architecture, but is likely asymmetric with *download* (to the home) being faster than *upload*. Latency is also likely to be higher than that of typical broadband. Latency is likely to be too long for some fast control functions.	Varies by location and service offering, but can range from 10ms one-way to 100ms or more one way, with the lower end of this range typical for areas with dense broadband connectivity. Note that TCP/IP networks do not guarantee latency. Latency is likely to be too variable for some fast control functions.

Comparison Area	900MHz Mesh Utility AMI Network	Customer Broadband
Control	Utility maintains control and can prioritize traffic (Quality of Service) within the limits of the technology.	Customer has control over some factors such as bandwidth provision and keeping the home routing equipment turned on. Internet service provider (ISP) has control over other factors such as QoS, bandwidth limiting, and in some cases restricting traffic types.
Cost	Utility bears this. Cost depends on deployment density.	Customer bears: $21 to $50/month for residential service is typical. Inverter traffic would "ride for free."
Location	Deployment can be focused where needed in the utility service territory.	Dependent on customer penetration and service availability from broadband service providers.
Co-existence with Other Applications	Utility controls the applications chosen to use the network (e.g., meter reading, end-of-line voltage reading, meter disconnect, etc.) These applications can interfere with one another if network is not designed properly or unexpected circumstances occur on the network.	Applications from other customers share portions of the network infrastructure, and can impact communications at times of high usage.
Availability of Channel	ISM Band, unlicensed communications can be subject to additional radio interference if other users in the locale choose to use the band. This can reduce available bandwidth and even cause erratic communications in some circumstances.	Service outages can occur from damage to the physical infrastructure due to construction, weather and other issues. Customers can also turn off their in-home routing equipment, causing connectivity to cease. Response time and repair time are not in control of the utility.
Security	Private network is likely a smaller target relative to customer broadband because it is a smaller network, a smaller geographic footprint and has less entry points. Additionally, the utility takes great lengths to ensure cyber security is paramount.	A range of end-end security mechanisms can be applied. Many of these are well developed and mature and in use for services such as on-line banking. The nature of public internet, however, is that malicious actors can be located virtually anywhere and may obtain access to customer targeted traffic.

Trends of Interest

The viability of and functionality of utility control of PV inverters will be impacted by two emerging trends – microinverters and third party leasing models. Microinverters could add functionality to control of PV inverters and third party ownership could complicate utility control of inverters if the third party wants to control the PV inverters as well. The discussion below provides an overview of both issues.

Micro-inverters

Microinverters are not a new concept; however, they had a breakthrough year in 2011 and are the most disruptive technology in the industry today. Microinverters are installed on the back of each panel, matching its rated capacity. The main benefit of microinverters is that their use results in an overall higher energy yield because they prevent one panel's failure or degradation from affecting the overall system's energy harvest (as is the case with most string architectures). With microinverters, each panel is effectively individually monitored, thus removing the need for DC cabling. This architecture distributes the overall risk of failure among the number of panels in the installation, and relies on information technology to identify and isolate the problem panel. By contrast, central inverters have a single point of failure, which can lead to longer periods of downtime if that inverter fails. With Multiple Power Point Tracking (MPPT) at the panel level, instead of the string level, microinverters are ideally suited for the residential and small commercial market segments, where a higher risk of shading is possible. The downside of microinverters is that they are typically two to three times more expensive than string inverters and have lower efficiencies (even though they do typically result in a better overall energy harvest).[16]

As if 2013, 38% of residential installations in the US now use microinverters. Approximately 50% of these installations are in California. Microinverters have been used in smaller installations (e.g., 2kW and below) but have been moving up into larger installations. The majority of these installations use detached architecture where the inverters are installed separately during installation; however, the market is moving quickly to fully integrated AC modules.

Whereas string inverters have an 8-10 year lifetime, the lifetime of microinverters is not well understood at this point. Microinverter lifetimes could turn out to be considerably shorter, given that they are positioned on the roof, and subject to daily heating and cooling cycles and other weather elements. This is a significant financial risk for leasing companies, as they can be required to replace this equipment upon failure. This fact is not lost on the investment community who are funding the leasing business. This unknown is slowing down the market adoption of microinverter based installations, and some smaller leasing companies are declining to work with microinverter installations due to fear of the risk exposure.

Residential Third Party Ownership Trends

Another recent phenomenon within the distributed PV market space is the solar lease model, whereby companies such as SunRun, SolarCity, and Sungevity finance solar PV arrays for customers. Such companies own the systems under a power purchase agreement (PPA) or lease,

---

[16] See "Inverters for Renewable Energy Applications." Research Report, Navigant Research. Q3, 2012. Dexter Gauntlett and Kerry-Ann Adamson, Ph.D., which contains significantly more detail on the solar inverter markets and players.

but offer customers fixed rates that typically lock in power costs at just below utility grid power. Since most utility rates go up over time, these solar PV customers – who may also employ net metering – pay less for electricity than those continuing to buy utility power. Contributing to these programs' popularity, many of these companies enable homeowners to install solar for little or no money down when the programs are combined with state incentives. In 2012, for example, the best SunRun deal in Oregon enables qualifying residential customers to pay $6,000 upfront and then receive $6000 in state and federal tax credits, in $1500 increments over the following four years.

These solar leasing options represented more than half the residential solar sales in California in 2011. The market share of solar PV leases is expected to exceed 75% for distributed installations in 2012. Solar leasing options – also known as solar power service agreements – are available in a dozen states and are causing a major shift in the demographics of today's typical solar PV customer. Median income zip codes are actually driving solar adoption. In the last three years in California, two-thirds of home solar installations have been in zip codes with median annual household incomes of less than $85,000 –not the wealthiest areas of the state. Moreover, the number of projects in lower income zip codes (666) was more than double the number in highest income zip codes (309) in 2011.

Almost all of these lease systems are monitored, as they need to perform within a certain performance parameters by contract to meet the PPA or lease. Various mechanisms are used for monitoring, including cellular network connectivity and consumer provided broadband. Customer broadband installations, while leveraging the connectivity paid for separately by the customer, has caused issues in cases where the broadband service is terminated by the customer, or where the in-home router gets unplugged for periods, etc.

Another issue that has plagued leasing companies is the wide range of vendor proprietary protocols needed to access information from the solar installation. A variety of different inverter vendor equipment can be selected by installers sometimes without respect to communication needs that will be required for management. This issue is being addressed by industry standards initiatives such as the SunSpec Alliance described above.

Rate Structures

Early in the project, SMUD held a rates workshop to discuss issues associated with high penetrations of PV, how energy storage might impact rate structures and consumer behavior under different rates structures. One goal of the study was to collect data on energy usage, PV output and usage of energy storage devices to inform rate making processes. However, during the course of the study, SMUD started a rate making process in which they are migrating all customers to time of use rates in the next five years, independent of technology adoption (e.g. PV, energy storage, etc.)[17]. Thus, SMUD will not be pursuing special rates for energy storage

[17] The new rate structures have not been finalized yet, so cannot report on them

customers in the near term. However, customers are free to respond to rates with technology they may adopt and SMUD is considering a deep discount for off peak hours that could benefit customers with energy storage.

In order to incent customers to use customer owned distributed storage in a way that benefits SMUD as a whole, rate design is not an option. Thus, SMUD will have to consider different incentive mechanisms to influence customer behavior. The team brainstormed ideas, some of which SMUD has been studying in other programs. The ideas include:

- Annual program participation incentives allowing for utility control. This would be similar to a demand response program for air conditioners in which the utility pays a residential customer an annual incentive for occasionally being able to control air conditioners.
- While the new rate structures have not been finalized, SMUD is rolling out a Critical Peak Pricing (CPP) program in 2018. A CPP rate typically has a very high energy charge for a limited number of hours per year, but this would likely incent a customer to dispatch their energy storage during this time.
- SMUD could provide event based incentives if customers use energy storage in a certain way. SMUD has experimented with this concept for demand response programs and had very favorable findings.
- To gain insight into what behind the meter energy storage systems are doing, SMUD could provide upfront incentives in return for installing monitoring equipment.
- SMUD could create a residential storage program parallel to its commercial auto DR program in which SMUD enters into contracts with commercial customers to deliver a minimum load during events. A similar program for residential customers would incent them to dispatch energy storage during peak times.

The SMUD team is taking these ideas into consideration for future program design. The key to successful implementation of any of these concepts is customer engagement and a lesson learned from the project suggests that some customers may be interested in new programs. At the outset of the project, SMUD flagged customer recruitment and engagement on the RES deployment as a high risk. However, the program was oversubscribed and customers showed lots of interest. Thus, as SMUD moves forward and considers new ideas for incenting certain behaviors with owners of energy storage SMUD can expect some customers to be highly engaged.

Chapter 6: Lessons Learned

The project involved many steps and touched several different areas of utility operations. During the project, the project team documented key lessons learned along the way and organized them in the categories shown here.

6.1 Billing

- SMUD was not able to implement a CPP rate because Customer/Billing pushed back on the difficulty of doing so for such a small group.
- Putting the RES customers on TOU rates was labor intensive and took longer than expected but once they were on the rate, it was easy to manage.
- As part of their participation in this demonstration of a new application of energy storage, SMUD promised to pay the customer for any excess electricity usage resulting from the testing. SMUD suspects this might have resulted in less behavioral changes than they might normally see.
- New rates or engagement techniques are need for these customers to influence behavior as they think they are using the most energy when their PV systems are producing. This is not the case as SMUD found summer transformer peaks after 7 PM in this neighborhood. One idea might be to send text messages and emails if a customer goes over a certain pre-defined amount of usage in a month.
- At the conclusion of the project, none of the RES customers wanted to stay on the TOU rate. The customers that participated in the study were very low users of electricity to begin with, so they stayed in the lower part of SMUD's tiered rate structure. Switching to a TOU rate resulted in higher bills for some of them

6.2 Customer Interaction

6.2.1 Customer Experience

- The RES customers valued participation and being involved in research effort sponsored by the DOE. They felt part of something big and that made an environmental impact. Many were also interested in trying something new.
- However SMUD did receive some complaints: child tampering that required resets; equipment noise when the RES were operating in smoothing mode; one customer requested SMUD to shut down their RES unit during a party; frequency and duration of visits for troubleshooting; and problems with internet related to an EMF issue between the RES unit and their broadband internet equipment.
- At the beginning of this project, SMUD identified the possibility of taking up too much customer broadband as a risk. This was never a problem during the project and SMUD did not receive any complaints about this.

- The project team established a detailed customer escalation process involving SMUD and Gridpoint, but customers ended up calling the team directly because the project team had established such a strong rapport.

6.2.1.1 Customer Recruitment

- Marketing and recruitment of CES customers was difficult. SMUD tried direct mailing, emails and phone calls and only signed up two participants. SMUD also offered a $50 gift card and suspect this was not enough to incent participation.
- SMUD had over subscription to host RES. This was due to many things: the project team had a recruiting event in the neighborhood and potential hosts got to speak with vendors and ask questions; SilentPower brought actual unit out so they could see it; and SMUD offered a $500 incentive for participating.
- While SMUD received lots of interest in RES participation, close, frequent contact was required to finally sign RES customers.
- During recruitment, the most common questions received from prospective site hosts were: "Can I buy it, can I control it, does it provide backup power, what benefits does it provide me or SMUD, and how will the installation impact me?" Answers to these questions will be integrated into future demonstration recruitment materials and could inform marketing materials if SMUD were to roll out a program like this.

6.3 Monitoring and Communications

- Relying on customer broadband for RES communication and control was not reliable and resulted in interference issues. SMUD used a lot of store and forward technology because SMUD anticipated that this might be an issue. In the future, SMUD should complete a pre-installation internet qualification to reduce instances where internet connectivity and stability interfere with system communication.
- This was SMUD's first time installing high resolution monitoring equipment on underground feeders and thus no design standard existed within SMUD. SMUD experienced several equipment issues with this: during the installation of monitors phasing got mixed up and required re-work, one piece of equipment had power problems, some of the communications equipment wasn't mapped correctly into SMUD's SCADA system, and some re-work required doing an outage which created scheduling difficulties. These findings are already informing how SMUD will do this in the future.
- Connection with the CES units via a cellular modem was lost regularly in the beginning of the project, but improved over the last two years as the cellular provider expanded coverage in the neighborhood. In the future, SMUD will make sure to test the cellular network early on.

- On the CES, SMUD had to move monitoring equipment to not be behind energized equipment. This improved the ease of trouble shooting and maintaining the monitoring equipment.
- The equipment vendors would have preferred direct access to the raw data from the OnDemand RES units. For the project, all raw data was fed to a central location. Though rare, there were instances where access to data was delayed due to a password, firewall or other security measure changes. This creates the potential for delays in accessing critical data for system monitoring or troubleshooting.
- Data transmission through the cellular network and the internet proved reliable with operational units regularly reporting more than 97% of their data points per day. The primary sources of data loss with these units were related to server uptime and RES or CES unit reliability. Software and firmware upgrades to monitoring equipment and storage units throughout the course of the project helped to alleviate these issues. The distribution transformer meters have configurable data reporting rates up to 60 points per second but bandwidth limitations through the cellular channels limit this to about 10 points per second in operation. The reporting rate for this project was set at 1 point per second based on the study parameters and the available resolution of the other collected data sets.

6.4 Integration

6.4.1 Storage Devices

- The project team engaged the City of Rancho Cordova Permitting Office early in project. SMUD also pro-actively engaged local fire service regarding the technology as they did not have any experience with it. Both of these steps helped expedite plan check and approvals.
- At the project proposal stage, SMUD had not decided to require the RES to be safety certified by UL. Once this decision was made after reviewing the RES unit design and battery characteristics in detail, this requirement as determined. This added substantial time to the project schedule. In the future, SMUD will allow more time for UL and IEEE compliance testing as this delayed the project.
- Equipment maintenance and trouble-shooting efforts were more complex than the project team expected and the project team did not have a test environment for troubleshooting. This will inform how SMUD does demonstrations in the future.
- The project team learned many lessons about operating and maintaining the CES units: the vendor had cooling fan issues throughout the project; the battery management module had issues; at SMUD's recommendation following deployment, the vendor went away from a lifting bar to a strap for lifting the CES during installation; had to replace whole circuit board because of capacitor issue; SD cards failed during the project; the vendor had to replace a modem; and the vendor had to replace batteries because they

went offline for too long and became unrecoverable. All of these findings will inform equipment design and operation for future products.

- The project team also learned many lessons about operating and maintaining the RES units: if voltage goes outside of range for the battery, it drops offline (this is still under investigation); SMUD had EMF interference between an RES unit and customer broadband equipment; the RES vendor had a manufacturing defect that caused SMUD to shut down all the RES units; the vendor had battery management module issues; and child proofing the equipment is necessary as there were kids turning off the equipment. To help with this, Silent Power, the RES vendor, will allow more qualification & testing time for specific battery types. We will expand testing into a broader range of operating conditions to ensure better performance and longevity from the batteries.
- Silent Power will allow more time for lab testing of hardware and software prior to deployment. This testing will include a broader sampling of operating conditions to better reflect real-world operating conditions and include all operational and communication paths to be used by Silent Power and its partners during the actual deployment.
- Silent Power Next-Generation product will allow for remote installation of code updates for all system components including the User Interface, Inverter, Charger and Shunts. This will further reduce in-home service calls and allow all RES units to be kept up to date with the latest software revisions without extensive travel and logistics.

6.4.1.1 Communications and Controls

- The storage scheduling software provided by GridPoint was easy to navigate by SMUD. However, storage unit programming was done event by event and time consuming to use. SMUD could have used more fleet level controls. Also it was not as user configurable like other operations tools.
- The project team did not have enough monitoring when something broke or malfunctioned. This would have reduced the trouble shooting time.
- The project team could have used a more definitive register map for error codes. SMUD received a large volume of error codes from the storage equipment and control systems, and this sometimes was a distraction.

6.5 Data Management and Analysis

- 10 second resolution was required to see the effects of smoothing. They could not be seen with five minute data.
- Spreadsheet tools were not adequate in handling sub-one minute data. The project team needed to develop database tools.
- The lack of time synching between data measurements was a time consuming issue to deal with. However, the project team was using equipment that was already installed (e.g., SCADA), so the project teamcould not change the time synching.

- Because the project team was integrating several sources of data and some were legacy, the project team did not have a single data repository for all the data. This might have sped up the analysis.
- The variety of high resolution data sources on the Anatolia circuit generated an immense about data over the study period of this project. The integration of metering from several different partners also resulted in a variety of data storage formats and transmission methods. These ranged from point-by-point one second data at the distribution transformer level to 5 and 15 minute resolution data collected at the households and forwarded to data concentrators on an hourly or daily basis. These varied sources resulted in several issues related to processing as sources from differing metering location types generally did not use common formats, requiring a large amount of post processing. Most of this was unavoidable however due the varied nature of measurement quantities and locations.

Chapter 7: Recommendations for Further Study

During the course of the study, the project team noted several items for further study. At the end of the project, they developed several more ideas for consideration. This section reviews each idea.

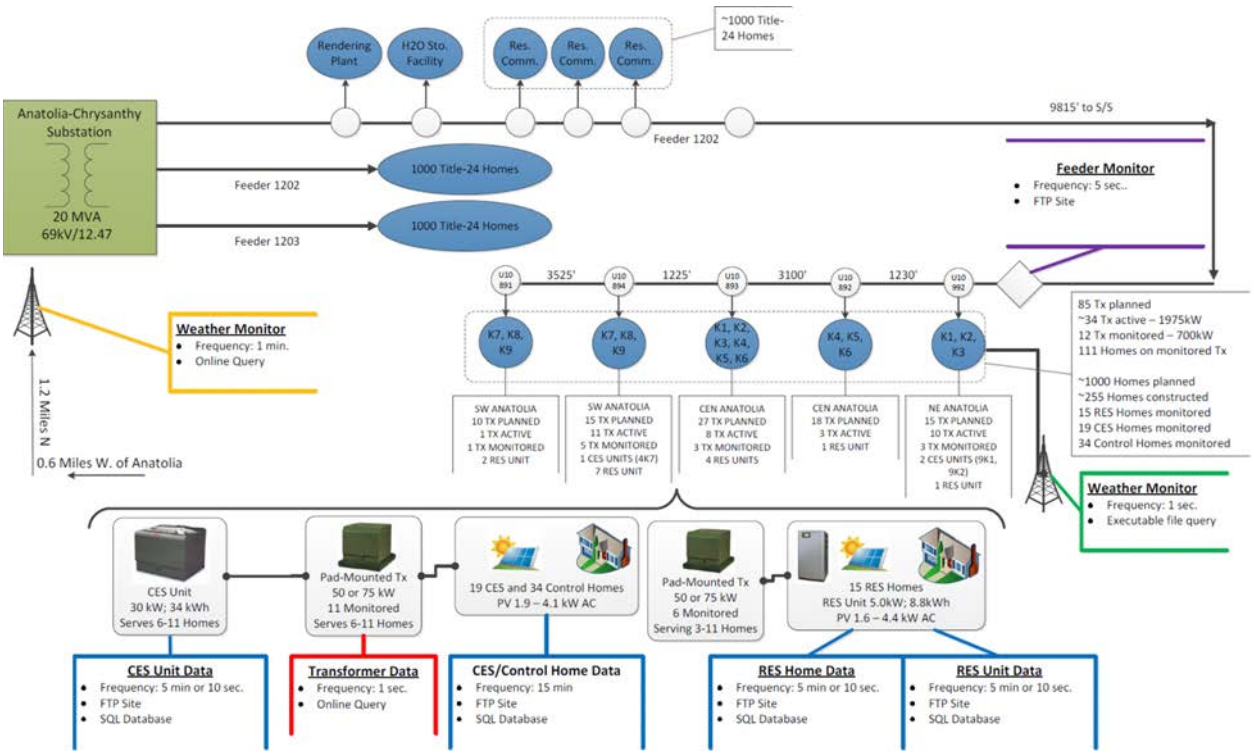
- Advanced control and communications architectures integrating the solar measurement locations with the battery systems and/or the PV inverters to provide firming.
- System modeling activities exploring the impacts of increased PV deployments and benefits of larger amounts of deployed RES and CES units. What amount of battery storage is required to produce the desired benefits?
- Integration of the high resolution measurement data with distribution modeling packages to assist with system identification, improved time series load modeling and better weather / irradiance modeling.
- Continued analysis of the data sets collected on this project. To this point the surface has only been scratched and a large amount of work remains to fully process the large amount of measurement data which was collected over the course of the project.
- Actually implement utility control of advanced inverters via AMI. The concept was explored in task 4.06 and the project team thinks the next step is pilot testing.
- Deploy customer controlled storage as this done in the study.
- Use findings from this study on current smoothing algorithm to develop and deploy new ones.
- Deploy storage at feeder/substation to contrast results for load shifting and smoothing with deployment at transformer and customer's homes.
- Deploy storage devices that can deploy four quadrant control for voltage and power factor management.
- Develop a white paper on how to do grid interconnected storage and have the device serve as back-up power for the customer.
- Look at a business model of swapping out batteries over time, but keeping appliance in the same place. This could be a way of extending equipment lifetime by swapping out degraded cells.
- Deploy rate structures that incent customers to use energy storage that benefits the utility and customers.
- Implement reverse power flow (e.g. backfeed) prevention at the CES. A mode could be designed in which the unit charges when it senses backfeed. Research would be needed on typical backfeed levels in order to size the energy storage correctly.

- Implement islanding capabilities with CES units in order to provide customer uninterrupted utility service. This would likely require additional equipment beyond what was tested in the project, but could add value to customers.
- Deploy more capabilities for remote shutdown and restart of the CES and RES units. This capability would have saved the project team considerable time and effort in the study.
- Conduct research on what form factor of RES units would be most appealing to

APPENDIX A:
Final Testing Results

We deployed high resolution monitoring throughout the neighborhood's electrical system, as shown in Figure 25. This allowed us to establish a baseline of the neighborhood and assess the impact of a high penetration of PV and the impact of energy storage. This appendix reviews the key testing metrics we tracked.

Figure 25: Diagram of Monitoring Plan



Distribution Monitoring

Most of the monitoring equipment we used was off the shelf, but twelve distribution transformers were instrumented with data collection hardware provided by NREL. Transformer metering was cited in order cover all three of the CES transformers, six transformers with RES attached (covering 10 RES units) and three baseline transformers. These units collect one second voltage, current, power, power factor and temperature measurements and transmit the data out in real-time to servers located at NREL where it is archived and made available to project team members for data analysis.

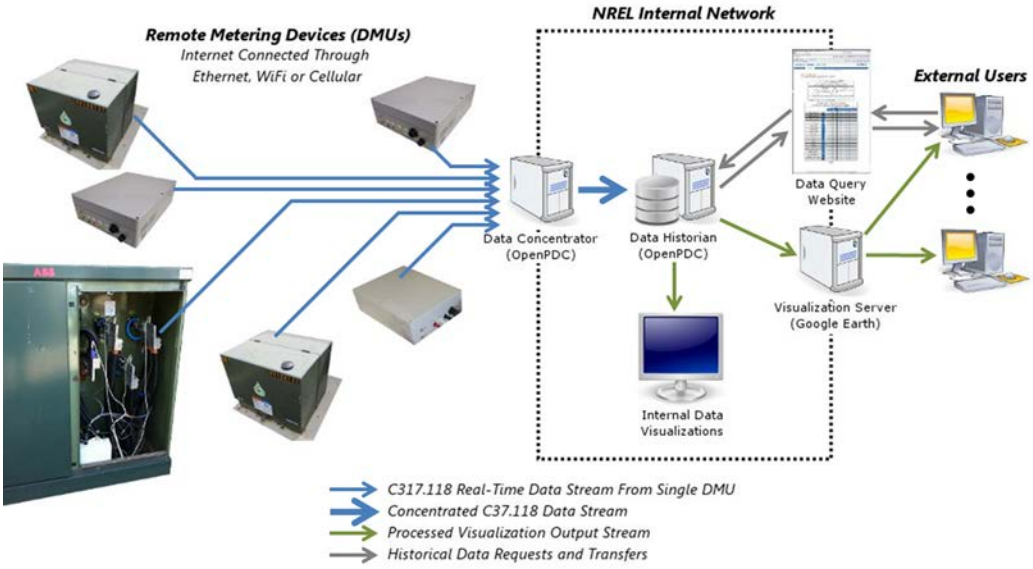
The basic system architecture is given in Figure 26. Each meter collects data from its location and transmits the data over the Internet back to the data concentrator. The data concentrator collates the multiple incoming data streams, producing one large data stream containing all of the information from the various measurement points. The concentrator data stream is then passed to the data historian. The data historian is responsible for maintaining and updating the

database that stores all of the received measurements. The historian also acts as the data hub for other applications, including various visualization applications, data processing, modeling inputs, and data retrieval tools. The data visualization applications present live and historic data in a variety of informative displays. Depending on the number of fielded meters and their data rates, hardware requirements, and reliability concerns, the concentrator, historian, and visualization applications may be hosted on one or multiple servers.

Data Collection and Storage

All of the collected data was eventually concentrated at an FTP site hosted by NREL. This site was available to all project partners for data processing and analysis tasks. Due to the varied nature of collected data sets all data was stored on this site in its native form with little preprocessing to standardize structures. All of these raw data sets are available in comma separated variable or excel spreadsheet format. Participating customer, RES, and CES data sets are uploaded daily by scripts running at Gridpoint and NREL. Anonymous home data collected by Sunpower is uploaded on a monthly basis. Weather, irradiance and distribution transformer measurement data is periodically uploaded by NREL using a series of scripts which process the raw binary data stored internally. The SMUD SCADA measurements were periodically uploaded by SMUD personnel. Several additional scripts and programs were developed specifically to process and analyze the large volume of data stored on the FTP site.

Figure 26: Distribution transformer data collection network architecture



The individual meters are outfitted with cellular modems and communicate with the data collection servers over the Internet using the IEEE C37.118 protocol[18]. When a connection is established, configuration information is exchanged and then data transmission begins. Each measurement set is packaged into a data frame, time-stamped, and transmitted to the data concentrator on a point-by-point basis.

The data concentrator maintains active connections to all of the fielded measurement devices. It also collates the incoming data frames by putting the measurements from the same time point into one augmented frame containing all of the measured values from that timestamp. In the system architecture of Figure 26, this combined data stream is then forwarded to the historian using the same C37.118 protocol for archival. The server side software for both the concentrator and historian is provided by the OpenPDC[19] package which handles the communications, data archival and provides an open source platform for integration of the data retrieval and visualization applications.

---

[18] "*C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems*", Dec 28 2011

[19] "*OpenPDC – Open Source Phasor Data Concentrator*", http://openpdc.codeplex.com/

A.1 Operating Scenarios Run

During the project, we ran many different operating scenarios that looked at variables of energy storage system operating mode, time of day, time of year, rate structure and solar insolation levels. The total number of tests run is shown in Table 23 and Table 24. Refer to the Monitoring and Testing Plan for details of the testing plan.

Table 23: RES Unit Testing Log

	Number of Tests Run			
Unit	Firming	Predictive Load Shifting	Custom Load Shifting	Load Shirfting by Price
RES1	150	90	140	24
RES2	165	91	143	25
RES3	98	83	66	24
RES4	108	43	112	7
RES5	140	74	116	17
RES6	70	33	28	25
RES7	71	35	70	20
RES8	159	90	138	24
RES9	145	90	138	24
RES10	120	84	70	24
RES11	36	34	39	17
RES12	151	91	130	30
RES13	98	79	55	17
RES14	83	56	98	7
RES15	143	88	134	24
Total	**1737**	**1061**	**1477**	**309**

Table 24: CES Unit Testing Log

	# of Tests Run	
CES Unit #	Firming	Load Shifting
1	121	258
2	110	216
3	83	245
Total	314	719

A.2 Amount of Load Shifted

During the project, SMUD ran several types of load shifting – optimal dispatch for SMUD, to optimal dispatch for the customer and dispatch via a predictive algorithm. The project team tracked the total amount of load shifted over the testing period and Figure 27 shows the results, by unit. Some units had a low about of load shifted, but that was due to their low down time, as shown by the availability data.

Figure 27: Total Amount of Load Shifted During Test Period, by Unit

Unit	kWh of Load Shifted	Availability
RES 1	1,025	82%
RES 2	930	93%
RES 3	509	66%
RES 4	543	69%
RES 5	660	84%
RES 6	183	42%
RES 7	493	61%
RES 8	751	95%
RES 9	667	93%
RES 10	471	75%
RES 11	154	35%
RES 12	833	94%

RES 13	334	64%
RES 14	758	57%
RES 15	1,010	87%
CES 1	3,848	80%
CES 2	3,468	73%
CES 3	2,695	76%

A.3 Battery Cycling

Table 25 summarizes the number of cycles run for smoothing. The units with a low number of cycles correspond to those units with low availability. Refer to the Q4 2012 data report for a more in depth analysis of the smoothing testing done and its effectiveness.

Table 25: Summary of Cycling for Smoothing Testing

RES Unit	Number of Cycles	Total Hours of Smoothing Testing	Average Cycles per Hour
RES 1	7,846	718	10.9
RES 2	4,274	493	8.7
RES 3	7,790	552	14.1
RES 4	617	102	6.0
RES 5	4,030	263	15.3
RES 6	5,833	227	25.7
RES 7	556	130	4.3
RES 8	6,272	566	11.1
RES 9	6,504	597	10.9
RES 10	9,500	615	15.4
RES 11	625	66	9.5
RES 12	7,586	457	16.6
RES 13	12,064	566	21.3
RES 14	6,587	535	12.3
RES 15	7,237	580	12.5
CES 1	12,860	1,006	12.8
CES 2	14,427	871	16.6
CES 3	14,265	874	16.3

A.4 Battery Efficiency

The project team tracked unit roundtrip efficiency in two ways throughout the project. The first was spot calculations throughout the project. Units were chosen s that had good availability and days which the units had a full charge and discharge. However, as shown in Table 26 and Table 27, a consistent trend in how efficiency changed with time was not seen.

Table 26: Sampling of RES Round Trip Efficiency

Unit	5/25/3013	1/25/2013	11/1/2012	7/4/2012	6/15/2012
RES 2	91%	90%	84%	83%	82%
RES 3	N/A	86%	81%	83%	85%
RES 5	87%	87%	80%	79%	83%

Table 27: Sampling of CES Round Trip Efficiency

Unit	5/25/2013	3/3/2013	11/2/2012
CES 1	82%	88%	85%
CES 2	86%	85%	86%

Second, the project team did a more in depth statistical analysis over a longer time period. The result is shown in Figure 28 and Figure 29 below. A total of 27 days were chosen for the RES data and 24 days for the CES data based on data quality, data availability, and battery operating scenario. These days were intentionally grouped throughout six weeks in order to use continuous logged data. The gap in data is due to a several month period in which the units mostly ran in firming mode. The figure shows that there is great variability in the performance of each battery.

Figure 28: RES System Efficiency Over Time

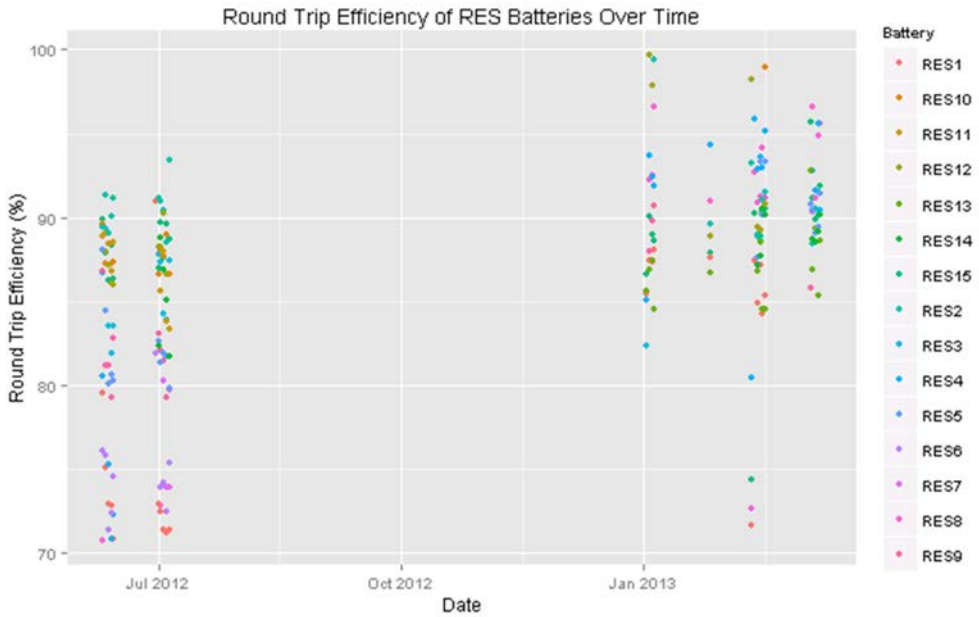
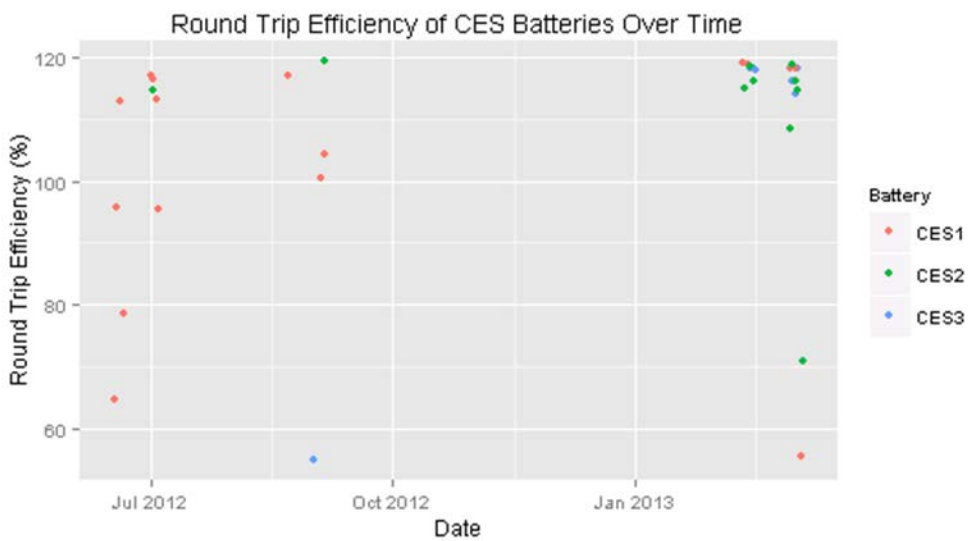


Figure 29: CES System Efficiency Over Time



From these two sets of analysis, the project team cannot draw any conclusions but this is not unexpected. The testing period was short compared to the typical lifetime of an energy storage unit (potentially 10+ years), so significant changes in efficiency might not be seen.

A.5 Solar Resource

During the course of the test period, the project team collected one minute solar insolation and weather data at a weather station in the neighborhood. Throughout the project, weather data was analyzed to characterize weather patterns and understand the variability in solar insolation.

To quantify the number of variable and sunny days, the project team leveraged a parameter that provides a pragmatic measure of short term variability. The parameter is calculated by first normalizing the measured global horizontal irradiation (GHI) by the output of a GHI clear sky model. In general, clear sky models estimate the terrestrial solar radiation under a cloudless sky as a function of the solar elevation angle, site altitude, aerosol concentration, water vapor, and various atmospheric conditions (Reno, Hansen, & Stein, 2012).[20] After normalizing the GHI values in this way, the result is known as the clear sky index. This index is useful because it captures the variability in solar resource that stems from cloud cover or other interference with direct sunlight but ignores that natural seasonal and daily variability of solar irradiation. Finally, the mean index change from one time interval to the next is calculated for each day. This parameter captures the mean expected change in resource likely to occur from one sampling interval to the next and is therefore a suitable measure of the type of short-term variability that we seek to quantify in this study (Perez, Kivalov, Schlemmer, Hemker Jr., & Hoff, 2011). Three levels of variability – high, medium and low – were chosen based upon correlations between visual observations of insolation patterns and the corresponding parameter value. A parameter value of less than 0.0078 typically represented a sunny day, as shown in Figure 30. A day scoring higher than 0.028 typically has frequent, large changes in GHI, as shown in Figure 31. Days between 0.028 and 0.0078 were categorized as medium.

Figure 32 summarizes daily insolation variability over the course of the testing period, from April, 2013 to September, 2013. 47% of days were low variability, 38% were medium variability and 16% had a high level of variability. These results aligned with the expectations of weather patterns in Sacramento.

[20] In this analysis a modified Berger–Duffie (BD) model (1979) was used; the coefficient was adjusted so that the model better represented the local GHI in Sacramento on a clear day. The extraterrestrial radiation parameter was calculated using the following equation: $I_0 = 1367.7 \times \left(1 + 0.033 \times \cos\left(\frac{2\pi}{365} \times DOY\right)\right)$ (Reno, Hansen, & Stein, 2012)

Figure 30: Typical Sunny Day (June, 13 2012)

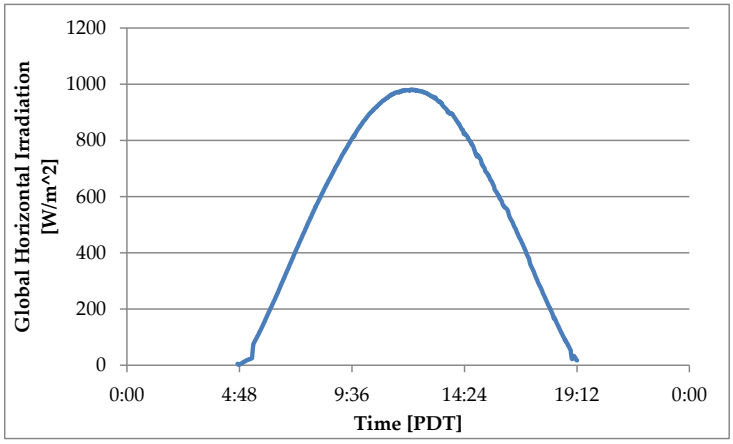


Figure 31: Typical High Variability Day (May 25, 2012)

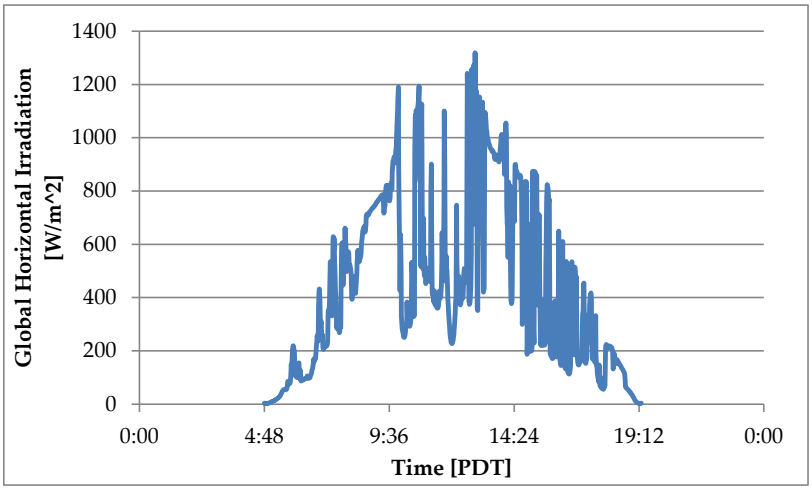
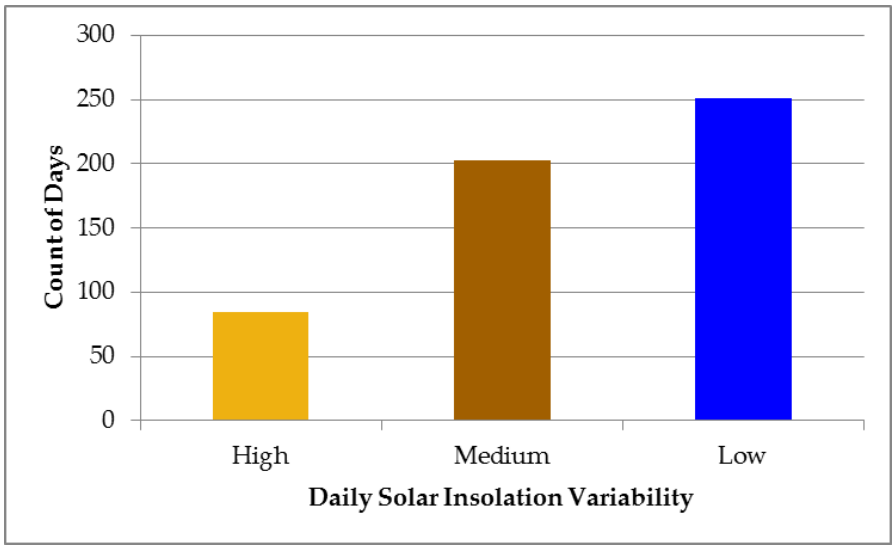


Figure 32: Daily Solar Insolation Variability from April 2012 through September 2013



APPENDIX B:
Focus Group Results

B.1 Introduction

At the end of the project, the project team solicited feedback on the program and equipment from the RES host customers. SMUD wanted their opinion to understand their experiences to:

- inform potential future SMUD programs,
- improve future demonstration projects, and
- inform future equipment design.

SMUD contacted participants via an online survey and by hosting a focus group. The online survey consisted of the questions below. 12 participants completed the survey and the major findings are discussed below.

Survey Questions

- Is your household participating in the Residential Energy Storage Group where a storage battery is installed in your garage or are you participating in the Community Energy Storage Group where storage battery is shared with other homes?
- Overall, how satisfied are you with the program?
- What could be done to improve the program?
- Thinking specifically about the equipment, how satisfied are you with the equipment?
- What could be done to improve the equipment?
- How likely are you to buy an energy storage device in next 3 to 5 years?
- How likely are you to purchase an energy storage system with a 10-year payback?
- How likely are you to recommend energy storage to others?
- How did having an energy storage unit change the way you used energy?
- Is this technology something you would like to manually control or set to an automatic mode?
- Did you use the Home Management Portal? How satisfied were you with the Home Management Portal? Which features did you use?
- Did you use the Sun Power monitor? How satisfied were you with the Sun Power monitor? Which features did you use?
- Please describe any issues you may have experienced with your energy storage system?

- As you may recall, your home was placed on a time of use rate. On a scale of one to five where one means no change at all and five means significant changes, how significantly did the time of use rate change the way you use energy?
- Your home was offered rate protection for your bill. On a scale of one to five where one means no change at all and five means significant changes, how significantly did the rate protection change the way you use energy?

SMUD also held an in person focus group for the RES site host customers. Eight customers attended, along with representatives from SMUD, SunPower, GridPoint and Navigant. The agenda included the items below, along with a facilitated discussion on feedback the customers had. The key findings from the focus group will be discussed below.

- Project Overview
- Project Goals
- Accomplishments
- Lessons Learned
- Conclusion
- Next steps
- Closing Comments

B.2 Key Findings

From the survey and focus group, SMUD received feedback around 5 major themes:

Customers participated because they: are interested in managing their energy, wanted to demonstrate new technology in a national study, wanted to help the environment, and wanted to control their energy costs. When recruiting for RES site hosts, SMUD received much more interest than we could accommodate. The customers were interested in participating in a US DOE funded project with national implications. They also were interested in trying out new technology that could help them control their energy costs and help the environment.

Customers were happy with SMUD and the team, but in some cases they would have liked the equipment to be outside or smaller and quieter. The whole team received compliments on the professionalism and quick response times to their inquiries or issues. Most customers were happy with the equipment, but those hosts with problematic (e.g. low availability due to problems and troubleshooting) were frustrated with the number of site visits required for maintenance. The most common feedback on the RES units themselves was that they were too loud and could have been smaller.

Customers would have liked to control the energy storage equipment themselves and directly charge the energy storage with PV. As discussed earlier in this report, the customers did not have control over the units. Most customers would have liked control in order to either discharge the units during times of high usage or to store excess PV output for use when the sun goes down.

Adopting energy storage and time of use rates drove some customers to change their behavior, but most did not. Because customers did not have control over the RES units, they did not change their energy usage patterns. A few customers said time of use rates drove behavior changes, but most said that the rates were not high enough to drive any big changes.

Appendix C: Business Model Analysis

Table 28: Potential Distributed Energy Storage and PV Business Models

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
1	Non-Customer	SMUD	Direct to Grid	N/A	SMUD 100% Controls Asset	N/A
2	Non-Customer	SMUD	Direct to PV	N/A	SMUD 100% Controls Asset	N/A
3	Non-Customer	Third Party	Direct to Grid	N/A	Owner 100% Controls Asset	Regular Fixed Payments
4	Non-Customer	Third Party	Direct to Grid	N/A	Owner 100% Controls Asset	Payment by Service
5	Non-Customer	Third Party	Direct to PV	N/A	Owner 100% Controls Asset	Regular Fixed Payments
6	Non-Customer	Third Party	Direct to PV	N/A	Owner 100% Controls Asset	Payment by Service

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
7	Non-Customer	Third Party	Direct to Grid	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
8	Non-Customer	Third Party	Direct to Grid	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
9	Non-Customer	Third Party	Direct to PV	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
10	Non-Customer	Third Party	Direct to PV	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
11	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Upfront incentives
12	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Payment by Service
13	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Upfront + Payment by Service
14	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Upfront incentives
15	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Payment by Service
16	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Upfront + Payment by Service
17	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
18	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
19	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront + Payment by Service
20	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives
21	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
22	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront + Payment by Service
23	Customer	Customer	Direct to Grid	SMUD Leases to customer	Owner 100% Controls Asset	Payment by Service
24	Customer	Customer	Direct to PV	SMUD Leases to customer	Owner 100% Controls Asset	Payment by Service
25	Customer	Customer	Direct to Grid	SMUD Leases to customer	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
26	Customer	Customer	Direct to PV	SMUD Leases to customer	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
27	Customer	Customer	Direct to Grid	SMUD Provides loan	Owner 100% Controls Asset	Payment by Service
28	Customer	Customer	Direct to PV	SMUD Provides loan	Owner 100% Controls Asset	Payment by Service
29	Customer	Customer	Direct to Grid	SMUD Provides loan	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
30	Customer	Customer	Direct to PV	SMUD Provides loan	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
31	Customer	SMUD	Direct to Grid	SMUD Owns	SMUD 100% Controls Asset	Regular Fixed Payments
32	Customer	SMUD	Direct to PV	SMUD Owns	SMUD 100% Controls Asset	Regular Fixed Payments

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
33	Customer	SMUD	Direct to Grid	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
34	Customer	SMUD	Direct to PV	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
35	Customer	SMUD	Direct to Grid	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	N/A
36	Customer	SMUD	Direct to PV	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	N/A

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
37	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Upfront incentives
38	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Upfront incentives
39	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Upfront + Payment by Service
40	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Upfront + Payment by Service
41	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Payment by Service
42	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Payment by Service
43	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
44	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives
45	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
46	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
47	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
48	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
49	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Upfront incentives
50	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Upfront incentives
51	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Upfront + Payment by Service
52	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Upfront + Payment by Service
53	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Payment by Service
54	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Payment by Service

Table 29. Pros and Cons of Each Business Model

	SMUD		Customer		Third Party	
Model #	Pros	Cons	Pros	Cons	Pros	Cons
1	SMUD retains 100% control; easy for SMUD to monetize benefits; asset could be moved if need be, can be installed anywhere and not just in high penetration PV community; Likely easier to integrate with existing SMUD communications and control systems	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	None	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
2	SMUD retains 100% control; easy for SMUD to monetize benefits; asset could be moved if need be	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate; SMUD would need a solar system to tie the ES to and this might require a longer timeline for negotiations	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	None	No involvement in business model beyond equipment manufacture and installation
3	Billing/payment is simpler and does not require equipment to monitor usage; Likely easier to integrate with existing SMUD communications and control systems	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement	Owner would not have opportunity to improve revenue beyond fixed payment

	SMUD		Customer		Third Party	
4	ES will be used efficiently because being paid for performance; Likely easier to integrate with existing SMUD communications and control systems	More complex billing and monitoring equipment required; SMUD cannot control energy storage	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue	Complex software and hardware might be required to track usage, performance, and revenue
5	Billing/payment is simpler and does not require equipment to monitor usage	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement; owner could offer as a product to enhance value of PV systems	Owner would not have opportunity to improve revenue beyond fixed payment;

	SMUD		Customer		Third Party	
6	ES will be used efficiently because being paid for performance	More complex billing and monitoring equipment required; SMUD cannot control energy storage	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue; owner could offer as a product to enhance value of PV systems	Complex software and hardware might be required to track usage, performance and reveneu
7	Billing/payment is simpler and does not require equipment to monitor usage; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used as efficiently as possible because not being paid for performance; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement	Owner would not have opportunity to improve revenue beyond fixed payment

	SMUD		Customer		Third Party	
8	ES will be used efficiently because being paid for performance; SMUD can control as needed; Likely easier to integrate with existing SMUD communications and control systems	More complex billing and monitoring equipment required; SMUD cannot control energy storage; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue	Complex software and hardware might be required to track usage, performance and revenue
9	Billing/payment is simpler and does not require equipment to monitor usage	Energy storage might not be used as efficiently as possible because not being paid for performance; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement; owner could offer as a product to enhance value of PV systems	Owner would not have opportunity to improve revenue beyond fixed payment;

	SMUD		Customer		Third Party	
10	ES will be used efficiently because being paid for performance; SMUD can control as needed	More complex billing and monitoring equipment required; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue; owner could offer as a product to enhance value of PV systems	Complex software and hardware might be required to track usage, performance and revenue

	SMUD		Customer		Third Party	
11	Incentive scheme is easy to implement; no monitoring or communications needed; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed	Customer controls and captures all the benefits; one time incentive is easier than on going incentives	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
12	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions ;Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer controls and captures all the benefits;	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
13	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer controls and captures all the benefits; upfront incentives reduce up front cost	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
14	Incentive scheme is easy to implement; no monitoring or communications needed	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; direct connection to PV might not allow for grid support functions	Customer controls and captures all the benefits; one time incentive is easier than on going incentives; customers can charge ES with PV	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
15	SMUD could design incentive scheme to promote usage it wants	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control	Customer controls and captures all the benefits; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
16	SMUD could design incentive scheme to promote usage it wants	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control	Customer controls and captures all the benefits; upfront incentives reduce up front cost; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
17	Incentive scheme is easy to implement; no monitoring or communications needed; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	energy storage might not be used in a way that benefits SMUD;	Customer controls and captures most the benefits; one time incentive is easier than on going incentives	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
18	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer controls and captures most of the benefits;	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
19	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer controls and captures most of the benefits; upfront incentives reduce up front cost	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
20	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	Energy storage might not be used in a way that benefits SMUD; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; one time incentive is easier than on going incentives; customers can charge ES with PV	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
21	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
22	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; upfront incentives reduce up front cost; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
23	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
24	SMUD could design incentive scheme to promote usage it wants; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; customers can charge ES with PV' no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
25	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
26	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; customers can charge ES with PV; no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
27	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD could specify required equipment features or controls in order to get the loan; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
28	SMUD could design incentive scheme to promote usage it wants; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; customers can charge ES with PV' no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
29	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
30	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; customers can charge ES with PV; no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
31	SMUD controls ES; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace	Customer does not have control over unit; unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
32	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace	Customer does not have control over unit; unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
33	SMUD can control ES if needed; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace; customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
34	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	gets payment in return for giving up floorspace; customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
35	SMUD can control ES if needed; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
36	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

	SMUD		Customer		Third Party	
37	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
38	Incentive scheme is easy to implement; no monitoring or communications needed	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

	SMUD		Customer		Third Party	
39	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue
40	SMUD could design incentive scheme to promote usage it wants;	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions; SMUD cannot control	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
41	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
42	SMUD could design incentive scheme to promote usage it wants;	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions; SMUD cannot control	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
43	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
44	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

	SMUD		Customer		Third Party	
45	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue
46	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry;

	SMUD		Customer		Third Party	
47	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
48	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
49	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
50	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	SMUD can not control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

	SMUD		Customer		Third Party	
51	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
52	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
53	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD controls; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; third party does not control; complex software and hardware might be required to track usage, performance, and revenue

	SMUD		Customer		Third Party	
54	SMUD could design incentive scheme to promote usage it wants; SMUD controls	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; third party does not control; complex software and hardware might be required to track usage, performance, and revenue

APPENDIX

Appendix D: Interim Report

This appendix is available as a separate volume, publication number CEC-500-2015-047-AP