The Calm before the Storage Tsunami: Lessons Learned from Evaluating California's First Behind-the-Meter Advanced Energy Storage Projects

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ABSTRACT

Advanced energy storage (AES) is one of the fastest growing and most anticipated distributed energy resources on the electricity grid. Behind-the-meter AES projects promise to deliver benefits through numerous value streams including increased customer reliability, reduced customer demand, reduced peak energy consumption (arbitrage), and balancing of intermittent renewable resources such as solar photovoltaics (PV) and wind. While much has been said about potential benefits, very limited data are publically available to assess the impacts of behind-the-meter AES. In California, the Self-Generation Incentive Program provides incentives for the installation of AES projects that offset all or a portion of a customer's electrical energy consumption. This paper presents analyses of the performance of four of these behind-the-meter AES projects, quantifying energy, peak demand, and greenhouse gas (GHG) reductions. We also discuss lessons learned and propose minimum data requirements for the evaluation of future behind-the-meter AES incentive programs.

AES projects can provide multiple benefits to system operators, host customers, and society. The potential for demand charge reduction and peak load management are the primary driving factors for siting storage at commercial customer sites. A variety of federal and state policies seek to increase the amount of behind-the-meter AES in the coming years. It is imperative that metering of these systems is setup in such a way that performance data will allow utilities, regulators, and evaluators to determine if AES's potential to reduce energy demand and GHG emissions is actually realized in the future.

Introduction

Background

The California Self-Generation Incentive Program (SGIP) provides financial support for behind the meter (customer-sited) storage and other technologies such as fuel cells, combined heat and power (CHP), and wind. The SGIP provides up front incentives based on system size (defined as kW capacity during 2 hour discharge) for systems less than 30 kW. For systems greater than 30 kW, the SGIP provides a Performance Based Incentive (PBI), where half of the incentive is based on system performance over five years.

Definition of AES

Advanced Energy Storage (AES) technologies convert electricity into energy, store it and then convert the energy back into usable electricity when needed. Batteries have been used for backup power and off-grid applications for many decades, but the advanced peak shaving and (potential) grid support functions of AES are a relatively new development. AES technologies can be implemented on large and small scales in distributed and centralized manners throughout the energy system.

There are a wide variety of possible forms in which the energy can be stored. Classification of energy storage technologies is shown in Figure 1. Additional technologies such as kinetic-potential conversion are also being explored.

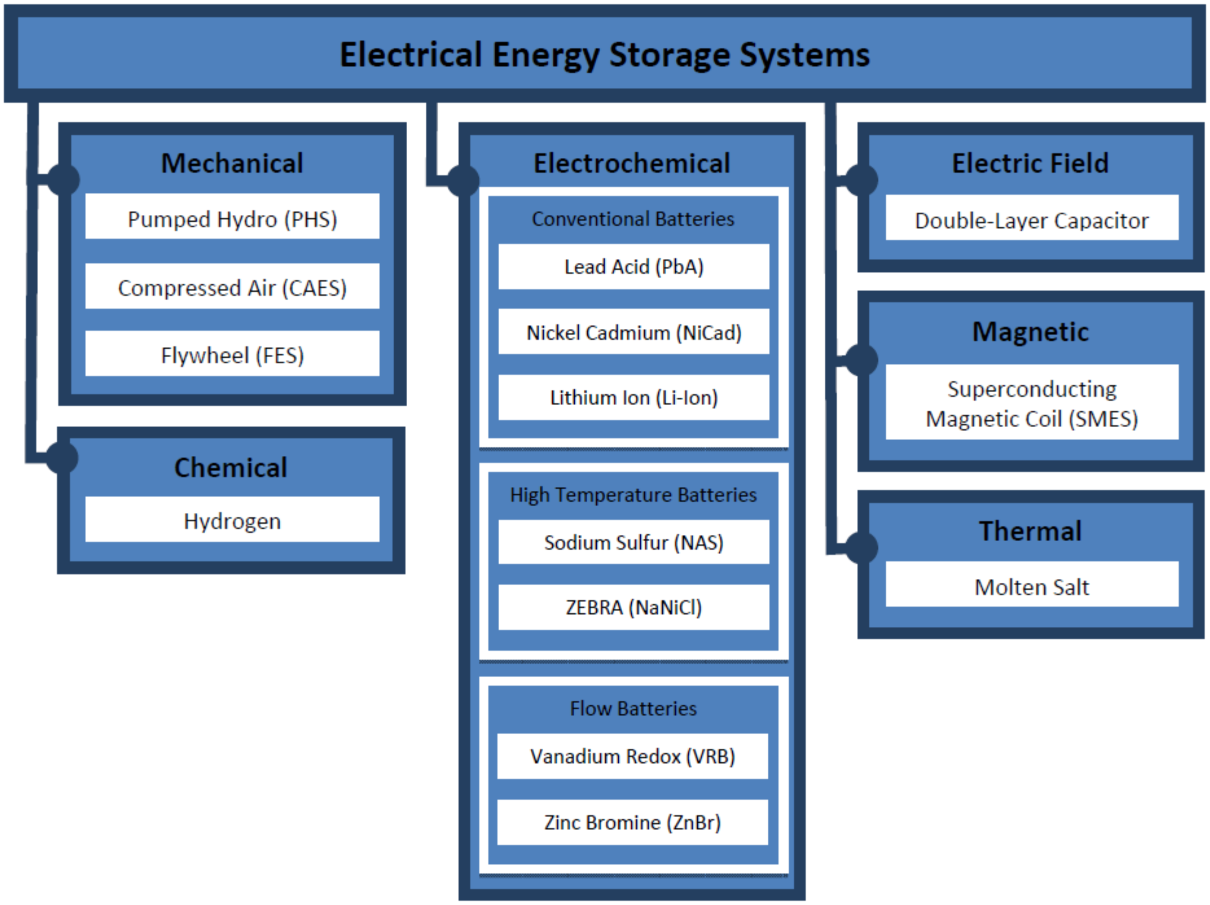

Figure 1. Storage Technologies (Rachel Carnegie et al State Utility Forecasting Group)

From the standpoint of the electrical system, these energy storage methods act as loads while energy is being stored (e.g. while charging the battery) and generators when the energy is returned to the system (e.g. while discharging the battery).

Even though there are several technologies available in the market, AES projects in the SGIP are currently dominated by two electrochemical technologies; lithium ion and flow batteries.

Lithium ion batteries (Li-Ion) components include: a carbon (graphite) negative electrode, a metal-oxide positive electrode, an organic electrolyte (ether) with dissolved lithium ions, and a micro-porous polymer separator. When the battery is charging, lithium ions flow from the positive metal oxide electrode to the negative graphite electrode. When the battery is discharging the reverse flow of ions takes place.

Flow batteries: Flow batteries are typically larger and have more capacity. Redox flow batteries are a reversible fuel cell in which electro-active components are dissolved in the electrolyte. A redox flow battery's energy is related to electrolyte volume and power is related to electrode area in the cells.

Potential Benefits

Advanced energy storage may provide benefits to balancing authorities, distribution companies, aggregators, rate payers, host customers, and society. While there are more than 20 discrete value streams for storage, depending on the point at which it is interconnected, the greatest potential opportunity for the layering of these value streams tends to be for systems interconnected closest to customer load (GTM Research, 2014). The potential for demand charge reduction and peak load management are the primary driving factors for siting storage at commercial customer sites. The primary benefit to residential customers, however, is often backup power (Carlson, E., 2014), although SGIP rules may prohibit this in the future. The increasing policy focus and drive to zero net energy at a building or community level may also lead to the increased value of siting storage in conjunction with on-site renewable generation.

The use of intelligent controllers that run the charge and discharge cycles of storage based on several operating and cost parameters to create desired load profiles is finding increasing use in the field.

Some developers are working to aggregate behind-the-meter storage to provide demand response in order to generate additional value streams from their projects. If successful, this aggregation will provide developers and host customers another value stream to make storage more cost effective. Furthermore, the ancillary services market is one of the biggest opportunities for the employment of distributed energy storage to help maintain stable grid operations on a short-term basis. However, behind-the-meter storage cannot currently bid into the ancillary services market in California.

AES projects may indirectly reduce greenhouse gas (GHG) emissions by allowing greater penetrations of renewables to interconnect into the grid. AES projects may also reduce GHG emissions directly, depending on the battery's round trip efficiency and its time of use. Batteries inherently consume more electricity than they discharge due to electrochemical losses; therefore, to provide GHG reductions, batteries must charge from the grid during relatively "clean" hours of grid generation and discharge during "dirty" hours of grid generation to overcome their net increase in energy consumption.

California Regulatory Background

On September 29, 2010, former Governor Schwarzenegger signed AB 2514 (Skinner, 2010) into law, requiring the California Public Utilities Commission (CPUC) to open a proceeding to determine appropriate targets, if any, for each load-serving entity to procure viable and cost-effective energy storage systems. The CPUC was to consider a variety of possible policies to encourage the cost-effective deployment of energy storage systems, including refinement of existing procurement methods to properly value energy storage systems.

In October 2013, the CPUC adopted an energy storage procurement framework and established an energy storage target for Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). A total of 1,325 MW are to be procured by 2020, with installations to be completed no later than 2024. The decision further establishes a target for community choice aggregators and electric service providers to procure energy storage equal to 1 percent of their annual 2020 peak load by 2020 with installations completed no later than 2024. An important component of the targets was the specific allocation to customer sited behind-the-meter storage with the intent to affect areas such as bill management, permanent load shifting, maintaining power quality, and electric vehicle charging. In total, 200 MW of behind-the-meter storage must be collectively procured by the electric investor owned utilities (IOUs) by 2020.

Table 1 shows the use case examples indicated by the CPUC. Behind-the-meter storage is used for bill management/permanent load shifting, power quality, and electric vehicle charging. In other states, behind-the-meter storage can be used for grid support and ancillary services. Some companies in California are working to aggregate storage to provide those sorts of services.

Table 1. Storage Use Cases (CPUC, 2013)

<table>
<tr><th>Storage Grid Domains (Grid Interconnection Point)</th><th>Regulatory Function</th><th>Use-Case Examples</th></tr>
<tr><td rowspan="3">Transmission- Connected</td><td rowspan="2">Generation/Market</td><td>(Co-Located Energy Storage) Concentrated Solar Power, Wind+ Energy Storage Gas Fired Generation + Thermal Energy Storage</td></tr>
<tr><td>(Stand-Alone Energy Storage) Ancillary Services, Peaker, Load Following</td></tr>
<tr><td>Transmission Reliability (FERC)</td><td>Voltage Support</td></tr>
<tr><td rowspan="3">Distribution- Connected</td><td>Distribution Reliability</td><td>Substation Energy Storage (Deferral)</td></tr>
<tr><td>Generation/Market</td><td>Distributed Generation + Energy Storage</td></tr>
<tr><td>Dual-Use (Reliability & Market</td><td>Distributed Peaker</td></tr>
<tr><td>Behind-the-Meter</td><td>Customer-Sited Storage</td><td>Bill Mgt/Permanent Load Shifting, Power Quality, Electric Vehicle Charging</td></tr>
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Scope

This paper focuses on behind the meter storage only, and primarily lithium-ion (solid-state) batteries. The results presented are drawn from the SGIP impact evaluation and market transformation efforts, so they are California-centric. However, California is not the only state that is incentivizing energy storage. Several other states such as New York, New Jersey, and Hawaii are working to tap the potential benefits of energy storage and grow energy storage markets, so the results have applicability beyond California.

The introduction of standalone AES to the SGIP has led to a large number of applications for incentives, but most of have yet to be installed. The addition of these systems will have profound impacts to program energy impacts and demand savings. Figure 2 shows that as of May 2015, 104 AES systems have been installed but over 1,000 systems are in the application process.

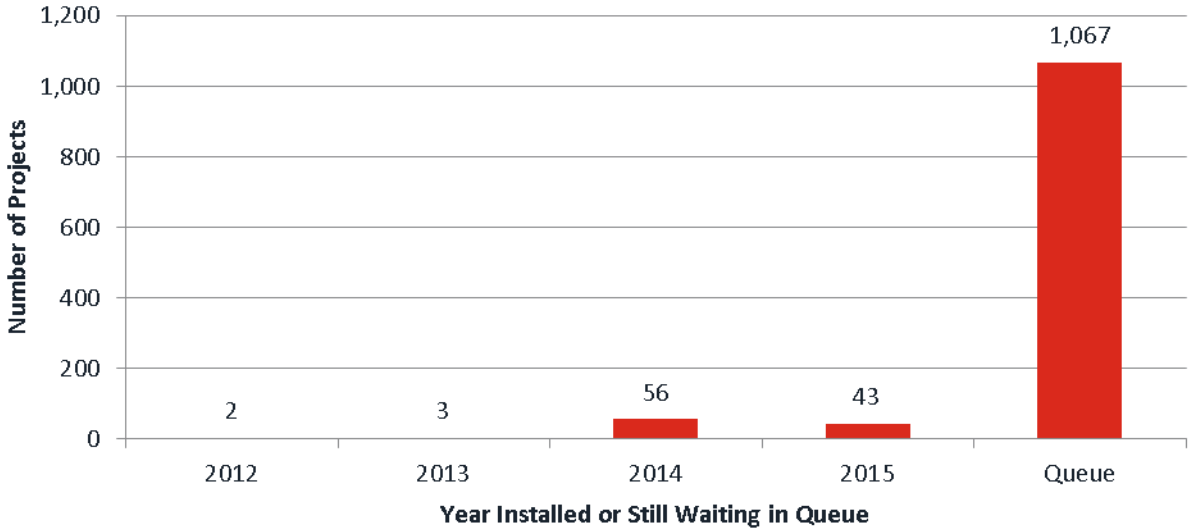

Figure 2: AES System Installs by Year

Methodology

As part of Itron's 2013 impact evaluation for the SGIP, we collected metered data for advanced energy storage projects that received incentives from the program. We use an automated process to validate AES charge, discharge, and load interval data. By the end of 2013, only five systems had been installed and metered data were available for four of them. All metered results presented in this paper are based on those four systems. All of these were commercial systems.

In addition, we collected data to support other analyses beyond what would be possible with just those metered data. That additional data collection included:

Facility load data that shows the hourly or 15-minute electrical demand at the site. We were able to collect facility load for two of the sites. These data can be collected from a dedicated meter or in many cases from interval net load data collected by smart meters.

Tariff/electricity rate information that shows how the customer is being charged for electrical energy and demand. Demand charges are quite important for storage and are based on the hourly or 15 minute monthly maximum demand the facility draws from the grid. Monthly demand charges are due to the maximum 15 minute peak in each month and split into three periods:

1. On Peak; billed on the maximum kW demand during peak hours
2. Semi-Peak; billed on the maximum kW during semi-peak hours
3. Max Demand; billed on the maximum kW during the month

We had to deduce what tariff each site was on based on the facility's size and location.

Hourly marginal grid emissions that show on an hourly basis how much each kWh of energy offset by the AES discharging saves in emissions and how much each kWh that the AES consumes by charging add to emissions (E3 2004). This methodology was selected to be consistent with other California programs but any other time-dependent grid marginal emission model could be used. The average heat rate of natural gas generators operating at the margin determines the emissions associated with grid generation during any given hour. Figure 3 shows the implied marginal heat rates used to quantify GHG impacts for three representative days in 2013. Gas generation plants with higher heat rates consume more fuel, and therefore, emit more greenhouse gases. Marginal heat rates are up to 80 percent higher during afternoon hours (when plants with higher heat rates are dispatched to meet load requirements) than those in the middle of the night. The GHG impacts methodology used to quantify SGIP impacts assumes that SGIP generation displaces a natural gas generator on the margin.

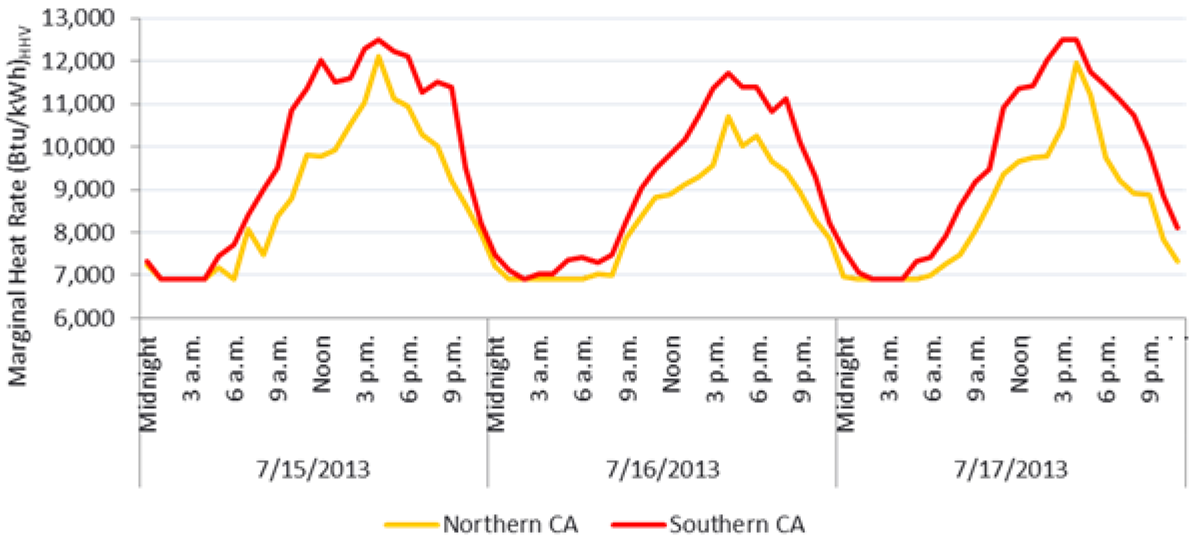

Figure 3: Representative Marginal Heat Rates Used to Quantify GHG Emission (E3, 2004)

Results

Efficiency and Capacity Factor Results with Charge/Discharge Data Only

The aggregated efficiency for all four metered projects was 73%,[1] meaning slightly less than three quarters of the energy stored was actually discharged. Figure 4 shows the monthly capacity factors for all four metered systems. This information is useful in understanding what typical levels of utilization were in 2013. Of the 30 monthly data points included in this analysis, 24 (80 percent) had capacity factors below 10 percent.

[1] This is based on monthly sums of energy charging the batteries and energy discharged from the batteries.

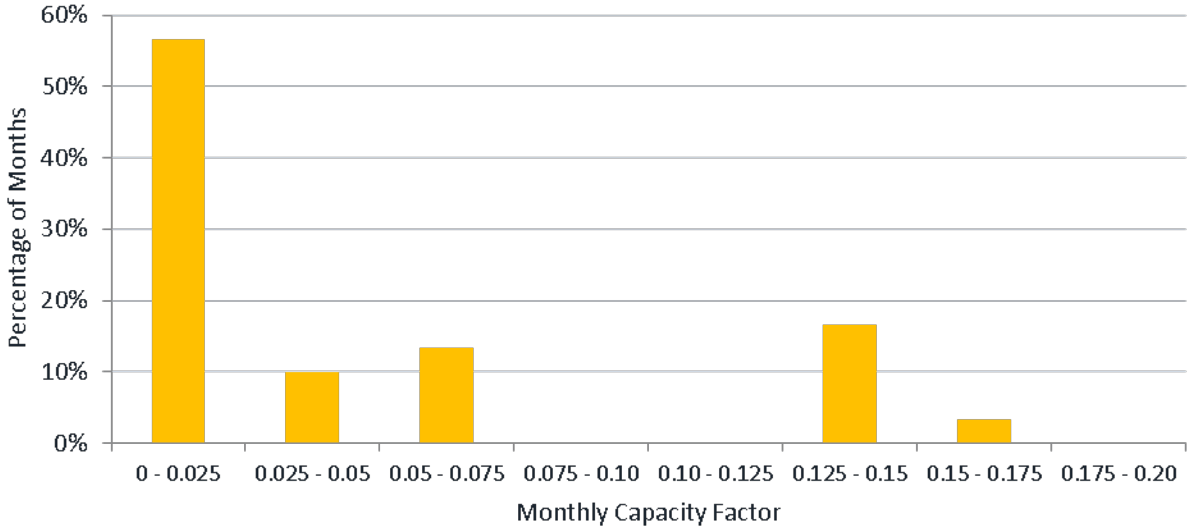

Figure 4. Capacity Factors for Metered Storage Systems

Customer Demand Results with Facility Load

Figure 5 illustrates the use of storage at a hotel to reduce peak demand. In doing so, the customer reduces the peak demand for that day 13kW and potentially reduces the magnitude of the billed demand charge. Note that this is for a nominally 9 kW system (18 kWh).

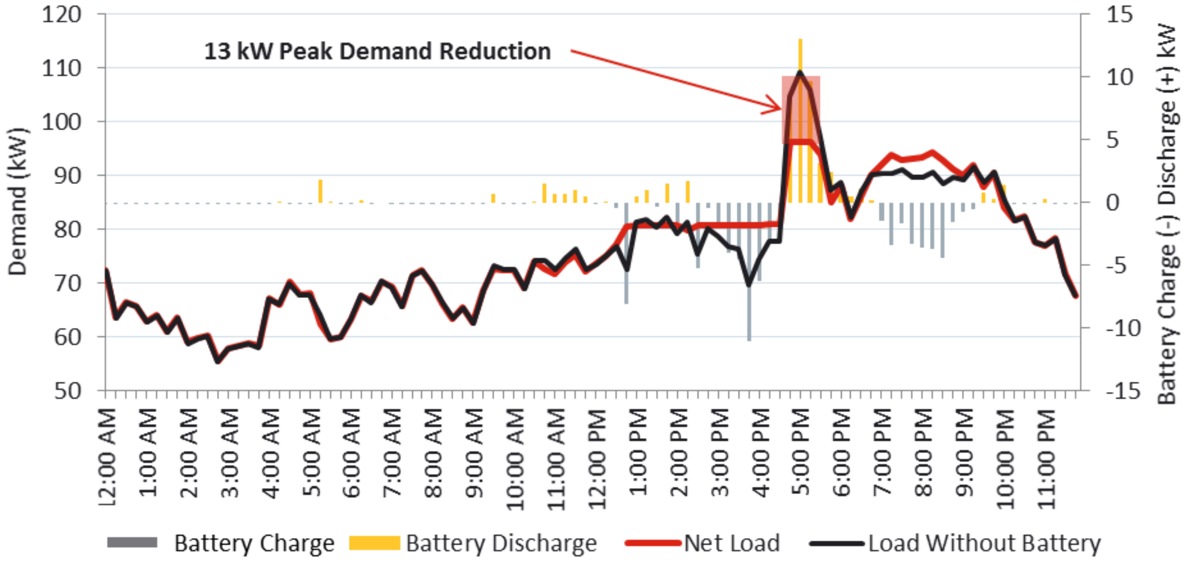

Figure 5. Battery Use Case for Peak Demand Reduction in April

The peak on this day in April is about an hour long, so the storage system is able to achieve demand savings in excess of the system's two hour rated capacity. During hotter days when peaks are longer and cooling load induced, the storage system is less able to reduce the peak demand, as shown in Figure 6. On this day, the storage system was only able to reduce peak demand by 4 kW.

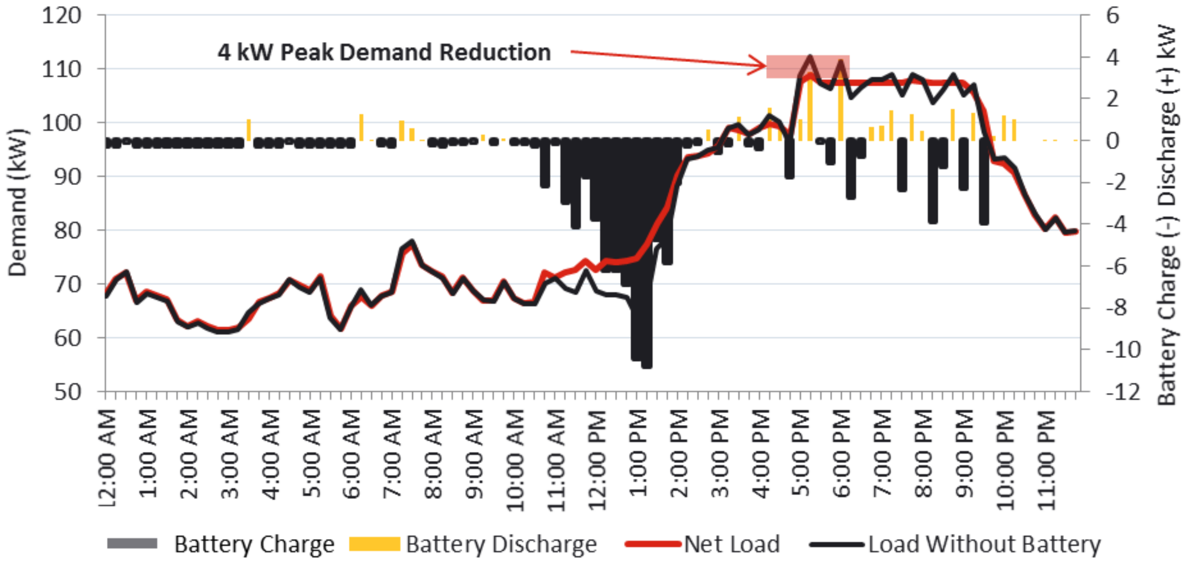

Figure 6. Battery Use Case for Peak Demand Reduction in July

Figure 7 shows how effective the AES system was at reducing demand by month and period over a year. In some cases like January, the system increased semi peak demand to significantly reduce overall peak demand. The lower effectiveness in the hotter summer months is also quite evident in this figure.

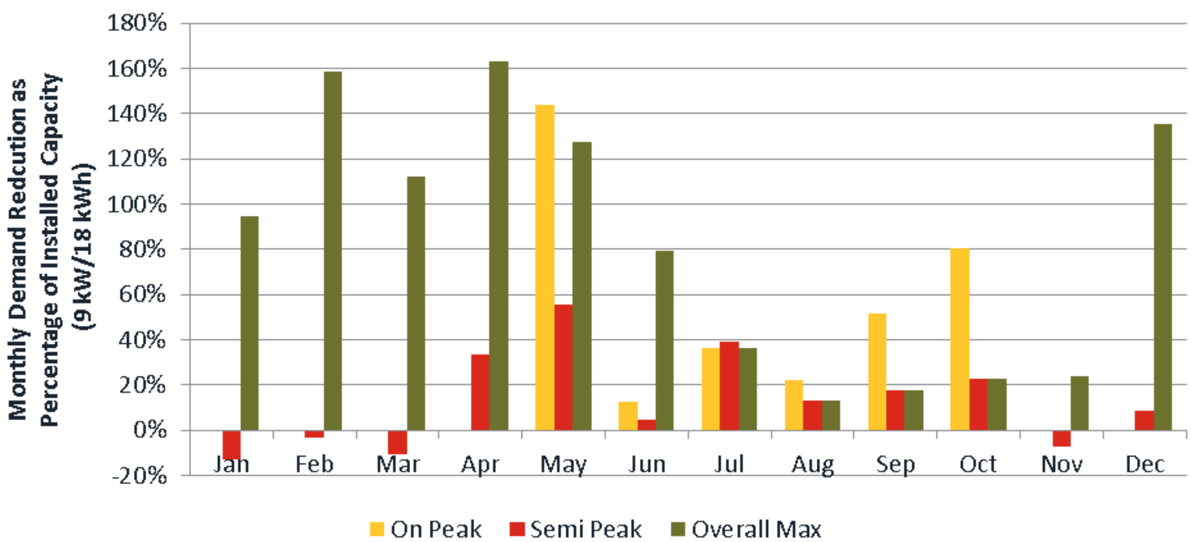

Figure 7: AES Demand Reductions by Month and Peak Period

Customer Bill Results with Customer Tariffs

Another key piece of the savings puzzle for energy storage is what the effect is on customer bills. This allows analysis of whether systems are operating as expected, i.e., discharging during peak periods and charging off peak. Figure 8 shows the timing of charge and discharge for sites with metered data combined with an assumed TOU rates and demonstrate that systems primarily charge off-peak and discharge on-peak, as one would expect in order to achieve bill savings.

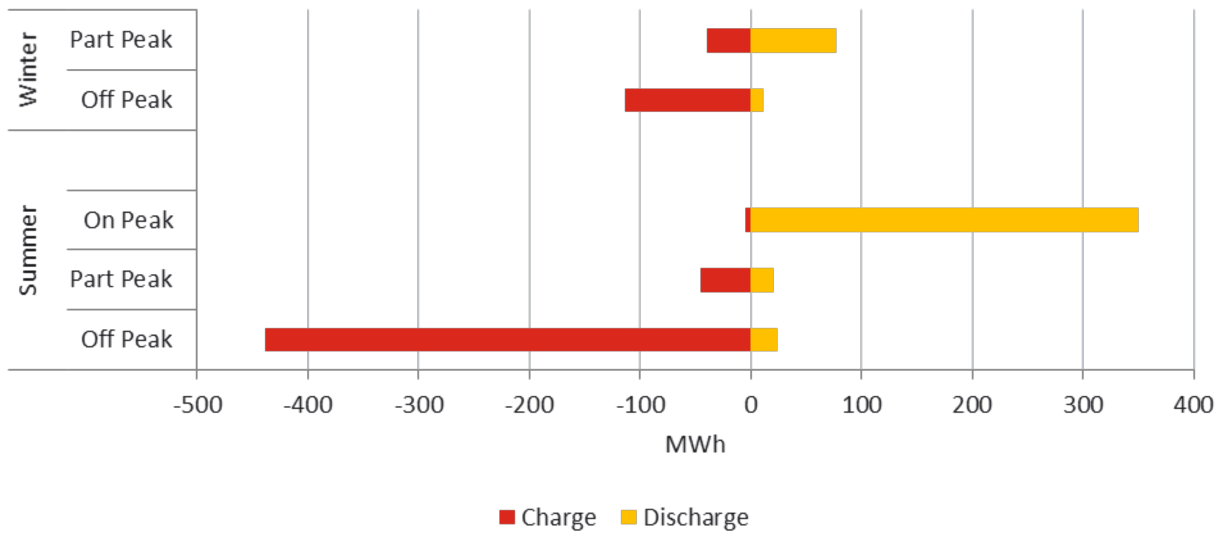

Figure 8. SGIP Storage Charge and Discharge Timing (Case study of TOU load shifting)

Inclusion of site tariffs combined with site load also allows analysis of customer bill impacts. Figure 9 shows the average monthly bill impacts per installed kW for the metered systems. The energy portion of the bills increases slightly due to increased consumption but these minor increases are offset by significant demand charge savings.

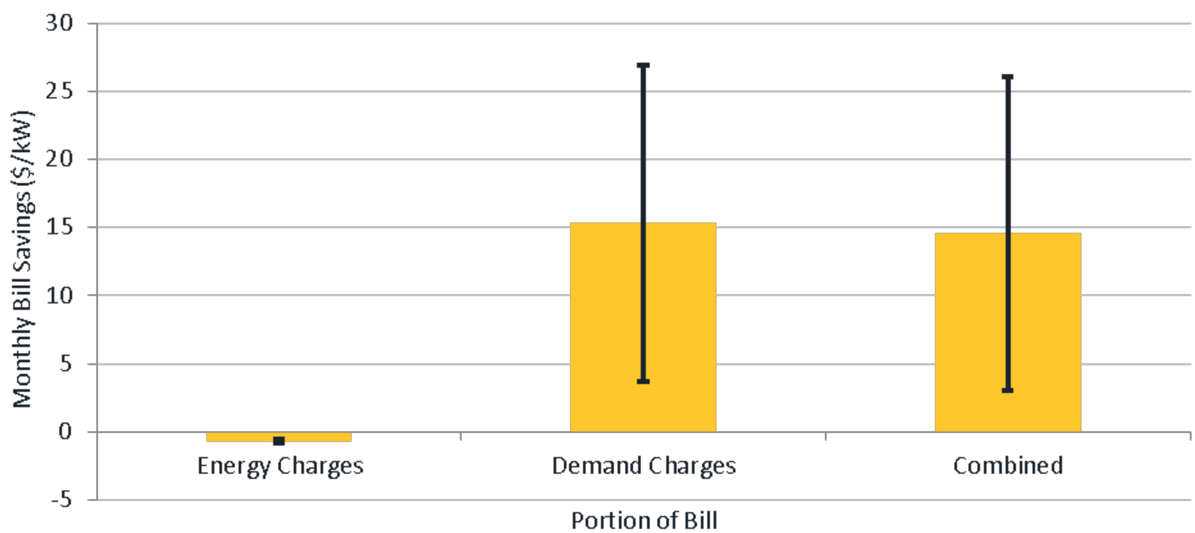

Figure 9. Average Bill Impacts

Emissions Results with Emissions Baseline Data

When an AES system is charging, consumption from the grid increases and therefore GHG emissions increase. Conversely, when an AES system is discharging, consumption from the grid decreases and GHG emissions decrease. In order to offset the net increase in energy consumption due to roundtrip efficiencies and achieve greenhouse gas reductions, AES systems must charge during hours of low marginal heat rate (baseload combined cycle), and discharge during hours of high marginal grid heat rates (peakers). Figure 10 shows the calculated greenhouse gas impacts for the metered systems using the avoided cost methodology. These systems slightly increased greenhouse gas emissions, in part due the relatively low overall efficiency of 73%.

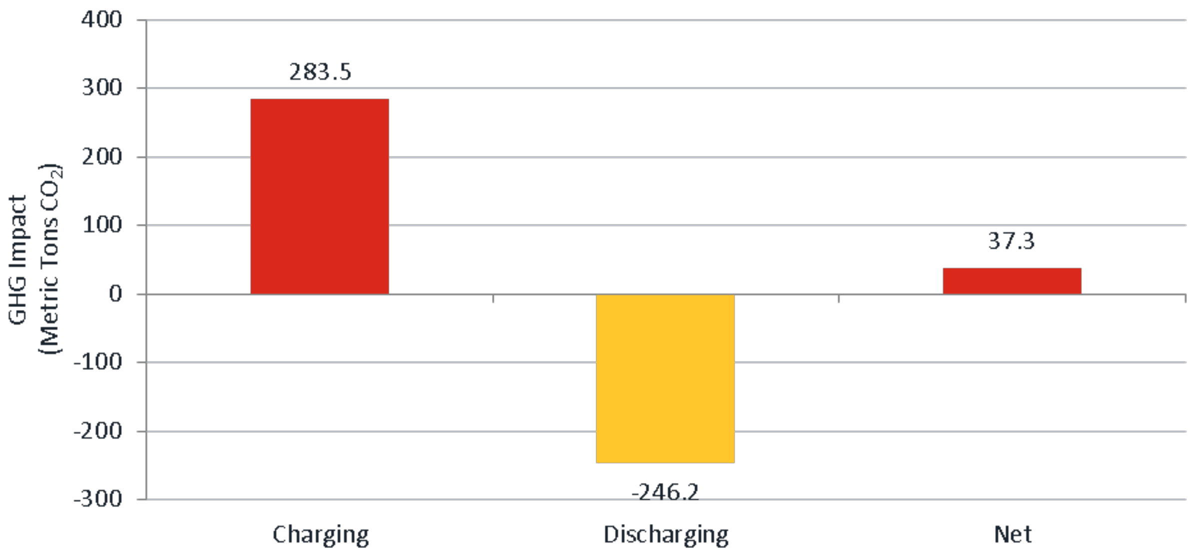

Figure 10. Greenhouse Gas Impacts of Metered Systems

Discussion

Data collection should be matched to program and customer goals. If a program goal is to reduce customer peak demand, data collection should be setup to properly evaluate how well systems meet that goal. That would require metering of 15-minute storage charge and discharge with the addition of metering of facility load. In this section we discuss the relationship between AES data streams and the calculation of performance metrics.

Charge/Discharge Interval Metering. The most fundamental unit of measure for AES systems is the charge and discharge of electricity. The SGIP currently requires systems above 30 kW (60 kWh) to install Performance Based Incentive (PBI) metering to capture 15-minute charge and discharge kWh data. These data provide the ability to calculate:

1. Round trip efficiency, defined as the total AC energy discharged divided by the total AC energy charged during a given period
2. Capacity factor (or fraction of the month/year that the system is discharging)
3. Impacts on overall energy consumption
4. Impact on utility peak demand (when combined with utility system load data)

Charge/discharge data provide information on how storage is functioning. It provides utilities, utility commissions, and grid operators some idea of how storage is impacting the grid. The first SGIP systems displayed a somewhat low round-trip efficiency and relatively low utilization. However, without facility load, these data do not provide enough information to calculate host customer savings or cost effectiveness.

Facility Interval Load. Facility load is a key piece of data needed to evaluate actual customer bill impacts. Those bill impacts are a key factor since behind the meter energy storage primarily operates to reduce customer peak demand. Just because a storage system discharges at, say 10 kW every day that does not mean the facility demand is reduced by 10 kW since the peak demand may have been moved to a different time. For one of the SGIP projects, the AES system was able to offset substantial peak demand in the spring months when peaks tended to be shorter. In summer months, the longer peak meant that the AES was less able to reduce the demand due in part to limited energy capacity. This is in many ways a game of Whac-A-Mole, where the optimal control needs to manage more than one peak and dispatch limited capacity to best reduce overall peak customer demand.

For the projects in our sample, the AES systems appeared to be quite effective, likely using load forecasting algorithms based on historical load and other factors, and reduced customer peak demand effectively. These demand impacts will drive how much benefit the AES provides to the host customer, and to a lesser degree, the utility providing the electricity. Future evaluations should include analysis using facility interval load in conjunction with charge/discharge metering to evaluate how effective AES really is at reducing customer peak demand.

Customer Tariff and Electricity Rates. Another component of customer characteristics is utility tariff and corresponding electricity rates. With this data, actual bill demand savings and electricity consumption impacts can be quantified. Combined with AES charge/discharge and facility load data, these tariffs allow actual customer bill savings to be quantified. In this study, we assumed tariffs based on customer segment, facility size, and utility. With these assumed tariffs, it appears that AES systems substantially reduced customer bills through the reduction of demand charges at commercial sites. Residential sites, with no demand charges, might be challenged to achieve bill reductions.

Emissions Baseline Data. Energy storage projects may provide societal benefits in the form of GHG emissions reductions. Direct GHG impacts from energy storage projects are due to the shift in energy consumption from "dirty" hours of grid generation to "cleaner" hours. Since most commercial AES systems operate to reduce facility peak demand, these systems will likely charge during times when the grid is relatively clean at night to minimize costs. These systems should discharge during facility peak demand, which usually coincides with the dirtier periods of higher marginal emissions. Despite this, the metered systems actually increased emissions slightly due to a relatively low average round trip efficiency. If future studies with larger numbers of systems show that those systems continue to increase greenhouse gas emissions, incentive program administrators may need to re-think program eligibility rules and reconsider if AES fits in with program goals.

Metering of Other Synergistic Services. The majority of SGIP energy storage systems are installed in conjunction with solar PV systems and many of the surveyed manufacturers and installers regularly combine storage with other technologies. Adding metering or at least simulations of solar performance for systems coupled with AES would round out the picture of the total impacts of these systems both to the customer and to the power grid. Our evaluation did not extend to the addition of storage, EV's, or other technologies.

Ancillary Service Metering. In California, behind the meter storage is prohibited from bidding into the ancillary services market to provide, for example, frequency support. Other states and ISO's allow behind the meter storage to provide these services. If customer sited storage is providing these services, additional metering would need to be installed to capture the impacts such as frequency support, voltage support, or other regulation. Quantification of these benefits would require more costly high-speed data acquisition systems than are usually deployed for measurement & evaluation purposes.

Conclusions

For the limited sample of metered systems rebated by the SGIP during 2013, AES systems provided customer peak load reduction, as expected. This peak load reduction came at the expense of slightly increased greenhouse gas emissions due to a low overall round trip efficiency of 73%. Customer bill impacts were estimated to be largely due to demand charge reductions.

Future data collection techniques for AES need to match the metrics and impacts of interest. In this paper, we illustrated how the data streams listed in Table 2 can be used to measure the metrics and impacts in the same table. Charge and discharge metering is necessary to quantify system operation, efficiency, and grid impacts. In addition to charge/discharge metering, facility load and customer tariffs are key to quantifying how storage impacts a customer's load. To quantify emissions impacts, an hourly estimate of marginal grid emissions is critical in addition to charge and discharge metering.

Table 2. Data and Impacts Cross Reference

Data	Metrics and Impacts
Charge/ Discharge Metering	Round Trip Efficiency
	Capacity Factor (utilization)
	Impact on Overall Energy Consumption
	Impact on Utility/ISO Peak Demand
Facility Load Metering	Customer Peak Demand Impact
Addition of Customer Tariff	Peak vs. Non-Peak Analysis
	Customer Bill Impacts (when combined with facility load)
Emissions Baseline	Emissions Impact
Synergistic Services Metering	Complete impact of combined systems
Ancillary Services Metering	Grid Support Impacts (may require other grid data)

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