Through the Looking Glass and What the Analyst Found There:
Energy Storage Behind the Meter

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ABSTRACT

Energy storage is a nascent but rapidly growing technology. It has been touted as a key revolutionizing technology necessary for a clean energy future. Behind-the-meter battery storage can provide a number of services to the host customer such as energy and demand bill management, backup power, and demand response. These primary services have the potential to provide secondary benefits and services such as reducing emissions, deferring transmission and distribution upgrades, and improving integration of intermittent renewables.

Quantifying impacts from real storage systems, whether autonomously or remotely operated, requires recognition of multiple power flows that may change direction. Hard-to-measure impacts, including carbon emissions and renewables integration, may depend on quickly changing baseline references such as hourly average grid emissions, locational marginal energy prices, and other needs. Data required by incentive programs and available from the industry may not be sufficient to quantify all of these impacts. These factors all combine to present somewhat unique challenges to evaluate how well energy storage programs are meeting program goals.

Real operation of behind-the meter storage may target specific benefits and disregard others. In this paper, we highlight some examples from California's Self-Generation Incentive Program to show how systems are being operated and that focusing on reducing customer bills can actually increase grid emissions and utility peak demand. We also discuss some of the limitations of the evaluation of storage due to data gaps and ways to mitigate these shortcomings in future evaluations.

Introduction

Energy storage is growing rapidly in both the United States and around the world as a way to help customers manage energy and demand bills, integrate more intermittent renewables, help maintain grid stability, and replace expensive and dirty 'peaker' utility plants. Lithium-ion batteries like those found in consumer electronics and the growing electric vehicle market are the dominant storage technology, in part thanks to the economies of scale inherited from other industries.

Figure 1 shows projected annual energy storage deployment in the United States with a 60% year over year growth rate. At this pace, storage is at approximately the same place solar photovoltaics (PV) was 10 years ago. Both the market and technology for energy storage are evolving rapidly, mirroring what occurred in the solar PV market last decade.

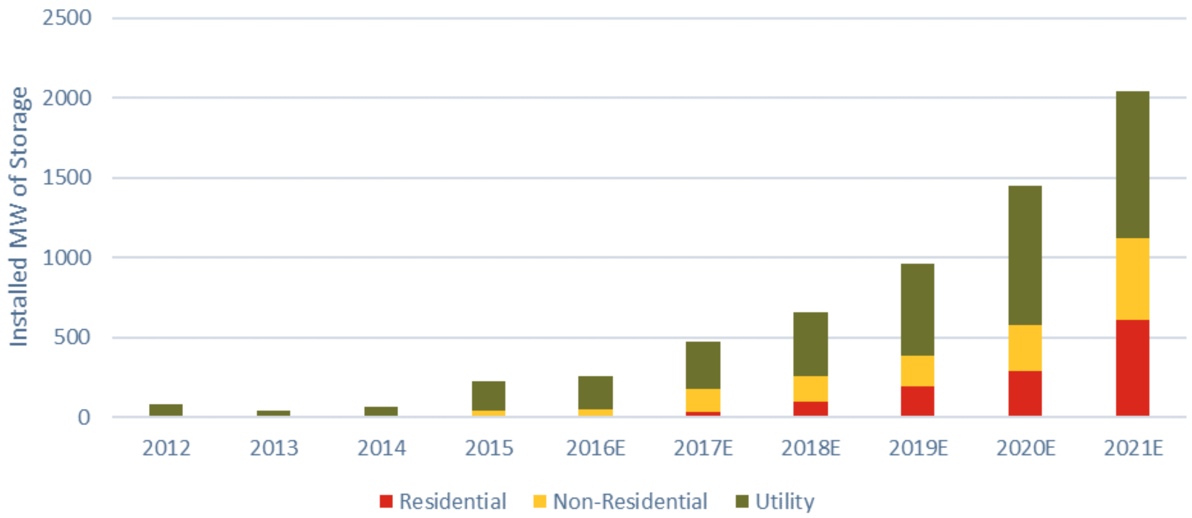

Figure 1. US annual and expected energy storage deployments
(source: https://www.greeantechmedia.com/research/subscription/energy-storage-data-hub)

This increasing amount of storage is a mixture of transmission connected, distribution grid connected, and behind the meter (BTM). Each connection point can provide several different services as shown in Table 1. This table is drawn from California-Public Utility Commission policy. In other states with different regulations, BTM storage can provide additional services such as frequency regulation and voltage support to improve grid stability.

Table 1. Storage use cases (CPUC, 2013)

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

By providing customer services such as demand charge reduction, time of use (TOU) bill management, and demand response, BTM storage may provide secondary services such as emissions reductions and transmission and distribution (T&D) upgrade deferral. Grid emissions may be reduced by reducing peak demand and shifting load to lower TOU periods, if tariffs are appropriately structured to move demand away from dirtier hours and towards cleaner hours. T&D upgrades can be deferred if peak demands are lowered; again, if tariffs are appropriately structured.

Energy Storage Evaluation

California, Massachusetts, and Oregon now have state mandates to install energy storage and provide incentives for customers and utilities to install storage. In California, the current incentive program requires regular evaluation to quantify how well the program is meeting program goals such as peak demand and emissions reductions. Unlike energy efficiency, energy storage increases end use customer energy consumption and the energy and demand impacts of energy storage are highly dependent on how it is operated. Some systems may sit idle for long periods while others are cycled daily for demand reduction or energy arbitrage. Given how dependent the impacts of energy storage are on actual operation, there is no substitute for metered data. Simulations often show how idealized energy storage *should* operate based on what services it is providing, but these simulations often show much 'better' performance than what is observed in the field. Energy storage has some similarities to demand response and in fact some energy storage companies aggregate BTM energy storage to participate in demand response programs. However, energy storage is often used to mitigate site-level demand peaks, and how it does so is highly dependent on the tariffs and other energy and demand price/cost signals the customer sees.

Data availability is paramount to storage evaluation due to the dependence of evaluation on, at a minimum, interval data showing energy charge and discharge combined with facility load. Unfortunately, our experience is that obtaining such data directly from the manufacturers of energy storage can be challenging and meters can be expensive, and in some cases, difficult to install properly. Additionally, the data collected by manufacturers for the purpose of battery management are sometimes not of sufficient accuracy for EM&V. Finally, data such as customer load and grid emissions are required to evaluate customer demand and emissions impacts. Given these challenges and the need to collect data from multiple sources, a well thought out and coordinated approach to data collection and analysis is critical for successful evaluation.

What We Have Learned from the Self-Generation Incentive Program (SGIP)

California's Self-Generation Incentive Program (SGIP) provides some early insight into the impacts of energy storage and some of the challenges of evaluating this technology. Established legislatively in 2001 to help address peak electricity problems facing California, the SGIP[1] represents one of the longest-lived and broadest-based distributed energy resources (DER) incentive programs in the country. The goals of the SGIP have expanded over time to include reducing emissions. The SGIP is funded by California electricity rate payers and managed by Program Administrators (PAs) representing California's major

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[1] During the summer and fall of 2000, California experienced a number of rolling blackouts that left thousands of electricity customers in Northern California without power and shut down hundreds of businesses. In response, the California legislature passed AB 970 (California Energy Security and Reliability Act of 2000) (Ducheny, September 6, 2000). http://www.leginfo.ca.gov/pub/99-00/bill/asm/ab_0951-1000/ab_970_bill_20000907_chaptered.html. The SGIP was established the following year as one of a number of programs to help address peak electricity problems.

investor owned utilities (IOUs).[2] The California Public Utilities Commission (CPUC) provides oversight and guidance on the SGIP.

Since its inception, the SGIP has provided incentives to a wide variety of distributed energy technologies including gas turbines; internal combustion engines; fuel cells and microturbines;[3] solar photovoltaic (PV) and wind turbine systems; and energy storage systems. Itron has been leading evaluations of the SGIP for well over a decade. Energy storage was only recently added to the program but has played an increasingly large role, with 75% of annual funds reserved for storage in 2017. In 2016, Itron worked with Energy + Environmental Economics, Inc. (E3) to develop the 2014-2015 Impact Evaluation, and this same team is currently working on the 2016 Energy Storage Impacts Report. These analyses share four goals:

- **To assess energy storage performance metrics:** including capacity factor, roundtrip efficiency, and proportion of charging from PV, for PV integrated energy storage.
- **To characterize energy storage dispatch:** by analyzing the timing of charge/discharge and metrics designed to reveal customer noncoincident peak demand reduction and TOU rate arbitrage behavior.
- **To assess peak demand impacts** of energy storage.
- **To assess the emissions impacts** of energy storage.
- **To assess the other benefits** of energy storage such as renewable integration and other grid benefits such as distribution system upgrade deferral.

SGIP Report Data Collection and Methodology

The Itron team's evaluation of SGIP energy storage for 2014-2015 relied entirely on third-party-metered data. Large SGIP projects (those 30 kW or larger) are required to have a data provider and provide these data for evaluation and payment purposes. The majority of energy storage projects are sized smaller than 30 kW, so are not required to have a separate data provider. However, nearly all energy storage projects under the SGIP are remotely monitored and controlled by the manufacturers.

To provide data for these evaluations, we requested charge and discharge data directly from the manufacturers that operate the SGIP energy storage projects. The Itron team also requested interval load data from utilities for each project. Unfortunately, a number or gaps and problems with these data limited the analysis that could be done.

Figure 2 shows the available data for non-residential projects by year and month. Our sample of 115 non-residential projects represents 21 (72%) of the 29 Large (>= 30 kW) SGIP projects operating in 2015, plus 94 (64%) of the 146 non-residential, small (< 30 kW) SGIP projects operating in 2015. Note that only four (three large, one small) of the non-residential projects with data in 2015 are installed at sites that also have solar PV.[4] Given the low fraction of projects installed at sites with solar PV, we did not attempt to analyze or quantify the interaction of solar and storage.

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[2] The Program Administrators are Pacific Gas & Electric (PG&E), Southern California Edison (SCE), Southern California Gas Company (SCG), and the Center for Sustainable Energy (CSE), which implements the program for customers of San Diego Gas & Electric (SDG&E).

[3] These distributed generation technologies can be fossil-fueled and biogas-fueled.

[4] Based on SGIP statewide tracking. Note that at least one of these sites does not appear to have any control or coupling between the AES and PV systems.

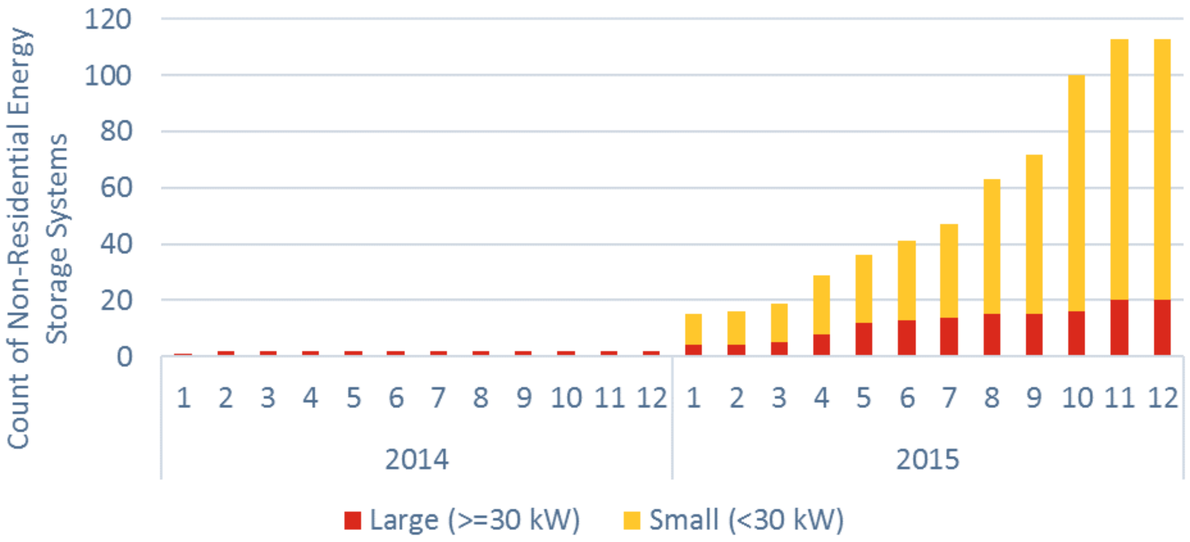

Figure 2. Available data

We used the available data to evaluate several metrics for energy storage including utilization (or discharge capacity factor), roundtrip efficiency, energy and peak demand impacts, when the battery was charging and discharging, and finally, emissions impacts. Emission impacts are calculated as the difference between the emissions generated or offset by SGIP projects and baseline emissions that would have occurred in the absence of the program. When in operation, energy discharged directly displaces electricity that in the absence of the SGIP would have been generated by a central station power plant to satisfy the site's electrical loads.[5] As a result, SGIP projects displace the accompanying CO_2 emissions that these central station power plants would have released to the atmosphere.

The avoided CO_2 emissions for the baseline conventional power plants are estimated on an hour-by-hour basis over all 8,760 hours of the year.[6] Conversely, energy used to charge energy storage causes an increase in conventional power plant emission. The estimates of electric power plant CO_2 emissions are based on a methodology developed by E3 and made publicly available on its website as part of its avoided cost calculator.[7] In California, the marginal emissions vary significantly hour to hour as the electricity mix varies, and can even drop to zero in times when renewable generators are curtailed. The marginal emissions during peak demand times when relatively inefficient natural gas 'peaker' plants are emitting twice as much carbon per MWh than more efficient (but less flexible) combined cycle gas power plants. Ideally, energy storage would charge during the times that the grid is cleaner (such as to absorb excess renewable energy) and discharge during times when the grid is dirtier.

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[5] In this analysis, greenhouse gas (GHG) emissions from SGIP projects are compared only to GHG emissions from utility power generation that could be subject to economic dispatch (i.e., central station natural gas-fired combined cycle facilities and simple cycle gas turbine peaking plants). It is assumed that operation of SGIP projects has no impact on electricity generated from utility facilities not subject to economic dispatch. Consequently, comparison of SGIP projects to nuclear or hydroelectric facilities is not made as neither of these technologies is subject to dispatch.

[6] Consequently, during those hours when an SGIP project is idle, displacement of CO_2 emissions from central station power plants is equal to zero.

[7] Energy + Environmental Economics, Inc. Methodology and Forecasting of Long Term Avoided Costs for the Evaluation of California Energy Efficiency Programs. For the California Public Utilities Commission. October 25, 2004. http://www.ethree.com/CPUC/E3_Avoided_Costs_Final.pdf

SGIP Report Results

This section will present the findings of how non-residential SGIP energy storage operated in 2015. Very little data were available for 2014 since few projects were online as energy storage was just entering the program. Vendor data accuracy limitations meant residential analysis was minimal. The non-residential results show some interesting trends but also highlight some of the limitations inherent in the available data such as limited customer peak demand analysis. Data for residential projects was of such low accuracy that it was not usable to quantify impacts.[8]

The first metric we investigated is how much the battery is used, or capacity factor. The capacity factor for a power plant is defined as the actual kWh generated divided by the total possible generation based on the nameplate rating (in kW) and possible hours of operation. The SGIP handbook assumes 5,200 maximum hours of operation in a year rather than the full 8,760 hours (60 percent). This is to account for the fact that "Energy Storage Projects typically discharge during peak weekday periods and are unable to discharge during their charging period."[9] The energy storage discharge capacity factor we calculate is thus:

$$Discharge\ Capacity\ Factor = \frac{kWh\ Discharge\ (kWh)}{Hours\ of\ Data\ Available \times\ Rebated\ Capacity\ (kW) \times\ 60\%}$$

Unlike energy efficiency measures, energy storage inherently increases energy consumption since less energy can be discharged than is stored in the battery due to losses in the battery. The more efficient a battery is, the less energy that is lost and the more likely that the battery can reduce emissions by charging during hours that the grid is powered by cleaner energy and discharging during hours that the grid is powered by dirtier energy. Figure 3 shows roundtrip efficiency and capacity factor and shows that the more the storage system is utilized, the more efficient it is at discharging energy used to charge the battery. That is likely due to parasitic energy needed during 'off' hours to keep the battery energy management system operating.

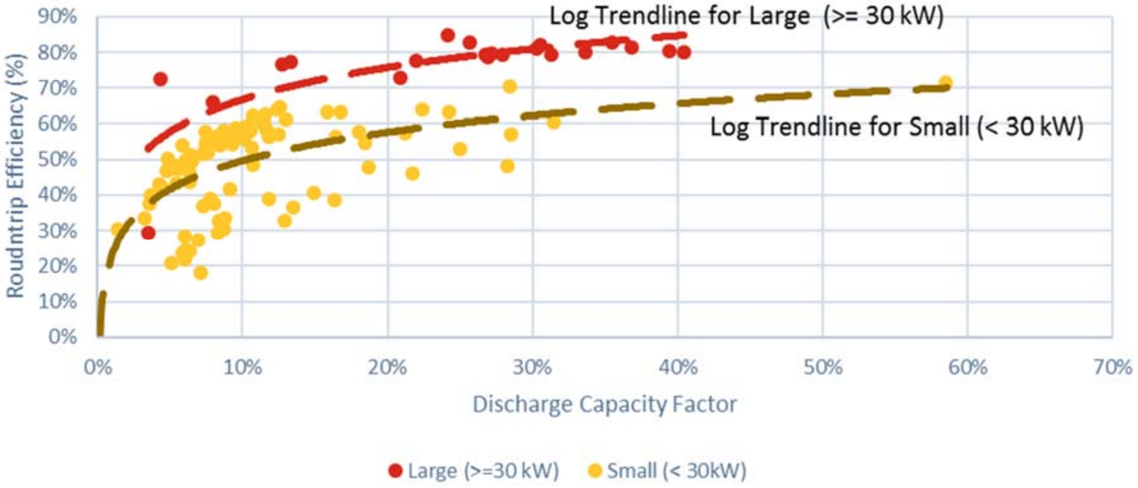

Figure 3. Roundtrip efficiency and discharge capacity factor

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[8] Multiple projects from both of the companies with residential projects showed round trip efficiencies over 100%, leading us to conclude the data were suspect enough to not be usable in quantitative analyses.

[9] See 2015 SGIP Handbook, p. 37.

One of the goals of the SGIP is to reduce utility (or coincident) peak demand. Figure 4 shows the impact by project during the top systems demand hours in 2016.[10]

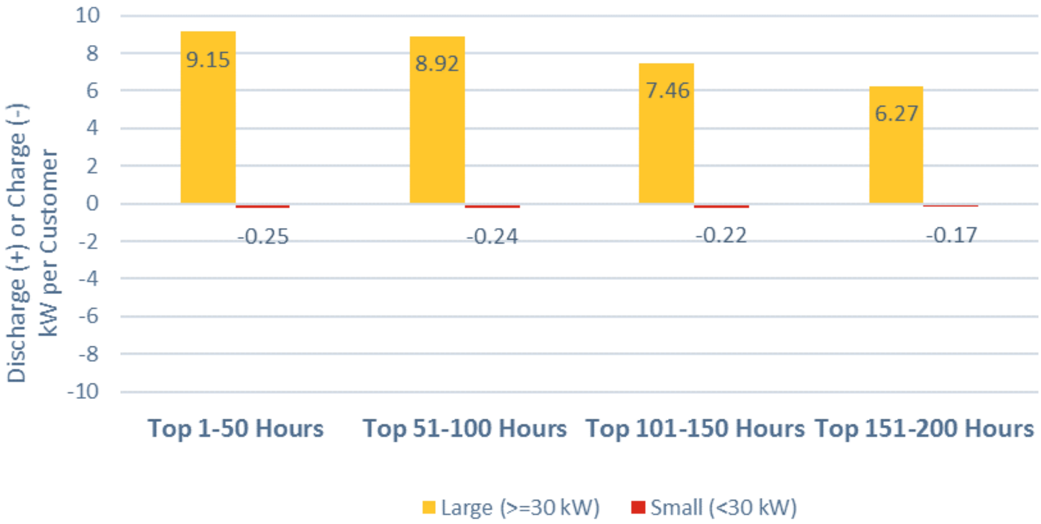

Figure 4. Energy storage coincident peak demand impacts

Both large (>=30 kW) and small (<30 kW), non-residential storage projects showed much lower negative consumption impacts in all of the top 200 system hours of 2015 than they did on average during the summer. That is, non-residential storage customers are at least somewhat avoiding charging during peak hours. However, while the large projects showed a net discharge during peak hours - reducing demand and benefiting the grid - the small projects were, in aggregate, charging during the top 200 hours of 2015. This implies that the incentives to avoid charging during peak hours may be insufficient, and that there is a significant opportunity to make better use of these projects from a grid-level perspective.

Many non-residential retail rates include higher demand charges in the summer than in the winter. We explored the possibility that this would incentivize relatively more demand charge minimization behavior in the summer. Figure 5 indicates that a seasonal discrepancy exists, although some storage projects may be dispatching to reduce demand charges throughout the year. In particular, we can see that summer months tend to have a significantly higher peak load reduction as a percentage of rebated capacity, as compared to winter months.

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[10] This is at the California Independent System Operator level that included PG&E, SCE, and SDG&E utility loads.

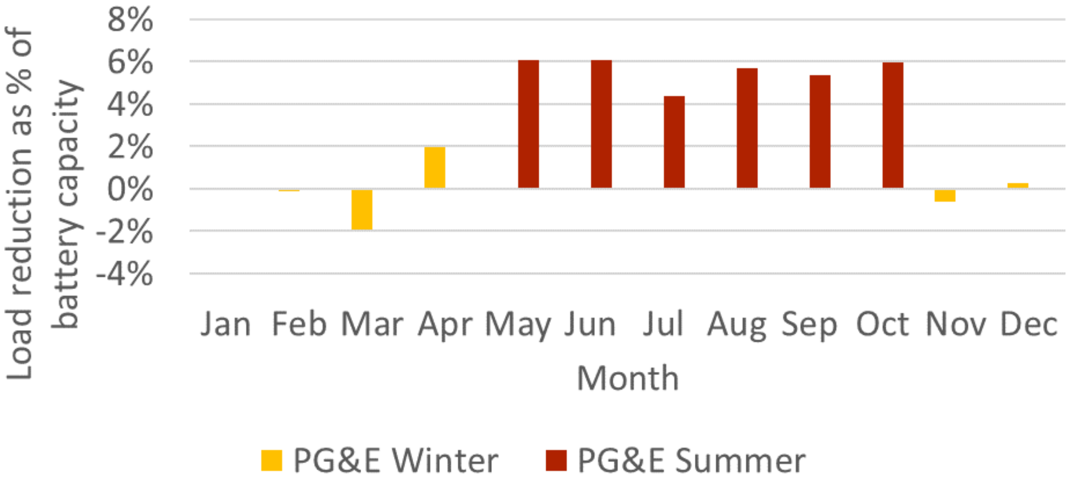

Figure 5. Non-residential demand reduction by month

This figure encompasses data from the five PG&E projects with demand charges and load data. We were not able to match load to charge/discharge data for the smaller non-residential energy storage systems since the vendors anonymized those data. Note that the installation of all except one of these projects occurred part of the way through the year. These relatively low percentages are likely not typical. Preliminary analysis of 2016 data spanning hundreds of projects shows significantly higher demand reductions with some projects showing demand reductions in excess of rated capacity.[11]

The combination of timing of battery charge and discharge with efficiency drives the emissions impact of energy storage. To reduce emissions, a battery needs to charge during cleaner hours and discharge during dirtier hours. In addition, the battery must be efficient enough that the energy losses do not overwhelm the difference in emissions during those periods.

Figure 6 shows average timing of charge and discharge for large non-residential (PBI) projects. The projects are largely discharging during periods of high marginal emissions in the afternoon and charging during periods of lower marginal emissions overnight. In general, that means these projects are being operated in a way to potentially reduce emissions. This figure also shows the importance of hourly data on both energy storage operation and grid emissions.

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[11] SGIP program rules rated energy storage at the kW the battery could discharge for 2 hours (i.e., kWh energy capacity divided by 2). Most current storage systems are capable of discharging at least twice that much power until they are out of energy.

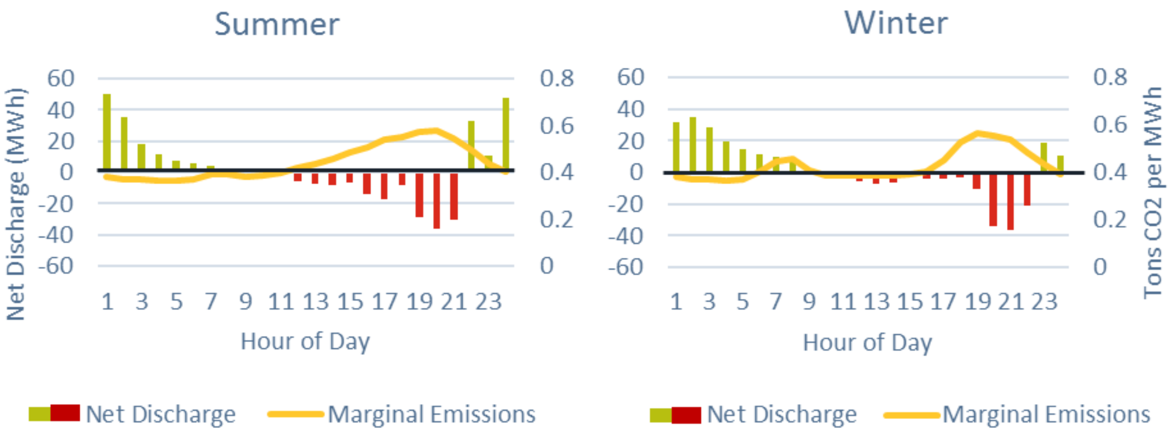

Figure 6. Larger non-residential (PBI) charging and discharging vs. marginal emissions

Figure 7 shows that these large non-residential storage projects are still increasing emissions due to a combination of not quite ideal operational timing and losses due to inefficiencies.

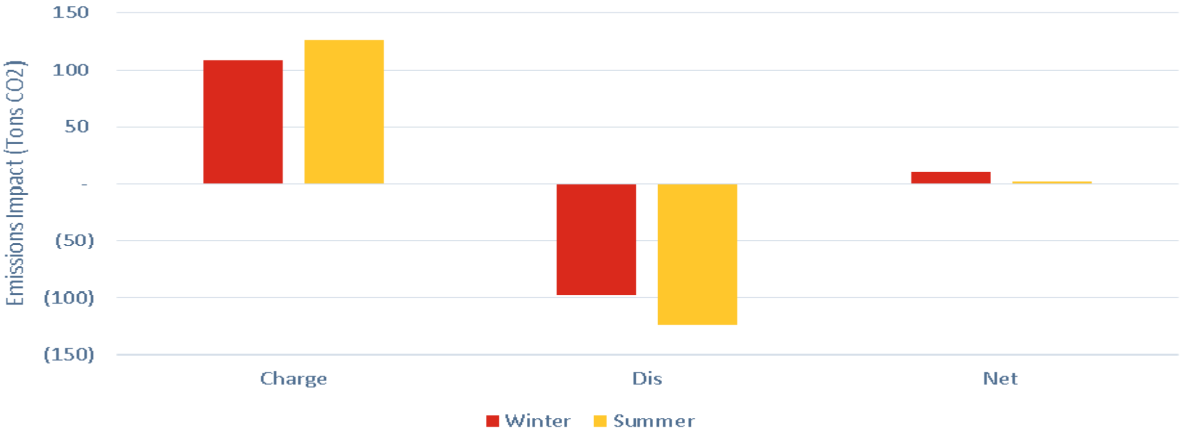

Figure 7. Larger non-residential (>= 30 kW) emissions impacts for 29 operational projects

The fact that energy storage is currently slightly *increasing* emissions is contrary to program goals and industry claims. Existing energy storage efficiencies *are* sufficient to reduce emissions if operated to do so. However, no holistic mechanisms exist to operate storage in that way or drive storage to operate in such ways. Some programs allow some storage operators to absorb excess electricity and provide demand response, but these programs do not yet appear to be sufficient to drive energy storage to reduce grid emissions.

Ways to Mitigate Data Issues

The 2014-2015 analysis was hindered due to lack of data:

- For smaller non-residential projects, vendors anonymized data due to confidentiality concerns so it was impossible to match to utility load data and fully characterize behavior and impact on customer load.
- For residential projects, the manufacturer data from battery management systems was suspect due to round trip efficiencies well over 100%.

The limitations due to lack of data or inaccurate data need to be remedied to allow complete assessment of program impacts. For future evaluations, we are working with the CPUC and program administrators to help ensure more complete data through direct EM&V metering and better industry engagement.

Since nearly all of the energy storage projects are controlled and metered by the manufacturers, the industry has a rich dataset. However, obtaining access to these data for evaluation purposes is not always straightforward and requires effort by the manufacturers to download and prepare. Many companies also expressed concerns about customer confidentiality and exposing operation that is driven by proprietary algorithms. Fortunately, through engagement with industry groups and manufacturers combined with CPUC backing, industry data are far more available for the upcoming 2016 SGIP Energy Storage Impact Evaluation.

Renewable (or Solar PV) Attribution

Increasingly, storage projects rebated by the SGIP are co-located with PV systems. This trend raises the question of whether PV impacts should be included in results reported for the SGIP impact evaluation even though the SGIP did not provide a financial incentive tied directly to the PV. How this question is answered has important ramifications for impacts evaluation results reported for the SGIP.

To address this question, additional information will be collected regarding program spillover and baseline assumptions. Most importantly, program applicant and host customer (participant) surveys will be employed. These surveys will include several questions specifically targeting participant decisions related to the SGIP impacts baseline. Additionally, sources of existing information will be reviewed to glean information about the SGIP impacts baseline. For example, review of marketing materials of vendors active in the SGIP could provide some insight into the relative roles storage and PV play in the marketing and sales process. If storage is marketed as a PV system upgrade, then we might be more inclined to believe that SGIP participation was not responsible for the customer's decision to install PV. We could also examine the relative costs of the PV and storage in joint installations. If storage is a relatively large proportion of the overall cost, then we might be more inclined to believe that the program was responsible for the customer's decision to install PV.

Metering

Using data that industry is already collecting is just one avenue to making sure sufficient data are available for analysis. As described earlier, some vendor data has round trip efficiencies well over 100%. That is due to little inaccuracies that add up for the many hours a battery is nearly idle. Since batteries are often nearly idle for the majority of the day, a small measurement error can add up to large discrepancies in kWh over time.

Installing metering on a sample of projects is a more robust way to ensure data availability and accuracy. Metering will ensure that all relevant energy flows are available to complete analysis. These include customer load, energy storage charge & discharge, PV generation, and any critical loads. Figure 8 shows where metering of AC loads might be placed to ensure all relevant energy flows are captured.

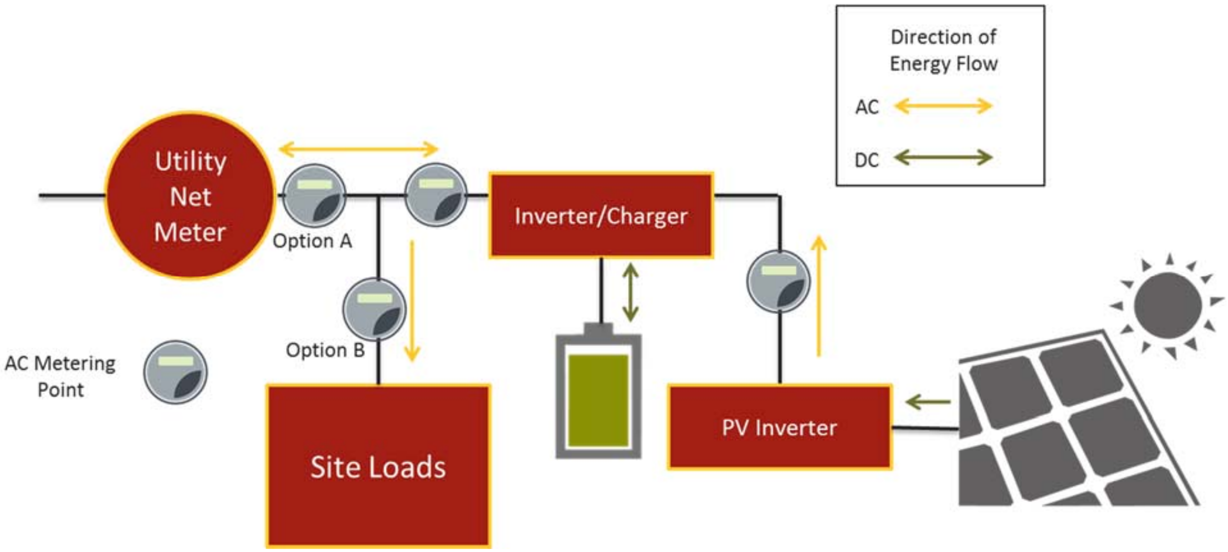

Figure 8. Metering points

In Figure 8, two options (option A and option B) for metering site load are shown. Option A would meter net load whereas Option B would only meter gross load, or what the load at the site is without the effect of solar or energy storage. Where that meter is actually placed is often dependent on the site configuration and layout. On paper, this seems like a minor nuance, but each metering point has similar variations so that rigorous documentation and bookkeeping is critical to assign data to the correct energy flow. Additionally, this is but one of over a dozen configurations seen in the field, again pointing to the need for rigorous record keeping in the field and in the back office.

We have installed metering on a sample of sixty projects (thirty residential and thirty non-residential) and will likely be expanding that sample based on analysis of data collected for the 2016 impact report and beyond.

Conclusions

Many BTM energy storage systems appear to be controlled to reduce customer bills, but are slightly increasing grid emissions. Further metering and analysis is needed to investigate how this technology is really impacting the grid and society. The Itron team, in coordination with the CPUC and SGIP Program Administrators, has outlined a plan to provide more of these critical insights into how energy storage is impacting the grid. We expect that the forthcoming 2016 SGIP Energy Storage Impacts Report will fill in some of these gaps and we are laying the framework to fill in the other likely gaps.

Despite these gaps, the 2014/2015 evaluation has some key findings that are already driving policy changes. These should be considered when designing energy storage incentive programs and structuring evaluations. These Include:

- BTM Energy Storage is not being operated in a way to reduce emissions, and in many cases to not reduce coincident peak demand. This is likely not a technology failing but is driven by lack of clear incentives to do so to energy storage operators.
- Energy Storage is reducing non-residential customer demand.

In essence, BTM energy storage is likely benefiting the host customers by reducing utility bills but is not yet producing the sort of societal benefits (emissions reductions and coincident peak demand reductions) that are part of the SGIP goals.