Battery vs. Generator

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If you are reading, you are likely already convinced battery storage is the answer to the energy woes of our time, particularly those relating to climate change.

Given their rapidly increasing performance per dollar, not to mention carbon-free technology, batteries have developed a significant buzz in popular culture and within the sustainability industry.

The hype is a product of their potential to act as a bridge to intermittent renewables, primarily at the utility level, and as a tool for reducing emissions, mainly through electrification. As the technology advances and as intermittent renewables proliferate throughout the nation and globe, utility level demand for battery storage is increasing.

Batteries are proving incredibly useful at powering vehicles and in providing services to the grid at the utility level; this comes down to the fact that utilities can utilize batteries for a wide range of services other than just backup. However, more recently, the battery hype has targeted the commercial and industrial landscape.

Despite their use at the utility scale, implementation of battery storage at the commercial or industrial scale is still cost prohibitive and likely to remain so even as prices decline through 2050, as the NREL (National Renewable Energy Laboratory) forecasts.

The technology simply has not evolved to the degree required to cost-effectively provide the green benefits of batteries as backup. Because of this, natural gas generators remain the primary solution for backup power and resiliency planning despite still emitting greenhouse gasses, the least harmful of all the fossil fuels.

This eBook aims to illustrate the differences between batteries and natural gas-powered generators as a form of backup power to provide resiliency from both a cost and practicality standpoint.

With its basic structure remaining the same since 1882, when Thomas Edison introduced electricity to a select 59 customers, the grid has powered the American economy to global prominence, all while fundamentally and permanently altering our way of life and the very fabric of our society.

The “biggest machine on Earth,” A.K.A. the grid, now supplies hundreds of millions of customers, delivering more than $400 billion of electricity annually through an interconnected system of power plants, nearly 7 million miles of transmission and distribution lines, transformers, and substations. At any given moment, the facets of the machine cooperate to keep everything from large factories, your child’s iPad, and everything in between on and fully charged.

Despite the grid’s foundational importance to nearly every aspect of American society, as a nation, we have failed to adequately invest in its maintenance, upkeep, and advancement, instead opting to permit its gradual depreciation. This, combined with more frequent extreme weather events and, more recently, the renewable energy transition, has negatively impacted grid reliability.

The decline in reliability is evident when examining the 5-year annual average of outages, which increased by almost 160 since 2000.

Moreover, as ambient temperatures rise, the grid, with stressed and often inadequate equipment at the local level, in combination with persistent transmission line congestion and a constantly changing governing structure growing increasingly complex, moves one step closer to the brink.

It is estimated the grid needs close to $1 trillion of investment to make it more reliable and efficient, particularly to achieve President Biden's 2035 goal for a carbon-free power sector.

Unfortunately, such investment is up to the whim of politics with new investment remaining uncertain and analysts pointing to a $500 billion investment gap in climate resilience for electric utilities. Sixty percent of that gap is needed for system hardening to protect from rising temperatures.

With rising ambient temperatures along with record levels of energy demand, the probability of transmission and distribution lines sagging, and contacting adjacent foliage causing large fires, has increased.

In 2018, a live wire broke free from the century-old Caribou-Palermo power line in California, igniting a heavily wooded and mountainous region, killing 85, and destroying the town of Paradise. The event caused significant public outrage and contributed to PG&Es bankruptcy.

In addition to age, another important factor is the increasing frequency of extreme weather-related events. With most distribution and transmission lines in the U.S. above ground, the grid's infrastructure is highly vulnerable to severe weather. Federal data shows that much of the increase in large outages, a figure that breached 100 in 2020 for the first time since 2011, has been driven by weather-related events, many of which are linked to climate change.

With the severity and frequency of wildfires, floods, and hurricanes increasing, outages are expected to be more frequent and prolonged.

The grid is not only threatened by age and weather, the transition to a carbon-free future also has the potential to place additional strain on the grid. With increased state and federal regulatory pressure, along with public support, traditional fossil fuel power plants are being phased out more quickly than renewable energy, and battery storage, can pick up the slack, at similar reliability levels.

Despite being among the cheapest forms of power generation, many renewables are intermittent in nature, they only generate electricity when the wind is blowing or the sun is shining and frequently when the grid is not experiencing peak load.

Renewables are not dispatchable in the same way combustible fossil fuels are during times of increased demand. As the switch to renewables picks up speed, issues relating to their intermittency have the potential to cause outages if there is not enough solar output and too few fast ramp fossil fuel generators to fill the gap. This is because the supply of energy must continuously match demand for the grid to not trip and it's hard to match demand and supply when renewable generation is highly uncertain.

Solar and wind can produce large surpluses, but without cost effective ways of storing those surpluses, there is no way to use them to supply power when renewable output is zero, placing strain on the grid.

Given the current trend in terms of grid reliability, the importance of resilience in the face of outages becomes even more important. The duration of an outage is vital in assessing grid reliability to plan for resiliency and is particularly relevant when choosing between battery storage or a backup generator. These implications are discussed more thoroughly in the following pages.

Regardless of whether your firm is looking for resiliency, with transmission and distribution-related costs projected to rise, and with these charges already comprising more than 40 percent of the typical energy bill, implementing either a backup generator or a battery could help save on energy-related expenditures on top of providing resiliency. Clearly, having either a backup generator or a battery storage system must be considered.

Conceptual Comparison:

Comparing backup generators to batteries is, in many ways, the same as comparing apples to oranges. They both have similar functions, but they are very different at the end of the day. This increases the difficulty of selecting the option that best satisfies your company's objectives.

Before diving deeper into this assessment, another analogy is particularly helpful in understanding the true difference between battery storage and the natural gas generator alternative.

First, try thinking of a battery as a bucket and a generator as a fire hydrant. The bucket has a limited amount of water, like a battery with energy, and works well against small fires. A bucket can stop as many small fires as needed so long as the fires come in wide enough intervals with ample time to refill the bucket.

Small fires are of little concern for the bucket; however, complications arise when the dreaded big fire rears its head. The bucket might quell 25% of the large fire, but if you cannot refill the bucket immediately, either because you don't have the time or the water, the fire will continue its path of destruction.

In this type of scenario, the fire hydrant is particularly handy. Because the hydrant is connected to a nearly infinite water supply, it will always provide the necessary water to stop the fire. This same advantage applies in the world of backup generators.

A battery, like the bucket with water, can only hold a specific amount of energy; therefore, it can only handle shorter duration outages, the small fires. After the battery, or the bucket, has been depleted, it is essentially useless if you cannot recharge it quickly. Because of this, longer, more prolonged outages present a logistical nightmare when it comes to using batteries to provide resiliency as you need to make sure you have enough of them to fight the large fire from the onset. So, if one bucket is 25% effective, you would need four buckets to stop 100% of the fire, meaning you would need to buy four buckets.

Like a fire hydrant with water, a backup generator is connected to a nearly limitless quantity of natural gas, increasing its capacity to service longer outages or larger fires. Furthermore, all you need to buy to use the fire hydrant is a hose. These conceptual differences underlie the main argument for backup generators over batteries; however, a deeper dive is required to truly understand their differences.

How Many Buckets?

The first step in implementing a battery storage system is to determine how many *buckets* or batteries are needed to supply the necessary energy for the entire length of an outage. To accomplish this task, one needs to understand the "un-advertised" reality of the duration and frequency of the average outage in the United States.

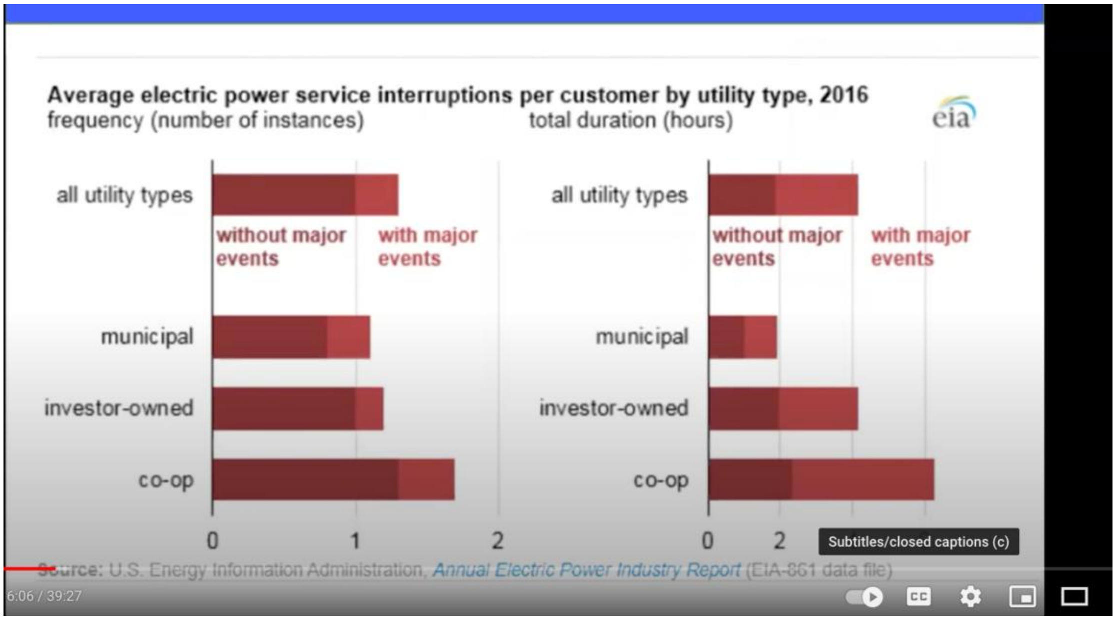
As seen in the figure below, the average duration of power service interruptions for all utility types in 2016 was 4.2 hours, with an average of 5 percent of users losing power during an event.

Given the longest duration batteries typically support energy discharge for up to 4 hours, one might ask, why are we even talking about a generator?

Yes, at the surface level, a 4.2-hour outage could likely be serviced by batteries; however, to the untrained eye, the figure is severely misleading.

The 4.2 hours was calculated by dividing the total quantity of outage hours by the entire customer base, regardless of whether a customer experienced an outage.

Standardizing the metric in this way makes it possible to compare reliability between grids; however, because the hours of outage are distributed among the entire customer base, the figure is useless in terms of resilience planning.



One can derive a more accurate calculation of the average outage duration by dividing the total outage hours by the number of customers that *experienced* an outage.

Following this alteration, the duration rises from 4.2 hours to 84 hours, a 20x multiple, nearly four days.

Hurricane Sandy is a prime candidate to help bring these statistics into context. During the superstorm, some 7 percent of customers lost power, with many going 7 to 31 days without it.

According to the traditional methodology, your firm would have a 93 percent probability of not experiencing an outage during Sandy. However, if your firm was one of the unlucky 7 percent, your probability of experiencing an outage rises to 100 percent.

The difference in outcome, in terms of outage duration between the average 5 percent outage probability of the traditional, unaltered grid reliability statistic and a 100 percent probability is a 20x multiplier.

You might have planned for the average outage of 4.2 hours with batteries, and believe you're in the clear, but if the outage is anything closer to the 84 hours calculated above, your firm would cease operations after only 4 hours. This event would likely result in significant opportunity cost and long-term harm.

Furthermore, 84 hours more closely resembles a base case, as it is an average—many customers experienced outages for anywhere between 7 to 31 days during Sandy. Therefore, if you planned for an 84-hour outage, you would still only be 50 percent confident in your ability to be resilient.

Assuming a normal distribution of outages, at a 50 percent statistical level of confidence, P50, the expected duration of an outage is 84 hours. However, there is a 50 percent probability of the outage being above or below this figure. If you were to plan for 84 hours, the probability that the outage will be within the planned 84 hours is the same as flipping a coin, and a flip of the coin hardly resembles true resiliency.

To achieve 99 percent confidence one can be resilient in the face of an outage; you must plan for 99 percent of outages, the 99 percent confidence interval.

With a mean of 84 hours and a standard deviation of 15 hours, 99 percent of outages are between 54 and 114 hours. Therefore, to be truly resilient, one must plan for and have the capacity to outlive a 114-hour outage. If one bucket is equivalent to one hour of capacity, you would need 114 buckets to remain in operation through the outage to be 99 percent resilient. By way of comparison, many municipal critical infrastructure systems, such as water and wastewater treatment plan for 336 continuous hours of outage.

	Outage Time	**Number of Buckets Needed**
Unadjusted Statistics	4.2 hours	4.2 buckets
Adjusted Statistic	84 hours	84 buckets
To be 99% Confident	114 hours	114 buckets

Table 1:

How much does a bucket cost?

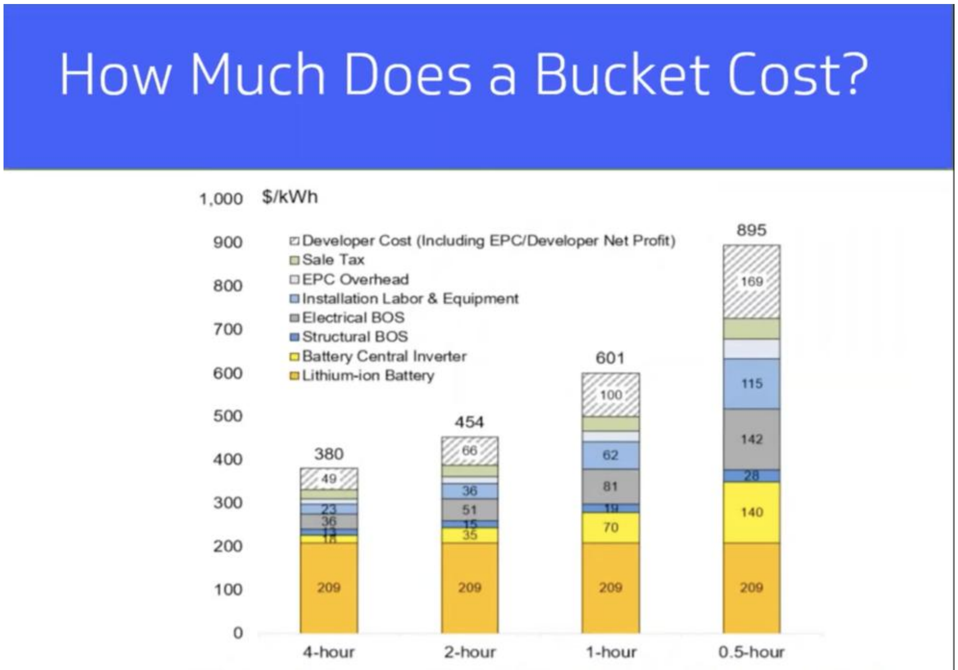
Why is Cost so Variable?

Now that we have determined the duration of an outage that must be planned for (i.e. how many buckets), the second step is to determine how much one bucket costs.

Despite battery prices falling in recent years, their cost remains high in comparison to the alternatives presented here. Furthermore, the price of a lithium-ion battery varies dramatically depending on the intended application of the battery.

Typically, batteries are priced in dollars per kWh stored. For example, seen in the figure below, batteries can range from $380 kWh to $895 kWh. The more expensive batteries have high power-to-energy ratios and are designed to provide high power for a limited period to handle significant demand surges.

Because of this difference in application, these batteries are manufactured differently and are therefore priced at a premium. Longer duration batteries that discharge evenly over a more extended period, say 4 hours, will cost less per kWh of installed discharge capacity.

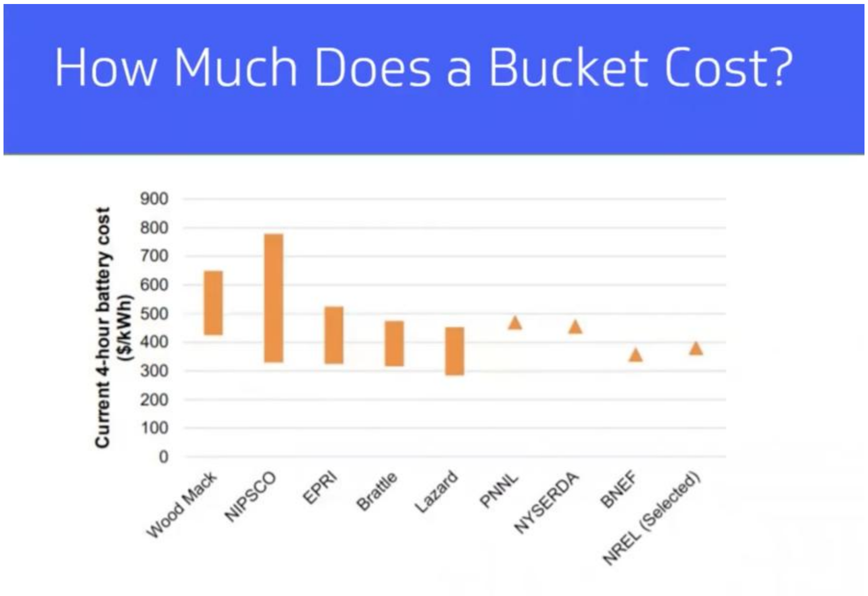


How Much Does a Bucket Cost?

Figure ES-1. 2018 U.S. utility-scale lithium-ion standalone storage costs for durations of 0.5–4 hours (60 MW_{DC})

Cost Analysis:

For this analysis, we will set the price of a battery, or a bucket, lasting 4 hours at $300, the price offered by Lazard and the lowest priced battery in the figure below.


How Much Does a Bucket Cost?

Current battery storage costs from studies published in 2018 or 2019. The NREL value (Fu, Remo, and Margolis 2018) was selected as the 2018 starting cost for this work.

A few cost assumptions, other than the cost per kWh, must be accounted for to complete the analysis. First, because the typical battery incurs energy losses when charging through the inverter and in the other direction when discharging energy, the total round-trip efficiency is typically around 90%, which we will use in this analysis.

Furthermore, most batteries cannot be discharged fully and have a charge minimum, frequently 10 percent, meaning that at least 10 percent of capacity must always remain, the value used in this analysis.

These factors result in a higher effective cost per kWh of installed capacity, the cost rising from $300 to $370 a kWh per unit.

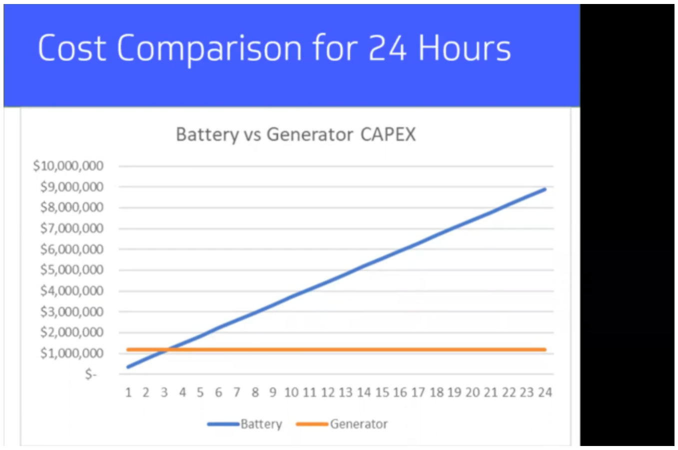
For a firm using a megawatt of energy per hour for 24 hours, the capital expenditure required for 1 hour of backup is initially about three and half times cheaper than the natural gas generator, which costs $1.2 million (1,000 kilowatts x $370 = $370k vs. $1.2 mn).

However, there is a substantial divergence between the cost of the battery and the generator over 24 hours, one that grows when considering how long some outages can last.

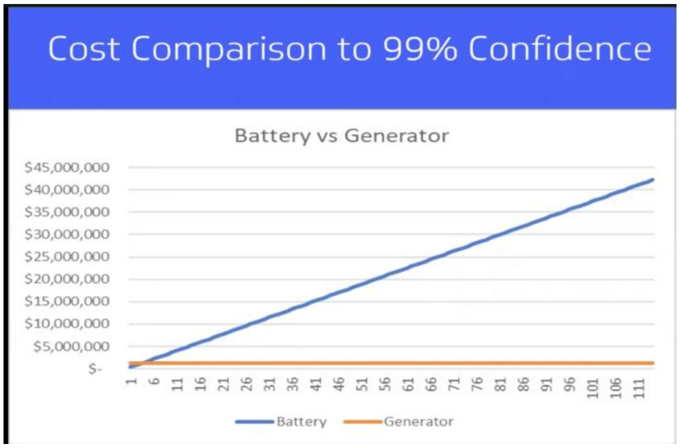
For this example, let's assume that $370,000 represents the cost of one bucket. For another hour of backup, to fight the fire for one more hour, you need another bucket, and so on. You would need 24 buckets for one day, bringing the total capital expenditure or investment needed to have enough backup storage for a day to $8.8 million (24 hours x $370,000).

At three and half hours or three and a half buckets, the battery's cost converges and later surpasses the generator's cost of $1.2 million. However, because the cost of the generator per kilowatt remains constant, following the initial capital expenditure, the only additional cost, other than maintenance, is the cost of fuel. Unlike the battery, there is no need to have another generator for every hour of the outage, you just need enough natural gas to feed the machine.

Because of this, the difference in CapEx needed to implement either a battery or gas generator backup system for one day is significant, the battery being $7.68 million more expensive.


Cost Comparison for 24 Hours

Unfortunately, this analysis is still incomplete. To be 99 percent confident that you have enough backup for the duration of the average outage, according to the analysis detailed earlier, you must have enough capacity to run for 114 hours straight, the change in is seen in the figure below.


Cost Comparison to 99% Confidence

With the cost of 1 bucket or battery being $370,000, you would need 114 buckets, requiring $42.18 million of investment. Meanwhile, the CapEx required to handle 114 hours for the gas generator remains flat at $1.2 million.

Scenario	Size of Battery (hours)	Size of Battery (buckets)	Total Cost of System (millions)	Cost as a Multiple of Generator's Cost
Battery Alone for 24-hour outage	24 hours	24,000	$8.88	**7.33 x**
Battery Alone for 114-hour outage (99% confidence)	114 hours	114,000	$42.18	**35.15 x**

Table 2

This difference in CapEx is enough to convince many that a battery alone as a backup is probably not the best use of capital; however, some still believe the combination of solar and battery technology could potentially solve the cost dilemma.

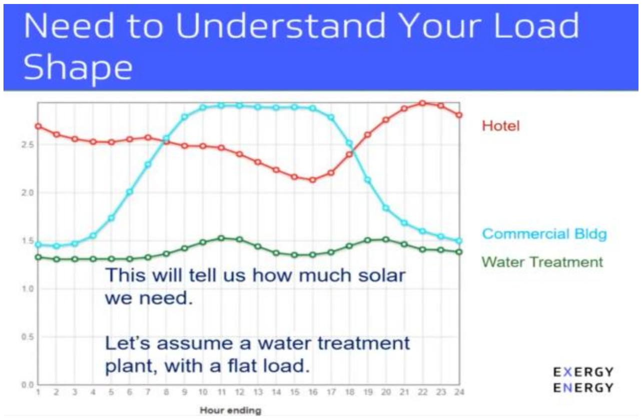
The Solar Solution:

What about batteries and solar? Could solar be used to refill the bucket every day in the same manner that the fire hydrant keeps the water supply constant? The answer is yes, but it's tricky.

To determine the solar capacity required to operate such a system, you need to know how much energy must be generated throughout the day and how much must be stored. To accomplish this, you need to first understand your load profile, as solar will only generate anywhere from 6 to 8 hours a day.

The figure on the following page graphically depicts distinct load shapes for three different industries: a hotel, a commercial building, and a water treatment plant. Notice how the various industries have variable energy requirements at different times of the day; this is very important when assessing the value of solar, the implications of which we will discuss in greater detail in the following pages.

For this analysis, to keep things simple, we will use the flatter load shape of the water treatment plant as it is statistically less complex.



Need to Understand Your Load Shape

This will tell us how much solar we need.

Let's assume a water treatment plant, with a flat load.

Necessary Adjustments:

The average capacity factor for solar panels in the U.S. is 20 percent, meaning a solar panel will only operate at total capacity for 20 percent of the time. After all, power is not generated in the middle of the night, and only a fraction of total capacity will be generated when the sun is very low.

To determine the size of the solar installation needed for a firm with a 1 M.W. per hour load for 24 hours, you divide the load by the capacity factor, yielding the required solar size, in this case, 5 M.W. A.C.

$$\left(\frac{1\ M.W\ .A.C.}{20\%\ Capacity\ Factor}\right)$$

Because most solar is quoted in D.C., after converting from A.C. to D.C. using the average ratios in the U.S., a 6.24 M.W. D.C. behind the meter solar farm is required to recharge the battery every day to provide 24-hour resiliency.

Although utilities can frequently expect to pay a dollar for a watt of solar generation, in a commercial and industrial setting, the cost per watt is typically anywhere from $1.30 to $1.45. For this analysis, $1.35 is used, still a conservative figure. Assuming $1.35 per watt of behind-the-meter generation, a 6.24 M.W. D.C. solar installation would cost ~$8.42 million. This figure is still without the cost of the almost 20 acres required to deploy such an installation, expensive but still much cheaper than the $43 million needed for the battery alone.

However, you probably guessed it, this is still incomplete because the size of the required battery will change when implemented in conjunction with solar. So how big does the battery need to be?

Assuming 9 hours of sunlight per day, the battery will charge for around 9 hours, meaning it will need to discharge for 15 hours (24 hours – 9 hours). If the load is 1,000 kilowatts per hour, the battery will need to be large enough to store 15,000 kWhs, in other words you need a 15-hour battery.

With a cost of $370 per kWh, you would need 15,000 of these buckets, bringing the total cost of the battery to $5.56 million (15,000 x $370). Adding the cost of the solar brings the total cost to $11.88 million.

Scenario	Size of Battery Installation (Buckets)	Cost of Battery (millions)	Size of Solar M.W. D.C.	Cost of Solar (millions)	Total Cost of System (millions)
Without Adjusting for Changes in Solar Irradiance	15,000 or 15 hours	$ 5.56	6.24	$8.42	$13.98
When Adjusting for Changes in Solar Irradiance	15,000 or 15 hours	$5.56	7.80	$10.53	$16.09

Table 3

Because solar irradiance levels are not constant throughout the year –they increase during the summer when the sun is high in the sky and decrease in the winter when the sun is low– we must account for these differences.

The 20 percent capacity factor discussed above is the average for the year. However, solar production is down almost 40 percent during the winter from its summertime peak. Therefore, we need to adjust the size of the solar to account for diminished solar radiation in the winter.

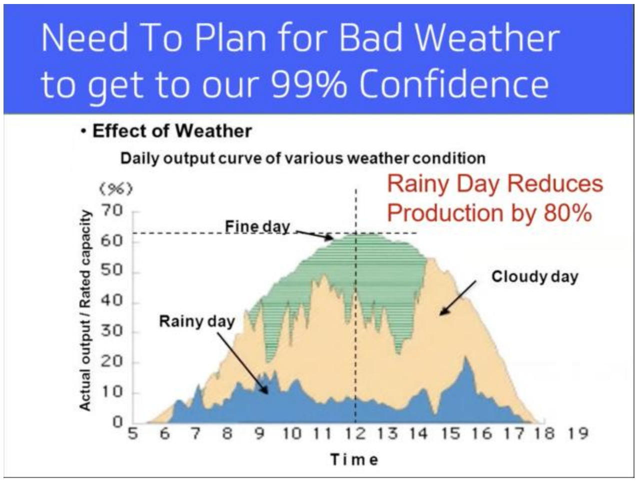
Because the position of the Earth in relation to the sun does not change dramatically year to year, the annual variability in solar production is relatively small at 6 percent. This makes planning for seasonal variations in solar irradiance relatively easy and reliable.

To account for this diminution in solar production, an additional 1.56 MW DC is needed, at the cost of an additional $2.10 million, bringing the total size of the solar farm to 7.8 M.W. D.C., costing $10.53 million.

Unfortunately, as with many of the steps before, this analysis is incomplete. It is based on average solar irradiance levels and does not account for weather events that might diminish solar production, be it a nor’easter in the winter or a hurricane in the summer.

Even though solar irradiance is relatively constant from year to year, it is increasingly variable the shorter the observed time interval, meaning the 7.8 MW DC solar farm would only provide enough energy to prevent an outage 50 percent of the time, a flip of the coin and far from true resiliency.

As seen in the figure below, depending on the weather (rainy, sunny, or cloudy) and the time of day, solar production (actual output / rated capacity) can vary from up to 60 percent of rated capacity to less than 10 percent, with rainy day production down up to 80 percent.



Given that 72 percent of outages are weather-related, this reduction in solar output could occur during a loss of power. If this happened, with a reduction in output of 80 percent, you would no longer have enough solar output to charge the batteries and continue operations, bringing you down for the count, especially if the storm lasts for more than a day – as is typical with hurricanes. Clearly, an adjustment must be made to account for this variability.

Planning for weather to get to 99% confidence (2 ways)

There are two different options when it comes to accounting for weather-related variability in solar output: either increase the size of the solar or of the battery. The first option requires increasing the size of the solar farm by a factor of 5 to 39 M.W. D.C. Given the specified load, a 39 M.W. D.C. installation would provide 99 percent confidence it can generate the needed 6.24 M.W. D.C even during a blizzard.

However, this increase in solar capacity is tremendously expensive. Other than quintupling CapEx requirements, the installation requires roughly 160 acres of solar panels behind the meter, limiting the solution's applicability for many firms, either cash-strapped or short on land.

Adjusting System for Weather Variability by:	Size of Battery Installation (hours)	Cost of Battery (millions)	Size of Solar M.W. D.C.	Cost of Solar (millions)	Total Cost of System (millions)	Cost as a Multiple of Generator's Cost
Bigger Solar	15	$ 5.56	39	$52.65	$58.21	**48.5 x**
Bigger Battery	57	$21.09	7.8	$10.53	$31.62	**26.35 x**

Table 4

If you don't have access to 160 acres, the alternative means increasing the size of the battery instead of the solar. A bigger battery makes it possible to store more of the solar output. On nice days the energy is stored, and when a blizzard or hurricane strikes, the energy is used up.

Given the statistics of solar radiation and assuming you have a 7.8 M.W. D.C. solar site, a 57-hour battery is required to achieve 99 percent confidence, costing roughly $21.1 million. When combined with the cost of the solar, the system's total cost comes in at $31.62 million, 26.35 times the natural gas generator.

Currently Effective Uses for Batteries?

The distinct advantage of the generator from a CapEx perspective raises the question of whether there is an appropriate use for batteries? The answer is yes, but it depends on a few key variables: load shape, location, and risk tolerances.

Remember, during an outage, only a small percentage of the grid goes down, close to 5 percent. This in combination with widely accessible statistics depicting the highest risk areas, and the average duration of an outage in those areas, makes it possible to determine whether a battery strategy is feasible.

Some areas of the country have average outage durations that are below the national average and are thus categorized as low risk. Outages in these areas are typically a lot shorter and, because of this, for commercial or residential facilities with the more classic midday peak load it can be possible for a battery to pencil in its role as backup power.

Despite the potential for it to pencil, the greatest use of the battery pertains to its role as a "ride-through" mechanism. Ride-through implies that the battery will handle the load following an outage until the backup generator is ready to function.

If the power goes out and returns, say within a minute or two, for many firms, there is little downside. For example, if the freezer at a grocery store goes down for 2 minutes and then returns, the frozen food is likely still frozen.

However, for other organizations employing more sophisticated technology or machinery, even 30 seconds without power can cause disruptions resulting in tens of thousands of dollars in repairs, all on top of lost output. In such a scenario, a battery must hold the load until the generator can begin supplying power.

During an outage, the generator will not turn on for about 3 seconds; this is to ensure that there actually is an outage. Following this buffer, the generator is fed a start command and typically begins production in the next 20 seconds. In such situations, the battery, implemented as a ride-through mechanism, effectively complements the backup generator by carrying the load for a brief period.

Conclusion:

Yes, it is possible to achieve 99 percent confidence in your firm's ability to weather an outage of up to 114 hours with batteries. The real question is why would you bear the unnecessary expense?

For most firms, depending on risk tolerance, the investment needed to obtain that level of confidence is completely inefficient compared to the cost of the generator, especially when those funds could be directed towards other corporate investments.

Say you choose the battery over the generator, revealing your preference for carbon-free technology, you would essentially be paying an incredible premium for relatively insignificant carbon reductions.

For example, you would only be using the generator during an outage event. If there was a 114-hour outage occurring annually, the generator would only emit for 114 hours or 1.3 % of the year. In addition, if renewables comprised a significant portion of the energy your firm consumed, if not all of it, this would be the only time your firm would be emitting carbon, at least with respect to energy consumed.

This is becoming a reality as renewables continue to penetrate the grid's energy mix. More renewables mean a behind the meter battery installation at the commercial or industrial scale as a source of backup, other than being very expensive and not requiring natural gas, won't really contribute in any significant way to reducing your firm's carbon emissions moving forward. Why would you pay more for this?

The reality of the transition to renewables is that natural gas is here to stay, and that's a good thing.

Until the grid is seriously revamped, and battery storage is widely deployed at the utility scale, as regulation motivates an energy mix increasingly dominated by wind and solar, with coal and diesel plants being retired, the grid will require a dependable and stopgap to account for the intermittency of these renewables and to supply excess demand during peak events.

Out of all the easily dispatchable fossil fuels, natural gas is the cleanest and greenest alternative for utilities to implement and is therefore essential in the global energy transition.

According to a UN report, natural gas will be critical in supporting decarbonization and the renewable energy transition as it can provide a "relatively low carbon backup at peak energy usage times."

In terms of the commercial, industrial, and residential scale, until battery technology is truly cost efficient, natural gas will continue to play a vital role. The natural gas generator has a decisive advantage when it comes to providing resiliency for businesses of almost all loads, and this advantage will likely extend for the coming decades even as the cost of batteries continue to decrease as forecasted.

As seen in the forecast below, the cost of a 4-hour lithium-ion system is forecasted to decline by up to 60 and 70 percent in 2030 and 2050 respectively. However, the implications for CapEx really don't change, at least from a decision makers perspective.

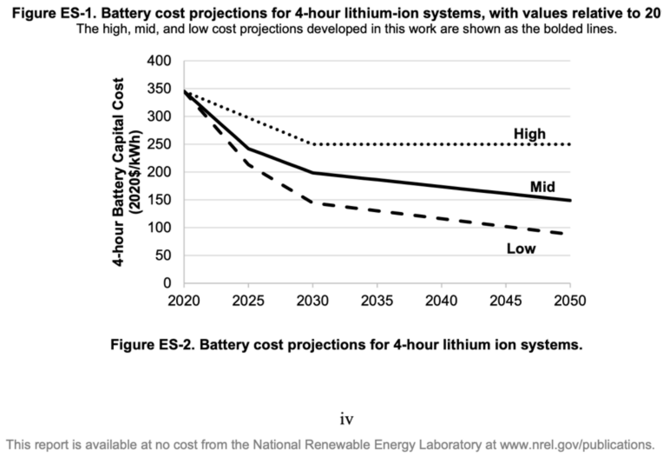


Figure ES-1. Battery cost projections for 4-hour lithium-ion systems, with values relative to 2019.
The high, mid, and low cost projections developed in this work are shown as the bolded lines.

Figure ES-2. Battery cost projections for 4-hour lithium ion systems.

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This report is available at no cost from the National Renewable Energy Laboratory at www.nrel.gov/publications.

Assume the cost of a 4-hour battery falls to $143 per kWh tomorrow. The effective cost being 23 percent higher at $160 per kWh, the same percentage used in the earlier analysis.

With batteries alone, the cost to service the same 1 MW per hour load for 114 hours is still very high at $18,240,000, despite a 56 percent reduction in CapEx from the $370 per kWh before.

The story is the same with battery and solar. The cost of the larger battery falls from $21.1 million to $9.1 million, with the total system including a 7.8 M.W. D.C. solar installation, costing $19.63 million.

One step further, if battery prices were to fall to a low of $87 per kWh, as some models predict for 2050, the battery alone would cost $12.2 million, with the battery plus solar alternative only setting you back $16.63 million. Despite the battery alone option actually being cheaper than the battery plus solar in both scenarios, the natural gas generator is still cheaper.

Scenario[*]	**CapEx Required for Natural Gas Generator (millions)**	**CapEx Required for Batteries Alone (millions)**	**Reduction in CapEx from $300 /kWh used in Analysis (%)**	**Multiple of Generator's CapEx**	**CapEx Required for 57-hour Battery + Solar**	**Reduction in CapEx from $300 /kWh used in Analysis (%)**	**Cost as a Multiple of Generator's Cost**
Battery Price Declines to $143/ kWh	$1.2	$18.24	56.75	15.2	$ 19.63	37.91	**16.4**
Battery Price Declines to $87/ kWh	$1.2	**$12.20**	71.07	10.2	$ 16.63	47.41	13.9
Battery Price Remains Constant at $300/kWh	$1.2	$42.18	-	35.2	$ 31.62	-	26.4

Table 5

At the end of the day, one must ask whether paying 35 x more than the generator today (15.2x in 30 years and 10.2x in 50) for a less dependable battery system is really worth preventing 114 hours of emissions, especially if resiliency is critical to your firm and with

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[*] All CapEx projections were calculated for a 114-hour average

natural gas being the least harmful of the traditional fossil fuels? For many, the answer is a resounding *no*.

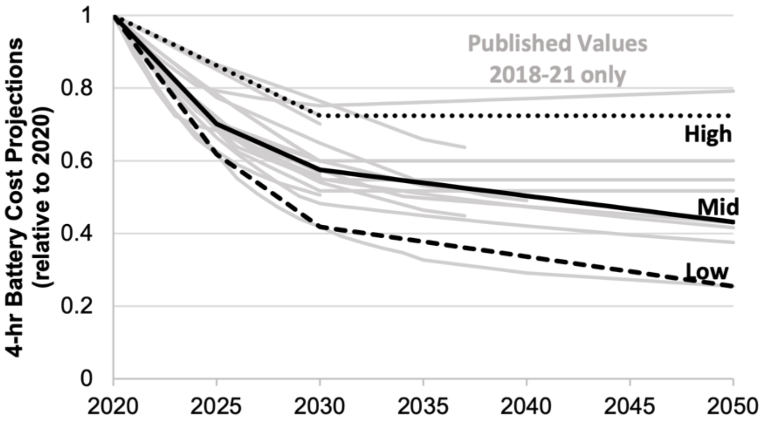

Figure ES-1. Battery cost projections for 4-hour lithium-ion systems, with values relative to 2019. The high, mid, and low cost projections developed in this work are shown as the bolded lines.

Takeaways:

- With the U.S. electrical grid under mounting stress from age, extreme weather, and the transition to renewables, the risk from outages is increasing, making backup power even more important for firms requiring resiliency.
- Natural gas generators remain the optimal solution to providing backup generation during outages at the commercial, industrial, and large-residential scale both in terms of cost and resiliency.
- Because standard grid reliability statistics distribute the duration of the outage over the entirety of their customer base, even those that did not experience an outage, to compare inter-grid reliability, they are effectively useless in terms of planning for resiliency.
- The duration of the average outage is closer to 84 hours as opposed to 4.2, the published figure.
- To be resilient for 99 percent of outages, you must plan for an outage of 114-hours, as 84 hours is still only an average.
- A 114-hour outage has drastically different CapEx implication as can be seen in the table 6 below.
- To provide resiliency using a battery alone requires $42.18 million in CapEx, 35.15 times more than the natural gas generator costing $1.2 million.
- You may think the addition of solar would potentially reduce CapEx requirements; however, you would be wrong.

- To provide 99% confidence you can withstand a 114-hour outage requires $31.62 million in CapEx, 26.35 times the natural gas generator – still extreme, especially when those funds could be used to drive growth in an increasingly competitive landscape.
- Once a battery has been fully discharged, it is essentially useless, and to prevent a loss of power, another battery must assume the load; therefore, the CapEx requirements increase as the duration of the outage increases – as you need to keep buying more batteries.
- Because the CapEx requirements for the natural gas generator remains constant at $1.2 million, regardless of the duration of the outage, the generator has a distinct advantage over the battery.
- As seen in table 5, this advantage will likely prevail even as battery prices are projected to decrease potentially up to 70 percent by 2050, even with cost of the natural gas generator remaining constant.
- The only reason one would pay upwards of 25x the CapEx of the natural gas generator would be to prevent the emissions produced by the generator; however, if the generator was only servicing a 114-hour outage per year, your firm would only be releasing emission for 1.3% of the year, especially if the mix of energy your firm consumes is primarily green.

Scenario	**Size of Battery Installation (hours)**	**Cost of Battery (millions)**	**Size of Solar M.W. D.C.**	**Cost of Solar (millions)**	**Total Cost of System (millions)**	**Multiple of Generator's CapEx**
Battery Alone for 24-hour outage	24	$ 8.88	-	-	$ 8.88	**7.33 x**
Battery Alone for 114-hour outage (99% confidence)	114	$ 42.18	-	-	$ 42.18	**35.15 x**
Bigger Solar + Battery	15	$ 5.56	39	$52.65	$58.21	**48.5 x**
Bigger Battery + Solar	57	$21.09	7.8	$10.53	$31.62	**26.35 x**

Table 6

At the end of the day, the battery option remains an inefficient use of sacred capital in comparison to the natural gas generator alternative. By avoiding batteries, your firm will save in two ways: in terms of CapEx but also in terms of opportunity cost if an outage is longer than 114 hours, such as during Hurricane Sandy – the 1 percent of outages.

If you are interested in implementing backup energy capabilities for your firm, but you still don't know what would be best for your unique situation, Exergy Energy can help.

Save your firm the time and money by not being swept up by the current battery hype. Exergy Energy will provide you with the most cost effect resilient and green solution with not upfront investment.

To inquire about becoming resilient, green all while saving money, contact march@exergyenergy.com

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