Behind-the-Meter Battery Energy Storage in Minnesota: Assessment of Value, Challenges, and Policy Opportunities

MS-STEP Professional Paper

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Abstract

Energy storage devices, including batteries, are capable to providing key services to the electric grid, which can partially compensate for services lost through retirement of coal-fired baseload generation facilities. Installation and operation of energy storage has traditionally been in the domain of utilities and large commercial and industrial customers, who can benefit from the efficiency that comes with large scale. However, as costs of batteries fall, many residential and small-commercial customers are expressing interest in employing energy storage on a smaller scale.

Energy storage devices offer a variety of services that can benefit residential and small commercial customers, including backup power for resilience to power outages and maximizing the customer's consumption of power generated through solar or wind equipment located on-site. In addition to these value propositions, behind-the-meter energy storage can provide up to thirteen different services which benefit the customer, their utility, and the grid as a whole. This paper evaluates several of these services with regard to monetization of the value provided for the benefit of the customer/owner and the mechanisms by which customers can get return on their investment in exchange for the services they provide. Finally, this paper will assess policy alternatives for application in Minnesota which may more appropriately compensate energy storage devices for the services they provide.

Table of Contents

List of Figures

List of Acronyms and Abbreviations

A.B.	Assembly Bill
BTM	behind-the-meter
CAES	compressed air energy storage
CIP	Conservation Improvement Program
CSP	concentrating solar power
FERC	Federal Energy Regulatory Commission
FTM	in-front-of-the-meter
GW	gigawatt
Hz	hertz
ISO	independent system operator
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
Minn. Stat.	Minnesota Statute
MISO	Midcontinent Independent System Operator
MW	megawatt
MWh	megawatt-hour
NEM	net energy metering
OPEC	Organization of Petroleum-Exporting Countries
PJM	PJM Interconnection
PUC	Public Utilities Commission
PV	photovoltaic
RDS	Reliability Demand Survey
RMI	Rocky Mountain Institute
RTO	regional transmission organization
SMART	Solar Massachusetts Renewable Target
SREC	Solar Renewable Energy Certificate
SRP	Salt River Project
TOU	time-of-use
VER	variable energy resource
VoLL	value of lost load

Part 1: Introduction to Energy Storage

1.1 Development of The Electric Grid

The conversion and storage of electrical energy as mechanical or electrochemical potential is often said to be a game-changing technology when it comes to the modernization of the world's electric grids. While this may be true in some ways, energy storage has always been the linchpin of grid reliability. However, modern technology is changing the way we are able to harness energy storage to the benefit of the grid, the climate, and energy consumers of all types.

In the early 20th century, as power lines first connected homes and businesses to electricity, the grid was designed for one-way flow of electrons. There was a clearly delineated path, wherein electricity was generated in power plants (typically coal, biomass, or hydroelectric), transferred through transmission lines and distribution networks, and ultimately consumed by residential, commercial, and industrial customers. In this way, the grid was designed to move electricity *through space* from producer to consumer.

It largely relies on simultaneous generation to meet electricity demand. This requirement has primarily been satisfied by the use of so-called baseload generation resources such as coal, hydroelectric, and later nuclear fission. These resources essentially feature built-in storage capacity in the form of their raw materials. Coal's hydrocarbon-rich composition has the capacity to store vast amounts of energy and makes it, historically, the world's most abundant and arguably most important form of energy storage. Ostensibly, power plant operators can simply add more coal to the steam turbine to ramp up production in response to increasing demand for electricity.

For this early grid, each kilowatt-hour of energy was treated the same because the majority of electricity was generated through coal, and because, at the time, there was no reason to think differently of coal than hydroelectric power. Additionally, each hour of the day was viewed as the same, since the high use of these baseload resources made time of production and consumption of little consequence. So too, the lack of air conditioning, high-consumption electronics, and many modern industrial practices made the daily and seasonal variations in load less significant than they are today.

While coal-fired electric generation has played a critical role in the development of the world's electric grid and, by consequence, its economy, it comes with a myriad of unintended consequences and externalities. The combustion of hydrocarbons in coal releases carbon dioxide, which has been found to exacerbate the greenhouse effect of the earth's atmosphere and contribute to rising global temperatures and exaggerated extreme weather events. As such, carbon dioxide is treated as an air pollutant by the United States Environmental Protection Agency.[1]

Nitrogen and sulfur compounds found naturally in coal deposits form nitrogen oxides and sulfur oxides respectively upon combustion. These chemicals can cause human respiratory health consequences,[2] form acid rain and cause acidification of surface water,[3] and contribute to nutrient pollution in rivers and coastal waters.[4] Mercury, also found naturally in coal, is released into the air after combustion, whereupon it can be deposited into surface waters.[5] There, mercury can bioaccumulate in high-trophic aquatic species and cause adverse health effects in humans who consume them.

1.2 A Changing Electricity Grid

In the 1970s, concerns about American energy security amid an oil embargo by the Organization of Petroleum Exporting Countries (OPEC) and declining domestic production, coupled with increasing awareness and understanding of ecosystem services and pollution driven by the environmental movement, led the United States to begin investing in modern renewable energy technologies.[6] These technologies, primarily wind turbines, solar photovoltaic (PV) cells, and concentrating solar power (CSP), have the potential to dramatically reduce the pollutant emissions and negative externalities of the energy sector.

However, these resources do not possess many of the characteristics that have enabled coal and nuclear generation to form the foundation of a durable and reliable electric grid. Most notably, wind and solar are variable energy resources (VERs), meaning that when the wind is not blowing or the sun is not shining, wind and solar generators are not producing at their full capacity. Furthermore, unless these resources are curtailed, or intentionally kept from operating at their full capacity, they cannot be ramped up to match increasing system load. Due to these characteristics and the uncertainty that these resources were thought to bring to grid operation and reliability, early in renewable development many utilities expressed skepticism that deployment of variable renewable resources could surpass just a few percentage points of total system generation without jeopardizing reliability.[7]

Around this time, in 1999, the Federal Energy Regulatory Commission (FERC) issued Order 2000, which facilitated the establishment of independent system operators (ISOs) and regional transmission organizations (RTOs).[8] These organizations are independent, non-governmental bodies which coordinate between utilities across multiple states to improve grid efficiency and reliability. Regional management of the grid integrates a broader regional diversity of VERs than any one utility can provide alone. Diversifying the variability of weather and generation capacity lowers the overall fluctuation observed and the risk to grid reliability. These policies, along with improvements to forecasting techniques and to the respective renewable technologies, has enabled utilities to incorporate increasing proportions of variable renewable resources into the generation mix.[9] However, as ever-increasing amounts of electricity generation is performed by variable renewable resources, concerns relating to grid reliability and grid services provided by generation resources are of increasing public interest.

While this is one of the largest technical hurdles for renewable energy to overcome to achieve broader adoption and decrease carbon emissions, wind and solar have faced economic challenges as well. Throughout most of their history, these resources have been significantly more expensive than coal, nuclear, and natural gas-fueled generation.[10] In response to this, several states have adopted policy mechanisms such as emissions reduction goals, renewable portfolio standards, or renewable generation goals to encourage utilities to invest in these nascent technologies.[11]

Over time, however, spurred on by investments and technological development, the cost of renewable generation has fallen dramatically. In many states, Minnesota included, on-shore wind and solar generation are cost-competitive with or cheaper than older non-renewable technologies such as coal, nuclear, and natural gas.[12] Given the projections that these resources will only continue to decline in price, many coal and nuclear facilities which are unable to compete economically with renewables and natural gas are being shut down. In Minnesota alone, over 4,000 MW of coal-fired generating facilities are projected to close by 2037.[13] While these closures represent a huge reduction in the emissions of the Minnesota energy sector, it also represents a large portion of the state's dispatchable, baseload generation and the grid services that it provides.

These changes represent just a few of the ways that the grid has evolved over time from its early iterations. Because of them, unlike the early grid, not every kilowatt-hour can be considered the same. Those generated through fossil fuel resources such as coal are associated with a much higher carbon emission profile and increased criteria pollutants than kilowatt-hours from renewable and/or clean resources. Likewise, not all hours are the same. At times of higher overall system load, often due to air conditioning use during the summer or high-energy industrial processes, utilities must use less efficient, more expensive, and/or more heavily polluting generation resources known as peaking plants. Consequently, the marginal cost and marginal emission profile of each kilowatt-hour used can be substantially different depending on the time of day or time of the year.

1.3 The Role of Energy Storage

The primary function of energy storage is to move energy *through time*. As mentioned before, fuel-powered energy generation resources benefit from innate storage capacity in the form of the fuel itself, whether that be coal, natural gas, biomass, or uranium. This fuel can be stored as stable potential energy until there is a need for electricity, at which point the fuel can be consumed and energy released and harnessed as electric current. Conversely, common renewable resources such as wind and solar do not have the same self-storage capacity. There is no conventional means to directly store wind or sunlight when the resource is abundant in a way that it can be used later when it is needed. Instead, external energy storage mechanisms must be used in order for these variable renewable resources to adapt to time constraints or be dispatchable at times of need in response to load.

The simplest decoupled form of energy storage is in the form of thermal energy. Individual homes or businesses can heat or cool their buildings or run their water heater at night or other times when electricity demand is low. If the building or water tank has good insulating properties, it can store the expended energy as heat (or cold air) through the time of day with high grid load. This example demonstrates the similarities between energy storage and energy efficiency, in that preventing energy losses and waste allows consumers to use their stored energy (hot air or water) when they need it. Furthermore, it demonstrates the most fundamental use case of energy storage – shifting energy consumption from times of high demand to times with lower demand.

The earliest form of bulk, non-carbon-emitting energy storage, pumped hydroelectric storage, has existed for as long as hydroelectric generation has been used. Unlike combustion-based generation resources, there is no extractable stored energy inherent to water as there is with coal or uranium. Hydroelectric energy is a function of the gravitational potential energy of water in one location relative to another. With this in mind, hydroelectric facilities were designed with two reservoirs, rather than just one. When energy is needed, water is released from the upper reservoir, runs through a turbine, generating electricity, and flows into the lower reservoir. When excess energy is available and needs to be stored, the turbine is reversed, pumping water pumping water from the lower reservoir back into the upper reservoir. As of 2017, there were roughly 25 GW of pumped hydroelectric storage in the United States and 184 GW around the world.[14] However, recent development has slowed due to capital costs, geographic limitations, and environmental and land use concerns.[15]

The grid was designed, and for its entire existence, has operated in the context of almost unlimited energy storage capacity. However, with the widespread retirement of coal plants, and the uncertainty surrounding the future of nuclear and hydroelectric generation, the energy storage capacity of the grid is rapidly declining. To compensate for these forms of energy storage which are being retired and replaced at least in part by variable, non-dispatchable generation resources, modern implementations of energy storage may be needed to supply some of the crucial grid services that are diminishing amid the renewable transition.

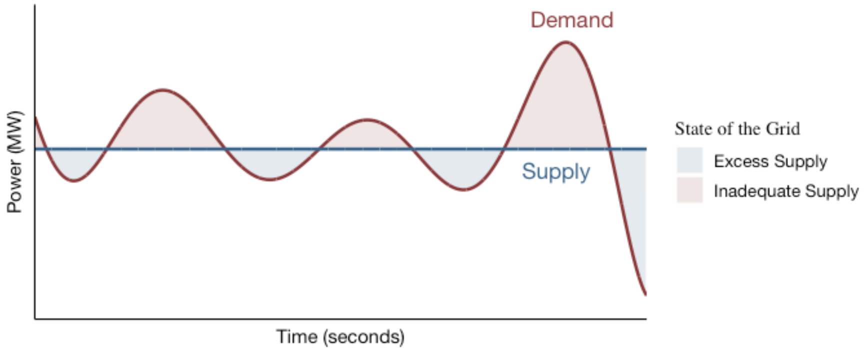

Figure 1: Rapid demand fluctuations with steady supply capacity. Under- and oversupply of energy can jeopardize system frequency stability and grid capacity.

Among the most important grid services required to maintain stability and reliability is the ability to modulate generation capacity to match fluctuations in load. This can take many forms. Load can fluctuate rapidly, changing by the minute, second, or on a sub-second time frame (*Figure 1*). Likewise, the output of variable renewable energy resources can have rapidly changing outputs depending on weather conditions (*Figure 2*). If left unaddressed, this can lead to a sequence of constant over- or underproduction, straining grid infrastructure and increasing costs of service. *Frequency Regulation* involves the rapid adjustment of generation output to match load, or of load to match generation. *Load Following* also involves adjustment of generation capacity to match load, but over a much longer time frame. In this case, generation must respond to changes in load throughout the day, such as in the middle of the day when most buildings have air conditioning devices in use, or at the end of the day when many people return to their homes from work or school and use lights, electronics, and kitchen appliances.

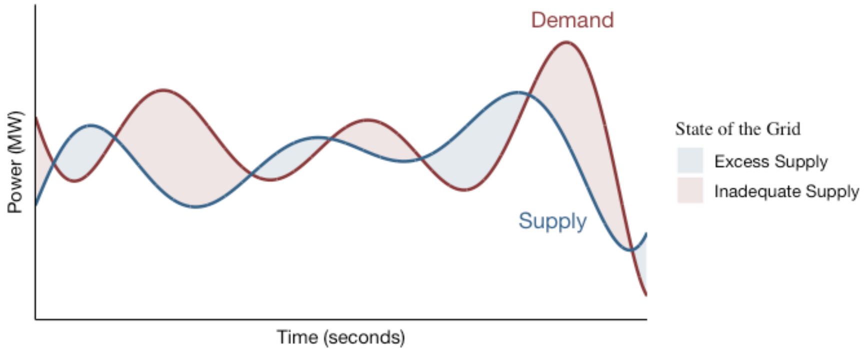

Figure 2: Rapid variation in both demand and supply curves. Integration of variable energy resources contributes to increased energy supply variability.

Finally, as a precaution to preserve grid reliability, each utility is required to make response plans in the event that their largest generation asset fails or must be taken offline. These plans involve the deployment of *reserve power* to make up for lost capacity. Spinning and non-spinning, or supplemental, reserves are those which can come online within ten minutes, while backup reserve comes online more slowly, but is able to fulfill demand for a longer period of time (i.e. firing up a dormant generation facility).

While these key roles have typically been filled by ramping up or down dispatchable generation resources, those with innate storage capacity, they are increasingly performed by stand-alone energy storage devices built specifically for this purpose. Devices designed for small, rapid charge-discharge cycles such as supercapacitors or mechanical flywheels are ideal for frequency regulation.[16] Meanwhile, larger devices with greater capacity and longer duration, such as pumped hydroelectric or compressed air energy storage (CAES), are well-suited for reserve power or for time-shifting energy use to smooth out peaks and decrease system costs.[17]

1.4 Battery Energy Storage Systems

In addition to these mechanical and electrical energy storage systems described above, electrochemical energy storage, in the form of batteries, possesses great potential for providing a wide range of services to the grid. Historically, high costs of batteries and technological limitations have hindered their use in grid applications. However, the recent surge in the electric vehicle market has seen battery costs fall precipitously, a consequence of the economy of scale.[18] Additionally, this market has spurred research and development efforts which have seen the technical capabilities of batteries improve significantly. Currently, lithium ion batteries are the dominant technology used, largely due to their use in electric vehicles and consumer electronics. However, several other chemistries in various stages of development and application have shown promise in a variety of different storage applications. These include vanadium redox flow batteries, advanced lead acid, zinc, nickel, and sodium chemistries, among others (*Figure 3*).

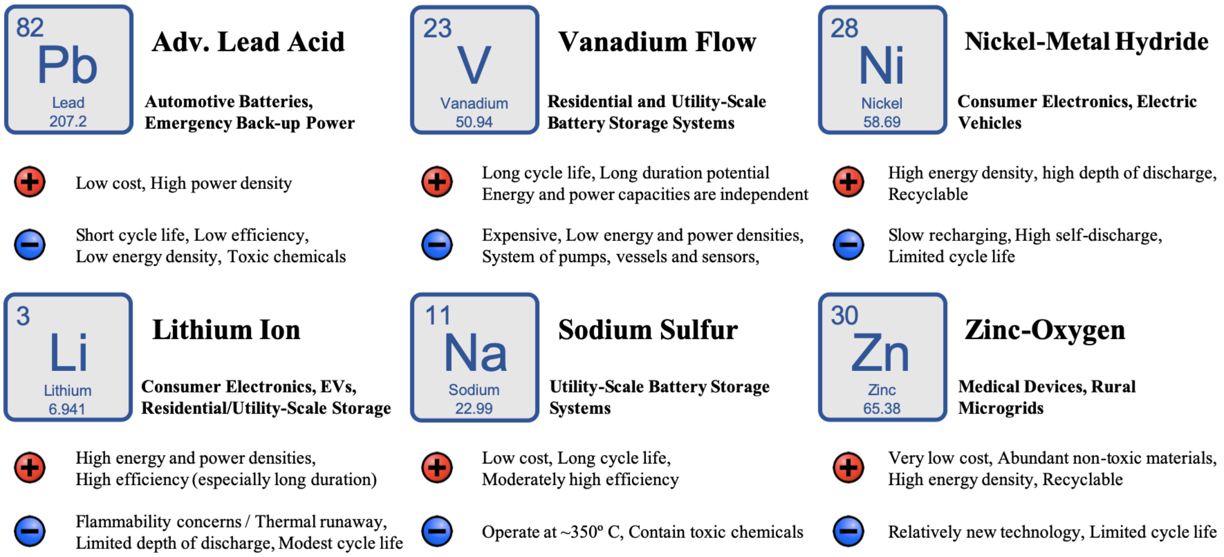

Figure 3: A selection of battery chemistries available for use in storage applications. Common use cases, advantages, and disadvantages listed for each.

All forms of energy storage are entropically required to suffer inefficiencies in the return of stored energy. The key metric measuring this is round-trip efficiency, which describes the amount of energy available to be discharged as a function of the amount of input when charging the device. Efficiency can vary from 65-75 percent for vanadium flow batteries to around 90 percent for many lithium ion battery chemistries.[19] What this means is that when energy storage is used to provide grid services, the overall load on the grid increases, increasing net carbon emissions.[20] Many energy storage use cases involve charging at night when demand is low and, in Minnesota, wind energy contributes a larger share of overall generation, and discharging during the day and evening, when coal and natural gas are at their peak (*Figure 4*). However, while the percent of energy generated from clean and renewable resources increases in these cases, the overall emissions still rise. Indeed, Goteti *et al.* estimate that for storage to break even in terms of carbon emissions, the generation sources charging it needs to be roughly 20 percent cleaner with respect to emissions than the resources being replaced when the battery discharges.[21] A separate study in 2017 estimated that for every solar-equipped house in Texas which pairs its solar generation with storage, carbon dioxide emissions are increased by between 153 and 303 kilograms per year.[22]

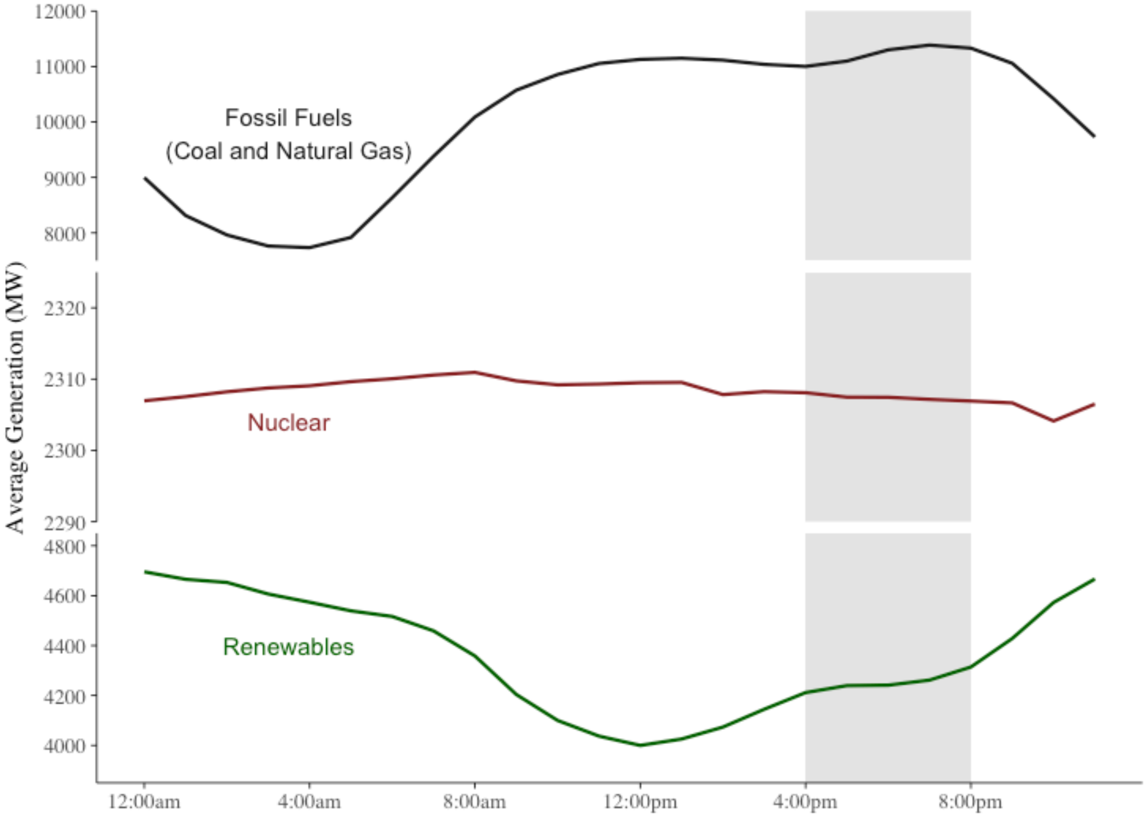

Figure 4: Average generation resource mix by time of day for the MISO North region in 2016. Peak system load times are represented by the grey shaded regions.

This vein of criticism to energy storage takes a misguidedly narrow and myopic perspective, however. For the majority of the history of the grid, critical services from energy storage and dispatchability were provided primarily by coal, petroleum, and natural gas. In the process of reducing our dependence on these heavily polluting resources, consideration must be paid to the source of these services in a fossil-fuel-free future. While there are strategies to adapt variable energy resources to provide some of these services, or to adapt the grid to rely less heavily on them for reliability, the development and application of energy storage technology is a particularly promising option. Although battery energy storage may increase marginal emissions in the short term, it is also arguably the key to enabling the grid to operate reliably on predominantly emission-free generation resources.

Similarly, when electric vehicles first became commercially available in the mid-1990s, Minnesota had virtually no wind or solar generation online. Coal made up roughly two-thirds of statewide generation, so any electric vehicle operated in Minnesota was actually responsible for more emissions than a comparable gasoline-powered car.[23] Today, this is no longer the case, as development and advancement in battery and renewable energy technology has enabled electric vehicles to reduce their attributed emissions well below the transportation sector average.[24] Likewise, energy storage has the potential to enable the net reduction of emissions for the grid and energy sector as a whole.

1.5 Distributed Energy Generation

While in most cases, economies of scale dictate that large, utility-scale generation and storage installations are the most economically efficient means of production, rapidly declining cost trends for photovoltaic cells have made residential and small-scale commercial ownership viable.[25] This distributed generation capacity offers owners several value streams, including both monetizable and non-monetizable value. At the forefront of these is financial savings, wherein utility customers are able to generate energy more cheaply than they can purchase it from their utility. Nevertheless, many who install distributed solar are motivated by non-monetizable value, such as contributing to the transition towards renewable energy, reduction of their attributable greenhouse gas emissions, or the ideals of resiliency, self-reliance, and independence.

1.6 Distributed Energy Storage

Distributed Storage is often seen as a complement to, or the next progressive step in line with distributed generation. However, the sources of value that are provided by storage are much more complex than with generation, primarily because storage assets do not directly create anything of value the way generation resources do. Distributed energy storage, like centralized, utility-scale storage, generally derives value from the provision of grid services. Many of these services are the same as those provided by utility-scale installations, but behind-the meter storage enables several additional services as well (*Figure 5*).[26]

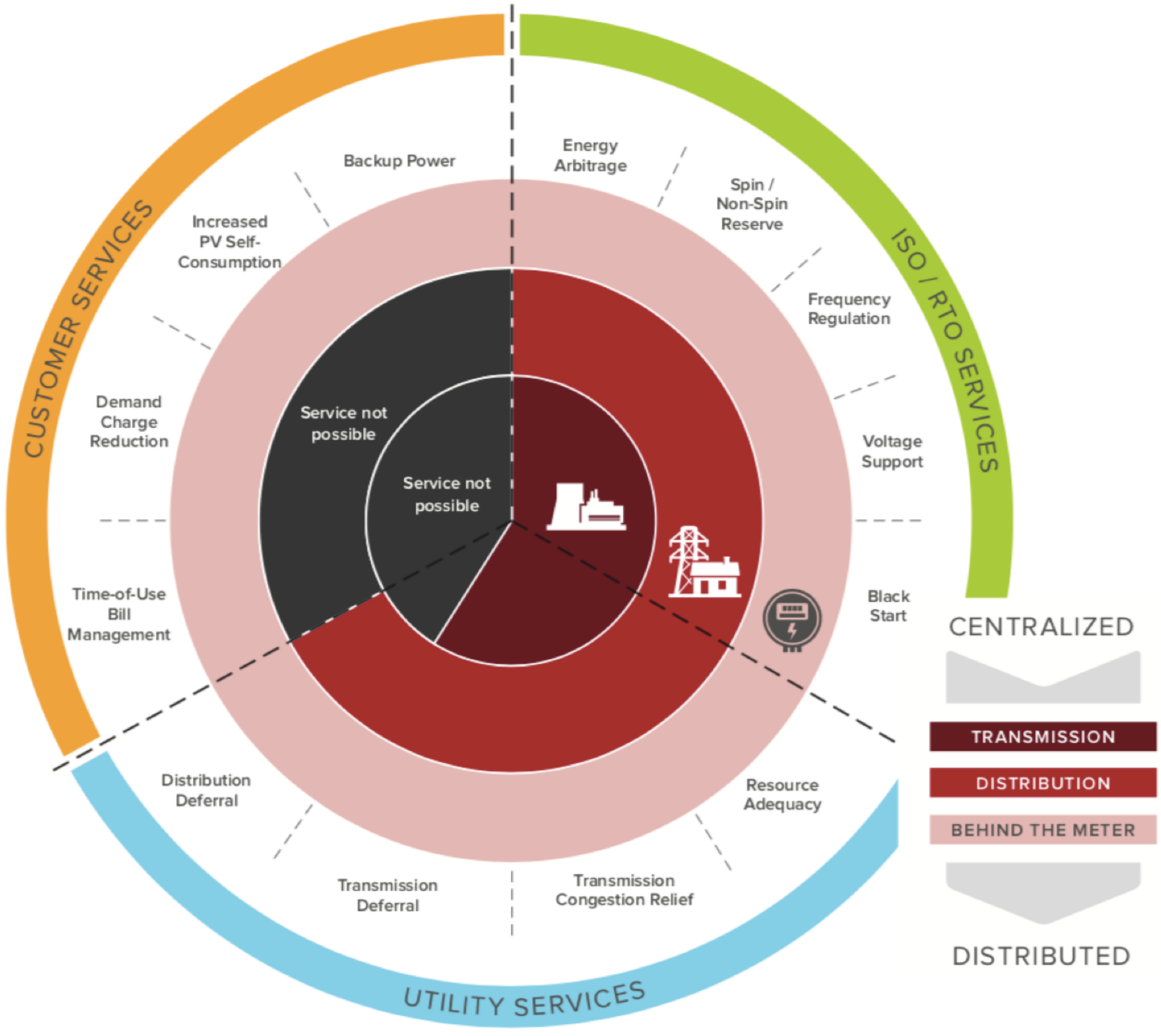

Figure 5: Thirteen vital grid services can be provided by battery energy storage systems depending on installation site. Some benefit the grid as a whole, utilities, and utility customers. (Image Source: Rocky Mountain Institute)

1.6.1 General Energy Storage Grid Services

The following services can be supplied by distributed, behind-the-meter storage as well as centralized, utility-scale projects:

- Frequency Regulation

Proper grid functioning requires that the frequency be kept as close to 60 Hz as possible. Significant or extended variation away from this baseline can threaten the reliability of the grid. When generation is greater than demand, frequency rises above 60 Hz. Frequency drops below 60 Hz when surges in demand or dips in generation causes a shortage. High-frequency events are typically easier to respond to than low-frequency events, since utilities can reduce the output of a generation asset to modify supply downward towards load. Low-frequency events, often caused by unexpected loss or reduction of generation output, can be much more difficult to correct and more consequential. It is necessary to respond rapidly by dispatching supply to arrest the decline in frequency and correct back towards 60 Hz. Rapid-response storage assets such as supercapacitors, flywheels, and lithium ion batteries are considered to be ideally suited for this purpose.

- Load Following / Reserve Energy

While frequency regulation involves reacting to very rapid fluctuations in load or supply, system demand experiences regular shifts throughout the day or week to which utilities must respond. These events, such as increasing demand in response to rising temperatures during the day, are often more predictable than frequency disruptions and do not require as rapid of action but may involve longer duration response. Energy storage has the ability to discharge in response to increasing load, or charge in response to decreasing load, allowing available capacity to match load throughout these daily variations.

- Resource Adequacy and Optimization

As variable renewable generation makes up a growing proportion of total generation assets and capacity, it is increasingly likely that renewable resources will, at times, overproduce relative to load. In this event, generation capacity will have to be turned off, or curtailed, in order to maintain stable system frequency and grid reliability. If storage capacity is available, however, it has the ability to charge during the overproduction event, and then discharge that energy when renewable generation drops below system load.

- Distribution Deferral and Congestion Relief

Most transmission and distribution infrastructure is built to accommodate peak load events, and must be upgraded as system peaks increase in scale. If storage is installed at or downstream from the distribution level, and can smooth out peak events, distribution upgrades and their associated costs can be deferred, saving the utility money. Furthermore, if conduction of electricity across the distribution system is shifted away from peak times, which typically correspond with warm weather, to the middle of the night when it is typically cooler and grid congestion is lower, then less energy is lost to line losses, which are more significant at higher temperatures.[27]

1.6.2 Behind-the-Meter Energy Storage Grid Services

The following grid services are unique to distributed, behind-the-meter energy storage, and cannot be provided by utility scale-projects:

- Backup Power

Perhaps the simplest (conceptually) service that behind-the-meter energy storage can provide is backup power in the event of a grid interruption of outage. The storage device simply powers the home or business with the energy that it has stored. Furthermore, solar PV installations are unable to generate electricity during outages unless they are paired with storage and disconnected, or islanded, from the grid.[28] Otherwise power from the solar panels would endanger utility repair workers or damage infrastructure. When storage is paired with solar, however, the system can continue to provide power as long as the solar panels are able to generate electricity to recharge the batteries (Figure *6*).

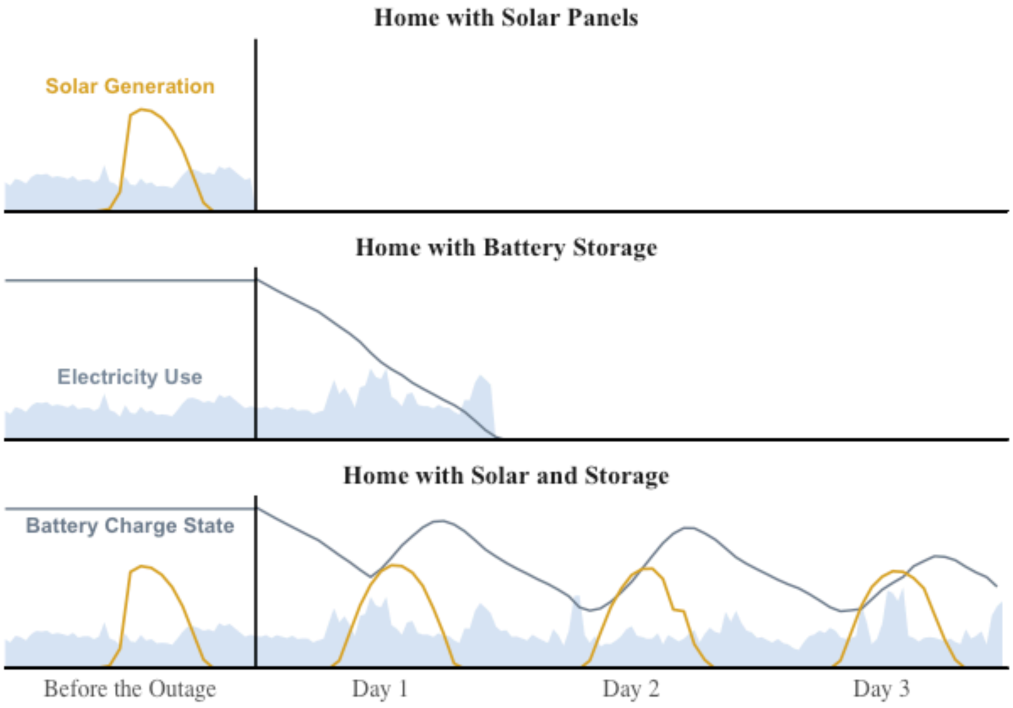

Figure 6: Capacity of solar and storage devices to provide backup power in response to power outages. The beginning of an outage is represented by the vertical black line.

- Self-Consumption of Distributed Generation

For most customers with on-site generation, particularly residential customers, there are times when the energy they generate is greater than their load, creating a net surplus, and other times when load is greater than generation, creating a net deficit. At times of surplus, these customers can export excess energy into the grid, only to draw energy back from the grid during deficits. Most states have net metering policies informing compensation rates for these customers, which are often set at the retail rate of electricity.

Critics of these policies allege that net-metered customers often use the grid as much if not more than other customers, but do not pay their fair share of grid infrastructure costs.[29] Indeed, for each unit of energy that is returned to the grid only to be bought back later, the distribution system is used twice, but under retail rate net metering, the costs are offset and the customer is not charged. Furthermore, solar generation is typically highest during some of the warmest days of the year when line losses are most significant. This inefficiency could be interpreted to mean that power sent into the grid during the day is lower in value per kilowatt-hour than energy drawn back out later in the day.

Energy storage has the ability to improve the value to the grid of distributed generation by decreasing use of the grid and increasing direct self-consumption. This is done by storing excess energy during times of overproduction, and then discharging when load exceeds generation (*Figure 7*). While this application provides value to the grid in the form of reducing distribution congestion and potentially deferring upgrades to the distribution system, this value is not currently monetizable in states which net meter at retail rates.

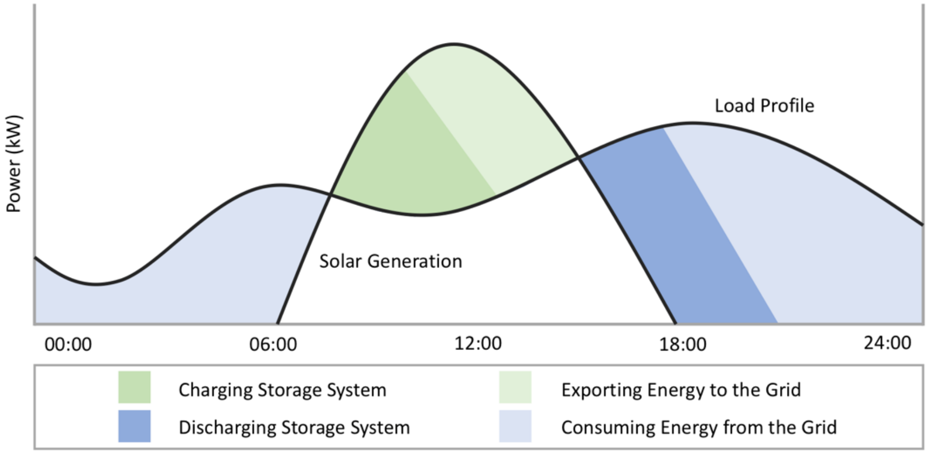

Figure 7: Energy storage has the ability to charge during overproduction of paired solar generation (green) and discharge when load is greater than generation (blue).

- Time-of-Use Rate Management

Because the provision of electricity incurs variable cost to the utility depending on the time of day in which it occurs, many utilities have begun to investigate rate designs which better reflect the cost of service. For residential ratepayers, this often takes the form of time-of-use rates, wherein the utility designates certain hours of the day as peak, mid-peak, or off-peak. Prices are lowest for off-peak electricity use and highest during peak times. Energy storage can provide a service to the grid as well as generate monetizable value by charging during off-peak times when demand, cost of service, and retail rates are low, and discharging at peak times when costs to the utility and to customers are high. This reduces the severity of system peak events, while saving the customer money on their electricity bill.

- Demand Charge Management

In addition to standard consumption charges on a per-kilowatt-hour basis, many commercial and industrial customers also pay demand charges. Demand refers to the amount of power being consumed at any one time, and demand charges are assessed according to the highest 15-minute sustained demand each month. While consumption charges are usually several cents per kilowatt-hour, demand charges are typically several dollars per kilowatt.

Energy storage can provide a service to the grid and return value to its owner though peak-shaving or shifting, charging when load is low and discharging during peak load events. This can reduce overall load and congestion on the grid and smooth out load distribution, while decreasing the monthly load charges for the customer, which can make up 50 percent or more of their monthly bill. Additionally, many utilities also have commercial demand response programs, wherein utilities indicate to customers when they are experiencing high load or low generation events and compensate customers who are able to reduce their load or shift it to a time when it would have less of an impact on the grid.

- Unit Diversity / Risk Management

Utilities are required to make contingency plans in the event that their largest generation asset goes offline. This generally involves dialing back the production at several other power plants or the installation of centralized, utility-scale energy storage. While large, centralized generation and storage assets are generally more economically efficient, they also concentrate the risk associated with failure of the asset. Unit diversity refers to the distribution of risk through distributing generation or storage capacity across several units. While economic and resource efficiency may be lower for distributed assets, they provide services to the grid in the form of risk mitigation and reliability, as shown in *Figure 8*.

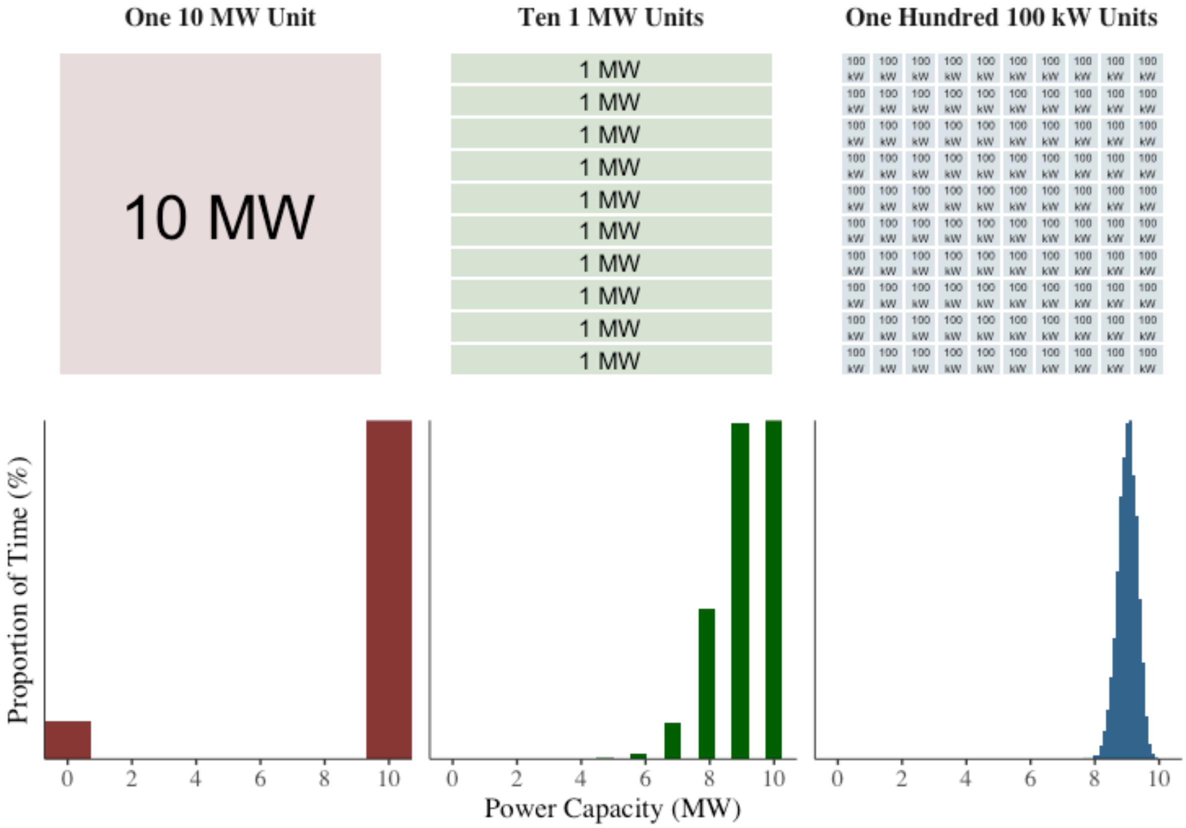

Figure 8: Distribution of energy resources distributes the risk of system failure. Each group has the same nameplate capacity (10 MW), but increased distribution of this capacity decreases the probability of low-production events.

Part 2: Assessing the Value of Distributed Energy Storage

2.1 The Value of Providing Services to the Grid

While it is clear that energy storage is capable of providing valuable services to the grid, to utilities, and to grid operators, it is a much more difficult proposition to estimate the precise value of those services. The value of any given service can vary dramatically based on a number of factors, such as the level of the grid from which it is provided (i.e. transmission, distribution, behind-the-meter), market forces such as the RTO/ISO, whether the market is restructured or not, limits and restrictions placed on ancillary service markets, and technical characteristics such as the age of transmission and distribution infrastructure and generation resource characteristics. Furthermore, the value of a service on a per-kilowatt-hour basis can depend on the number of kilowatts providing the service, as well as its proclivity to be combined with other use cases.

Given the number of variables impacting a value determination and the variety of ways that certain factors can affect is, estimations of the value of grid services from energy storage widely. Below is a compilation of value estimations collected in a meta-analysis conducted by the Rocky Mountain Institute (*Figure 9*).[26] While frequency regulation services are generally found to be more highly valued than other ISO/RTO services (which explains the popularity and profitability of participating in frequency markets such as PJM's), services tend to increase in value the further downstream that they impact the grid. Customer services are, with the exception of two potential outliers, found to be more valuable than utility services, which in turn are more valuable than ISO/RTO services.

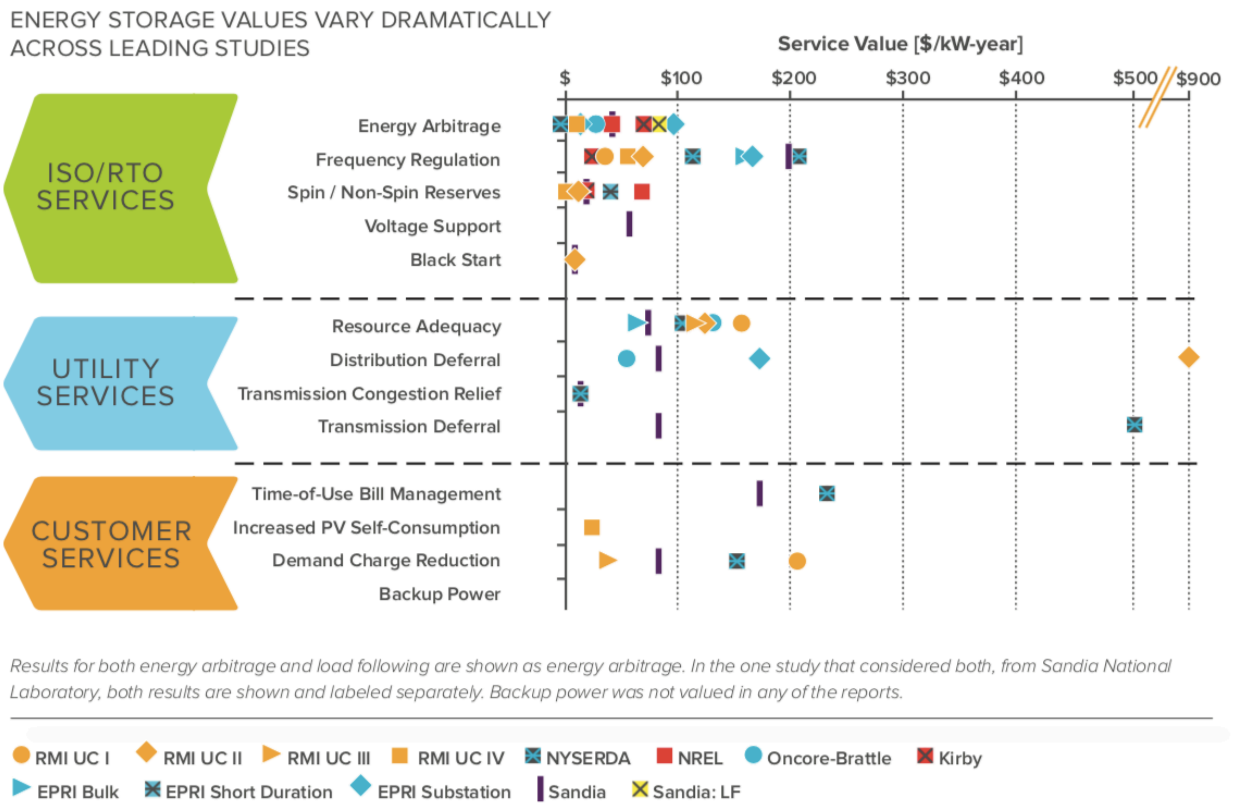

Figure 9: A meta-analysis of value of energy storage studies depicts a wide range of estimated values for many of the grid services that energy storage can provide. (Image Source: Rocky Mountain Institute)

In pursuit of more clarity amid the vast number of variables involved, the RMI study investigated four specific case studies. These involved estimating battery costs based on industry averages and estimating value through analysis of sample commercial and residential load curve datasets. While the value calculations for these case studies are specific to their individual parameters, a few generalizations can be gleaned with regard to assessment of value for storage systems:

a. Inclusion of customer-oriented use cases is critical in maximizing value. Grid and utility services have lower value per unit of energy than do customer-oriented services, since grid services are generally provided by extremely large generation facilities or storage installations which benefit from economies of scale. However, these services generally require lower time investment than customer services and can be beneficial if used to fill unused time to maximize storage value.

b. Depending on the accessibility of ancillary services markets, not all services may be able to be provided by all storage devices. Furthermore, a certain service may be able to be provided, but without a mechanism for proper compensation. If either of these conditions is true in a certain market, a storage device may represent a net benefit in terms of value or potential value, but the owner of the storage will not be properly compensated for the added value.

c. Two important components of the value of provided services are service stackability and service efficiency, or the amount of value that is created per unit of time that the battery is actively providing that service. If a service has a high value but uses all of the battery's time to provide it and cannot be combined with any other use cases, it may ultimately be less valuable than two or more services with lower values individually, but which take less time and can be stacked to combine value.[30]

2.2 Non-Energy Benefits of Energy Storage

In addition to benefits relating to the cost and reliability of electricity service, energy storage can have a number of benefits outside of energy markets. While quantifying these benefits can be challenging and imprecise, failure to consider them at all effectively places their value at zero. A study by the Applied Economics Clinic in 2019 in support of Clean Energy Group's analysis of Massachusetts' Energy Efficiency Plan established several such services that provide value to the grid, the utility, or to society as a whole.[31] However, owners of energy storage rarely experience direct financial benefit through these mechanics.

- Avoided Power Outages

A 2014 study conducted by researchers at Worcester Polytechnic Institute found that by reducing strain on the electric grid, increased use of energy storage has the potential to reduce the frequency, severity, and duration of power outages.[32] This reduces total system costs through avoided repairs and benefits utilities by minimizing their lost revenue during the outage, or value of lost load (VoLL). Additional value is provided collectively to all utility customers in the form of avoided losses from power outages, such as opportunity costs, data loss, spoilage of sensitive materials such as refrigerated foods or medication, or health complications relating to reliance on electric devices such as IV pumps or oxygen machines.

Several states and regulatory agencies have the authority to fine utilities for power outages resulting from equipment failures. In 2010, Florida Power and Light was fined $25 million for a single power outage,[33] while in 2012, Massachusetts fined three utilities $24.8 million for outages following Tropical Storm Irene and the Halloween Blizzard of 2011.[34] Reducing the frequency and breadth of these outages is likely to reduce the severity of the fines imposed on utilities.

Additionally, grid outages often result in a significant increase in safety-related emergency calls. These calls and their responses from emergency services represent substantial costs to communities. Implementing energy storage to reduce the frequency of power outages can also reduce the number of emergency calls and responses and their associated costs.

- Increased Property Values

Because energy storage has the potential to decrease energy bills and improve resilience to grid interruptions, storage installations can also increase the value of the property in which they are installed. Similar to solar PV installations, this can increase the price or speed at which the property is sold or improve the marketability of rental properties.

- Avoided Collections, Terminations, and Reconnections

Utilities incur significant costs through terminating or referring to collections agencies customers who do not pay their bills. The estimated cost for termination and reconnection for the utility is $1.85 per customer per year. If energy storage is employed to reduce total system costs and lower customer bills, fewer customer would have difficulty paying, and fewer would have to be referred to collections agencies or disconnected.

- Job Creation

Similarly to the proliferation of distributed solar generation, behind-the-meter storage has the potential to support job growth at several levels of the market. Manufacturing, sales, installation, and maintenance jobs all rely on the sales and operation of storage devices. There are also roles in software development and support for storage system, among other indirectly connected industries.

- Land Use for Power Plants

The use of energy storage to mitigate peak energy demand events has the potential to obviate the need for natural gas-fired peaking plants. While the storage installations necessary for this purpose require a large footprint, it generally constitutes far less land use than a comparable generation facility. In this way, the use of energy storage can provide value to its local region or utility service territory in the form of avoided land use.

2.3 Value Provided to the Owner of Distributed Storage

In Rocky Mountain Institute's 2015 meta-analysis, Fitzgerald et al. conclude that services directly benefitting the owner of the storage device are critical in maximizing benefit to cost ratio.[26] However, these can be some of the more difficult value streams to predict, since they depend heavily on a number of variables, including several characteristics of load profiles, battery specifications, rates and rate design, and the priority and stackability among multiple use cases. Herein, we will attempt to elucidate with greater clarity value considerations for each directly customer-serving function of behind-the-meter energy storage.

2.3.1 Backup Power / Reliability

Because of the difficulty of directly estimating the value of electric reliability, most studies use as a proxy measurement the costs and losses related to power outages. This is largely considered an appropriate representative measure, since these costs would be avoided in a counterfactual situation with perfect reliability. The costs of power outages can generally be estimated through survey methods, comparison of the costs of substitutes such as on-site backup generators, or analysis of elasticity in energy markets.

A 2010 study conducted by Centolella at al. for SAIC surveyed residential customers as well as small and large commercial and industrial customers.[35] For those who had experienced one or more power outages, they were asked to estimate the amount of value that had been lost between lost revenue, damaged or devalued property, or some other means. Comparing this value to an estimate of undelivered load during the outage allowed them to approximate the cost of an outage on a per-kilowatt-hour basis. They reported these costs to be $5/kWh for residential, $28/kWh for large commercial and industrial, and $56/kWh for small commercial and industrial customers.

A key limitation with this metric is that customers, particularly residential may not accurately represent the cost or lost value associated with an outage. Furthermore, there are forms of lost value which are very difficult to estimate. In terms of commercial and industrial customers, opportunity costs can pose a challenge; some aspects such as production or transportation are relatively straightforward to predict, though others, like sales or research and development can have a non-linear trajectory. Likewise, for residential customers, lost perishable goods are easily quantifiable, but enjoyment value of activities involving electricity use and other quality of life metrics are more complex and subjective.

Another means of estimating the value of reliability is through surveying customers' willingness to pay for perfect reliability (no outages). An analysis by King in 2012 of the Reliability Demand Survey (RDS) sheds light on customers' estimation of the value of reliability.[36] In this survey, respondents revealed that the two most significant inconveniences of power outages are loss of perishable goods and loss of heat or air conditioning. Behind-the-meter storage is capable of mitigating both of these inconveniences. Additionally, several respondents reported having to move due to poor reliability and frequent outages, which storage could help avoid.

Respondents to the RDS were asked to estimate their willingness to pay on a per-month basis to have perfect reliability and avoid all outages. This value varied somewhat depending on a number of customer characteristics but was generally between $15 and $19 per month. If we consider this to be the customer's personal valuation of back-up power and reliability as it can be provided by energy storage, convert it to a per-year value, and apply a discount rate of 4 percent, it is possible to estimate ranges for the value of long-term reliability provided by energy storage. For a battery capable of eliminating outages, whose predicted functional life is 10 years, the value falls between $1,508 and $1,910, while a battery with a longer predicted functional life of 20 years, such as a flow battery, has a reliability value between $2,511 and $3,180. These estimates do not consider load characteristics of respondents, however, so are unable to estimated value on a per-kilowatt or per-kilowatt-hour basis for the energy storage system required to provide these services.

2.3.2 Self-Consumption of Co-Located Renewable Generation

The monetizable value of self-consumption is highly contingent on the policy environment governing the customer's energy market and rate design, as well as the capacity of the on-site generation. If generation capacity is small enough as to never be greater than gross load, then adding storage represents no increase in monetizable value. If, however, solar generation is adequately sized to overproduce during the middle of the day, energy storage can add value by storing this overproduction and using it later rather than putting it back onto the distribution network. It can also add value by slowing the rate at which solar-producing customers increase their electricity consumption from the grid as the sun sets and their solar generation wanes. Applied on a large scale, this service can reduce the "duck curve" effect observed in areas with high solar generation capacities.

Figure 10 depicts a load and generation profile of a residential customer with behind-the-meter solar generation. Solar generation is represented by the red peak in the middle of the day, and direct consumption of solar energy is represented by the dark blue band; the amount of electricity drawn from the grid is the thick black line, while the load profile without solar is defined by the dotted grey line. The light blue band represents the amount of energy that is generated by the solar panels, stored in the battery, and then used later when production declined. This is representative of the value of energy storage with regard to self-consumption of behind-the-meter generation, both in terms of value gained by the utility (that amount of energy was kept out of the distribution grid), and the potential value to the consumer.

Value is also dependent on each state's net metering laws. In Minnesota, for distributed generation installations less than 40 kW, customers receive the full retail rate for energy they return to the grid.[37] Retail rate net metering creates no incentive for and no value from increasing the amount of energy generated and consumed on-site.

For distributed generation greater than 40 kW, customers are compensated with the utility's avoided cost rate. Several other states use avoided cost net metering for all net-metering customers, or have some other metric that is less than the full retail rate. Under these policy constraints, the value of increased self-consumption is equal to the difference between the retail rate and the net-metering compensation rate for each additional kilowatt-hour that can be stored and consumed behind the meter. The amount of additional energy consumed is dependent on both the energy capacity of the battery and the amount of excess energy that is generated.

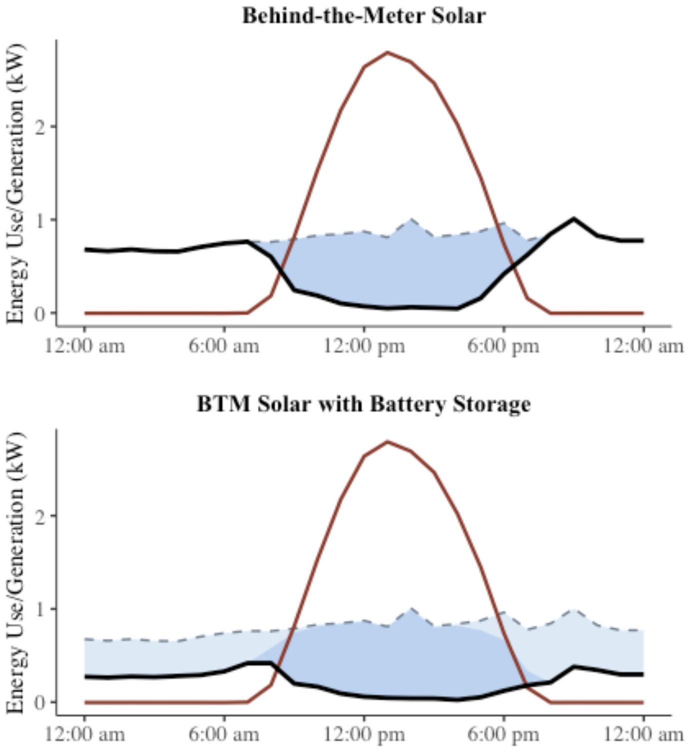

Figure 10: *Potential impacts of battery energy storage systems on self-consumption and net metering of behind-the-meter solar generation. Dark blue represents solar generation consumed directly, while light blue represents energy that was stored before consumption.*

2.4 Value Estimation of Rate Design Management (Original Analysis)

Because the value that energy storage offers with regard to resiliency and backup power is primarily not directly monetizable for residential customers and self-consumption of on-site solar generation does not create value for the customer in the 38 states (including Minnesota) mandating retail-rate net-metering, practicing rate-design management is critical for earning a return on the investment of purchasing and operating a battery storage device. The value of providing these services is difficult to assess, since it is highly contingent on individual characteristics of customer load profiles and specific rate design factors such as time-of-use period definitions and demand charge rates. This section describes original analysis of the value of rate design management. A sample residential load profile is used which depicts an average-sized American house, and the analysis assumes Xcel Energy's residential time-of-use and commercial demand-metered rate designs. Descriptions of analytical methods and the algorithms employed follows the discussion of the outcomes of the analysis.

2.4.1 Time of Use Rate Management

Employing energy storage for time of use rate management involves shifting load from times of high cost to times of lower cost. Therefore, the simplest conception of the value of storage on a per-kilowatt-hour basis is the gap between the peak and off-peak consumption charges. For example, shifting one kilowatt-hour from a peak hour rate of 25¢/kWh to an off-peak rate of 5¢/kWh creates 20¢ in value.

This simple formula is complicated somewhat by a number of factors. First, due to the inefficiency of the battery, more energy is added to off-peak hours than is shaved from peak hours. A battery with a round-trip efficiency of 90 percent displaces nine kilowatt-hours from peak for every ten kilowatt-hours added to off-peak, for an average value of 17.5¢ per kilowatt-hour using the prices in the previous example.

Furthermore, ignoring net metering capability, energy storage is only able to shave as much energy from peak times as the customer uses during those hours. If the storage device has a greater capacity than there is energy use in peak hours, then it may also shave energy from mid-peak times. There is still value to be gained from this; however, it returns less than shifting energy away from peak times. Again, using the previous example, with off-peak rates of 5¢/kWh and peak rates at 25¢/kWh, mid-peak rates may be 10¢/kWh. In this case, ignoring efficiency, each kilowatt-hour shifted from mid-peak to off-peak only creates 5¢ in value.

Applying a time-of-use algorithm simulating a battery energy storage device to a load profile of an average-sized house,[38] it is possible to visualize how the value of storage, with regard to this use case, can vary dramatically depending on several load and battery characteristics (*Figure 11*). Time-of-use rate management favors batteries with large energy capacities and long durations; the value generated by these batteries can be significantly greater than batteries with the same power capacity but shorter duration.

This occurs because the value generated is a function of the amount of energy shifted from one time to another, which corresponds to energy capacity more directly than power capacity.

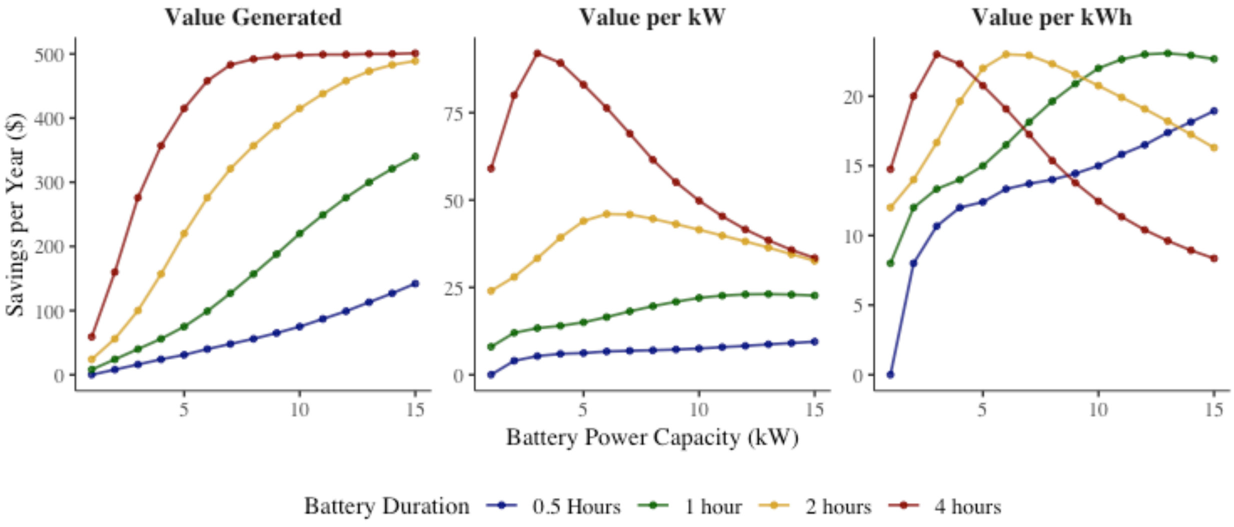

Figure 11: Estimated monetizable value of a battery performing time-of-use rate management for an average-sized residential customer.[39]

Based on this analysis, the value of an energy storage device appears to have a roughly sigmoidal or logistical relationship with its power capacity. The load profile of an individual customer has a theoretical maximum for the value that can be generated through this use case, represented by the variable L; in this example it looks to be approximately $500 per year. This maximum is the cost savings associated with shifting all energy use from peak and mid-peak rates to the off-peak rate, which has a direct relationship with theoretical value at a given power capacity. The other variables that define a logistical curve are k, the logistic growth rate, and x_0 the midpoint of the curve, each have complex relationships with the specifications of the battery and specific characteristics of the customer's load curve and have inverse logarithmic relationships with theoretical value.

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}}$$

Ultimately, the precise value of an energy storage installation is highly specific to each individual case. For this load profile, the maximum value per kilowatt and per kilowatt-hour appear to be achieved for batteries with an energy capacity of 12 kilowatt-hours and is approximately $23 per year per kilowatt-hour. However, the economically optimal battery size is the greatest size for which the marginal benefit is greater than the marginal cost.[40] While estimations of value can be made retrospectively and on an individual basis, as is being done here, prospective or generalized valuations can be difficult and imprecise.

2.4.2 Demand Charge Reduction

For many commercial and industrial customers, demand charges can make up a substantial portion of their monthly bill. Xcel Energy's standard commercial rates combine a 3.5¢/kWh consumption charge with an $11/kW demand charge. Assuming adequate energy capacity based on the individual customer's load profile, an energy storage device is capable of decreasing the customer's peak load by the available power capacity, or the rated power capacity multiplied by the depth of discharge. This correlation of power capacity to value is not unlimited, however, as the peak demand event cannot be decreased to such an extent that there is inadequate time and capacity to recharge the battery between events.

Again, applying a peak-shaving algorithm simulating a battery energy storage device to the same residential load profile, it is possible to see how battery characteristics impact the value of a battery employed in this use case (*Figure 12*). Compared to time-of-use rate management, the value of peak shaving has considerably lower dependence on the duration of the battery used, but rather relies more on the power capacity. This is observed because peak shaving often involves reduction of large but short-duration peaks in the load profile. Similar to that of time-of-use applications, the value of peak shaving has a theoretical maximum value based on the particular load profile, which corresponds to the peak use event of each month being reduced to its minimum achievable value. After this point, the marginal value of power capacity declines, since negligible additional value is being generated.

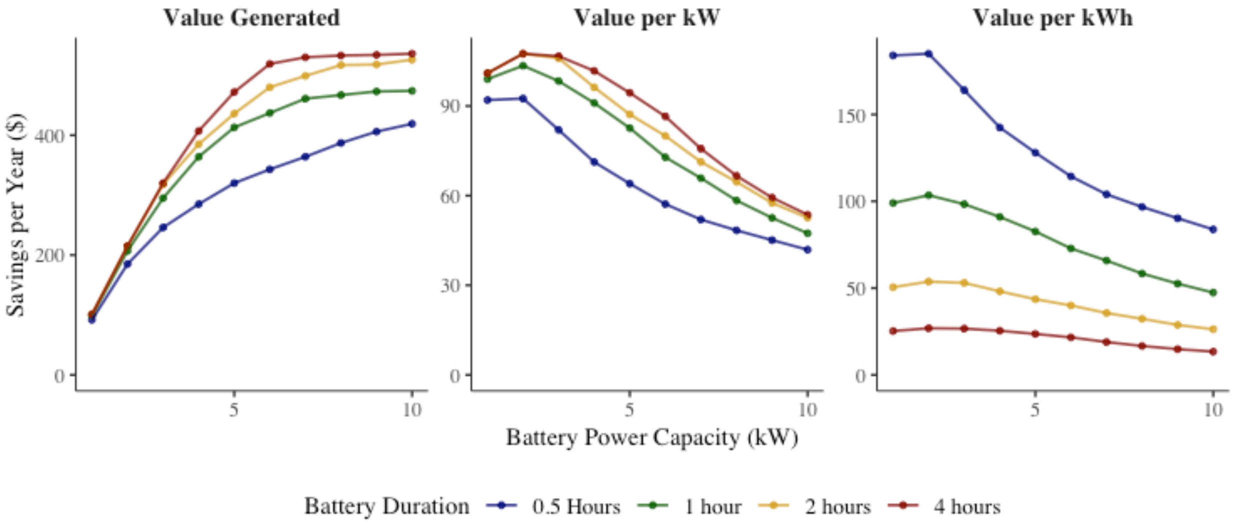

Figure 12: Estimated potential monetized value generated by employing a battery for peak shaving in an average-sized residential property.

2.4.3 Analytical Methods

The analysis in Section 2.4.1 employs a time-of-use management algorithm to model the function of a battery storage device providing this service. The data depict energy consumption for an average-sized house in 15-minute intervals throughout 2016, and were acquired from the University of Massachusetts Trace Repository.[38] Time-of-use prices and peak/off-peak window definitions are those employed in Xcel Energy's Minnesota time-of-use rate pilot program.[44]

A simulated battery is charged at full power capacity during off-peak hours until the battery has reached its energy capacity (*Figure 13*). Because the greatest value is obtained by discharging during peak hours, that behavior is prioritized. The amount of energy to be discharged during the daily peak is calculated by integrating the area under the load curve, excluding areas where the battery does not have adequate power capacity to offset energy use entirely. If this area, which defines the total energy use of these hours, is greater than or equal to the energy capacity of the battery, the battery simply discharges as much as possible during this peak.

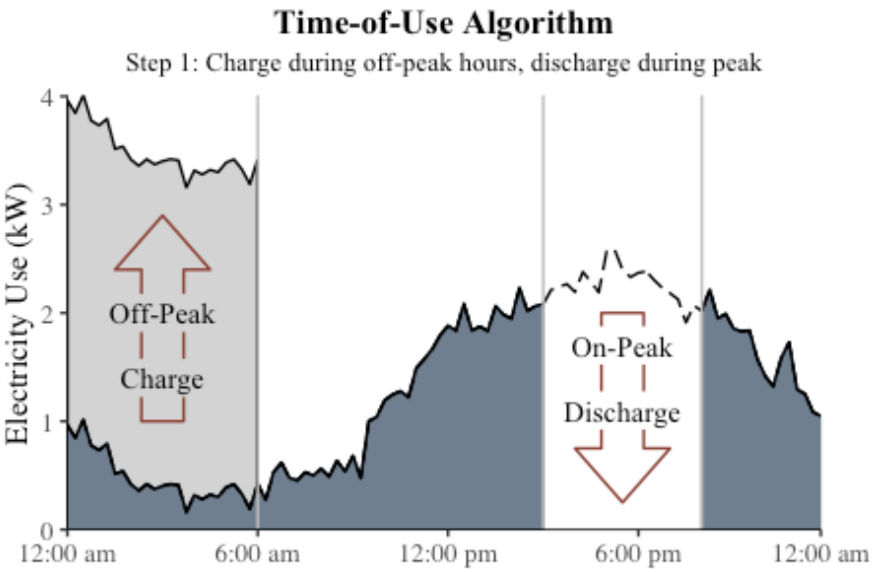

Figure 13: To achieve optimal value, the TOU algorithm prioritizes charging at full capacity during off-peak hours (grey) and discharging at full capacity during peak hours (white).

If, on the other hand, the battery has excess capacity beyond what is required to discharge during peak hours, it is discharged during mid-peak hours (*Figure 14*). For the sake of simplicity, the prospect of discharging excess energy during peak hours and returning it to the grid is disregarded. The issue of how to compensate energy that is purchased at retail from the grid only to be returned to it later at a higher price is currently under consideration by a number of state regulatory agencies. The resulting load curve, shown in blue with a solid black line, minimizes energy use during peak times, when the price is the highest, shifting as much electricity use from this period to off-peak hours, when the battery charges as much as possible. Mid-peak times are used to disperse any excess energy from the battery, but the value to be gained from shifting energy away from these times is minimal.

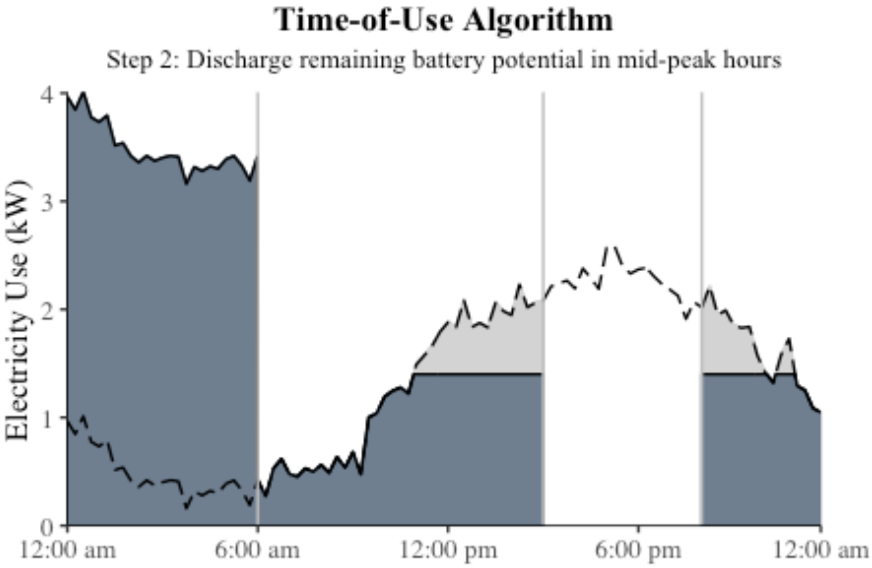

Figure 14: All additional energy stored in the battery is discharged during mid-peak hours (grey). The resulting load profile is shown in blue.

Similarly to the time-of-use analysis above, the analysis performed in Section 2.3.3 employs a peak-shaving algorithm to model the function of a battery storage device and maximize the value available from demand-metered rate designs. This model employs the same data as does the previous one, and it applies Xcel Energy's demand-metered commercial class rates.[41]

For each day in the year, the maximum observed load is determined. Twenty different potential levels to which the peak may be shaved are calculated; these levels are depicted as blue lines in the top half of *Figure 15*. For each of these levels, the area between the load curve and the line is calculated. The area above the load curve and below the line describes potential charge energy, while the area above the line and below the load curve depicts where the battery will discharge.

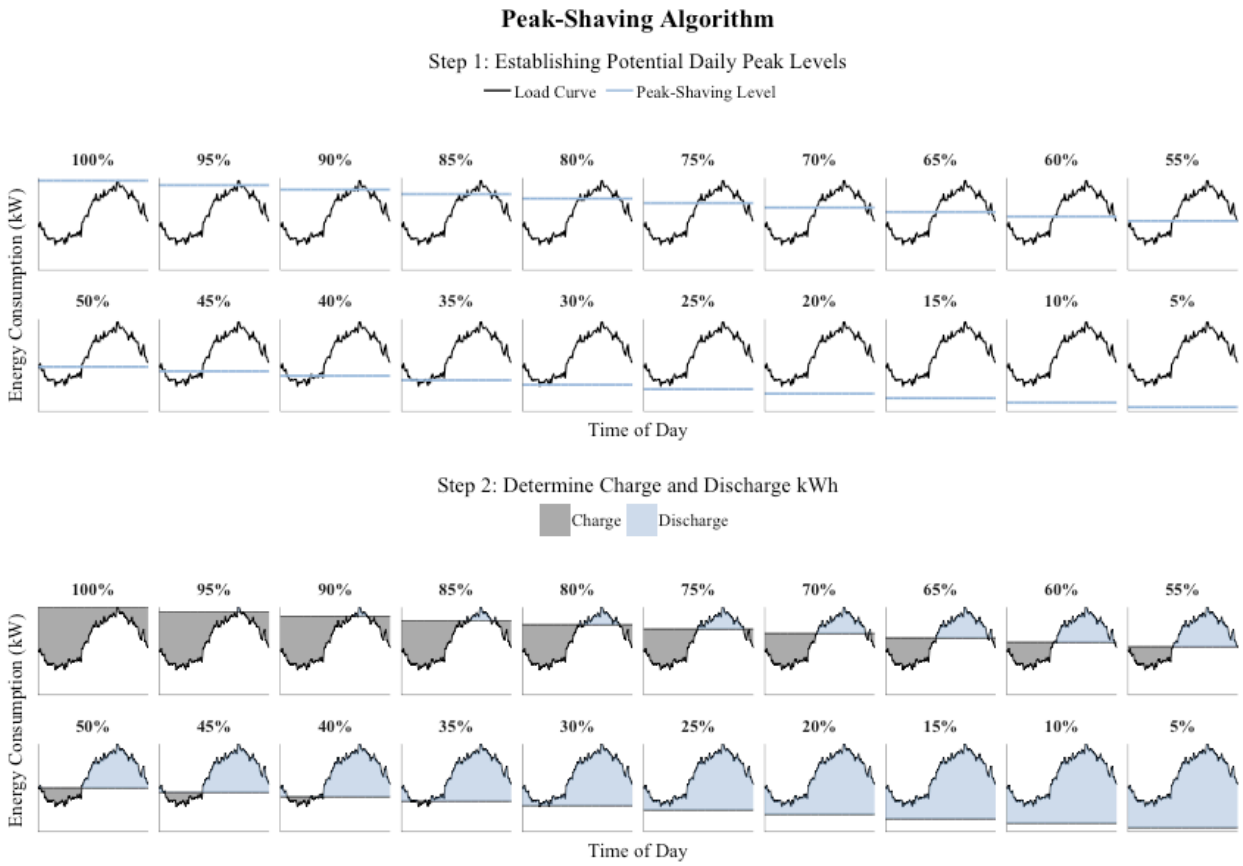

Figure 15: Depiction of two stages of the algorithm employed to calculate the minimum achievable peak. This process is performed systematically for each day of the year.

At this point, all peak-shave levels wherein the discharge needs (in blue) are greater than the charge capacity (in grey) for that day are eliminated. Next, given the specifications of the battery to be simulated, any scenario which requires greater energy capacity than the battery possesses (taking into account the round-trip efficiency and depth of discharge) is also eliminated. This leaves only peak-shaving levels which are technically achievable and sustainable by the simulated battery. In order to maximize the value achieved in the model, the peak-shaving level that sets the minimum achievable level is selected for each day and is set as the daily maximum energy for the particular day.

For each 15-minute segment of the day which is lower than the daily max, the battery is instructed to charge if possible, and for each block that exceeds the daily max, the battery is instructed to discharge. The charge and discharge power levels are limited to bring load up to or down to the daily max and no further. When the battery is set to charge, but has reached its maximum energy capacity, it simply goes to standby until it is instructed to discharge. New peak demand values are calculated for each month, and a simulated bill is calculated using consumption and demand charges, which is compared to a bill for the home without storage capacity. The counterfactual employed is a simulated bill using standard residential flat rates, as the situation fabricated is one in which customers have choice with respect to their rate design, and customers would presumably not choose a time-of use or demand-metered rate design if they did not stand to save money through time-shifting their energy use with batteries.

2.5 Monetizable Value Streams for Residential and Commercial Customers

Because some forms of monetizable value are accessible to one customer class and not another, the value of energy storage can differ dramatically depending on if it is installed on a commercial or residential property. Even the same battery providing the same or similar services can produce vastly different value for is owner. For instance, while both classes can employ batteries for backup power and reliability, this typically provides far greater financial value to commercial customers because the avoided losses that they would have experienced during an outage are more directly monetizable, rather than quality of life metrics.

Rate design varies by state and by utility, but the rate designs available to residential customers are typically different than those available to commercial customers. Time-of-use rates have historically been available more so to commercial customers than residential and do create monetizable value for energy storage services. Flat- or block-rate designs, which are more common in the residential class, offer little in the way of value for storage, since each hour is valued the same. Recently, however, several utilities across the countries, including Xcel Energy, have been launching pilots to test the efficacy of time-of-use rates for residential customers, though these remain rare compared to commercial applications.

The other prominent rate design that offers value for energy storage, demand metering, is almost exclusively applied to the commercial class. Residential customers who use energy storage to reduce their peak use and smooth out their demand curve may provide some value to the grid and their utility by doing so, but they are seldom compensated for it. Additionally, demand metering generally creates more value per kilowatt and per kilowatt-hour than does time-of-use rate management (*Figure 11* and *Figure 12*), while employing the battery for less time, and leaving greater potential for stacking multiple use cases.

Likewise, residential customers who use energy storage to maximize self-consumption of on-site solar generation benefit the grid, but if their generation is less than 40 kilowatts, under current Minnesota law, they do not benefit from providing that service. Commercial customers, on the other hand, are more likely to have on-site generation capacity of greater than 40 kilowatts, so are more likely to be compensated for the services of energy storage.

2.6 Key Questions Facing the Future of Distributed Energy Storage

- *Can the benefits of battery energy storage systems outweigh the costs?*

Under current economic conditions, several reports have demonstrated that the benefits of battery energy storage can outweigh the costs if employed wisely. This is especially true of behind-the-meter storage for which more grid services are available. It is likely that this will be increasingly true as battery technology improves and costs decline. However, the value of behind-the-meter energy storage to its owner is highly dependent on the regulatory environment in which it is employed. Customers for whom certain value streams, such as time-of-use rates, are not available are unlikely to receive the true value of their storage, even if that storage is providing services to the grid and to utilities.

- *How does the marginal value of storage change as storage capacity on the grid increases?*

As the generation capacity of renewable energy resources such as wind and solar increases, the marginal benefit of behind-the-meter solar decreases because the difference in carbon emissions between solar and the grid resource mix decreases. A similar effect may be observed with energy storage. As the amount of storage added to the grid increases, it will satisfy many of the grid service needs that exist. Each additional kilowatt and kilowatt-hour of storage would then have less marginal value, as the value for meeting needs that have already been met in whole or in part is diminished. At present, this scenario remains distant and hypothetical; however, regulatory agencies which weigh in on the determination of these values may benefit from periodic revisitation as the market conditions evolve over time.

- *What consideration is owed to the potential for lost revenue by utilities?*

If a utility offers its residential customers the option to use a time-of-use rate design, and those customers employ behind-the-meter energy storage to shift energy use away from peak times, they can save money on their electric bills. The other side of this is that the utility loses revenue that it would otherwise have received. Ideally, however, these rates should be designed to reflect the benefit to the utility when load is shifted away from peak times. Therefore, with lower peaks, utilities spend less money on peaker use and generation, and a portion of those savings is passed through to the customer. Furthermore, regulatory agencies have several options to decouple utility revenue from the number of kilowatt-hours sold, including performance-based ratemaking or conservation incentives to offset these costs.

- *How does energy storage impact the value of distributed solar, and vice versa?*

There are ongoing debates surround the true value of behind-the-meter solar generation and the fair compensation rate for excess generation. One side alleges that net-metered customers do not pay their fair share of infrastructure costs for grid upkeep,[29] while the other contends that the importance of renewable energy and risk mitigation/distribution makes the true value of distributed solar greater than the retail rate.[42] This debate has significant implications for the value of energy storage. The ability of energy storage to improve self-consumption of behind-the-meter generation has many benefits including lower line losses, less congestion on the distribution system, and lowering evening peaks while mitigating the duck curve effect.

Each of the services from storage improves the value that distributed generation provides the grid. However, reflecting these improvements in net metering compensation metrics is a complex and controversial proposition. This would involve either increasing compensation rates for solar with storage above the retail rate, which would certainly be viewed by many as regressive cross-subsidization, or lowering the net-metered value of solar without storage, which others likely would allege is devaluing and disincentivizing a critical energy resource. This dilemma has led many proponents of energy storage incentives to support value propositions outside of the net metering/value of solar space, such as rate design or incentive programs, to improve the monetizable value of storage without jeopardizing the value of solar.

- *What considerations are owed to the balance between data privacy / individual control and effective use / aggregated control?*

For many owners of residential energy storage devices, two of the primary reasons that drive their investment are notions of greater self-sufficiency, independence and privacy with regard to their energy use as well as a desire to contribute to the transition to renewable and low-carbon energy sources. These two ideological frameworks for residential energy storage use are not always fully compatible. For distributed storage devices to maximize their impact on reducing system peaks they must be coordinated so as to shift the maximum amount of energy use away from these peak events. This can be done in a number of ways, including pricing signals, such as time-of-use rates, communication of peak load events to storage devices and/or their owners, or centralized control of the batteries themselves.

Centralized control can ostensibly turn many distributed storage systems into a single functional unit. This allows the more efficient provision of grid- and utility services, including entering auxiliary services markets, which are typically restricted for batteries under 100 kW. However, this may restrict the batteries' ability to provide customer services such as backup power. Additionally, this contradicts the intent of storage for many residential customers who want greater energy independence. On the other hand, batteries which operate fully independently can provide customer services, but may not provide grid and utility services in an optimal manner if there exists no method for signaling times to charge and discharge.

In between these two extremes lies a continuum of methods for communication and signaling with storage devices. If utilities or grid operators were to signal to energy storage program participants that a peak time is approaching, but the customer is unable to or simply does not set the battery to discharge, then potential peak mitigation capacity is wasted. On the other hand, if a utility or grid operator were to signal peak periods directly to the battery, while falling short of outright control over the device, the effect on peak mitigation is likely more significant. However, communication between a utility and the battery storage device would enable the utility to acquire energy use data for each participating household. Many customers have concerns about data privacy and data ownership when it comes to providing their utility or some third-party organization access to sensitive data. Any potential energy storage program designed to mitigate gaps in accessible value must consider what sacrifices storage-owning customers are required to make in order to obtain that value.

Part 3: Case Studies of Energy Storage Policies

3.1 Massachusetts Energy Efficiency Plan

In 2019, Massachusetts became the first state to include incentives for behind-the-meter storage in their energy efficiency and conservation plan. A key factor in enabling this policy shift was changing the way the state defined energy efficiency. Most state efficiency plans aim to reduce overall consumption of energy by improving the insulation in buildings, replacing old, inefficient appliances, and educating residents on how to reduce energy use through lifestyle changes. This focus on decreasing energy use overall is inconsistent with energy storage, since the inefficiency of storage devices causes total energy use to actually increase.

However, Massachusetts' plan aimed to acknowledge and target the inefficiency of peak demand events. Because energy system infrastructure must be designed to fulfill yearly peak load, it is severely oversized for its purpose during the majority of the year. Massachusetts found that just 10 percent of the hours in the year were responsible for 40 percent of the total annual cost of the energy system.[31] Recognizing that not all load-hours are the same with regard to cost and resource use, the state expanded their definition of energy efficiency to include the reduction of peak demand events.

This resulted in the creation of the Active Demand Reduction Program. The program is open to residential and commercial customers with or without on-site renewable generation. It features a performance-based incentive, wherein peak periods are announced in three-hour blocks, and customers are compensated at a rate of $100/kWh in the summer and $25/kWh in the winter for the amount that their battery can discharge in that window.[43] Peak blocks are planned to coincide with system-wide peaks, rather than individual customer peaks in order to more effectively and directly target overall system efficiency. Participating customers enter into 5-year contracts with their utility, with incentives paid at the end of each season or year.

All eligible, participating devices are connected to a demand response platform through an applied programming interface (API). The API is a mechanism that allows two different electronic systems to exchange data. Program administrators in the Massachusetts Department of Energy Resources (DOER) send a signal to the devices during the event, which activates them to discharge and reduce the severity of peak events. These events are announced in advance, and customers can opt out of individual events, but will be removed from the program if they do not participate regularly. Management of the API by the DOER is intended to mitigate data privacy concerns by serving as an intermediary between the customer and the utility, while taking advantage of efficiency gains that come with centralized organization.

3.2 Xcel Energy Residential Time of Use Rate Pilot

In 2017, Xcel Energy proposed a pilot program in Minnesota for a residential time-of-use rate design.[44] The proposal was approved unanimously by the Minnesota Public Utilities Commission in 2018 after consideration by the commission and input from numerous stakeholder groups and is scheduled to begin in early 2020. It will include two different residential areas, one in the Hiawatha neighborhood in South Minneapolis and the other in Eden Prairie, operating on an "opt-out" basis, where all customers are included unless they request not to participate.

The intent of the rate design is for retail prices to better reflect generation and acquisition costs. This would result in less subsidization across time, wherein off-peak energy use is overpriced to allow peak energy use to be charged less than the actual cost of service. From standard flat rates of 13.437¢/kWh in the summer and 11.742¢/kWh in the winter, peak hour consumption between 3pm and 8pm on weekdays is increased to 25.949¢/kWh in the summer and 22.385¢/kWh in the winter. Off-peak rates between 12am and 6am are lowered to 5.676¢/kWh all year, while mid-peak rates applying to all other hours become 12.125¢/kWh in the summer and 10.430¢/kWh in the winter (*Figure 16*).

Shifting to this new rate structure could increase a customer's bill if much of their energy use falls within peak hours and they are unable to shift it to cheaper times of day. However, this rate design could provide Xcel's residential customers with a viable revenue stream for behind-the-meter storage where one has not previously existed. In summer months, every kilowatt-hour that customers can shift from peak to off-peak represents up to 20¢ in value, and every kilowatt-hour that can be shifted from mid-peak is worth up to 6.5¢. Additionally, this rate structure allows energy storage to enhance the value of behind-the-meter solar generation by using stored solar-generated energy to offset peak energy use rather than selling it back to the utility at mid-peak rates when it is generated.

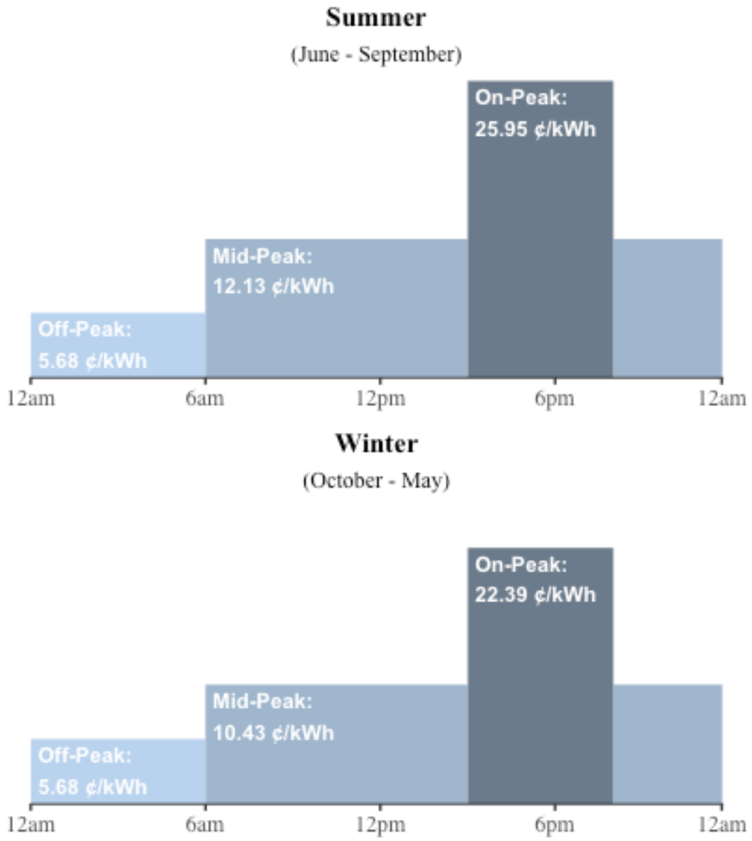

Figure 16: Xcel Energy's Minnesota residential time-of-use pilot rate structure.

It is important to note, however, that Xcel's time-of-use rate pilot is not accessible for customers with solar generation or energy storage capacity. These estimated values of storage capacity assume broader application of and access to these rate structures after the pilot program has run its course.

3.3 Net Energy Metering Reform in Nevada

Prior to 2016, the Nevada Public Utilities Commission mandated that all utilities compensate net-metered customers at the full retail rate for any excess generation that they returned to the grid. However, in December 2015, the PUC issued an order increasing fees on net-metered customers and decreasing the compensation rate from retail to the wholesale electricity rate.[45] This was done in part to ensure that net metered customers paid their share of grid infrastructure costs.

However, the more immediate effect of the policy shift, which did not include exceptions for existing net-metered customers, was that behind-the-meter solar suddenly ceased to be economically viable. Most residential customers do not use enough energy during peak solar generation hours and rely on their ability to return energy to the grid in exchange for use later. Applications for residential solar installations dropped precipitously, falling to 287 in 2016, and several solar businesses, including Vivint Solar, Tesla, and Sunrun stopped operating in the state altogether.[46]

Ultimately, the policy change bore significant costs to Nevada with respect to jobs, lost economic growth, and lost renewable generation capacity. In 2017, the Nevada legislature passed A.B. 405, raising the net-metering rate back to 95 percent of the retail rate.[47] Immediately following the passage of the bill, solar companies in the state reported rapid rebounds in sales and hiring. Residential applications rose over 1000 percent from 2016, up to 3,308 in 2017, most of which were submitted after net metering had been restored (*Figure 17*).[48]

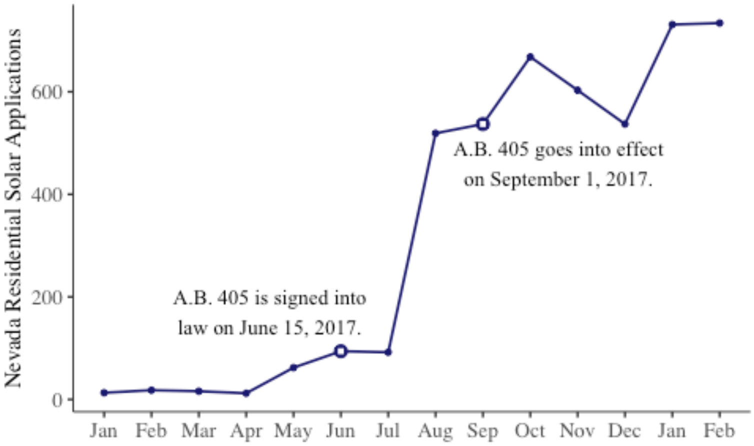

Figure 17: Applications for the SolarGenerations Electric Incentive Program in Nevada from January 2017 to February 2018.

3.4 Solar Massachusetts Renewable Target (SMART) Program

As part of a state goal to add an additional 1,600 megawatts of distributed solar to Massachusetts' generation portfolio, the state's Department of Public Utilities announced an initiative proposed to create a stable, long-term incentive for solar development. SMART is an application-based program which pays a per-kilowatt-hour fixed tariff to distributed solar generators with capacity under 5 megawatts. It is intended as a stable alternative for solar renewable energy credits (SRECs), which are traded on an open market and face frequent price fluctuations, discouraging sustained investment in the industry.

In recognition of the added value that energy storage brings to solar generation when paired, the SMART program features an adder for solar-plus-storage, which provides additional benefit. The amount added to the incentive is dependent on the duration of the battery and the ratio of storage capacity to solar generation capacity. These values are shown in *Figure 18*. Batteries must have a duration of two or more hours and a capacity at least 25 percent of coupled solar capacity in order to qualify for the increased incentive. Installations with a duration longer than six hours and capacity greater than 100 percent of solar generation may still qualify for the incentive, but the adder does not increase further beyond these bounds. While this program rewards some of the services provided by battery storage devices, the structure of the incentive does not consider or reward the benefits of energy storage by itself, in the absence of paired solar generation.

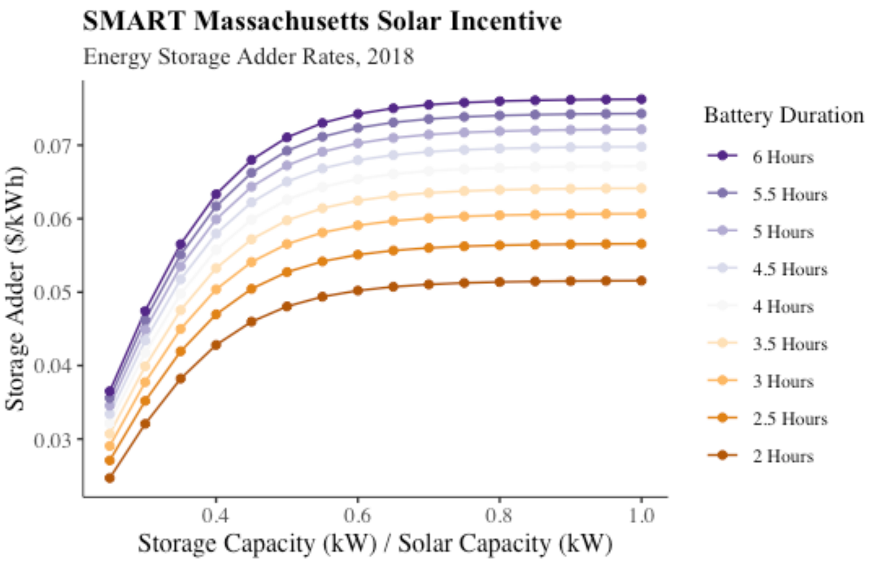

Figure 18: SMART solar incentive program adders for energy storage paired with solar generation capacity.

3.5 Salt River Project Residential Demand Charges

In 2015, Salt River Project (SRP), an electric utility serving most of the Phoenix, Arizona municipal area, began offering its residential customers a rate design pilot which combined aspects from time-of-use rates and commercial demand-metered pricing.[49] This rate design divides the year into three categories; winter is defined as November through April, summer includes May, June, September, and October, and summer peak includes the months of July and August. On-peak hours during winter months include 5am-9am and 5pm-9pm on weekdays, while on-peak hours in the summer and summer peak months run from 1pm to 8pm on weekdays. The primary appeal of this rate design to customers is that consumption charges are less than half the rate of standard flat rates. Per-kilowatt-hour consumption rates for each time-period and season are shown in *Figure 19*, below.

Demand charges are only assessed for energy used during on-peak hours and are assessed in three tiers for each season of the program. For example, during summer peak months, the first three kilowatts of a customer's on-peak peak demand are charged $9.59 per kilowatt. The subsequent four kilowatts are charged $17.82 per kilowatt, while all demand in excess of seven kilowatts are charged $34.19 per kilowatt. The rates for each demand echelon in each season are depicted in *Figure 19*.

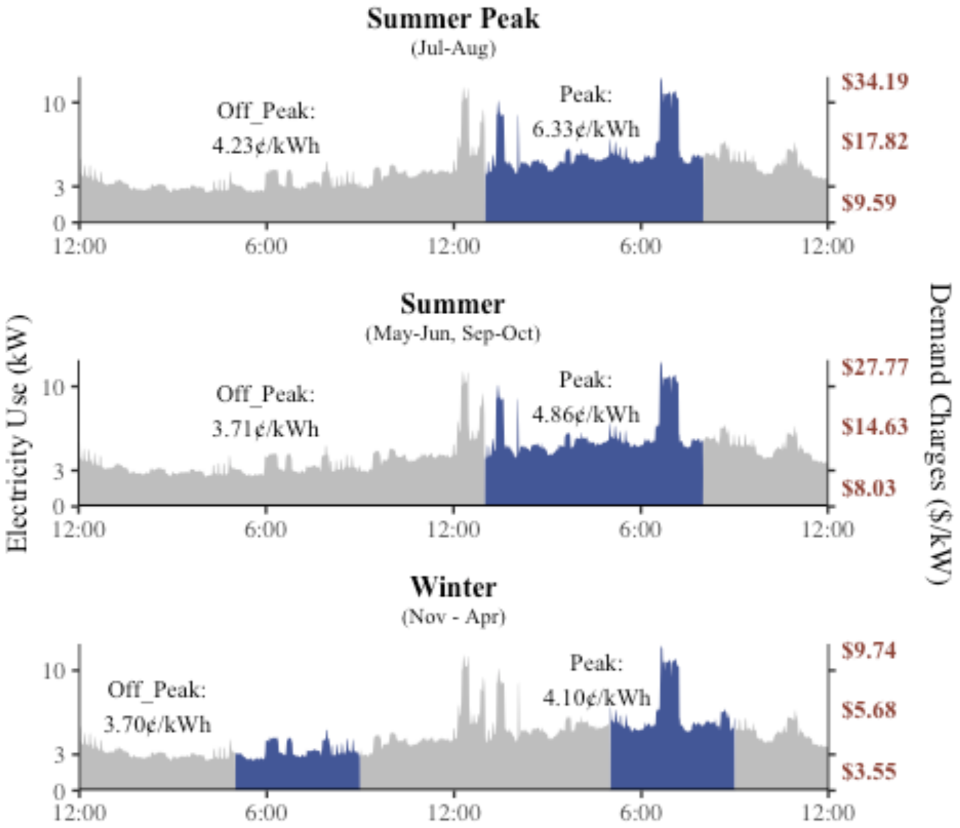

Figure 19: Salt River Project's rate design for its residential demand price plan pilot, which combines aspects of demand metering and time-of-use pricing.

Combining these two principles in rate design has the potential to maximize the value available to energy storage and allows storage to enhance the value of distributed generation. Shifting energy use from on-peak to off-peak hours is rewarded twice over, as it decreases consumption charges on the energy and removes load from the demand charge calculation altogether. However, this rate design features three seasons each with their own on-peak hours, on- and off-peak consumption charges, and three tiers of demand charges. In James Bonbright's 1961 book *Principles of Utility Rates*, he includes as one of his core principles of rate design that the attributes of simplicity, understandability, public acceptability, and feasibility of application and interpretation apply to all rate structures. SRP's residential demand-metered rate design, though potentially effective at shifting residential load to ease the burden on the utility and the grid, is certainly not simple or widely understandable by a cross section of the utility's customers who are not specifically knowledgeable about energy policy and rate design.

Part 4: Analysis of Energy Storage Policy Opportunities in Minnesota

4.1 Problem Definition

Energy storage technology has the potential to play a crucial role in the transition of the electricity grid from fossil fuels to renewable energy resources, which, itself, is fundamental in mitigating and reversing the effects of global climate change. Several factors are limiting the use of storage devices for the provision of grid services, both in front of and behind the meter. Foremost among these is the cost of the devices. However, in recent years, battery costs have fallen dramatically, which has coincided with increases in their application, both in front of and behind the meter (*Figure 20*).[50]

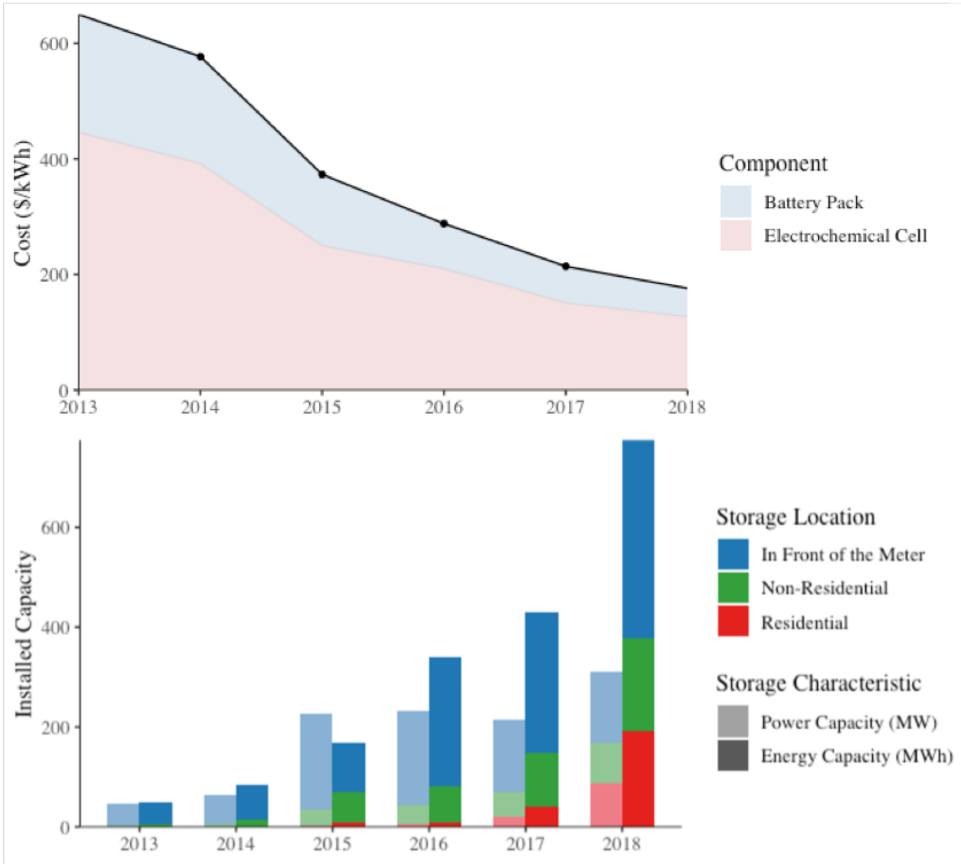

Figure 20: Cost and deployment trends of battery energy storage devices between 2013 and 2018.

In-front-of-the-meter (FTM) battery storage has experienced greater installed capacity over this time than behind-the-meter (BTM) applications. This can be attributed to a number of factors, including that FTM batteries are typically much larger than BTM devices, and that FTM batteries generally benefit from economies of scale which reduce make them less expensive on a per unit of capacity basis.

In addition to being less expensive relative to capacity than behind-the-meter devices, In-front-of-the-meter batteries generally generate more monetizable value than do BTM batteries. Many markets for grid services are not available to customer-sited batteries or those smaller than a certain threshold, or utilities employ rate designs which do not monetize the value that they provide. As a result, while BTM

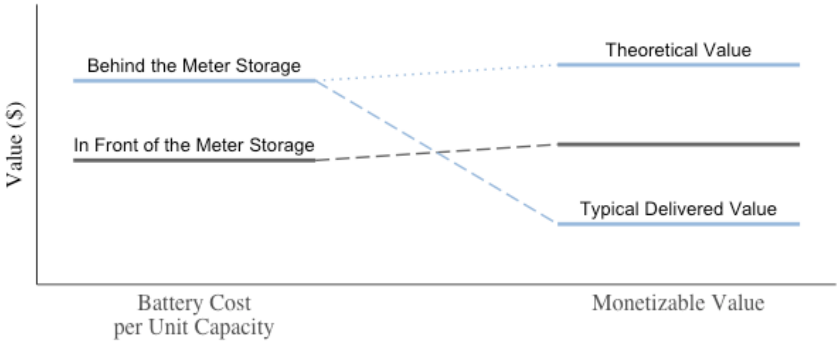

Figure 21: Inaccessible or uncompensated value streams of several grid services for behind-the-meter residential batteries lower the average deliverable monetized value relative to its theoretical value and decrease the likelihood of a return on investment.

storage is able to provide more services to the grid than FTM installations, the typical value returned to the battery owner is lower relative to capacity. In many cases, as demonstrated by the Rocky Mountain Institute's Economics of Battery Storage report,[26] behind-the-meter storage devices generate enough value to offset the cost of the battery, but typically encounter market inefficiencies, whereby the theoretical value is not fully compensated, and the typical delivered value does not make storage installation cost effective. Incentives and rate designs for behind-the-meter battery energy storage do not adequately compensate storage owners for the services they provide so as to incentivize more widespread use of storage devices.

4.2 Evidence

Residential customers in many states and utility service territories do not have options available to them to create monetizable value from battery storage. These customers often receive retail-rate net metering compensation and usually do not have options for time-of-use or demand-metered rate designs. This denies them access to some of the most crucial value streams available to behind-the-meter storage. While energy storage is a relatively nascent market, and the residential storage market is particularly underdeveloped, key analogies can be drawn to behind-the-meter residential solar installations. Between 2009 and 2016, many of the same states were among those with the greatest installed solar capacity year after year (*Figure 22*).[51] While a few of the states with high solar generation rates have large populations (i.e. California, New York), or an abundance of solar capacity (i.e. Arizona, New Mexico, Texas), several of the states have neither. Notable among the top ten in 2016 are Massachusetts, New Jersey, Connecticut, and Delaware, which have modest populations and solar capacity. The more indicative factor with regard to adoption of residential solar in these states appears to be policy levers which incentivize its use.[52]

Likewise, policy measures have significant impacts on the installation rate of behind-the-meter battery storage. BTM residential energy storage installations are led primarily by California and Hawaii, making up 72 percent of total energy capacity, with Massachusetts and Arizona the next two highest.[53] Each of these states has incentive programs, tariff structures, and/or favorable rate designs which add value and incentivize storage installation.[54] Minnesota, on the other hand, does not have any state-wide initiatives to encourage behind-the-meter energy storage,[55] and many of the utilities in the state do not offer rate designs to residential customers which monetize the value contributed by storage devices.

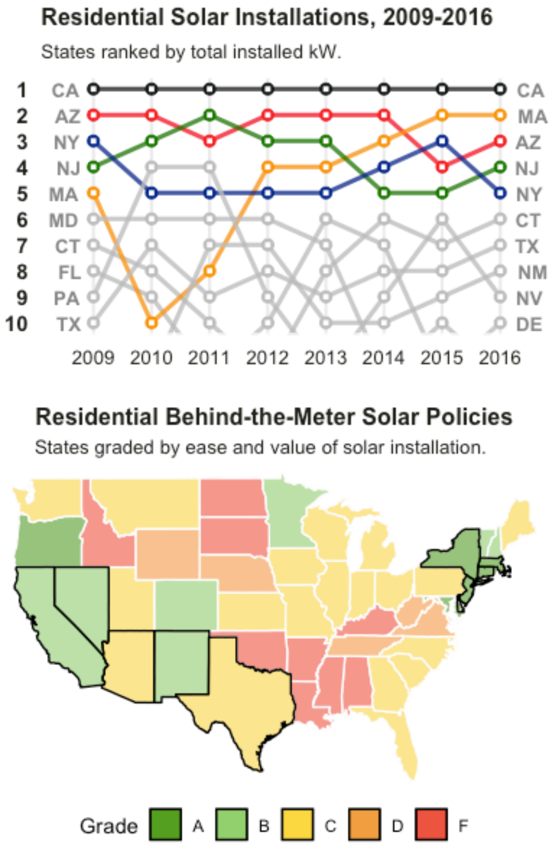

Figure 22: Leading states with regard to residential solar capacity installed by year, 2009-2016; assessment of state residential solar policies. Outlined states are among top ten for installed capacity in 2016.

4.3 Alternatives

Presented herein are a number of policy alternatives which may be able to create value for behind-the-meter residential energy storage in Minnesota and to incentivize its employment.

4.3.1 Mandatory Residential Time of Use Rates

The Minnesota Public Utilities Commission has in its power the ability to mandate a certain rate design for commission-regulated utilities if it determines that rates cannot be “just and reasonable” if the rate design is not employed.[56] This proposal involves mandating the use of time-of-use rate designs for all residential and non-demand-metered commercial customers. Marginal costs for the production or procurement of energy vary depending on the season, the time of day, and the overall load on the grid.

Standard residential rate designs typically feature flat rate designs irrespective of time of day, though many differentiate by season. Rates in off-peak times, such as early mornings, are inflated to subsidize and decrease rates during peak afternoon and evening hours. Customers who use most of their energy during off-peak and mid-peak hours are therefore being significantly overcharged, while customers who use more energy during peak hours are often paying significantly less than their cost of service. This cross-subsidization violates Minn. Stat. § 216B.03 with regard to sufficient and equitable rates, and could be considered to inadequately encourage energy conservation, as required by the statute. As such, it is within the regulatory authority of the PUC to mandate time-of-use ratemaking.

Utilities would be able to determine peak and off-peak timeframes based on their system peak profiles, and electricity rates for each based on their costs of generation and acquisition for each window. These rates are subject to the same standard rate case process before the Commission by which utilities currently set their rates. While subdividing rates into two to three periods throughout the day does not approximate the real-time cost of service for electric customers, it is a far more accurate estimation model than are flat rates throughout the day.

4.3.2 Residential Demand-Metered Rate Design

As an alternative to time-of-use rates, utilities may opt to employ demand-metered rate designs for residential customers (or a combination of the two[57]). This rate design encourages customers to more evenly distribute their energy use, in order to contribute less to system peaks and grid congestion. While utilities in Minnesota may be interested in pilot programs to learn more about implementation and how it would affect customer bills and loads, demand-metered rate design has a weaker case for being made mandatory than time-of-use rates. However, utilities typically have more experience with demand-metered rates, since most large commercial and industrial customers use this rate design.

4.3.3 Net Metering Reform – Restructure Compensation Metric

Out of concern for equity between customers and to prevent regressive cross-subsidization, wherein low- and moderate-income ratepayers underwrite the grid and infrastructure-use costs for more affluent customers who can afford behind-the-meter solar, many states and utilities are considering reducing or otherwise altering the rate of compensation for net-metered customers. Net metering has proved crucial in incentivizing distributed generation and providing value for distributed generation resources.

However, many utilities have expressed concerns that net-metered customers continue to use grid infrastructure and services for every kilowatt-hour they return to the grid only to use later. Nevertheless, if retail rates are used for this transaction in both directions, these costs offset, and these customers do not pay for the services they use. Additionally, retail rate net metering does not recognize or compensate the added value that energy storage brings to behind-the-meter distributed generation. Pairing solar and storage has the potential to reduce use of grid infrastructure and services by storing energy for later use on-site, rather than by returning it to the grid, only to draw electricity back from the grid later.

A common strategy for addressing these concerns is the use of fixed charges for net-metered customers. These charges are taken as payment for the use of the grid in exchanging electricity where costs cancel out. However, fixed costs do not change with variable uncompensated use of the grid, whether by generation capacity or performance. For example, the same charge is applied for a cloudy month in which a customer returns little to no excess generation to the grid, or to a customer with a small solar capacity which seldom overproduces relative to load, as is applied for a customer with a large solar array for a sunny, highly productive month. Fixed charges also do not compensate the added value that energy storage contributes, unless they are omitted or reduced for customers with storage. Adjusting the net-metered compensation metric downward to the wholesale or avoided-cost rate of electricity has the potential to more accurately reflect a net-metered customer's use of grid infrastructure.

4.3.4 Solar Incentive Reformulation – Incentivize Storage

As an alternative means of assigning value to energy storage aside from net metering reform, which reduces the value of standalone solar, states have the option of increasing the value of solar generation when paired with energy storage. This could take a form similar to the Solar Massachusetts Renewable Target (SMART) program, wherein all solar generation up to a certain capacity is granted a performance-based incentive, a per-kilowatt-hour tariff for its generation. In recognition of added value storage contributes when paired with variable energy resource generation such as solar, such a program would feature an increased tariff for solar-plus-storage installations.

4.3.5 Include Storage in Energy Efficiency Programs – Redefine Efficiency

The Conservation Improvement Program (CIP) is the primary state-mandated energy efficiency program in Minnesota. CIP was established by the Next Generation Energy Act of 2007;[58] it is funded by ratepayers, administered by utilities, and overseen by the Minnesota Department of Commerce.[59] The primary goal of the program is to help "Minnesota households and businesses use electricity and natural gas more efficiently – conserving energy, reducing carbon dioxide emissions, and lessening the need for new utility infrastructure."

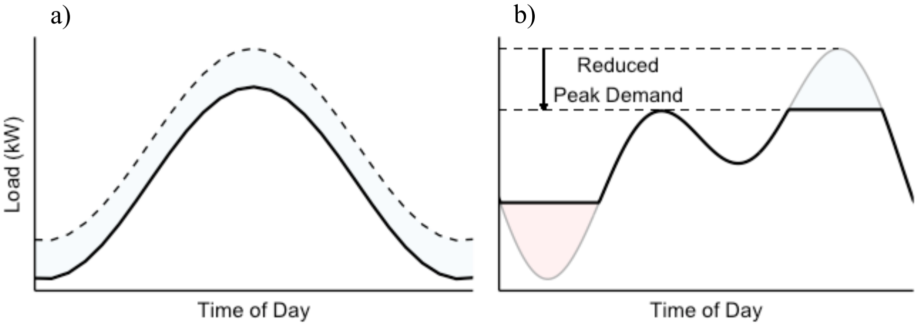

Figure 23: Competing concepts of energy efficiency - focusing efforts on reducing overall energy consumption (a), and reducing energy use at key times through conservation and energy time-shifting to reduce system peaks (b).

These goals typically manifest through reducing the overall amount of energy consumed. A competing notion of efficiency focuses on when energy is used and shifting energy across time to reduce the burden of system peaks *(Figure 23)*. This method can arguably have a greater impact on reducing emissions and obviating new utility infrastructure projects. While energy storage is well suited towards fulfilling the second type of efficiency, it is typically not included in efficiency programs such as CIP because round trip inefficiency in batteries and other forms of storage increase the total load on the grid, despite shifting it to times when it is less impactful and burdensome.

For the MISO-North footprint, which encompasses virtually all of Minnesota and Iowa, along with parts of North Dakota, South Dakota, and Montana, yearly peak events make up a significant portion of the overall system maximum load. *Figure 24* depicts hourly generation throughout 2016 and demonstrates that only 5 percent of the hours in the year makes up almost 24 percent of yearly peak load. Because grid infrastructure has to be sized to meet peak load events, a significant portion of grid costs go towards meeting customer energy needs for just a fraction of the year.

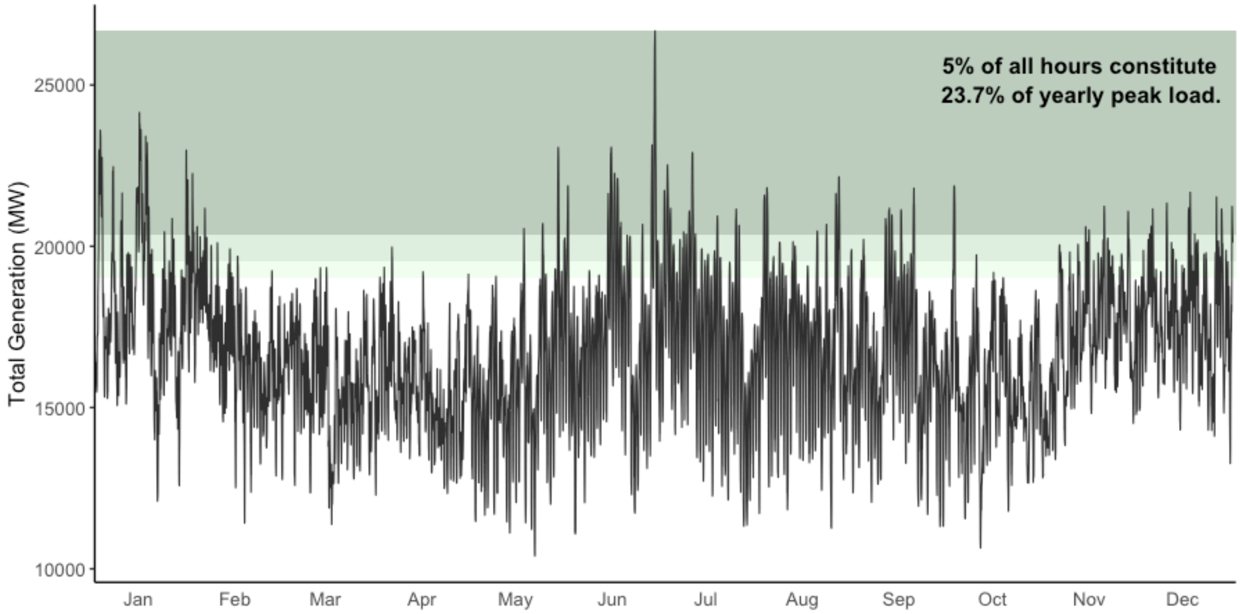

Figure 24: Hour-by-hour electricity generation in MISO North region in 2016. Shaded regions represent top five, ten, and fifteen percent of all hours in the year with regard to generation.

Refocusing energy efficiency investments towards reducing system peak load events through the use of energy storage could have a greater impact on reducing system costs than simply reducing energy use. Furthermore, many of the generation resources used to meet peak demand events, such as natural gas peaker plants, have higher marginal emissions than the average generation mix during a normal day. Therefore, mitigating peak load events using storage can also reduce overall emissions from electricity generation, even though it causes overall load to increase.

4.3.6 Apply Investment Tax Credit (ITC) to all Storage Installations

Currently, the federal investment tax credit (ITC) is only available to energy storage devices if they are paired with a renewable generation resource. Furthermore, the ITC is scheduled to decline and then be phased out after 2022. This tax credit is intended to support and incentivize renewable energy devices which are immature technologies by making them more affordable and increasing consumers' ability to recoup their investment. These credits are being phased out as the technologies mature and costs come down.

While distributed solar is becoming increasingly cost-effective without tax credits or subsidies, battery energy storage is still a relatively immature technology. Costs remain high, and, in many cases, consumers are unable to recoup their full investment. Moreover, battery energy storage devices contribute value to the electric grid whether or not they are paired with renewable generation resources. Only providing a tax credit for paired devices unnecessarily prioritizes some grid services storage can provide over others. Applying the ITC to standalone energy storage devices and extending it past 2022 may be appropriate given the nascent state of the market and the technology, and a public interest in promoting the use energy storage and the provision of grid services it can deliver.

4.4 Assessment Criteria

The primary criterion by which these policy alternatives are to be assessed is whether they create value which more accurately compensates behind-the-meter energy storage for the grid services that it provides. Furthermore, the policies should enable storage to improve the monetizable value of distributed solar, and vice versa, without unfairly devaluing or disincentivizing either technology individually. This creation of value is critical to appropriately incentivize investment in and use of behind-the-meter energy storage. However, these incentives and value streams are assessed by their ability to promote the most efficient and beneficial (to society) application of energy storage.

On the other hand, incentives for energy storage should not burden utilities or non-participating customers with costs incommensurate with their level of benefit from the services provided. Policy alternatives are evaluated on their consideration of equity between customer groups, particularly owners of storage devices and non-owners. Likewise, these alternatives are judged on three modes of viability. First, the policies must adhere to Bonbright's principles of utility ratemaking, primarily general understandability for a broad cross-section of the utility's customers. Policies must be technically viable, with clear and logical mechanisms between inputs and desired effects, and, finally, they should be politically viable, not facing opposition from powerful or influential stakeholder groups.

4.5 Projected Outcomes

Based on analysis of energy storage performance and case studies of energy storage policies across the country and in Minnesota, the following are projected outcomes for each of the proposed policy alternatives.

4.5.1 Mandatory Residential Time-of-Use Rates

Time-of-use rate designs create value for battery energy storage through enabling customers to shift energy use from high-cost times to lower-cost times. They create value for storage when it is deployed independently of solar generation, but also allow storage to improve the value of behind-the-meter solar, although the value of stand-alone solar generation may decline somewhat, as the value of energy generated during mid-peak or off-peak hours is reduced. However, this rate design can be customized for each utility to accommodate its characteristic system peak and cater to its particular generation mix to align the interests of storage-owning customers with those of the utility and ratepayers in general.

A further projected benefit of these rate designs is that the value available to customers for shifting their energy use is not exclusive to employment of batteries or energy storage more broadly. Customers who are able to reduce their energy use during peak times through efficiency upgrades or behavioral changes contribute equally to reduction of system peaks. Using time-of-use rates, the mechanism by which energy use is shifted or reduced is not considered, so any reduction in peak-time energy use is rewarded by this rate structure. The cost burden for time-of-use rates generally falls on those customers who use the most electricity during peak times, since those customers also place the greatest burden on the electric grid and have the greatest costs associated with the provision of their electricity. However, there are some equity concerns relating to low- and moderate-income ratepayers who may be unable to shift their load profile and may have their energy burden increase as a result.

4.5.2 Residential Demand-Metered Rate Design

Applying demand-metered rate designs to the residential customer class enables these ratepayers to create value for energy storage through the mitigation of peak load events. This prospect has the potential to reduce the gaps in value generation capacity between commercial and residential customers. It provides value for energy storage in the absence of collocated solar generation, but also improves the value of solar when paired with energy storage without devaluing distributed generation on its own.

Demand metering may be expected to reduce households' peak contributions to system demand, grid congestion, and overall grid/service costs, or charges customers more for it if it is unmitigated. However, residential peaks are much more difficult to predict or model than commercial and industrial peaks. Furthermore, residential peaks are not consistently coincident with total system peak. Standard demand metering values the reduction of a peak early in the morning the same as reducing a peak in the early evening, however, reduction of off-peak load adds little value to the grid. Employing rate design to accommodate this (such as Salt River Project's residential demand metering) can result in overly complex rate structures.

4.5.3 Net Metering Reform – Restructure Compensation Metric

Restructuring net metering compensation mechanisms to pay customers less than the full retail rate for energy returned to the grid is thought by some to reduce the potential for regressive cross-subsidization, wherein ratepayers who do not own generation resources subsidize the typically wealthier, more affluent customers who do. These rate structures provide greater savings for net metered customers who are able to use more energy directly rather than returning it to the grid. This creates value for storage devices through maximizing the amount of electricity that is directly used by storing excess generation and discharging when generation declines.

On the other hand, net metering reforms do not compensate the value of stand-alone energy storage devices, and they decrease the value of distributed solar generation. These factors disincentivize investment in distributed solar generation and can reduce the amount of renewable generation added to the grid, ultimately increasing carbon emissions from energy generation. Furthermore, policies such as these face strong opposition from a number of stakeholder groups, including solar manufacturers and installers, ratepayer advocates, and environmental organizations.

4.5.4 Solar Incentive Reformulation – Incentivize Storage

Encouraging energy storage through solar incentives enables storage to improve the monetizable value of solar without decreasing the value of solar itself. If employed similarly to Massachusetts' SMART program, offering the standard incentive to all installations up to a capacity limit (5 MW), regardless of customer class, reduces the gaps in achievable value between residential and commercial customers. However, a program such as this only provides value for energy storage when it is paired with solar generation. Furthermore, the value of the storage device is contingent on energy production from the solar panels, rather than performance of the storage device itself. This disregards the value of additional services that energy storage can provide the grid and utility customers.

4.5.5 Include Storage in Energy Efficiency Programs – Redefine Efficiency

Refocusing efficiency programs to emphasize the reduction of overall system peaks has the potential to optimize the benefits of storage on infrastructure and generation resources, decreasing overall costs and emissions. As a performance-based incentive, this policy option returns value to battery owners based on the services that they provide to the grid. As the policy is implemented in the Massachusetts Energy Efficiency Plan, creating peak time frames for which energy storage owners to target their discharge guides provides the greatest value for behavior that provides the greatest benefit to the grid as a whole, rather than basing it on a particular customer's load profile, which may or may not reflect total system load.

A program such as this creates value for storage independent of co-located renewable generation without reducing the value of solar generation itself; though it does not explicitly add value when the two technologies are combined. Equity issues regarding who is able to access energy storage technologies and the value that is created by them can be addressed using interest-free loans to finance storage installations through funds available to the state energy efficiency program, increasing access for low-income ratepayers. However, steering the state energy efficiency program in this direction may shift funds away from other cost-effective efficiency improvements, such as insulation, upgrading appliances, and public education efforts.

4.5.6 Apply Investment Tax Credit (ITC) to all Storage Installations

The federal investment tax credit has been a vital resource in promoting investment in wind and solar generation when the technologies were too expensive to be cost competitive with alternative forms of generation. Expanding the scope of technologies covered by the ITC to include battery energy storage devices and extending the horizon for the credit past 2022 would create a predictable incentive for an immature technology to promote installation and technological development. This would provide value streams for energy storage independent of solar generation and does not devalue generation resources in order to do so.

However, an investment credit is not performance-based and does not reward or incentivize the provision of grid services. Nor does it provide continuing revenue throughout the life of the storage device, but simply provides a discounted purchase price. On the other hand, because accessing the tax credit does not require any specifically designated time with regard to the battery, it is capable of adding an additional layer of incentive to storage use cases which already have other revenue streams (i.e. time-of-use rate management, peak shaving, etc.).

4.6 Recommendations

Based on the evaluation of projected outcomes for each proposal, it is expected that two policy options would have optimal results based on the criteria set forth herein. These include the use of time-of-use rate designs for residential ratepayers and retooling Minnesota’s energy efficiency program (CIP) to target system peak reduction in addition to general reduction in load and generation. Both of these proposals create value for behind-the-meter residential storage that is more accurately reflective of the value of the services that it can provide the grid. Furthermore, these policies incentivize the employment of storage to target the reduction of system peak events and reduce overall costs and emissions associated with energy generation, rather than mitigating the burden that individual customers have on the grid.

4.7 Stakeholder Analysis / Perspectives

The implementation of policies affecting such a wide cross-section of society and such a critical aspect of infrastructure as the electric grid relies heavily on the support of key stakeholder groups. The following are a sample of the groups who may have an interest in the matter of behind-the-meter energy storage and how their perspective and preferences may shape policy choices and outcomes.

4.7.1 Utilities

All utilities in Minnesota are required by state law to participate in energy efficiency programs such as CIP,[59] and to reimburse all net-metered customers with generation capacity under 40 kW at the full retail rate.[37] However, they can often view efficiency and distributed generation incentive programs which decrease load as a form of competition, decreasing sales and revenue for the utility. Employing energy storage for energy efficiency and self-consumption of renewables, on the other hand, present two propositions which utilities generally favor.

Storage reduces system peak events while increasing the total load on the system, which reduces costs of service while increasing sales. Additionally, improving self-consumption of renewables reduces the amount of grid congestion on the distribution system for which the utility is not compensated. Conversely, if energy storage implementation reduces peak demand to the extent that peaking assets are no longer needed or used less often, utilities could be concerned with *used and useful* determinations of these assets, and their ability to include them in their rate base and recover their investments. With regard to achieving comparable value propositions for energy storage throughout the state, legislative action may be necessary, since cooperative and municipal utilities are not as directly regulated by the PUC and do not file rate cases with the commission or need approval for rate design decisions.

4.7.2 Residential Ratepayers / Advocates

Advocates for residential and low-income ratepayers prioritize efforts to keep residential electricity rates as low as possible and promote opportunities for ratepayers to lower their energy costs. Adapting rate design to more accurately reflect the cost of service such as time-of-use rates serves this purpose by charging residential customers a more accurate representation of the marginal cost of providing them service. It also provides customers with the ability to reduce their electricity costs by shifting electricity use away from peak times through storage use or behavioral changes.

Residential customers also generally want increasingly clean and renewable energy, assuming it can be provided at reasonable rates. This includes options for behind-the-meter energy resources, both solar generation and battery storage, with appropriate value streams that allow them to recover their investments. For this reason, residential ratepayer advocates would likely favor mechanisms which provide appropriate value for energy storage installations without reducing the value of behind-the meter solar generation.

Finally, ratepayer advocates, especially those who advocate on behalf of low-income utility customers, maintain that access to cost-saving programs should be equally accessible to all customers, regardless of financial means. A common criticism of residential solar incentives is that they primarily available to those who own their own home and have the means to invest thousands of dollars into these installations. Therefore, the potential for savings is only available to affluent customers. Likewise, with regard to energy storage, residential advocates would likely support opportunities for broader access to devices and programs which allow customers to lower their bills, particularly for low- and moderate-income communities.

4.7.3 Solar Installers / Manufacturers

The livelihoods of solar installers and manufacturers relies in part on the strength of the residential solar market. This market, in turn, relies on the value proposition the behind-the-meter solar installation provides to residential customers. While the solar industry would likely welcome more appropriate valuation of energy storage, it should not come at the cost of the residential solar market. As demonstrated in Nevada in 2016, reduction of solar incentives can have dramatic effects on the solar industry and on the regional economy as a whole.

4.7.4 Environmental Organizations

Generally speaking, environmental organizations strongly favor any and all efforts to reduce carbon emissions in the energy sector. Energy storage, however, can have the effect of increasing electricity use and the corresponding carbon emissions through round-trip inefficiencies. Environmental groups are generally in favor of employing energy storage and incentives therefor, particularly in cases where emissions can be reduced, infrastructure construction (particularly fossil fuel infrastructure) can be avoided, and more variable renewable generation resources can be employed. Many such organizations also have strong energy democracy platforms, favoring efforts to empower customers, particularly low-income customers, to have more control over energy, from generation through consumption. This typically takes the form of promoting residential, behind-the-meter generation and energy efficiency programs, both with adequate revenue streams to facilitate and then fairly compensate these investments.

4.7.5 Large Commercial and Industrial Customers

The primary concern of commercial and industrial customers with regard to energy and electricity is to keep their rates low and service reliable. Large corporations rely on inexpensive electricity rates to keep costs down and compete in a global economy. These organizations will likely embrace the prospect of employing battery energy storage to reduce their demand charges as battery costs continue to decline and would welcome additional revenue streams to compensate other grid services that these devices can provide. However, commercial and industrial customers would contest any effort that they judged to facilitate cross-subsidization between classes to offset the costs of residential energy programs.

4.8 Limitations of Analysis Techniques

A number of factors limit the accuracy, precision, and completeness of this analysis. While all facts, figures, and assertions included herein are true or valid to the best of our knowledge and ability, the following qualifications should be considered.

- **Variability in the value of storage - dependence on/sensitivity to myriad other factors.**

Two seemingly incongruous conclusions that can be drawn from this analysis is that it is not possible to generalize a precise value of energy storage for residential applications and that energy storage is undervalued and undercompensated for most residential utility customers. Energy storage has a vast array of services that it can provide which benefit the grid, utilities, and the customer in various ways. Value provided by a storage device depends on the choice of these services to provide, which to prioritize, the shape of the customer's load curve, behind-the-meter solar generation capacity (if any), age and value of the utility's distribution infrastructure, system load and peak characteristics, and many more considerations. However, while precise values of these services are often elusive, many are uncompensated with common rate designs and incentive structures, effectively setting their value at zero.

- **Dynamic and responsiveness of storage - opportunities and challenges of stacking use cases.**

One of the greatest assets of energy storage devices is their ability to be dynamic in response to changing circumstances and adjust their behavior or the service they are performing based on the needs of the customer or conditions of the grid. This ability makes predictive modeling difficult, due to the uncertainty of combining the value of several grid services provided for variable amounts of time under variable circumstances. For the purpose of simplicity, in this analysis, each service was considered individually. However, then wholistic value of a storage device includes the marginal value of each service for the time it is provided.

- **Post-hoc modeling - assumes perfect forecasting ability, optimal battery performance.**

Similarly, this analysis employs post-hoc techniques which essentially assume perfect load forecasting abilities. As is detailed in the analytical methods section, both the time-of-use and demand-charge management algorithms make calculations based on a day's electricity usage information before executing that day's charge and discharge directives. While this demonstrates the theoretical potential value for each use case, it does not always reflect practical, achievable outcomes.

- **Limited demonstrated use of storage (residential and utility-scale) in Minnesota**

While battery energy storage technology is generally a new and uncertain proposition in many parts of the country, this is particularly true of Minnesota. The state's first utility-scale solar-plus-storage facility was installed by Connexus Energy in late 2018,[60] and there remain few residential and small-scale commercial storage installations, due in part to the lack of viable value propositions. Due to the state lacking a breadth of experience with the technology, it is difficult to predict how storage devices will perform. Most battery technologies suffer efficiency losses in the cold weather, or they must expend additional energy to control the climate surrounding the battery. When attempting to predict the functionality of battery devices in Minnesota, it is valuable to have real-world data from which to construct a model.

- **Uncertainty of energy storage costs due to industry opacity, non-linear pricing scales, and challenges with market forecasting.**

As mentioned above in Section 2.4.1, the economically optimal battery for any given application is the one whose marginal cost is equal to its marginal benefit/value. Ideally, for each individual use this would be determined, and a value could be selected for optimal benefit. However, several factors prevent proper comparison. Energy storage prices are generally not accessible for prospective analysis. Manufacturers and vendors are somewhat reticent with regard to price estimates for battery systems. While there are general cost estimates which reflect changes over time or comparisons between chemistry types, these often refer to utility-scale installations. Devices on a residential or small commercial scale can be expected to be much more expensive than utility scale on a per-unit basis. Finally, while costs of energy storage are falling rapidly, it is difficult to forecast the rate at which prices will change in the future. This likely depends heavily on the scale of manufacture, resource availability, and technological advancement, which are each subject to deviation from projections.

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