POWERING COMMUNITY RESILIENCE:
A Framework for Optimizing Resilience Hub Power Systems

Project Report

Prepared for Urban Sustainability Directors Network

USDN urban sustainability directors network

AMERICAN MICROGRID SOLUTIONS

muGrid Analytics

www.usdn.org

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Acronyms

AC	alternating current
AMS	American Microgrid Solutions
ATS	automatic transfer switch
DC	direct current
DOE	U.S. Department of Energy
HyRS	hybrid resilience system
IRR	internal rate of return
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
LCC	life cycle cost
MACRS	modified accelerated cost recovery system
mGA	muGrid Analytics
MW	megawatt
NPV	net present value
O&M	operations and maintenance
PPA	power purchasing agreement
PV	photovoltaic
UPS	Uninterruptible Power Supply
USDN	Urban Sustainability Directors Network

Abstract & Executive Summary

Resilience Hubs are community-serving facilities augmented to support residents and coordinate resource distribution and services both under normal conditions as well as during or after a natural hazard event.

Using techno-economic analytical tools, the authors of this paper demonstrate that a Hybrid Resilient System (HyRS) is the optimal power solution to meet the unique operational, financial, environmental and social goals of a Resilience Hub. More than backup power, these systems combine renewable and conventional generation assets as well as energy storage. The authors provide a decision-making framework geared to both technical and non-technical audiences to help them select and install an appropriate HyRS for their facilities.

Executive Summary

Sites that make good Resilience Hubs are trusted and well-utilized community-serving facilities. To be successful, these facilities need to be enhanced to support residents, coordinate communication and distribute resources before, during, and after disruption. In addition to hosting supplies, communications, and resources in the event of an emergency, they should also serve community members year-round as a center for relationship-building and community revitalization.

The Urban Sustainability Directors Network (USDN) Resilience Hub initiative works at the nexus of climate mitigation, adaptation and equity to enhance and improve community sustainability and resilience through a bottom-up approach centered on community co-development and leadership.[1] Resilience Hubs, the centerpiece of this effort, are community-serving facilities augmented to support residents and coordinate resource distribution and services during or after a natural hazard event. They are not only locations for supplies, communications and resources, but also can be utilized as a mechanism for community revitalization. Resilience Hubs shift power from city government to residents and businesses within a specific neighborhood or set of neighborhoods. This includes increasing community equity and access to resources, improving community education and outreach, reducing heat island impacts and sequestering carbon by increasing green space and tree canopy, improving energy efficiency and reliability, and enhancing community members' ability to access resources and respond to hazard events. Resilience hubs shift capacity to citizens and reduce burden on city emergency response teams. When conditions are at their worst, community Resilience Hubs must be at their best and provide a full range of services even when few other community resources can. For these facilities, a reliable, continuous supply of electricity is not a luxury, but a necessity.

This Framework, commissioned by USDN, presents strategies and tools for Resilience Hub pioneers to keep the power flowing and provide mission-critical services. Solutions can range in complexity and cost from simple standby generators to intricate microgrids. Navigating the options can be daunting. However, by following a basic decision-making framework, setting appropriate goals, building a fundamental understanding of system basics and selecting the right technical partners, Resilience Hub operators can readily identify optimal solutions to their resilient power needs.

[1] Baja, Kristin. "Resilience Hubs: Shifting Power to Communities and Increasing Community Capacity," 2018. https://www.usdn.org/public/page/136/Resilience-Hubs.

Too often, the process is derailed by asking the wrong question first – how much does a solution cost? Answers can be as frustrating as they are misleading. When asked this question, one resilient power expert quipped: "What does a house cost?...Just as houses span from builder basic to celebrity mansion, [solutions] range in size and sophistication."[2] Each Resilience Hub presents a unique set of operational and financial hurdles. The roots of a successful Resilience Hub power solution lie in understanding the facility's requirements, constraints and goals.

This document presents a framework for Resilience Hub operators to define each facility's needs, evaluate potential solutions (including technology, cost and finance) and select the right partners to deploy an optimal power solution. The framework seeks solutions that are operationally effective, cost-efficient and scalable. The foundation for this solution is a clear set of operational, financial, environmental and social goals established by each Resilience Hub and the stakeholders it serves. The assumptions underlying that understanding are critical. This analysis provides Resilience Hubs operators a framework to ask the right questions, collect relevant data and make informed assumptions. These inputs then populate a model designed to select an optimized combination of generation and storage assets within each Resilience Hub's context.

A Resilience Hub's power solution must meet a robust set of operational, financial, environmental and social goals that are greater than what simple backup power solutions deliver. For the vast majority of time, Resilience Hubs operate in normal conditions with reliable power delivered from the grid. During these times, they need a power system than can provide a range of operational, financial, environmental and social benefits. During power outages, the Resilience Hub's mission shifts and operational goals (delivering continuous reliable power) take the fore. Typically, backup power strategies rely on onsite standby generators (diesel, natural gas or propane) to deliver a bare minimum of operational capability (emergency lighting, a few pumps and an elevator, for example) most often to provide safe egress. To achieve a Resilience Hub's goals in both normal conditions and during a power outage, however, these solutions are inadequate. Conventional onsite standby generation strategies have a checkered operating record in major outages. Likewise, despite the aspiration to design solar + storage systems that provide all of a facility's backup power needs during a power outage, factors such as cost, space and weather conditions often render these inadequate to provide the full measure of continuous power required by a Resilience Hub.

Instead, the optimal solution for Resilience Hub is a Hybrid Resilience System (HyRS) that includes solar photovoltaic (PV) generation, energy storage (batteries), conventional generation and other systems. HyRS creates generation diversity, offers value during normal operating conditions, and can be more economically sized to meet full operational requirements. This approach also empowers communities with energy choice and contributes to reductions in carbon emissions over time. Importantly, the HyRS is just one element of the Resilience Hub's energy strategy that should also include improvements in efficiency and reductions in demand.

From an operational standpoint, Resilience Hubs serve their communities under two basic conditions or modes: Normal Mode and Outage Mode (also called "Island Mode" as the facility becomes separated or "islanded" from the rest of the power grid). During Normal Mode, the Resilience Hub receives electricity from the local utility. With a HyRS, the Resilience Hub will generate a portion of its own electricity, offsetting a portion of what it would otherwise buy, and either store or sell back any excess to the utility.[3]

[2] Wood, Lisa. "*What does a Microgrid Cost?*" Microgrid Knowledge. (April 26, 2016). https://microgridknowledge.com/microgrid-cost/. Microgrids are similar in form and function to resilient power and Hybrid Resilience Systems, except that they serve multiple buildings at a site.

[3] "Net Metering by State" Solar Energy Industries Association. https://www.seia.org/research-resources/net-metering-state. Currently 43 states and Washington DC have Net Energy Metering (NEM) policies. As described by SEIA: "Net metering or net energy metering (NEM) allows electricity customers who wish to supply their own electricity from on-site generation to pay only for the net energy they obtain from the utility. NEM is primarily used for solar photovoltaic (PV) systems at homes and businesses (other distributed generation (DG) customers may have access as well). Since the output of a PV system may not perfectly match the on-site demand for electricity, a home or business with a PV system will export excess power to the electric grid at some times and import power from the grid at other times. The utilities bill customers only for the net electricity used during each billing period. Alternately, if a customer has produced more electricity than they have consumed, the credit for that net excess generation will be treated according to the NEM policy of the state or utility."

Under the right conditions (sufficient space, capacity, etc.) HyRS can help a Resilience Hub achieve Net Zero operations. A Resilience Hub HyRS can be expected to operate in Normal Mode more than 99.9% of the time in the Continental U.S.[4]

During Outage Mode, the Resilience Hub's HyRS generates the electricity it needs to continue operations. A Resilience Hub HyRS should be designed to serve the facility's normal operating load (potentially more) continuously during a grid outage lasting up to 72 hours. While most outages are much shorter and some much longer, for resilient solutions and anticipated impacts from climate change, this is an appropriate window to design for.

Without conducting a feasibility analysis on the site, a few rules of thumb can help identify sites that will be able to host an economically viable project. Some of those qualities are:

- A "peaky" load profile with significant spikes in demand if the site is on a rate tariff with demand charges (for more, see page xx)
- A rate tariff with time-of-use rates, favorable to time-shifting energy usage (see page xx)
- High utility rates, including demand charges, energy charges, and riders (see page yy)
- Availability of roof or nearby land area to install the required solar array[5] (see page zz)
- State incentives for renewable energy and/or battery storage (see page xx)

The HyRS Framework for Resilience Hub planners addresses key data requirements and how to collect or synthesize them. The process generally follows six steps:

1. **Select Team:** Identify Resilience Hub planning team members with the range of skills, experience and responsibilities to manage and execute the process (see p. xx).
2. **Set Goals:** Engage the team and other stakeholders to set operational, financial, environmental and social goals for the system. Establish a preliminary project budget. (see p. xx).
3. **Design System:** Collect data, analyze options and generate an optimized preliminary design (see p. xx)
4. **Finance System:** Refine the project budget, evaluate sources of funding and develop a finance strategy to fund the lifetime capital and operating costs of the system (see p. xx).
5. **Engineer & Install System:** Working with selected partners, convert the preliminary design into a fully engineered and installed solution (see p. xx)
6. **Operate & Maintain System:** Establish processes to operate and maintain the system over its lifespan (see p. xx)

A Resilience Hub HyRS is as much a process as it is a solution. Optimizing a system to meet operational, financial, environmental and social goals during both normal and outage conditions involves a series of tradeoffs based on prospective assumptions about the future. Focusing on decisions in the initial phases, this framework provides guidance for municipal governments and community-based organizations to address those decisions and assumptions. There is no one-size-fits all Resilience Hub HyRS. This analysis seeks to provide a general guidance framework and consistent approach to aid all stakeholders in prudent planning and essential dialogue.

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[4] Wirfs-Brock, Jordan J. "How Long is Your Blackout?" Inside Energy. March, 2015. http://insideenergy.org/2015/03/20/ie-questions-how-long-is-your-blackout/.

[5] Solar carports are an interesting opportunity for some Resilience Hub HyRS. However, these are limited in their production capacity by space (generally tight in most Resilience Hub sites) and component costs (particularly steel). At the outset of a project, the design team should certainly include these in the conversation.

Powering Community Resilience

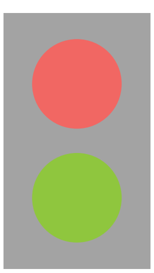
Powering Community Resilience

Resilience Hubs are community-serving facilities augmented to support residents and coordinate resource distribution and services during or after a natural hazard event. They are not only locations for supplies, communications, and resources, but also can be utilized as a mechanism for community revitalization. Resilience Hubs shift power from city government to residents and businesses within a specific neighborhood or set of neighborhoods. This can include increasing community equity and access to resources, improving community education and outreach, reducing heat island impacts and sequestering carbon by increasing green space and tree canopy, improving energy efficiency and reliability, and enhancing community members' ability to access resources and respond to hazard events. They shift capacity and power to citizens and reduce burden on city emergency response teams. When conditions are at their worst, community Resilience Hubs must be at their best and provide a full range of services even when few other community resources can. For these facilities, a constant supply of electricity that meets specific, defined goals is not a luxury, but a necessity.

The Urban Sustainability Directors Network (USDN) commissioned American Microgrid Solutions, in partnership with muGrid Analytics, to produce this Resilience Hub Hybrid Resilience Framework to help municipal agencies, community organizations and other stakeholders evaluate options and identify optimal onsite power systems that are operationally effective, cost-efficient and scalable for deployment. Project feasibility guidance will include methods to evaluate the potential of the facility to support the required equipment, available economic revenue streams and associated costs and requirements.

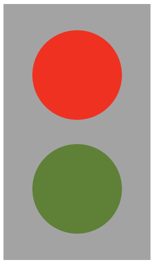
A Resilience Hub Hybrid Resilience System (HyRS) is an electric generation and storage system that typically incorporates solar photovoltaic generation (PV) with an energy storage system (batteries) and firm generation (diesel or natural gas). A Resilience Hub HyRS optimizes the combination of assets and how they are deployed to meet operational, financial, environmental and social goals of Resilience Hubs and the stakeholders they serve.

From an operational standpoint, Resilience Hubs serve their communities under two basic operating conditions: Normal (or "grid-supplied") and Outage (also called "islanded" as the facility separates or "islands" from the rest of the power grid and continues to operate).



Normal Mode: During Normal Mode the HyRS receives electricity from the local utility. With a HyRS, the Resilience Hub generates a portion of its own electricity that it either uses, stores or delivers back to the utility. When energy storage is included in the HyRS, PV also charges a battery. More than storing electricity for later use, energy storage systems provide benefits that reduce utility costs, pollution and grid inefficiency. In some regions, these systems can provide valued and compensable services to the utility grid ("ancillary services"). Several states (notably California, New York and Massachusetts) have created incentives to increase the amount of energy storage integrated with the grid.

[6] Other forms of generation and storage may be used in a Resilience Hub HyRS. However, solar PV, diesel generators and batteries tend to be the most common tools.



Outage Mode: In the event of an outage, a HyRS allows the Resilience Hub to disconnect from the grid ("island") and continue operations using a combination of the onsite PV, energy storage and standby generation. For safety reasons and as required by international electrical codes (IEEE 1547), onsite power systems must fully and completely disconnect from the utility grid to prevent back-feeding electricity onto the system and jeopardize the safety of line crews working to restore power. For older PV systems, this meant powering down completely (often to the chagrin of system owners). Modern PV systems include switching technology that can accomplish this safely and automatically. As grid power is restored, a HyRS automatically and safely reconnects to the grid and returns to normal operation.

Figure 1: Normal Grid Operation
Generator sits idle

1. Solar charges batteries
2. Solar feeds house load, then
3. Solar exports excess to grid

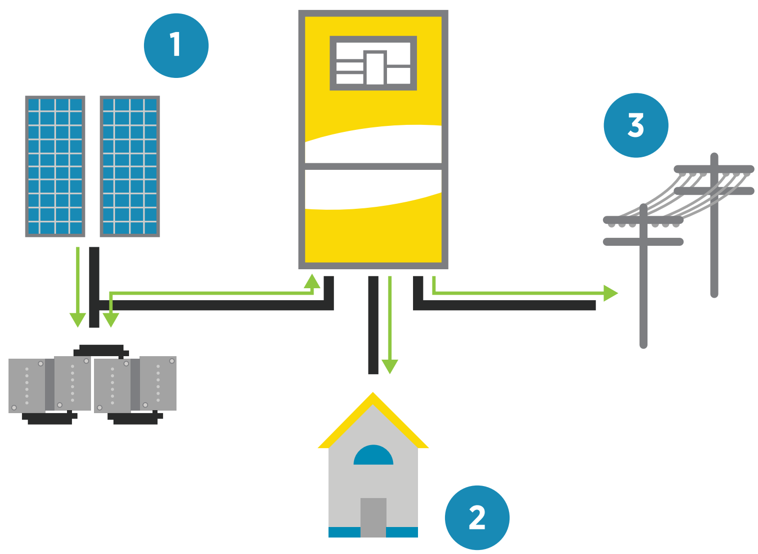
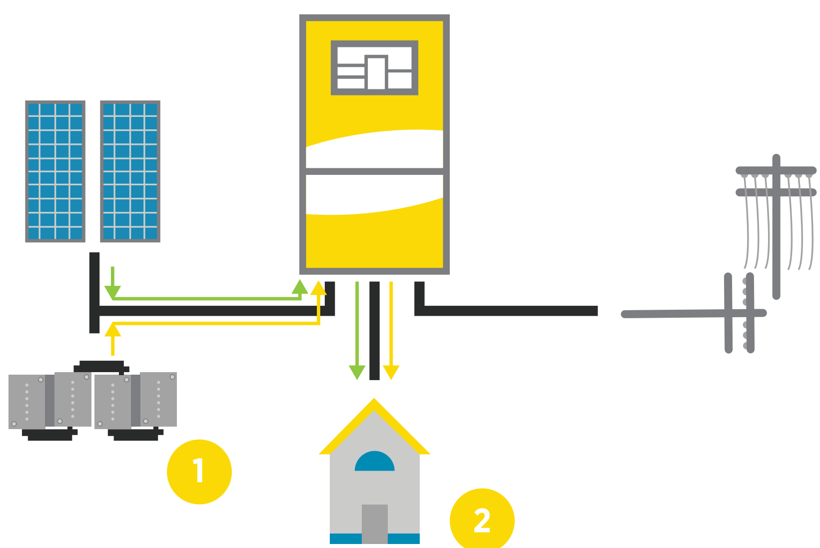


Figure 2: Grid Failure Operation
Back-up provider to all or a portion

1. Solar charges batteries
2. Solar and batteries supply house load only
3. The automatic transfer switch prevents electricity from back-feeding on to the grid

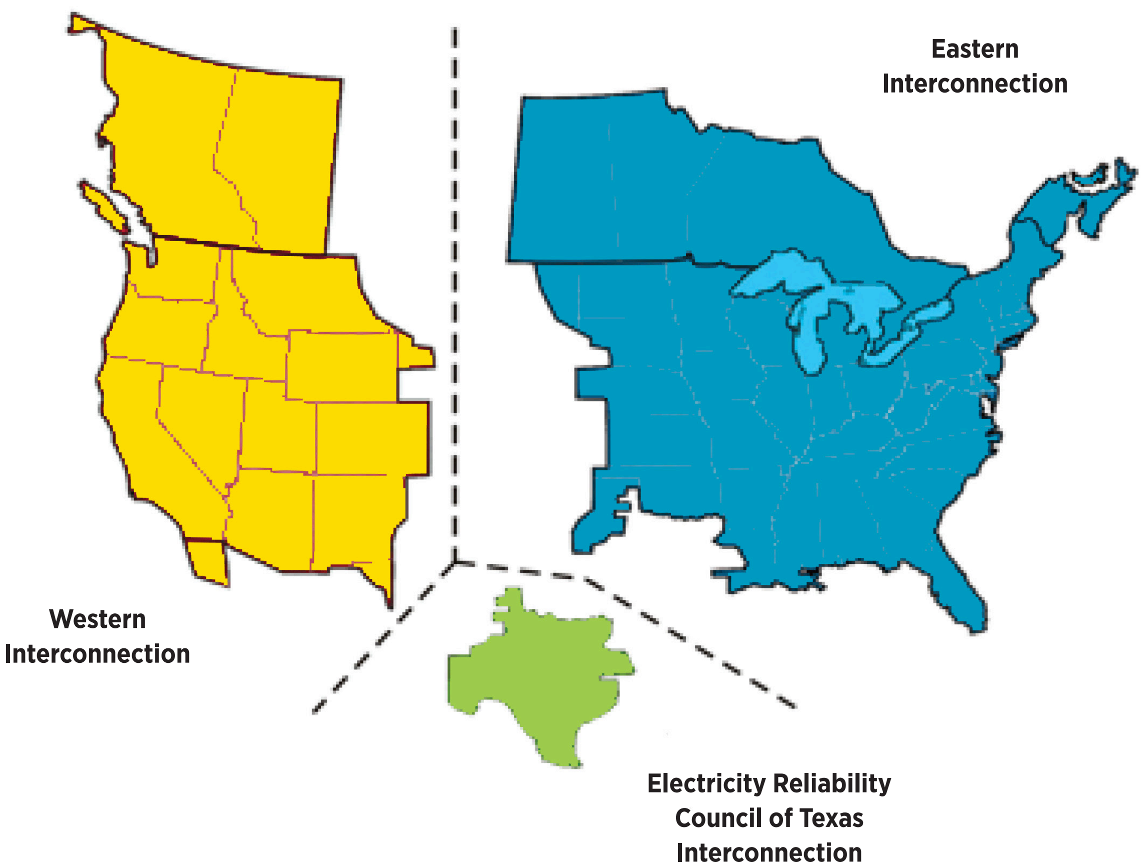


Resilient Power Considerations

Resilient Power Considerations

More than a century of investment, innovation, experience and system redundancies ensure that when the switch is flipped, the lights go on. The U.S. has three power grids: Eastern Interconnection, Western Interconnection, and Electric Reliability Council of Texas Interconnection. Each grid is made up of a high network of high voltage transmission lines to deliver at power plants that generate electricity, substations that adjust the voltage for efficient transmission, from where power is generated to where it is consumed, and local distribution networks that deliver power to homes and businesses. We take for granted our universal access to electricity in a world where 1.2 billion people still lack it.

Figure 3: North American Electric Reliability Corporation Interconnections



[6] Other forms of generation and storage may be used in a Resilience Hub HyRS. However, solar PV, diesel generators and batteries tend to be the most common tools.

Figure 4: Average electric power service interruptions per customer by utility type, 2016

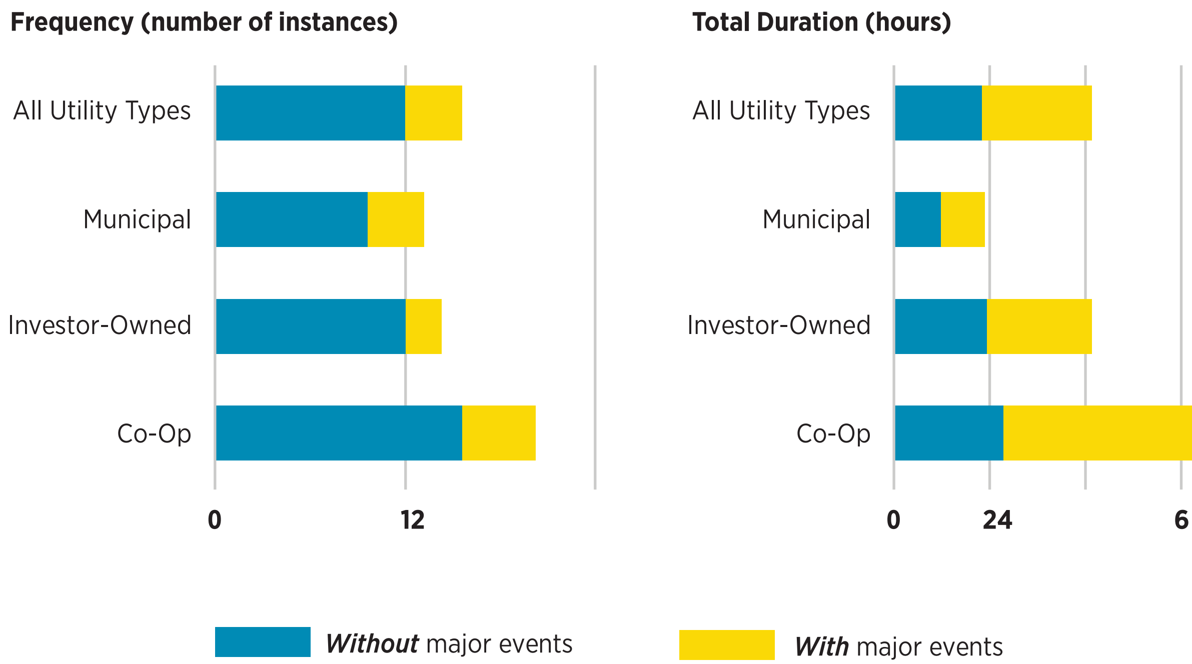
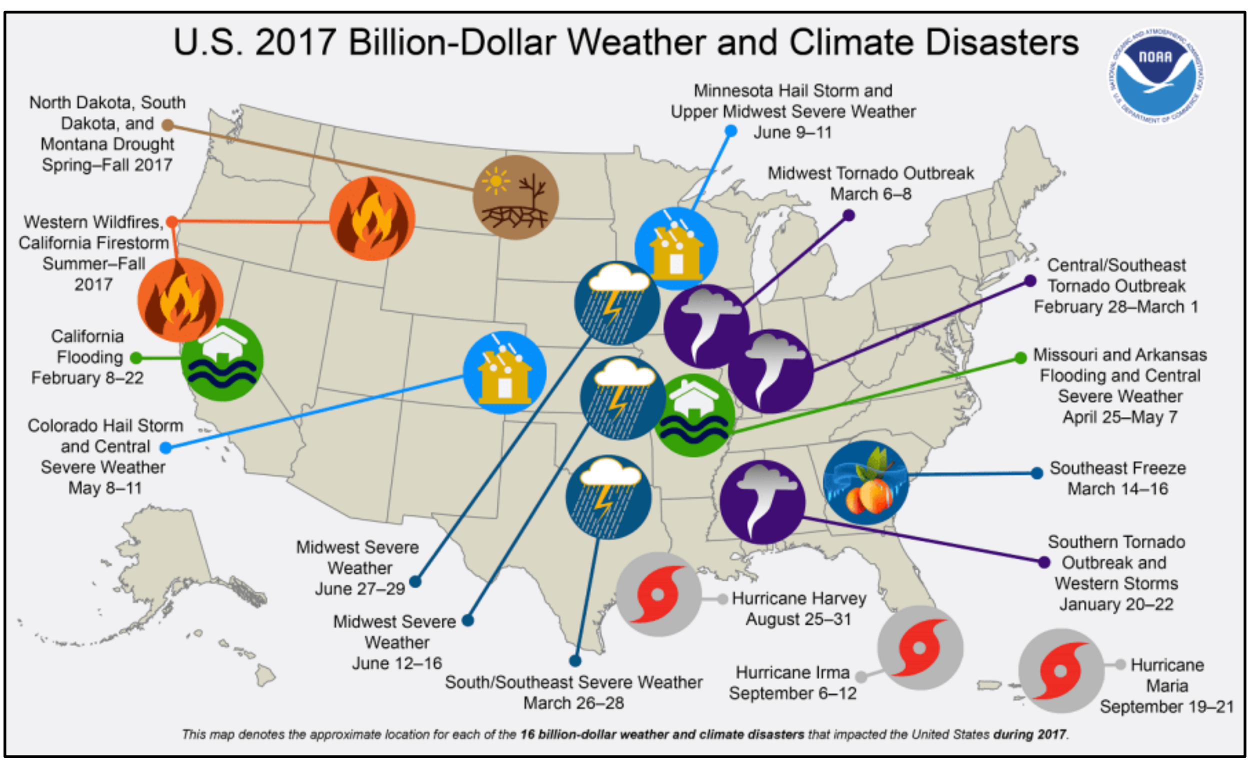


Figure 5: U.S. 2017 Billion-Dollar Weather and Climate Disasters



For all of its reliability, the U.S. power grid still experiences outages, though on average, they are rare and infrequent. In 2016, American utility customers experienced an average of 1.3 interruptions and went without power for an average of 4 hours during the year.[7] Excluding outages caused by major events, the average U.S. electricity customer experienced 1 outage lasting 112 minutes.[8] The primary concern in the United States is neither the frequency nor duration of outages on average, but the damage to local communities during high-impact events like hurricanes, forest fires, earthquakes, tornadoes and nor'easters. The majority of power outages in the U.S. are caused by disruptions in the local utility distribution systems. Threats to the system include aging infrastructure, severe weather, animals, physical and cyberattack and human error.[9]

A marvel of 19th and 20th Century engineering and development, the U.S. power Grid is showing its age. Approximately 70% of U.S. transmission lines and power transformers are more than 25 years old.[10] Aging infrastructure increases vulnerability to severe weather and large-scale outages.[11] The American Society of Civil Engineers (ASCE) gave the United States infrastructure a cumulative GPA of D+ in its quadrennial report card.[12] Most electric transmission and distribution lines were constructed in the 1950s and 1960s with a 50-year life expectancy, and the more than 640,000 miles of high-voltage transmission lines in the lower 48 states' power grids are at full capacity, according to the report.[13]

"Much of the U.S. energy system predates the turn of the 21st century," reports the ASCE. "Without greater attention to aging equipment, capacity bottlenecks, and increased demand, as well as increasing storm and climate impacts, Americans will likely experience longer and more frequent power interruptions."[14]

Our legacy power grids also grapple with the challenge of integrating generations innovations in energy efficiency, energy storage and distributed (though renewables still represent 11% of total U.S. energy consumption and about 17% of electricity generation).[15] This evolution has challenged infrastructure and regulatory structures that was never designed for customers to also be producers (as in a solar PV system).

To provide this high level of reliability, utilities oversize the grid to meet peak demand that only occurs briefly each year. A significant portion of this capacity sits idle for all but that peak consumption period. In New York, for example, approximately half the system's capacity sits idle most of the year, costing ratepayers an estimated $2 billion annually to meet peak demand during the hottest days of summer.[16]

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[7] "Average frequency and duration of electric distribution outages vary by states," Today in Energy. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=35652

[8] "Average frequency and duration of electric distribution outages vary by states," Today in Energy. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=35652

[9] "8 Common Causes of Outages," Inside Edison. Edison International. https://www.insideedison.com/stories/8-common-causes-of-outages

[10] "Large Power Transformers and the U.S. Electric Grid," Office of Electricity Delivery, U.S. Department of Energy, June, 2012. https://energy.gov/sites/prod/files/Large%20Power%20Transformer%20Study%20-%20June%202012_0.pdf

[11] https://www.infrastructurereportcard.org/cat-item/energy/

[12] https://www.infrastructurereportcard.org/americas-grades/

[13] https://www.infrastructurereportcard.org/americas-grades/

[14] https://www.infrastructurereportcard.org/americas-grades/

[15] "How much of U.S. energy consumption and electricity generation comes from renewable energy sources?" U.S. Energy Information Administration, 2018. https://www.eia.gov/tools/faqs/faq.php?id=92&t=4

[16] https://www.ny.gov/sites/ny.gov/files/atoms/files/WhitePaperREVMarch2016.pdf

While for most of us, a power outage is an inconvenience, various studies have demonstrated significant financial, environmental and social impacts. By one estimate, a 16-hour electrical service interruption can cost about $32.40 for residential customers, $9,055 for small commercial and industrial customers and $165,482 for medium to large commercial and industrial customers.[17] In 2016, Talari Networks surveyed more than 400 IT professionals and estimated the cost of outage in the data industry at more than $9,000 per minute, with larger enterprises losing tens of millions of dollars every hour networks are down.[18] Nine out of 10 large corporations reported that they had experienced at least one network outage in the 2016, and 69 percent endured two or more — with some 60 percent of network outages lasting more than an hour.[19] Annual monetary damages resulting from power outages, surges and spikes are estimated to cost more than $150 billion to the U.S. economy in 2016.[20]

Beyond the direct financial impacts of power outages, social and environmental impacts, while challenging to quantify, can have far more direct and devastating impact on communities. Multiple studies have shown these impacts to include reduced access to medical care, disease, carbon monoxide poisoning and mortality.[21] According to the Federal Emergency Management Agency (FEMA), almost 40 percent of small businesses never reopen their doors after a disaster.[22] Those hit the hardest tend to be low-income communities that lack the financial resilience to bounce back. Residents tend to be less mobile and forced to shelter-in-place during events and unable to relocate after.

Electric infrastructure is not alone in its vulnerability to outages. As the 2015 Aliso Canyon gas leak in California demonstrated, the natural gas system faces threats and challenges as well. The leak cost nearly $1 billion (costs are still mounting from lawsuits)[23] and has been estimated to have a larger impact (in terms of carbon emissions to the atmosphere) than the Deepwater Horizon oil leak in the Gulf of Mexico.[24]

Resilience

Resilience, as used in this framework, is the ability to anticipate, accommodate and positively adapt to or thrive amidst changing climate conditions, while enhancing quality of life, reliable systems, economic vitality and conservation of resources. Resilience differs by setting, facility and community. While a temporary outage for a single-family home may be little more than a nuisance, mere seconds can have devastating impacts for a data center. A facility that provides support, capacity, and connectivity to a neighborhood year-round and additionally provides critical services in the event of an emergency, is a critical facility. Thus, Resilience Hubs are critical physical and social infrastructure. "Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events, according to the US Department of Homeland Security. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event."[25]

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[17] "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States," Lawrence Berkley Labs, https://emp.lbl.gov/sites/all/files/value-of-service-reliability-final.pdf.pdf

[18] https://switchon.eaton.com/blackout-tracker

[19] https://switchon.eaton.com/blackout-tracker

[20] https://switchon.eaton.com/blackout-tracker

[21] http://currents.plos.org/disasters/article/power-outages-extreme-events-and-health-a-systematic-review-of-the-literature-from-2011-2012/#ref29

[22] https://www.fema.gov/media-library/assets/documents/108451

[23] https://www.scpr.org/news/2018/05/07/82879/the-cost-of-the-porter-ranch-gas-leak-is-closing-i/

[24] Walker, Tim. "California methane gas leak 'more damaging than Deepwater Horizon disaster," Independent. January 2, 2016. https://www.independent.co.uk/news/world/americas/california-methane-gas-leak-more-damaging-than-deepwater-horizon-disaster-a6794251.html

[25] A Framework for Establishing Critical Infrastructure Resilience Goals, Final Report and Recommendations by the Council October 19, 2010. https://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf

Resilient Power

The Clean Energy Group, a non-profit specializing in energy issues for low-income communities defines Resilient Power as the ability not only to provide critical power to essential facilities and services during a power outage, but also to provide economic benefits throughout the year, by reducing power bills and generating revenue through providing services to utilities and grid operators.

While Resilient Power systems like the Resilience Hub HyRS can provide benefits in both operational conditions, integrating the systems into existing power architectures (both within the buildings they operate and the local distribution utility) often creates conflicting design challenges pitting resilience during outages against economics during normal operating conditions and sustainability. As a broad example, one can design a Resilient Power solution that provides no economic benefit during Normal Mode, but nearly perfect resilience during Outage Mode. Likewise, one can provide a Net Zero system to provide 100% renewable energy during Normal Mode, but which cannot reliably sustain operations during Outage Mode. This conflict is more pronounced when retrofitting resilient power solutions into facilities that were not designed to support them.

Hybrid Resilient Power Technology

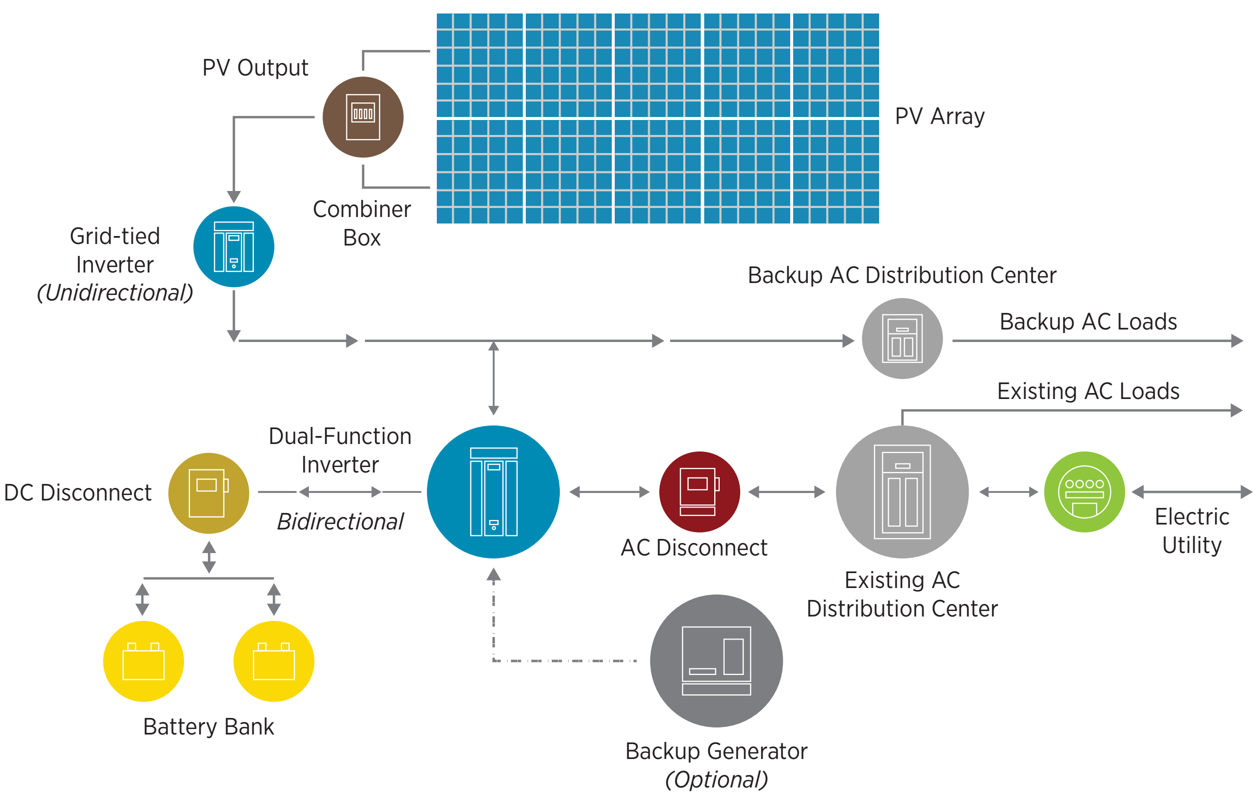
Hybrid Resilient Power Technology

A Resilience Hub HyRS includes a wide range of components beyond generators and batteries. Familiarity with these components and their fundamental architecture are important as the Resilience Hub team considers a HyRS strategy. The power grid delivers alternating current or AC power and most appliances use AC power. However, solar photovoltaic generators (PV) and batteries produce direct current or DC power. Prior to being used for the appliances and systems in a building, power from PV and batteries must be converted to AC power using an inverter and, in the case of the battery, must be able to convert AC power back to DC for the purpose of charging.

Solar and battery components can be coupled in either a DC or AC format. In general, DC-coupled systems have a lower overall cost because they more efficiently pair solar and storage.

Inverters are designed as either off-grid (can only be used in off-grid settings), dual-use (also called “bi-directional” and can be used for off-grid or on-grid) or grid-tied (can only be used in on-grid settings). Bi-directional inverters employ control software that dictate whether to connect to or isolate from the grid, when to charge batteries and a range of other features. Designing a solar PV system for one function and then later trying to modify for others can involve additional cost in either replacing installed equipment or adding more complex solutions.[26]

Figure 6. Typical AC-Coupled PV Grid-Tied System with Battery Backup



[26] For an excellent overview of the basic components of Resilient Power Systems, visit https://nysolarmap.com/media/1451/dechardwarefactsheet.pdf. Sustainable CUNY of the City University of New York is the lead implementer of NYSolar Smart DG Hub in partnership with Meister Consultants Group and the National Renewable Energy Laboratory. Their factsheets are among the best high-level explanations of Resilient Power solutions.

In an AC-coupled solution, additional components are required to couple battery and solar. This solution is typical when storage is later added to existing solar. Integrating generators into either DC or AC coupled systems is feasible. However, coupling PV and diesel without storage is complex and not recommended. As solar PV technology developed, system owners were often surprised to learn that their PV system could not provide backup power in emergencies. To protect utility line workers during power outages, solar PV systems had to be completely isolated from the grid to prevent feeding electricity back onto lines that are assumed to be "dead."

In early systems, isolation switching was too expensive for most residential systems. In most systems today, however, inverters include features to automatically isolate from the grid, but continue to provide power to the building until power is restored.

Solar PV

A solar PV system converts energy from the sun into energy to power appliances, buildings and the grid.

- **Capacity:** The "size" of a solar PV system is commonly described in kilowatts of direct current power (kWDC) measuring the peak instantaneous output. This is a measure of power, not energy.
- **Production:** The output of a solar PV system over time is described in the kilowatt hours (kWh) of electricity it generates over time (typically one year).

An increasing number of modelling tools are available to help model and design solar PV systems. Two commonly used are Helioscope and the National Renewable Energy Laboratory's (NREL) PVwatts. These tools allow designers to estimate the production from the solar arrays given available roof or land areas. Each model can be adjusted to select different features (premium panels, angle of the system, tilt of the system, etc.).

While these tools allow users to develop a general sense of what a PV system might produce, these outputs are general. Actual design and output will be impacted by site conditions, regulatory restrictions and utility tariffs. Regardless of the modeling system used, an experienced designer with detailed knowledge of tariffs and other regulations is essential to achieving a more accurate model.

- **Racking:** One the key considerations for siting solar is where and how the panels will be mounted. Ground mounted systems are set at ground level and mounted on steel racks. Canopy systems are set on elevated racks, usually above a parking lot or similar area. Roof-mounted systems are set on top of a building. Within each of these are a range of design, material and feature options each with its own cost and performance considerations. Solar arrays can be fixed (pointed in the same direction all year long) or tracking (moveable to track the orientation of the sun).
- **Space Requirements:** As PV systems become more efficient, they generate more power from smaller footprints. For ground-mounted systems, the ratio is approximately 1,000 kWDC per 5-6 acres. For roof-mount systems, 100kW per 100 square feet. Many factors (including racking, tilt, panel efficiency, etc.) can alter these.
- **Inverters:** Inverters will be one of the most important components in the Resilient Power systems. Inverters convert the DC output of solar panels to the AC power for use. Inverters used in HyRS must also synchronize with the power grid and automatically disconnect during a grid outage.
- **Balance of System:** A solar PV system includes a variety of other components (meters, wiring, transformers, etc.) typically lumped into the category of "Balance of System."

[27] TBD

- **Project Lifespan:** Solar PV systems have minimal moving parts and thus have demonstrated long operating lives (in excess of 30 years in some cases). Most analyses will use a 20- or 25-year lifespan, however inverters typically require replacement during the project lifespan. Most systems experience some level of degradation over time with standard assumptions that the output of the PV system degrades by 0.5% per year.

- **Cost Considerations:** PV systems incur both capital and operating costs. The upfront capital cost is typically described in dollars per watt of capacity (for example, $3.50 per watt). Close attention must be paid to what is included in the described "cost" of the system during any conversation. The cost may only include materials, the cost of the materials and the labor to install them, or a "turnkey" cost that includes all of the permitting and legal work ("soft costs") and other costs beyond the system materials. Even this may not include roof upgrades and other structural work required. PV systems have future costs (the replacement of inverters, for example) that may or may not be included as part of the estimated operating and maintenance expenses that should be considered as well.

  Cost will vary significantly from project to project and region to region. Key drivers of those variances include not just components, but constructability issues (complexity of racking systems, structural improvements to be made to the roof), and labor costs and wage rates. Smaller projects will have a higher cost per watt as the impact of fixed costs (site costs, permitting, etc.) have a much larger bearing on the overall cost. In some of the cases evaluated, PV costs were estimated at as much as twice this rate.

- **Operations & Maintenance Expense:** PV systems require regular maintenance over the lifespan of the asset.

Energy Storage Systems

Though energy storage pre-dates the power grid, the availability of affordable, large-scale systems (from residential to utility scale) has been a significant change in the market in the past decade. Energy storage encompasses more than just batteries. All manner of technologies can be used to store energy including pumping water into a tank, using the momentum of a flywheel or releasing compressed air. However, for the Resilience Hub HyRS these solutions tend to be impractical due to space and cost constraints. This study focuses on battery storage. While building- and grid-scale battery systems are still not common, the market is growing and projected to be a $2.5 billion market in the United States by 2020.[28]

Batteries produce electricity using an electrochemical reaction between the positive terminal (cathode) and negative terminal (anode) when connected by an external circuit. The anode releases electrons that travel along the circuit (and through any device like a light or a motor attached to the circuit) before reaching the cathode.

- **Components:** As used in HyRS, battery systems require several components including the battery cells, inverter (to convert the battery's DC power to AC and that allows the battery to be charged from the grid), a charge controller (to prevent the battery from overcharging) and a battery management system. The size and complexity of the system will dictate its footprint. However, for a HyRS, the size of the battery system will generally range from a few suitcase sized boxes to the size of several refrigerators. Larger systems (typically up to the size of small shipping container occupying a parking spot) are possible, though not common for Resilience Hubs.

- **Chemistry:** Batteries are often defined by the chemistry they use. Lead-acid batteries, like those in most cars, are often used in off-grid HyRS because they have low cost and can sit idle for longer periods of time between use than other chemistries. However, they lack the energy density and

[28] https://www.energysage.com/solar/solar-energy-storage/how-do-solar-batteries-work/

ability to charge and discharge as often throughout their lives as other systems. Lithium-ion batteries (like those in smartphones) are relatively light, have high energy density and the chemistry of choice for most grid-tied storage applications. They are, however, typically more expensive than lead acid. Recent improvements in flow batteries (batteries where the electrolytes are stored in tanks that can be easily refilled making them appealing from a safety standpoint) increasingly make them worth considering in resilient power applications.

Resilience Hub planners should remember that they are selecting an energy storage system as part of an overall power system, not a battery. Questions of chemistry and other technical details will be managed by the engineers and solutions providers selected to deliver the project. However, a general understanding of the components and their functions is useful.

- **Sizing:** Battery energy storage systems are sized based on the power and energy required. The power rating (measured in kW) is the amount of power that the battery can deliver instantaneously. The energy capacity (measured kWh) is the amount of energy that the battery can store. As an example, a battery may be rated for 100 kW of power and 400 kWh of energy. This would mean that the battery can deliver a maximum of 100 kW of power and has enough capacity to do so for four hours. The optimal power-to-energy ratio can vary based on the application that the battery is expected to serve. Frequency response applications where the battery owner receives compensation for using the battery to support power grid operations may use a 15-minute battery since they generally charge and discharge the entire battery very quickly. Peak shaving (using the battery to reduce utility charges for periods of high demand) often uses 2- or 4-hour duration batteries since they need to deliver modest amounts of power over longer time frames.
- **Lifespan:** Batteries typically have a lifespan between 5 and 15 years and require proper maintenance. Likewise, they must be protected from fluctuations in temperature.
- **Cycling:** The amount of a battery's capacity that can be used each re-charge cycle ("Depth of Discharge") and the number of times it may be charged and discharged or cycled over its lifetime ("Cycle Life") are important metrics when evaluating systems.
- **Costs:** Battery costs are falling rapidly and are generally forecast to continue to decline over the next several years. Typically, battery pricing is expressed as a combination of a cost per kilowatt of power and for each kilowatt hour of capacity. Depending on the project and the vendor, this may be a "turnkey" price (all costs, including installation, are included) or may exclude the cost of installation, finance and other "soft costs." Just as with the solar PV, it's important to understand what is included in the cost estimates provided by battery system solution providers. Likewise, be careful not to put too fine a point on cost estimates provided prior to detailed analysis, site surveys and preliminary engineering. Rough order magnitude (ROM) estimates may be useful in creating a ballpark estimate, but they can be misleading as to the precise costs. Rather, those estimates should be considered to fall in a range of potential costs. For example, a recent sample of projects produced energy storage system pricing from $800 to more than $1,400 per kW and $250 to $1000 per kWh. These systems ranged from modular components from major manufacturers intended primarily for mass residential markets to customized systems from specialized manufacturers for one-off projects. Prices are heavily volume driven and then the installation and BOS prices are heavily site specific. Resilience Hub HyRS often find themselves in the middle ground between small, residential projects and much larger commercial projects. This creates challenges in design, operation and cost that can lead to higher costs.

  For the purpose of illustration, the scale of the facilities included in this Framework assumes a typical cost range of $800-$1200/kW and $500/kWh and uses a default model assumption of $400/kWh and $1000/kW with round-trip efficiency of 85%. Maintenance costs will vary with the system as well, but are often in the range of $3 per rated kilowatt of capacity per year.

- **Uninterruptible Power Supply (UPS):** A Resilience Hub HyRS may also incorporate an Uninterruptible Power Supply (UPS) for appliances that are very sensitive to even minute fluctuations in power supply. UPS systems are available for computer servers and other equipment. Depending on its size, integrating a UPS system with a Resilient Power system can be challenging.

Generators

Backup or standby generation usually comes in the form of a diesel, propane or natural gas-fired generator that automatically start in an outage. These systems convert fuel to electricity by using an internal combustion engine to spin a generator that produces electricity. These systems are typically housed outdoors in rectangular boxes. Backup generation incorporates automatic transfer switches to ensure that they do not feed electricity back onto the utility's distribution lines during a power outage. A diesel system will require an external fuel tank while natural gas systems are fueled by the local gas utility's distribution lines. Energy storage in these systems is largely limited to fuel tank capacity. Some generator manufacturers have begun entering the hybrid power market with complete solutions that include solar, storage and generators.

- **Output:** Generators are designed to provide either single-phase (residential and small commercial) or three-phase power (larger commercial) to meet the same configuration as provided by regular utility service. This information is typically included on a utility bill and will be readily recognized by an electrician.

- **Size:** Generators are classed by their generation capacity in kilovolt amps (kVA) and kilowatts (kW). While related, these measures are not the same.

- **Fuel:** Choice of fuel will be a matter of preference and availability. Natural gas is available via pipeline where local distribution networks exist. Diesel is readily available in most location, but system operations is limited size of the fuel tank. Propane will be stored in a tank as well. Fuel considerations should be part of both the goal-setting process (availability of fuel supply during a major event, capital costs of various systems).

- **Cost:** The capital cost of generators is relatively modest for the amount of backup power they can provide. Systems will incur regular fuel and maintenance costs as well.

- **Space:** Depending on the size of the service and the required fuel storage, the footprint of a generator may be as small as a drink cooler or as large as garage. Typically, however, for Resilience Hubs of the size included in these case studies, units will be closer in size refrigerator turned on its side and enclosed in a sound-attenuated cabinet.

- **Performance Considerations:** As a backup power supply, firm generation seems like a simple fix. However, as a resilience measure, in both Normal and Outage conditions, generators have significant limitations that Resilience Hub should consider before using them as the only source of resilience.

- **Reliability:** Historically, generator performance during large scale outages is checkered. Aside from periodic exercises and maintenance, most diesel generators lie idle until an outage occurs. If not properly maintained, they can fail when called upon to support full building loads or operate for extended periods. Likewise, generators (or their components) installed below flood levels can become inundated and fail as they did during Hurricanes Katrina, Rita and Sandy. Common causes of failure include fuel contamination, failures with starter batteries and cooling system failures.[29]

- **Fuel Supply Issues:** Standby generators represent single points of failure reliant on a ready supply of fuel, which may be unavailable during an extreme event. During a sustained grid outage, accessing diesel supply can be a challenge. This is particularly true in emergency situations when

[29] https://www.power-eng.com/articles/print/volume-111/issue-8/departments/dg-update/diesel-generator-failures-lessons-taught-by-hurricanes.html

demand for fuel spikes. Flooding, downed trees, and damage to roadways might prevent the delivery of fuel to locations where it is needed. In the case of Hurricanes Irma and Maria, for example, resupplying fuel to the Caribbean islands can take days to weeks. Also, there are competing uses for limited supplies of diesel fuel during disasters because fuel is used for transportation too.

- **Limited Capacity:** Standby generators are typically designed to meet critical loads established by regulation, such as the National Fire Protection Association Life Safety Code as implemented in local jurisdictions. Many prospective Resilience Hub sites have incumbent generation to meet requirements for safe egress during an emergency and nothing more. This, of course, is significantly insufficient to the mission of a Resilience Hub.
- **Limited Economic Return:** From an economic standpoint, standby generators provide little value except during an emergency. With few exceptions, they cannot be used to provide the ongoing revenue streams and offset to expenses that battery and solar can.[30]
- **Related Costs:** Generator cost is more than simply the unit itself. Installation may require a considerable amount of site work for proper pads (elevation), transformers, floodproofing, anchoring, tanks and interconnection equipment. This is particularly challenging when retrofitting a generator into an existing facility where space is tight.
- **Operational Expertise:** Standby generators require experienced operators who can monitor, service and maintain them during extended operations. In Puerto Rico following Hurricane Maria, hospitals reported an elevated incidence of emergency room admissions for people suffering from burns or smoke inhalation due to inexperienced generator operation.

  Alternative standby generation strategies are available as well. Some generator suppliers offer leased services where a generator may be delivered to a site only when needed. This solution, while it reduces initial capital costs, includes challenges. The ability to access a generator when road conditions are marginal is problematic. High demand may cause supply issues as well. Further, proper generator operation requires experience and may require dedicated staff, even for the units brought in on a leased basis.

  Unlike traditional generators, PV and battery energy storage systems can operate in grid-connected mode and provide value when the grid is operating normally through regular monthly electric bill savings to system owners.[31] Because PV systems are used regularly, they are likely to be operational when called upon in an emergency (with the required islanding capabilities). PV and battery energy storage can provide power for an extended period, when there is enough solar resource to continue charging the batteries, without operators on hand.[32]
- **Control Systems:** Coordinating the operations between the various sources of power (utility grid, solar PV, battery, generators) becomes increasingly complex with multiple assets. Backup power is straightforward – when the system perceives a loss of power from the utility it separates from the grid and starts up. Dispatching various forms of generation (and the two-way flow of a battery) is more complex.

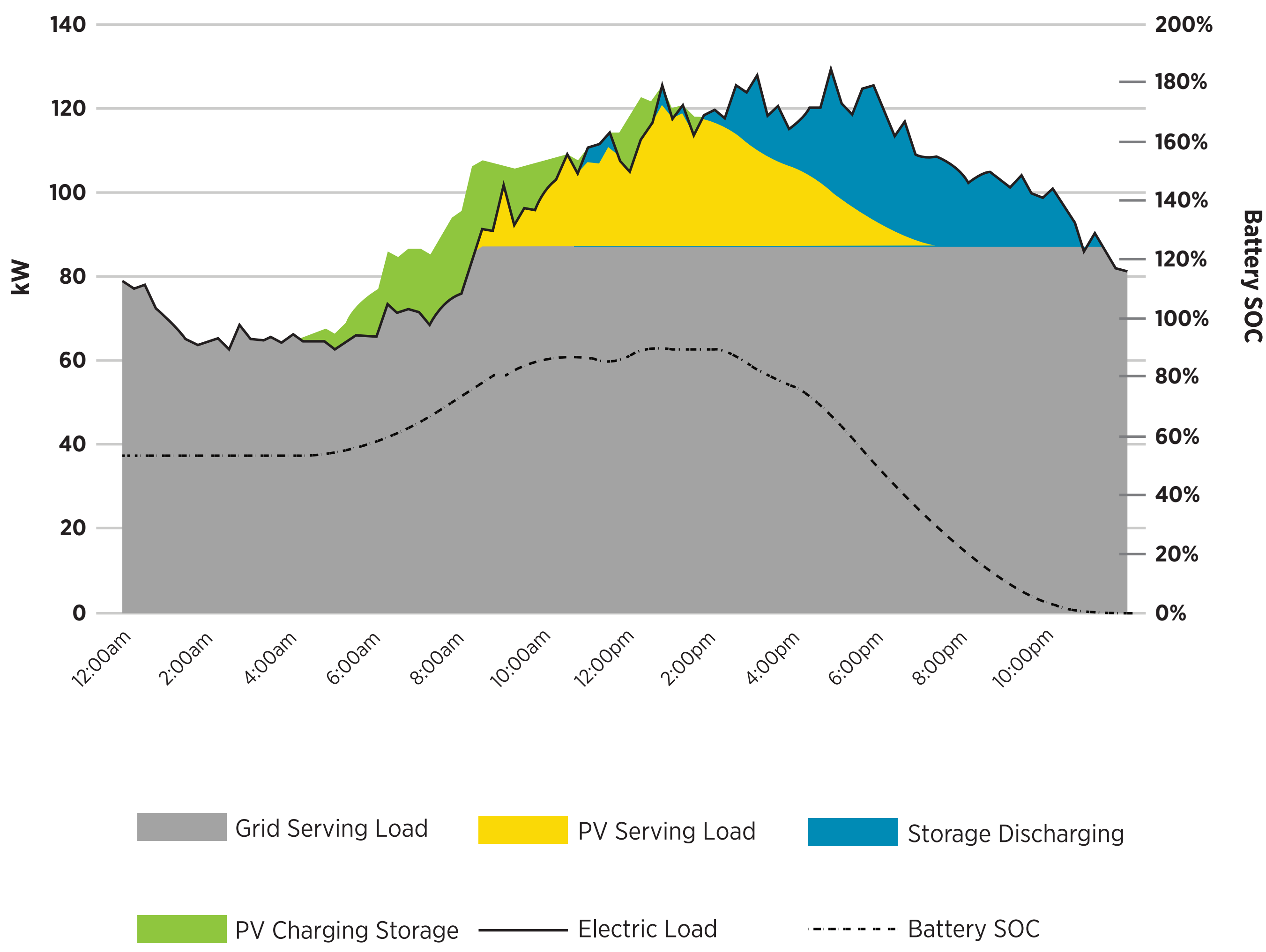
[30] At a certain scale (that is growing increasingly smaller with new technology), generators incorporated into building operations can provide some economic benefit normal operations. Combined heat and power systems, for example, maximize the use of waste heat to provide hot water. Some utilities have programs to compensate owners of onsite generation for their ability to island from the grid during peak consumption periods. Of course, these benefits are offset by additional cost and emissions.

[31] In some locations, there is also the potential to generate additional revenue by providing valuable grid services such as frequency regulation or by participating in utility programs such as demand response.

[32] https://www.cleanegroup.org/wp-content/uploads/Valuing-Resilience.pdf

Figure 7. Daily dispatch strategy of Case 1 solar + storage system

Sample dispatch strategy for a single day using the optimal system outlined above in a grid-connected case. During the day, a combination of solar and battery storage limits peak demand from the grid thus minimizing demand charges. When extra solar production is available above the demand target, it is used to charge the battery.



Source: MI Grid Analytics

Resilience Hub HyRS Framework

Resilience Hub HyRS Framework

A Resilience Hub HyRS is as much a process as it is a solution. Optimizing a system to meet operational, financial, environmental and social goals during both normal and outage conditions involves a series of tradeoffs based on prospective assumptions about the future. This Framework provides guidance for municipal governments and community-based organizations to address those decisions and assumptions. There is no one-size-fits all Resilience Hub HyRS. This analysis seeks to provide a general guidance framework and consistent approach to aid all stakeholders in prudent planning and essential dialogue.

Step 1: Select Team

While HyRS can provide benefits like power during grid outages or reducing utility bills, many customers are challenged to deploy them because of their complexity and capital costs. These projects involve an intricate set of engineering, legal and finance challenges. Project design requires expertise in structural, electrical, mechanical and environmental engineering. To minimize cost and maximize incentives, projects may require significant legal tools and agreements among suppliers, contractors, utilities, regulators, third-party financiers and landholders. Resilience Hub teams should recruit the necessary experts to navigate these.

Key skills on the team should include project management, engineering, operations, finance, community resilience and construction. Decisionmakers in the area of finance and operations are critical. If they are not involved from the start, a significant amount of time and energy can be wasted preparing plans that cannot get off the ground. Team members should include a combination of stakeholders both from within the organization and outside subject experts.

The team should also include external subject matter experts in the areas of power engineering, resilient power or similar fields. Be aware, however, of the biases that they may bring toward particular products or solutions. Not all experts are objective, and some will champion a preferred design approach or system. Make sure the planning team's goals are aligned as there is no single "right answer" in designing a Resilience Hub HyRS.

Checklist: Select Team

- [ ] Recruit Internal Resources
    - Finance
    - Senior Management
    - Board of Directors
    - Community Stakeholders
    - Facility Operations & Management
- [ ] Recruit Subject Matter Experts
    - Project Management
    - Mechanical, Electrical, Plumbing, Engineering
    - Distributed Generation and Storage
    - Power Engineering
- [ ] Check state and national organizations specializing in Resilience and Resilient Power
- [ ] Check that team members are experienced in and committed to resilient power

Step 2: Set Goals

Establishing clear goals for the Resilience Hub HyRS is critical. We address goals in four areas: operational, financial, environmental and social.

Checklist: Set Goals

- ☐ Select goals for both Normal and Outage modes.
- ☐ Select Operational Goals.
- ☐ Select Financial Goals.
- ☐ Select Sustainability Goals.
- ☐ Select Social Goals.

Operational Goals

These include basic measures like outage duration, critical load, as well as human considerations such as ease of operations and maintenance, availability of fuel supply, preferred level of redundancy.

Critical Load

Critical loads vary from building to building but typically include those systems (lighting, heating, pumps, etc.) and appliances (computers, lamps, refrigerators, etc.) either the building operator and/or relevant regulations deem essential for operations during a power outage. An effective resilient power solution identifies these loads specifically, prioritizes them, and considers the best set of tools to support them. In some cases, they are powered by standby generation (a generator to power lights and elevators to meet Life Safety code, for example). In other cases, they may be powered by load-specific storage which is comprised of an uninterruptible power supply, or "UPS" battery on a critical computer server.

- **Load Management Strategies:** An effective Resilient Power solution considers not only all of the generation and storage assets in a building, but also load-management strategies. A load management strategy prioritizes the various equipment and settings a building will use during a power outage to utilize the least possible power. Load management systems may be as simple as having a plan to manually shut down non-critical loads or may be automated with building management systems. Resilience Hubs will typically lack this level of automation and control. Instead Resilience Hub operators should create a load management checklist for the facility and practice implementing it.

- **Estimating Critical Load:** From a modeling standpoint, the simplest method to estimate critical load is to estimate it as a percentage of the nominal load - typically around 15% of the nominal load.[33] After determining the critical load percentage, multiply it by the load at each of the time intervals available in the nominal profile. It is best to model the outage case during selected days in the summer to catch the "worst case" loads.[34] While an easy method to use, this is not the most precise.

- **Measuring Critical Load:** A more precise measure requires collecting data in a critical load study by recording the peak demand of all power consuming equipment and adds its consumption up to determine a critical load. This may be desirable if the loads from these consumers are relatively constant and not variable (e.g. residents who come home and turn their lights on at random times). Resilience Hubs face the challenge that while most facilities reduce power consumption during outages, a Resilience Hub may increase or at least sustain normal usage. After all, the mission of the Resilience Hub is to provide service and support to members of the surrounding community during

[33] While critical load varies significantly by the type of buildings, a recent study in San Francisco suggested a rough average of 11% of total nominal load.

[34] In general, peak periods are regionally specific. The Mid-Atlantic, for example, has two peaks each year, a winter and a summer peak. Southern climates favor a summer peak when air conditioners are running at their maximum and people stay indoors. Events like the Polar Vortex where cold temperatures and high winds drain buildings of heat can drive a winter peak. However, summer peaks typically prove the most severe in the regions for which we evaluated Resilience Hubs.

an outage. As nearby residents pour in to access supplies, seek to escape the extreme heat or cold, charge cell phones, and/or interact with one another, and additional staff and volunteers work in the facility, a Resilience Hub may require more power and consume more energy than during normal daily operations. Heating and cooling systems may be used harder than normal. Resilience Hub operators may want to consider the demand that community members will place to charge cell phones and plug in other appliances relative to normally light or intermittent daily use in Normal Mode. In at least one potential Resilience Hub, consideration has been given to building an external set of outlets for temporary charging. Another potential site is evaluating the use of solar-powered cell phone chargers.

Outage Duration

The second parameter needed to determine resilience performance is the anticipated duration a Hub may need to operate in Outage Mode. To address this concern, it is important to ask how many hours the site will need to operate (serving its critical loads) before the grid power is restored. This parameter is a critical issue when fuel and battery storage are involved. When solar is part of the HyRS, the site will receive intermittent power during daylight hours that varies across each day and seasonally. While some weather clears quickly (thunderstorm or tornado), other storms (hurricane, nor'easter, blizzard) may have prolonged overcast conditions that reduce solar productivity. Earthquakes and other structural damage can last much longer.Systems that use generation powered by conventional fuels, like diesel, (sometimes called "firm generation" because it provides power regardless of weather condition) can be challenged by fuel storage or ongoing deliveries during an extended outage. When firm generation uses natural gas from pipeline sources, operation is again grid-dependent (natural gas is delivered across a network of underground pipes), but assumed to be more reliable than the power grid.[35] Again, a HyRS using renewable and firm generation provides a more robust solution.

Financial Goals

All systems have costs and most sources of capital (even internal) have certain financial performance requirements (payback period, return on investment, budget, etc.). Understanding and establishing these early is critical. Typical goals include meeting a defined budget (both capital and operating) and may include simple payback period (the amount of time it takes for savings and revenue generated from the HyRS to offset the initial capital cost). While helpful, these paint only part of the picture. Taking a life cycle cost approach is better. Life cycle costs consider not just the initial capital cost of the equipment, but also all capital costs of future equipment replacements, fuel costs, operating costs, incentives, tax benefits, resilience requirements and other parameters and assumptions. Net Present Value (NPV) and Internal Rate of Return (IRR) are often used to evaluate similar scenarios. Net present value (NPV) measures the value in today's dollars of a series of future cash flows (revenue and expense) created by the system. The IRR compares various NPV scenarios to one another in an apples-to-apples comparison. Project sponsors may have a hurdle rate or required rate of return that they expect the project to achieve.

Environmental Goals

Resilience Hub HyRS provide benefits to the facility, local stakeholders and broader community. Resilience Hub planners may seek a system that will help their facility achieve net-zero operations (where energy produced onsite offsets energy consumed over the course of each year). Using the HyRS battery system for peak shaving helps reduce the need for the grid to bring on additional power plants. Expanding the number of facilities with solar PV (and the variety of use cases) helps expand the industry.

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[35] This is not always the case. During Hurricane Sandy, natural gas lines were inundated with salt water from storm surge in some areas that compromised their ability to deliver. Distribution system failures can occur (natural gas is delivered through an extensive set of pipelines that then deliver to a local distribution system at a gate station). And, in severe cold, demand on the pipeline can strain the ability to deliver at required pressure. However, these are rare cases and thus we treat natural gas a firm supply for the purpose of this analysis.

Social Goals

A Resilience Hub provides a wide range of benefits to the community it serves. The Resilience Hub HyRS contributes to these values both directly (by supporting Resilience Hub operations) and indirectly by furthering goals like localized control of energy decisions and workforce development.

Sample Goal-Setting Framework for Resilience Hub HyRS

MODE	OPERATIONAL	FINANCIAL	ENVIRONMENTAL	SOCIAL
Normal Mode	Provide continuous reliable power Provide high quality power (no dips, sags, brownouts, flickers) Produce sufficient power to serve all load	Reduce utility bills Achieve simple payback requirement Maximize net present value Meet investor return requirements	Reduce carbon emissions from generating and delivering energy to serve facility Achieve net zero operations for the facility	Energy control Increase local–energy equity Demonstrate new technologies to speed market adoption Stimulate increased demand for renewables Contribute to community resilience
Outage Mode	Serve critical load Provide power for 72 hours Reduce fuel supply risk	Optimize cost to serve critical load	Minimize environmental impacts from onsite operations	Sustain services to community during outage Expedite recovery

Economics vs. Finance

While the terms “economics” and “finance” are often carelessly intermixed, they have different meanings that are important to appreciate when setting Resilience Hub goals. Economics typically measures the value (or net benefit) of an outcome to society as a whole. Economics includes financial metrics, but includes a broader range of factors, including environmental and social ones. Financial goals focus on the narrower set of economic benefits related to revenue and expense as measured in dollars. Financial metrics like Net Present Value, Internal Rate of Return and Payback Period provide a common language and facilitate comparisons. However, embedded within these quantitative metrics are important environmental and social goals. For example, return on investment is heavily impacted by the social and environmental goals that led to policy initiatives like the federal Investment Tax Credit that significantly reduces the capital cost (and thus improve the return) of a solar + battery solution. While financial metrics are important, Resilience Hub’s stakeholders weigh and evaluate these in a broader context.

Step 3: Design System

With the team and goals in place, Resilience Hub planners will set out to create a preliminary design for the system optimized to conditions and assumptions associated with each site. The central tool planners will use is a Techno-Economic Feasibility Analysis (or simply, "Feasibility Analysis"). A Feasibility Analysis helps determine whether and how to incorporate onsite power solutions. Analyses can be as simple as a home-built spreadsheet or as complex as a graphic model of multiple operating conditions. Planners should beware of developers, vendors and others offering simple solutions based on generic data. While complex modelling tools may be challenging, overly simplified models may miscalculate key regulatory, constructability and finance considerations that can scuttle projects and waste precious resources.

Collect Data

To properly design a HyRS, the team must first understand not simply how much electricity a facility uses in a year, but also how much it uses at peak times or during certain seasons. A Resilience Hub HyRS feasibility analysis requires an interval load profile that shows how a customer uses electricity (typically recorded at hourly intervals or finer resolution intervals and ideally for a year or more). This allows for more accurate predictions of the impact solar, energy storage and other assets will have on operating costs (utility bills), carbon reductions and other metrics. Interval load profiles at hourly intervals are commonly called "8760 Profiles" reflecting the number of hours in a year.

Collecting 8760 load data can be challenging. For sites without smart meters[36] or, for new construction, still in the design stage, historical time-series data will not be available. In this case, synthesizing a load profile and validating it against monthly consumption and peak demand data collected from utility bills or building energy models are important steps. Many sites in this analysis or under consideration for Resilience Hubs lack readily available 8760 data. In some cases, the utility company had not yet installed a meter capable of collecting the data. Likewise, it is rare for buildings the size of Resilience Hub candidates to have more sophisticated tools like a building energy management system (BEMS). Property owners who want to collect this information should consider data loggers. Installed on electric systems, these devices track a variety of metrics including interval data. Once installed and operational for a period of time, high resolution interval data will be available.[37] However, to be truly meaningful, data must be collected over at least 12 months and analyzed by an expert with experience in interpreting the results. Repeating an initial analysis with actual load data replacing the synthesized data will yield greater accuracy of economic and resilience performance predictions.

In new construction, some engineers do not rely on hourly load profiles in their calculations. Instead they often use monthly trends. When evaluating new construction as a potential resilience hub site, the team should be aware of this limitation. Moreover, estimated utility costs can be based on average or typical rate classes. This can further distort analysis.

Absent data from either the utility company or a data logger, an hourly load profile may be created using information from the U.S. Department of Energy Commercial Reference Buildings dataset.[38] This dataset includes modeled load profiles for 16 building types across the various American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) climate zones. The analyst will select an appropriate building

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[36] Smart Meter describes a class of electric and meters, typically provided by a utility, that have measurement and communication capabilities beyond just reading how much electricity one consumed in a given period time. Among the benefits of Smart Meters is the ability to collect interval data to define a more specific load profile for a facility. Two-way communication between the meter and the utility is another feature.

[37] As devices, data loggers range in prices but range in price from several hundred dollars up. However, they must be installed by a licensed electrician and the data collected and analyzed, thus increasing cost.

[38] https://www.nrel.gov/docs/fy11osti/46861.pdf

type to approximate the proposed Resilience Hub site and synthesize load profiles from DOE commercial reference buildings to select the best approximate climate and usage characteristics of each building. Profile statistics can then be validated against available utility bills for simple average and peak demand.

Conduct Site Audits

During the design phase, Resilience Hubs and their prospective vendors will visit sites on many occasions. Even cursory site audits will often identify issues that desktop analysis and other modeling will miss. However, Resilience Hub planners will want to conduct three types of audits with the aid of trained professionals and should consider allocating sufficient budget (either from the project of what's available from the utility, state or other agencies) to do so.

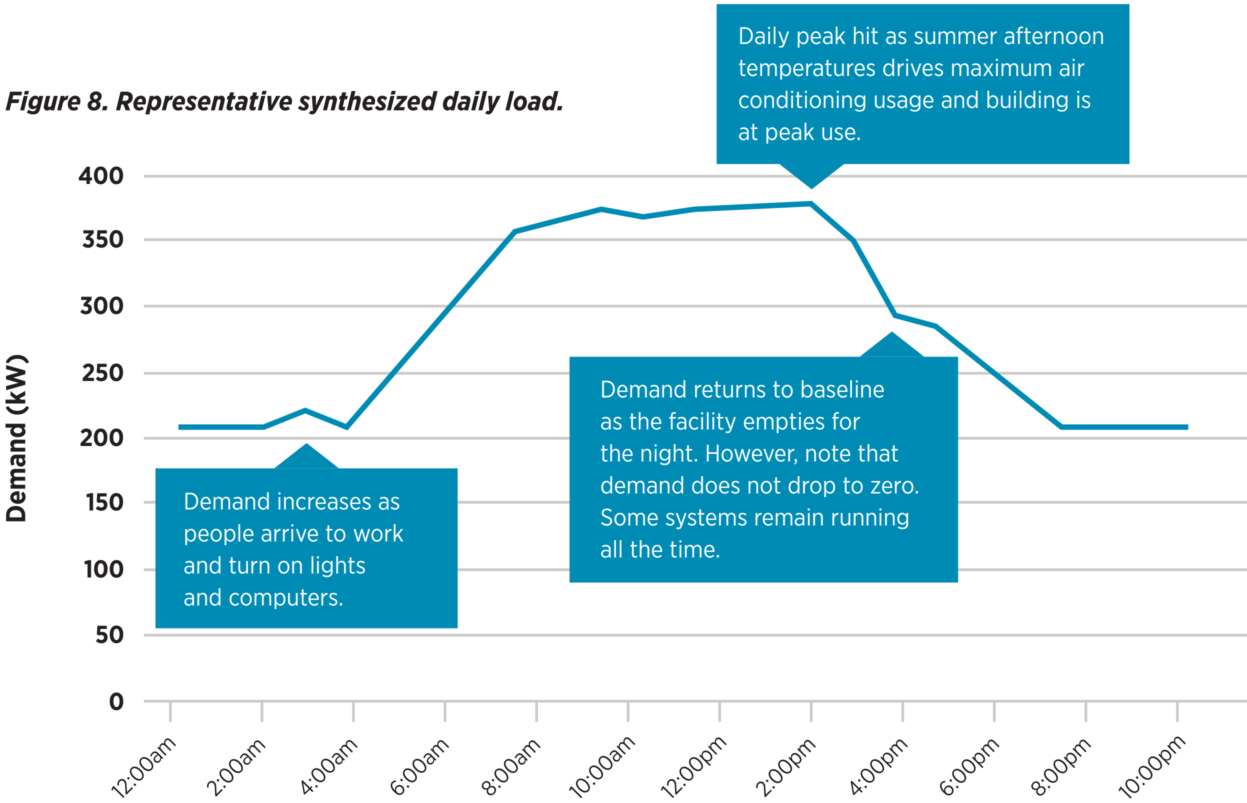
- **Energy Audit:** These audits will identify efficiency and demand reduction opportunities that may be taken before embarking on the HyRS design. For example, an investment in upgrading aging, inefficient HVAC systems may result in reducing the size of the HyRS to power it. A variety of vendors and non-profit organizations offer these services. However, planners may find that they must consult with an HVAC contractor for audits of the HVAC system, lighting vendors for lighting, etc. Some utilities offer rebates for efficiency upgrades and have special programs for non-profits.
- **Electric Load Study:** For existing facilities, a load study will help to confirm the assumptions used in the modeling as well as to verify the loads, panels and other information available from the as-built drawings. The study may include review and logging of specific load data as noted above. If the drawings are out-of-date or non-existent, an experienced electrical engineer can produce updated load schedules (lists of circuits, panels, and their major loads) as well as an updated single-line drawing of the current electric system. The importance of having this information cannot be stressed enough. For Resilience Hubs this is one of the most commonly and costly overlooked steps.
- **Constructability:** As part of the design and engineering process, specific analyses of structural and electrical systems will be performed. As part of the procurement process, installers and EPCs will visit the site to do preliminary analyses. However, experience shows that it is important to have an experienced system installer inspect the site in the feasibility stage for significant issues that might impact the design and construction of the system. This audit may not uncover all of the issues associated with building a system on the site, but will be invaluable for the ones it does pick-up.

Build a Load Profile

Figures 1 and 2 (shown on next page) show representative weekly and daily load profiles from an example site. These graphical representations of power demand help qualitatively identify the challenges and conditions the Resilience Hub team must consider. Among these are how "peaky" the load is (how much energy demand spikes to a peak versus the average load), what kind of demand reduction might be achieved by a HyRS system, and what kind of capacity might be needed to ensure resilience. Minimizing peak demand (the maximum amount of power a facility requires during a brief interval, usually measured in 15-minute increments) is critical.

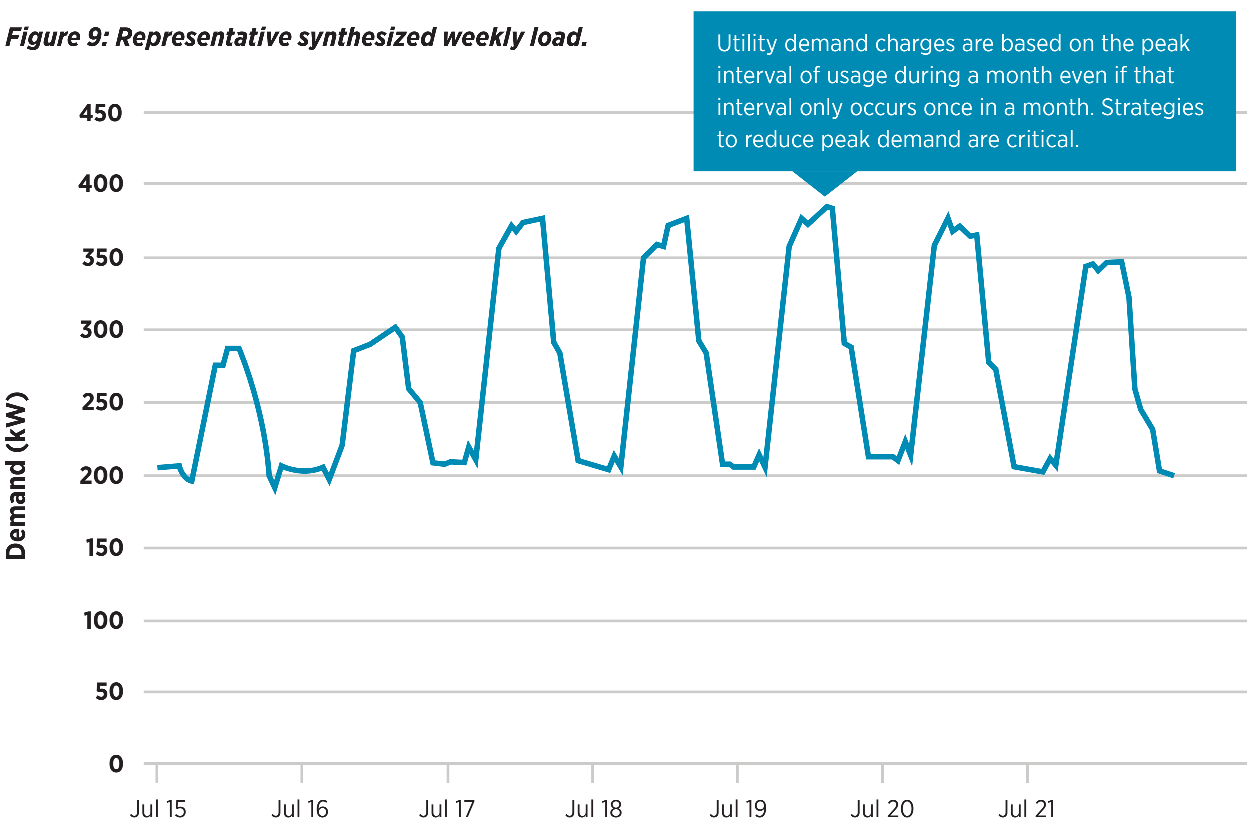
Energy demand fluctuates on a daily basis the characteristics of which may change from day to day and seasonally. Forecasting the behavior of the demand for energy is critical to properly sizing and designing a HyRS.

Figure 8. Representative synthesized daily load.



Electric demand changes throughout a day as heating or cooling systems cycle on, people arrive in a building, use lights, computers and other appliances, and then leave at the end of the day.

Figure 9: Representative synthesized weekly load.



Planning for daily cycles is important to the design of a HyRS. Designers use data, models and experience to fit the right profiles to each Resilience Hub. Synthesized load profile data can be compared to actual recorded load metrics by looking at the peak and average. This provides a reasonable validation that a synthesized load profile is accurate. For most Resilience Hub sites, in Normal Mode, peaks will be weather-driven.[39] However, a Resilience Hub in Normal Mode could vary from these "typical daytime fluctuations" as the site will ideally be used in evenings and on weekends for events, gatherings and other community adaptive capacity building opportunities. During Outage Mode, a Resilience Hub's energy usage will be significantly different. Lightly used facilities that may have a small staff and intermittent events, become full-time, 24/7 operations with increased demand for electricity.

Reducing Peak Loads

Minimizing peak demand (the maximum amount of power a facility requires during a brief interval, usually measured in 15-minute increments) is critical. A load profile with high peaks (see below) increases operating costs (higher monthly utility bills) and capital costs (designing and building a system large enough to meet peaks even when normal usage is much lower). "Peaky Demand," when it coincides with peaks on the utility system, contributes to additional pollution (more generation must be available on the system than would otherwise be needed), and societal costs (the over-sizing of utility infrastructure is charged to all customers).

Under many utility tariffs (the set of rules and conditions, including rates, under which a utility provides service), customers (primarily commercial customers) may be assessed a demand charge based on the peak consumption as measured during a specified interval each month. The demand charge will be assessed in addition to normal charges for the amount of electricity a facility uses. Peak demand may be reduced in several ways installing efficiency measures (HVAC systems with variable speed drives, for example), shifting the time when certain equipment starts, and using batteries to offset what would otherwise come from the utility.

Analyze Utility Rates

Beyond stipulating conditions to interconnect a HyRS with the power grid, utility rates and market participation programs affect the economics of the system when operating in Normal Mode. For Resilience Hub planning, savings resulting from use of these systems help to offset or "pay for" the cost of other system benefits. Understanding utility tariffs and their rate classes (most utilities have more than a dozen) is essential to optimizing the design of HyRS.

Electricity is the only commodity demanded, produced, delivered and consumed in the same instant. In most parts of the country an independent system operator or regional transmission operator operates competitive wholesale markets that manage the flow of electricity so that supply meets demand. In a remarkable feat of economics and engineering, power grid operators bring power plants (coal, nuclear, hydro, solar, wind, natural gas, diesel) on and offline constantly to meet demand as it fluctuates instantly, daily, seasonally and over the years. Energy storage systems, though a very small part of the overall systems, help maintain that balance while improving efficiency and sustainability of the system. A complex set of rules and industry practices regulates safe and reliable operations. Additional rules govern how various system components (generators, transmission and local utilities) may recover costs and owners earn reasonable rates of return for their investment. This creates a dynamic and critical set of incentives to motivate behavior.

[39] TBD

As regulated monopolies, utilities must recover their costs plus a return on capital invested. They set electric rates to allocate costs fairly across all customers classes. These rates must be approved by state regulatory entities. The rate-making process is complex and lengthy and multiple stakeholders have input during the process. Once rates are approved, customers are assigned to rate classes that set the structure and amount they pay for service.

An energy consumer who becomes an energy producer (by putting a solar PV system on their property, for example), complicates matters. If the output of these behind-the-meter systems is less than the customer consumes from the grid, then the customer pays for their own generation system that offsets the cost of what they buy from the grid.[40] But when the customer produces more than they use, most states require that their utilities credit back the extra energy under the Net Energy Metering (NEM) system.

Utility Rates & Charges

The Resilience Hub team should consider how the rate class under in its utility tariff may impact the HyRS strategy. Most commercial utility bills are comprised of four main components: energy, distribution, demand, fixed or customer charges, and taxes and surcharges. The terms and conditions of the tariff must be approved by a public utility (typically at the state level) commission and are published on the utility's website.

1. **Energy ($/kWh):** Charge to cover the cost of the electricity generated for each customer based on the amount of energy a customer uses during the billing period. Measured in kilowatt hours (kWh).

2. **Distribution ($/kWh):** Charge to cover the cost of delivering energy to the customer based on the amount of energy a customer uses during the billing period. Measured in kilowatt hours (kWh).

3. **Demand ($/kW):** Charge to cover the cost of having enough utility infrastructure (wires, transformers, etc.) to provide enough power to meet a customer's highest needs (usually measured over the peak 15-minute period for the month). Demand charges are typically applied only to commercial customers.

   Peak demand charges are also variable and are based on the peak rate at which energy is consumed during any single period during the month – consuming a lot of energy in a short period of time will result in a high peak demand charge even if less energy is consumed during other times.

4. **Fixed Charges ($/month):** Customer charges are fixed costs that do not change each month. These cover the cost of basic utility overhead (billing, administration, meter reading, etc.) that don't vary without the amount of electricity you use or demand.

5. **Other:** Taxes and surcharges are mandated by each state but may apply differently to for-profit and non-profit entities.

[40] TBD

In planning a HyRS for a Resilience Hub, consideration of all four of these categories is critical. Strategies to reduce both consumption and demand not only achieve cost reductions, but also prevent unnecessary investment in over-sized systems. On rare occasions errors have been found in the rates applied and taxes charged to certain customers.

Evaluate Incentives

Many utility tariffs include rebates or discounts as an incentive to achieve certain goals. For example, most states require utilities to pay owners of solar PV systems for any excess energy that they produce and provide back to the grid. Some utilities offer rebates and on-bill financing for energy savings measures like more efficient appliances or HVAC. Others help reduce capital cost, finance cost and operating cost. Identifying all of the incentives available can be daunting. Utilities often publish a list of some of them on their websites and may offer some advisory services. State agencies (state energy offices or state environmental agencies) may provide additional incentives as well. A great place to start looking is the www.dsireusa.org, a state-by-state database of renewable energy and energy programs operated by the N.C. Clean Energy Technology Center at N.C. State University and funded by the U.S. Department of Energy.

- **Renewable Energy Credits:** Environmental attributes can be an important benefit for the HyRS. Solar Renewable Energy Credits (SRECs) are a market-based production incentive paid on electricity produced by the solar array. For each 1,000 kWh of solar production, the system owner receives 1 SREC. In states that have implemented a renewable portfolio standard (RPS), utilities are required to procure a certain amount of the electricity that they sell to customers from renewable sources. They can do this by purchasing a number of SRECs equivalent to the amount of energy from renewables the state in which they operate requires. SREC's are a commodity that trade on open and often very dynamic markets. Their valuation can fluctuate over time. Each state's rules are different, and markets offer an array of SREC products. For example, Washington DC values SRECs are $400 per credit whereas neighboring Maryland currently values them at about $15.
- **Time of Use Rates:** Time of Use rates address the "when" of electric consumption. By charging on-peak and off-peak rates, these rates create incentives for customers to use electricity when demand on the grid is low (at night, for example). This helps mitigate the need and expense for utilities to build oversized systems just to meet infrequent peak demands. Time of use rates vary by state and utility.
- **Net Metering & Export Rates:** Net metering compensates the owners of distributed generation (solar PV, for example) for providing excess electricity back to the grid. The customer-generator (sometimes dubbed a "prosumer") receives a credit for the excess electricity that can be used at a later time. This is particularly useful with solar arrays since the time at which the solar power is generated may not completely align with when it is needed at the site. The structure of NEM programs varies by state and utility. Some utilities limit the production capacity to an onsite system may have or the rate at which excess generation may be credited. Net metering agreements often have subtleties, however, so it is important to study the policy of the specific utility.
- **Community Solar:** Community Solar projects include typically larger-scale, centrally located solar PV facilities from which customers lease a portion of the facility. This solution takes advantage of the economies of scale that can reduce the cost of a facility to provide access to solar for renters and property owners whose roof or property is not well-suited for onsite solar. In some cases, Resilience Hub sites will make good hosts for community solar systems. However, Resilience Hub planners should carefully scrutinize whether these systems can be used for onsite backup power during Outage Mode. The engineering and metering of these systems often prohibit them from being used as both.

Depending on the state and utility service territory in which they are located, battery energy storage systems earn revenue from a variety of services. Services may include peak shaving, energy arbitrage, demand response, ancillary services, transmission and distribution deferral, and added resilience. While it is easy to think of the value of energy storage systems purely as a reserve during power outages (like batteries in a flashlight), the value they provide both to customers and the grid is more diverse.

- **Demand Reduction (Peak Shaving):** For utility customers who face demand charges (typically larger commercial customers), batteries can offset sudden spikes in demand when equipment comes online. The Clean Energy Group estimates that there are nearly 5 million commercial customers in the United States who can subscribe to retail electricity tariffs that have demand charges in excess of $15 per kilowatt (kW), over a quarter of the 18 million commercial customers in total in the United States. High demand charges are often cited as a critical factor in battery project economics.[41]

- **Energy Arbitrage:** Customers who have time of use rates, can charge their batteries in the off-peak hours and discharge their batteries at peak time.

- **Demand Response:** Some utilities have programs to compensate customers who can reduce demand when called upon by the utility when the Grid is strained. Programs vary by customer size and utility service territory and various companies specialize in enrolling customers to participate in these programs.

Changing Incentive Structures

Recent years have seen a flurry of changes in state-level goals for energy, particularly for renewables and energy storage. While these policies typically share the common theme of addressing climate change, they are often geared to the specific challenges faced by each state. In states where solar production can exceed demand in the middle of the day and then causes a spike in demand for conventional generation in the evening, incentives are structured to better balance the integration of renewables. In states where portions of the utility grid are heavily used for portions of the day (dubbed "congestion"), policy favors strategies to reduce demand at those critical times and places. In several states, significant changes to the incentive structures will have a bearing on Resilience Hub HyRS.

New York, for example, sought a system that would position distributed generation and storage solutions where and when they are needed the most. All kilowatt hours delivered to the grid are not of equal value. Where the kilowatt hours are delivered matters because some circuits on the grid are more congested with traffic than others. When kilowatt hours are delivered is important as delivery during at peak hours (like the middle of a hot summer afternoon) is far more important than on a mild spring morning.[42] New York's Value of Distributed Energy Resources (VDER) system creates "stacked" incentives that add the value of various system components (location, time, function). Massachusetts is in the process of launching SMART a program 10- or 20-year fixed price incentives that set base compensation rates according to project size, location and specific benefits (community solar, low-income, public and energy storage projects).[43] SMART then creates adders (incentive payments) for each kilowatt hour of electricity generated meeting those conditions. For Resilience Hub planners, these little changes have big impact on optimizing design and dispatch of the HyRS system. Modelling to the nuances of these systems (particularly in the early stages of their development) requires careful attention.

41 [1]https://www.cleanegroup.org/wp-content/uploads/NREL_BatteryStorage_2017.pdf

42 Visit www.dsireusa.org, a state-by-state database of regulations and incentive programs pertaining to distributed generation operated by the N.C. Clean Energy Technology Center at N.C. State University and funded by the U.S. Department of Energy.

43 https://www.mass.gov/files/documents/2017/01/zu/final-program-design-1-31-17.pdf

Rate Escalation

The cost of electricity can be expected to increase over time, though this will vary by state and by utility. Hence, using national averages can be misleading. Escalation rates are projected and published by U.S. Department of Energy on a state-by-state basis, but the empirical escalation rate may be verified using utility bill data over the course of several years. Table 4 shows the current DOE electricity escalation rates for the states of Maryland, Pennsylvania, and Virginia.

Table 2. Sample electric rate escalation

LOCATION	DOE NOMINAL ESCALATION RATE
Maryland	3.19%
Pennsylvania	3.63%
Virginia	3.19%
Nationwide (Federal Projects)	2.50% - 3.00%

Resilience Hub planners should not underestimate the importance of this seemingly innocuous number. In projects that are financed over long-terms (20 years is common for solar projects), the compounding impact of this assumption can have a significant impact on Resilience Hub financial goals. Some solutions providers will choose more aggressive estimates of utility rate inflation to emphasize the potential savings from their systems. As with any industry, the buyer should beware to make sure the assumptions provided are reasonable. The team's finance specialists should work closely with lenders and investors to determine the appropriate number.

Meter Configurations

Utility companies provide electric service to the customers through a meter that measures usage (kWh) and may also measure demand (kW). The meter typically creates the point of demarcation between where the utility company's facilities stop and the customer's begins. Properties may have a single meter that serves the whole facility or multiple meters that serve various buildings. The rules and regulations for meter configurations will be found in the utility tariff.

Determining the optimal metering configuration for a Resilience Hub site (when the option to change it exists), can significantly impact the type and cost of generation assets in a HyRS. This is easier in new construction than when retrofitting HyRS into existing buildings. Sites may have multiple utility accounts but may be dominated by a single load which comprises the vast majority of the load on that HyRS. The dominating load could be considered the "anchor tenant" of its respective HyRS. In this case, optimizing a Resilience Hub is relatively straightforward. However, in the majority of the cases analyzed for this study, the potential Resilience Hub site has multiple meters serving different loads or additions.

A particularly challenging issue arises when a facility has both residential and common loads and where the residential loads are individually metered. This is typical in housing facilities and apartment buildings. In these cases, the common load (a service for the common areas, hallways and exterior) may be on a different rate schedule than the residential loads. Recognizing this configuration is critical early in the design of a HyRS is critical, particularly if the team's intention is that residential units be included. In a net-metered configuration, a HyRS can provide resilience and economic benefit to the load it serves. This load is defined by the meter behind which it sits. If common loads are on one meter and the residential loads are on separate meters, then the HyRS can serve the common meter or the residential meters, but typically not both. In two recent cases, despite the desire to serve these residential loads, the HyRS could only serve the common area load. Significant additional cost in the re-design and engineering of the facility would be required to create a condition where both the residential and common loads could be served by the HyRS in an emergency. The planning team should consult with engineers and the utility when considering these modifications as they will have an impact both on cost and potentially revenue.

Some sites may want to consider master-metering in which they would combine each of the sites onto a single utility meter. This would allow the solar plus storage assets to combine for economic and resilience purposes. This is a project-by-project decision that a proper techno-economic feasibility analysis should consider. The terms and conditions for a master-metered solution will be set by the utility company's tariff and typically very restrictive.

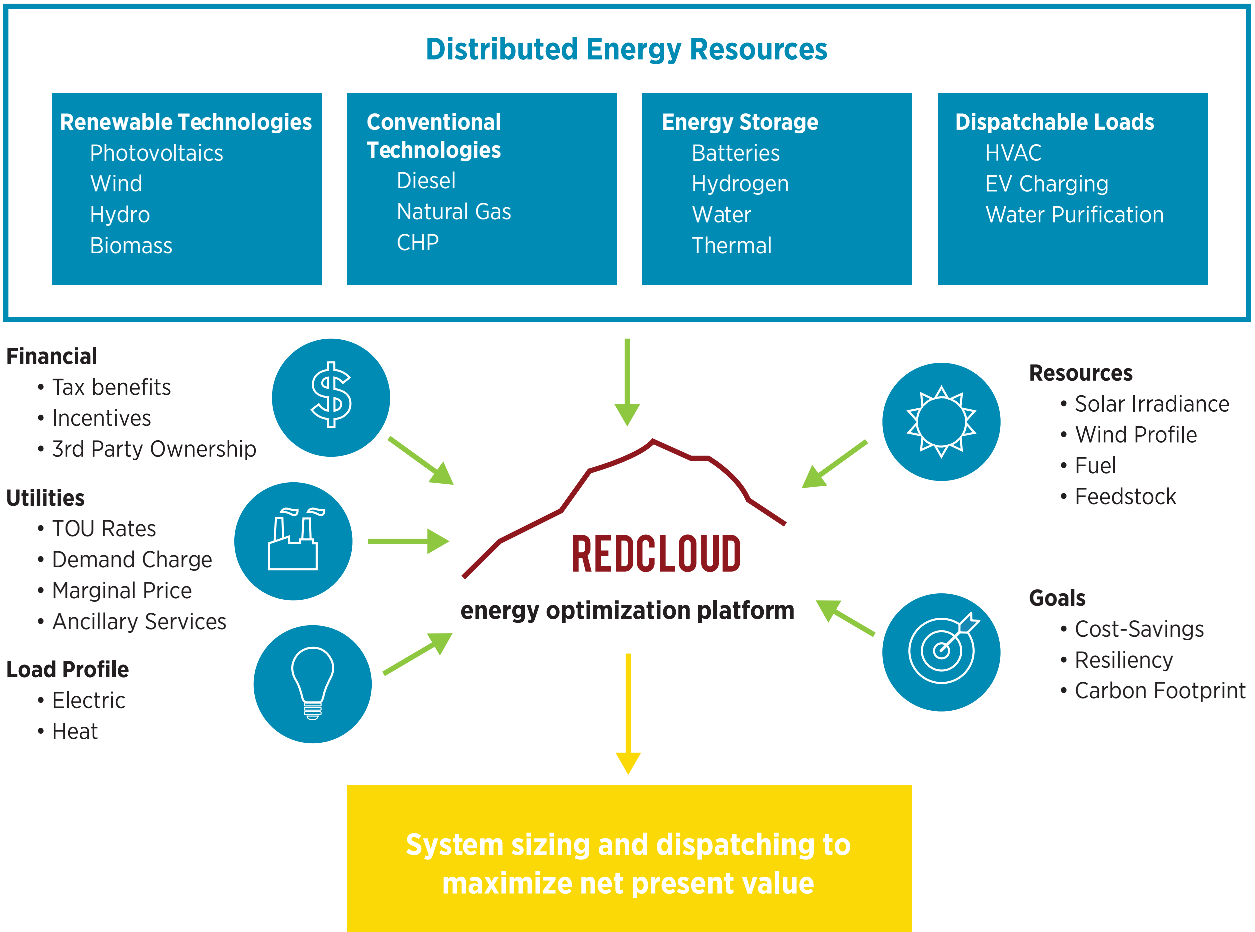
Model Solutions

With the team in place, goals established, and data collected, a Resilience Hub team would next model and analyze a range of HyRS configurations to select the right fit for each site. This process starts by selecting a suitable model to evaluate a variety of requirements and produce preliminary design parameters. Once the Resilience Hub team selects the appropriate parameters, an experienced system engineer will produce a preliminary design.

This set of case studies uses the muGrid Analytics Redcloud modeling platform to determine the optimal solar sizing, battery sizing, generator sizing and battery and generator dispatching strategy given the goals and assumptions provided by Resilience Hub planners. The model's objective is to minimize life cycle cost of energy, given the aforementioned assumptions, for the site over the analysis period. Life cycle costs consider not just the initial capital cost of the equipment but also all capital costs, fuel costs, operating costs, incentives, tax benefits, resilience requirements and other parameters and assumptions. For each case evaluated, the analysis calculates net present value (NPV) as the difference between the current case lifecycle cost and the base case lifecycle cost. Commonly used in financial analyses, NPV measures the value in today's dollars of a series of future cash flows (revenue and expense). The model then also calculates an internal rate of return (IRR) for the project. The IRR compares various NPV scenarios to one another on an apples-to-apples comparison. Moreover, the results of these analyses will be evaluated in context of the operating, environmental and social goals established in Step 2.

Figure 10 (shown on the following page) shows the Redcloud system architecture.

Figure 10. Redcloud Software Architecture



The analysis addresses the potential for all three assets at each of the HyRS locations, generally sizes the systems to maximize the economic benefits, and then discusses the enhanced resilience that the system might offer as a qualitative benefit. Note that the offset to grid-supplied power and reduction in peak demand are both benefits with significant sustainability impacts.

Techno-Economic Feasibility Analysis Methodology

- **Determine Base Case:** The analysis begins by determining the base case, or "business as usual" case, for each utility account at a potential Resilience Hub site. The base case assumes that the specific Resilience Hub continues to purchase electricity from the grid in the future as it does today. The life cycle cost of electricity, therefore, is the present value of their payments to the utility over the next 25 years, including increases in the cost of electricity at the escalation rate, and then discounted back to the present using the discount rate. In short, this is the reference to which the economic return of renewable energy projects should be compared.

- **Determine Economically-Optimal Case:** This case maximizes the NPV of the project. This case may contain solar, solar+storage, firm generation, or in some cases, no technologies at all (i.e. if solar is not economically viable, then the optimal size of the solar array is zero.) It should be noted that the economically-optimal case may or may not maximize the amount of solar on the site – depending on the rate tariff, net metering agreement, annual load, etc. the economics of the project may be maximized by building less than the maximum possible solar.

- **Evaluate Other Scenarios:** Depending on the results of the economically-optimal case, the analysis runs several excursion scenarios. If, for example, the economically optimal case builds solar on all available land and roof area, the analysis typically includes a case in which solar is only installed to the point that the facility achieves net zero, that is, the annual solar production equals the annual electricity consumption. We believe this is a relevant case since it is common for utilities to restrict their net-metering agreements (or "buy-all, sell-all" programs) such that sites cannot be a net exporter of electricity.

Desktop vs. Real World

The first level of analyses Resilience Hub will receive are high-level or "desktop" analyses. They are not yet refined into an actual cost to construct the system. They will be based on generalized assumptions about production, cost and ability to finance incentives. When the planning moves from desktop to site-specific, results can and will vary significantly with localized factors like labor costs and permitting. Constructability can be another critical issue. Some sites that look good on paper (and in popular design tools) will be stymied by site-specific issues such as the ability of the roof to carry the excess load of the PV system or appropriate space to locate the battery system.

Resilience & Probability

Modelling the contribution to backup power that the solar and battery storage systems provide is a moving target that varies with season and weather conditions. If the days are sunny and use of the building is limited, then HyRS will provide additional backup power longer. If the days are cloudy and the building is used intensively, then the duration is more limited. The contribution of a solar + storage system can provide varies based on:

- Time of day and season of year outage happens
- Electrical load
- Solar production
- State of charge of battery at time outage starts

Step 4: Finance System

After the fundamental design questions have been answered, stakeholders considering a Resilience Hub will want to consider closely the financial impact on both a capital and operating basis of the proposed solution. This is not simply a cost question. Different elements of a HyRS are subject to the various revenue streams, incentives and rebates that will vary from state to state. The Resilience Hub planning team should include key personnel involved in making financial decisions for the organization. Financial advice, including the use of tax incentives, should only come from qualified professionals. The following is a general overview of financial impacts, not specific advice. The matrix of generation and storage options, particularly as integrated with incentives, creates a more dynamic picture.

Ownership & Finance

Decisions about financing are critical to the success of projects. There are a variety of financing models to choose from ranging from self-financing (the property owner funds all capital and operating expenses), to equipment leasing, and third party-owned systems. The optimal option is particular to each site and the goals and risk tolerance of property owners and the project team. To arrive at these decisions, financial models, the assumptions on which they are based and the experience of those who run them are critical. While basic models are openly available to size generators, finance PV systems or match PV and batteries, they are only as good as the assumptions used to drive them. A proper model will evaluate financial return from the project under different ownerships structures. The model should then consider different financial structures like owner-operators, third-party financing, and power purchasing agreements (PPAs). Grants or external funds may be available and taken into consideration as well.

In a third party-owned systems, the Owner is separate and distinct from the Developer and from the consumer of the electricity produced by the system (“Offtaker”). The Offtaker may be the owner of the land or building on which the project is located or may be the utility to which the system interconnects.

Even for small projects, HyRS expense can be significant. Many of the best-suited customers for these projects are tax exempt and cannot directly use powerful investment incentive tools including the 30% Investment Tax Credit (ITC) or Modified Accelerated Cost Recovery System (MACRS) depreciation.

To reap the benefits of advanced energy solutions, these critical community operations need a partner who provides value by navigating through the complexities and unlocking the financial tools. For example, PUSH Buffalo, a non-profit community organization dedicated to housing, energy and other social equity issues has been an ambitious community partner. For its renovation of School 77 and consideration of a HyRS, PUSH orchestrated a consortium of project sponsors in both for commercial and non-profit finance. Together, they structured a unique ownership model both for the facility and for the solar PV array constructed on it.

The use of third-party finance has been a boon for the expansion of distributed generation as it frees property owners from the heavy capital costs and ongoing operations and maintenance of a HyRS system. However, this structure of financing has also created unmet expectations in Resilience Hub candidate sites, many of which are simply too small to attract third-party financiers. These structures require a significant amount of fixed costs, such as legal and tax work, which can easily swallow any profit in the project. The credit risk associated with smaller, non-profit entities can add to the cost of capital at best and kill deals at worst. Fortunately, a number of organizations are stepping into this void for small, third-party financed projects to attempt to overcome these hurdles.

Avoided Cost

Avoiding utility costs by using HyRS-generated energy on site can provide considerable value to a Resilience Hub. The simplest method for estimating avoided costs is to use a blended rate utility bill analysis. With this approach, the utility bill charges and the energy consumption (in kWh) are summed for the entire year and then divided to obtain a simple cost per kWh. The flaw with this approach is that it assumes that distributed generation is able to reduce fixed charges and demand charges with the same efficacy as it does energy charges, which is generally not the case. When considering solar-only Resilience Hub projects, this approach always overestimates the avoided cost. Therefore, we do not recommend using this approach, but include it for comparison as many solar developers will base their analysis on a blended rate. The more accurate method of estimating the avoided cost disaggregates the various components of the utility bill into fixed costs, volumetric energy costs, and demand charges. This provides clarity into which charges solar and battery storage will be able to offset.

Investment Tax Credit

The federal investment tax credit is a tax credit in the amount of 30% (not deductions, but dollar-for-dollar credit) of the installed cost of the solar array or solar plus storage system. The tax credit is scheduled to decline from 30% in 2019 to 10% in 2022 for businesses. It can be claimed after the system is installed and is included in the cash flow for the first year or the system. A site would need to have a tax liability in order to claim these tax credits directly, however, which can naturally preclude government-owned buildings, non-profits, and presumably many Resilience Hubs. These types of clients may want to explore alternative financing structures that must rely on private sector partners in more complex finance models. Early in the conversation about a HyRS, the Resilience Hub Project Team should seek guidance from accounting and tax professionals. To qualify, the system owner must have sufficient tax liability. Liability may be rolled ahead into future years.

For commercial properties (as most Resilience Hubs will be), the battery must be charged by renewable resources 100% of the time. While these incentives (along with state-level programs like the Self-Generation Incentive Program in California, SMART in Massachusetts, VDER in New York and the Maryland energy storage credits) can greatly improve the economics of the type of system a Resilience Hub will employ.

Depreciation

Solar arrays are eligible for the Modified Accelerated Cost Recovery System (MACRS) method of depreciation. This allows the depreciation tax benefit to be claimed sooner, thus increasing its value.

Table 5. Standard MACRS table

YEAR	1	2	3	4	5	6	Total
MARCS	20%	32%	19%	12%	12%	6%	100%

The bonus depreciation schedule further accelerates the MACRS schedule by allowing an additional 40% to be claimed in the first year for systems installed in 2018 (30% for systems installed in 2019). However, MACRS offers benefits to certain customers.

Solar Renewable Energy Credits (SRECs)

Environmental attributes can be an important factor in driving economic benefits for the HyRS. Solar Renewable Energy Credits (SRECs) are a market-based production incentive paid on electricity produced by the solar array. For each 1,000 kWh of solar production, the system owner receives an SREC. In states that have implemented a renewable portfolio standard (RPS), utilities are required to procure a certain amount of the electricity that they sell to customers from renewable sources. They can do this by purchasing an amount of SRECs equivalent to the amount of energy from renewables the state in which they operate requires. SREC's are a commodity that trade on an open and often very dynamic market, so their valuation can fluctuate over time. Each state's rules are different. Over the counter markets offer a wide array of SREC products to the market. For example, at the time of publication, Washington DC values SRECs are $400 per credit whereas neighboring Maryland currently values them at about $15 per credit. Virginia does not have a mandatory program. Complex SREC trading strategies can be implemented which are beyond the scope of this analysis.

Valuing Resilience

Currently, there is no consistent market mechanism to value the additional resilience benefits that a HyRS offers to the grid as a whole. Regulators and the industry are still not fully aligned and methods and metrics differ. But state regulators across the country have started the process to quantify this important economic driver. For stakeholders creating a Resilience Hub, that work may yield future benefits in additional revenue streams. Today, these benefits remain site specific and particular to each Resilience Hub's goals. For the case studies used in this analysis, resilience has not been assigned an explicit financial value. Instead, the model values resilient energy by constraining the system to size the battery storage and generator assets to meet the critical load and outage duration parameters set for each project.

Budgeting Considerations

Ultimately, the Resilience Hub team will need to determine the cost of its system and how to pay for it. Unfortunately, HyRS do not yet come off the shelf at standard prices. The size and configuration of the system will vary from site to site based on utility rates, regulatory costs, labor costs and other factors. The variances are too significant to provide a rule of thumb for pricing systems. Given the relatively small size and complexity of the systems, soft costs (like engineering, project management, legal, etc.) can make up over one third of the cost of a project. A review of recent construction proposals (without the cost of firm generation) showed the following breakdown:

- Soft Costs (Engineering, Project Management, Legal, etc.) = **35%**
- Solar PV Components (Labor & Materials) = **25%**
- Storage Components (Labor & Materials) = **30%**
- Balance of System Components (Labor & Materials) = **10%**

For this reason, it is important to revisit budgetary considerations at several points through the project.

Hybrid Resilience System
Case Studies

Hybrid Resilience System Case Studies

The following case studies demonstrate recent analyses for sites where a Resilience Hub would be feasible and where the hosts are evaluating HyRS components. The analyses include a variety of cases with different combinations of generation and storage assets and under both normal and outage conditions.

Case 1: Community Center in Washington DC

Background: This case analyzed the newly constructed Marvin Gaye Recreation and Community center in Washington DC. The center features an innovative design and significant attention paid to energy efficiency measures. The facility will serve a range of functions in the community including recreation, education and other activities. Early design iterations included rooftop solar PV at commissioning. However, the facility was built as "solar-ready" with design features to facilitate the inclusion of solar as a post-construction retrofit. Rather than installing a fixed standby generator, the facility includes a 600-amp roll-up generator termination box to allow a 400kW mobile generator to be connected. This analysis evaluated adding a Resilience Hub HyRS to the facility under a variety of scenarios.

Load Analysis: At the time of the analysis, the site had not been commissioned. The analysis used a simulated hourly load profile and assumed the facility would be assigned to the PEPCO utility's GT LV rate tariff. Utility rates are assumed to escalate at 2% annually. When solar is installed, it will be eligible under Washington DC's net energy metering policies for compensation up to the annual forecast electrical load for the site. In other words, the system will not be a net-exporter of electricity over the course of the year. Demand charges, calculated on the monthly peak, are $12.45/kW with an additional $1.18 is charged on peaks in the "on peak" hours. Critical Load is assumed to be 100% or normal load.

Solar PV: Solar PV system was limited at 100% of the annual estimated electric load or 77 kW DC. The analysis is based on an estimated turnkey system installation cost of $3.50 per watt based on input from several installers. The PV System is assumed to have a 25-year lifespan and require replacement of the inverters between year 10 and 15.

Energy Storage: This case study evaluated two battery solutions (both using lithium ion batteries), a solution sized to maximize financial return and a larger solution to increase resilience. Neither solution could feasibly provide 72-hours of backup power using solar and storage.

Generator: While the building was designed with the capability to "plug in" a large, mobile generator, for this analysis evaluated a more typically sized 80kW natural gas fired generator permanently installed on site.

Revenue Streams: This analysis uses the simplest and most conservative SREC trading scheme which is to sell the first 15 years of SREC's immediately for a lump sum payment, $1,400/kW-DC (April 2018).[44]

Incentives: The model assumed third-party ownership of the system and the ability to fully monetize the ITC and MACRs.

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[44] https://www.solsystems.com/srec-customers/state-markets/washington-d-c/

Results: The facility benefits from a HyRS strategy that includes solar and storage. During Normal Mode, solar meets operational, financial, environmental and social benefits very well. An appropriately sized battery system contributes to peak-shaving. Early model runs considered several storage + solar combinations and found that a modest gain in resilience (increasing from 2 hours to 4 hours) added 30% to the cost of the system. As neither approached the capacity needed to support operational goals during Outage Mode, future iterations focused on optimizing the battery for peak shaving. During Outage Mode, the natural gas generator provides needed backup power. A standby generator, whether fixed or mobile, provides benefit only during an outage. Battery storage provides benefit primarily under economic conditions by assisting in peak-shaving for the projected load curve. However, operating a Resilience Hub with a standby generator and without solar + storage is always more expensive as well.

Case 1: Marvin Gaye Community Center

SCENARIO	BASE CASE	SOLAR ONLY	BTM BATTERY ONLY
PV Size [kW]	77	77	77
Battery Power [kW]		43	25
Battery Energy [kWh]		1205	52
Generator			80
Operations			
Hours of Backup Power *(Critical Power = 100% Load)*	0	72	72
Additional Hours of Storage			2.1
Financial Metrics			
Life Cycle Cost			
NPV	$206,528	$(332,181)	$216,459
IRR	15.1%	-5.8%	9.4%
Utility Bill Savings			
Monthly Demand Savings	$319	$4,604	$3,309
Avoided Energy Charges	$10,855	$10,475	$10,705
Total Utility Bill Savings 1st Year	$11,174	$15,079	$14,014
Sustainability			
Solar Energy Production Year 1 (kWh)	112,292	112,039	112,039

Case 2: Recreation Center in Washington DC

Background: The King Greenleaf Recreation Center is a 17,000 square foot, multi-purpose facility with gymnasium, multi-purpose rooms, exercise rooms, shower facilities, locker rooms and learning facilities near the Navy Yard in Washington DC. The facility is surrounded by playing fields and playgrounds. As a potential Resilience Hub, it has a number of promising features including new construction, open space, centralized location in a vulnerable community and an operations staff. The building includes facilities for cooking and food storage. Two electric services provide power to the Center and were considered individually for this analysis.

Load Analysis: The site is served by PEPCO under the GT LV rate tariff. Demand is calculated on the monthly peak, regardless of timing, is charged at $12.45/kW. An additional $1.18 is charged on peak hours. The meters have a peak demand of 10.6 kW and 20.7 kW respectively. The analysis assumes that the site will maintain two meters (thus requiring two sets of generation and storage solutions). The meter with the larger of the two demands exhibits a high degree of demand fluctuation.

Solar PV: While the building's configuration allows for a maximum of 125 kWDC solar array, net metering regulations limit the facility to 55kW. The regulations allow for systems to be sized at 100% of the maximum annual load. While generally open and accessible, the building's domed roof may present constructability challenges (and potentially higher costs) that must be verified with local PV installers.

Storage: The analysis modeled a lithium-ion storage system sized to each of the two systems.

Generation: The facility does not currently have onsite generation. The analysis therefore include a generic natural gas fired generator.

Incentives: The model allows for power and energy to be sized independently. In order for the storage system to utilize the investment tax credit and MACRS tax benefit, the model assumes the battery will only be charged by the solar PV array.

Results: Several configurations were evaluated: Solar Only, Solar with a battery configured to meet the resilience requirement, solar with a standby generator, and solar with generation and a battery configured to optimize financial performance. The modeling shows that both the HyRS solar plus generator and solar + generator + economic battery cases showed positive financial returns, while the solar plus large battery for resilience has a negative financial return. Note, the highest financial return is the solar-only solution; however, this again does not provide the resilience requirement. While the backup generation provides the operational requirements in Outage Mode, it does not provide benefit in Normal Mode. As modeled, the facility achieves annual net zero operations.

Case 2: King Greenleaf

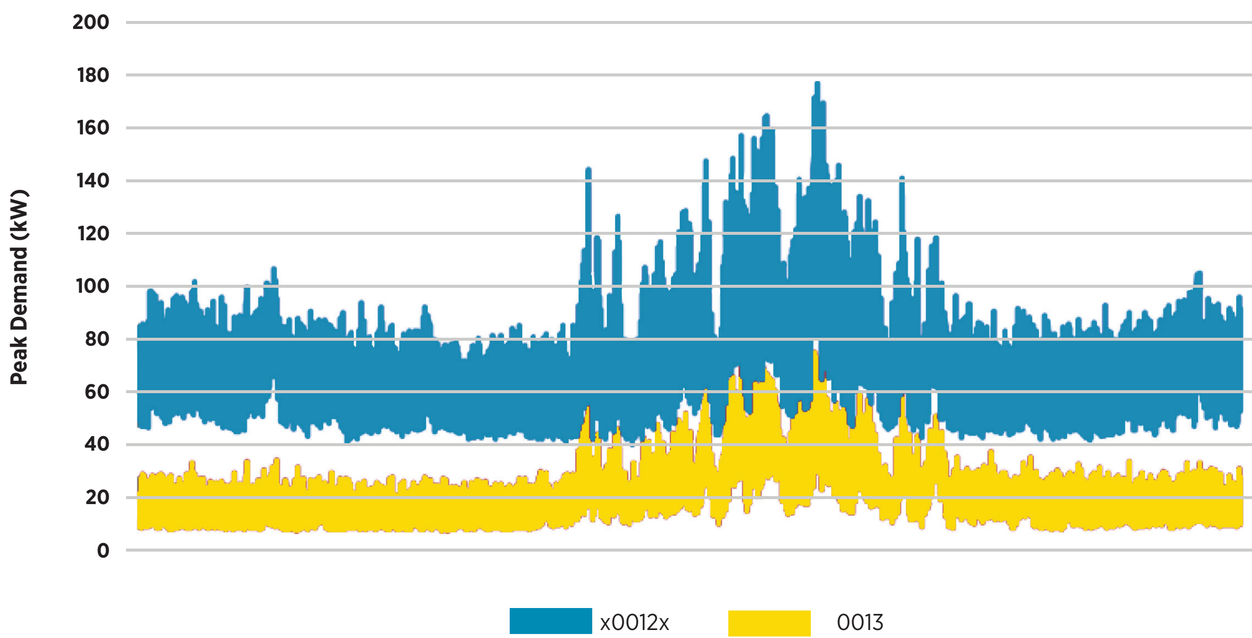
SCENARIO	HyRS *(Meter 1)*	HyRS *(Meter 2)*
PV Size [kW]	16.9	38.4
Battery Power [kW]	2.3	6.7
Battery Energy [kWh]	4.6	16.8
Generator	20	30
Hours of Backup Power *(Critical Power = 100% Load)*	72	72
Additional Hours provided by Storage	2	2.1
Financial Metrics		
NPV	$48,344	$98,106
IRR	17.4%	17.1%
Utility Bill Savings		
Monthly Demand Savings	$543	$876
Avoided Energy Charges	$2,072	$4,679
Total Utility Bill Savings 1st Year	$2,615	$5,555
Total 1st Year Revenue	$2,615	$5,555
Sustainability		
Solar Energy Production Year 1 (kWh)	21,351	48,523

Case 3: Senior Housing in Boston

Background: Coleman House is a multi-story, senior residential and community center outside Boston, Massachusetts. Though larger than many potential Resilience Hub sites, this facility (serving a low-income, vulnerable population), may be well suited to performing Resilience Hub functions. As with a number of prospective Resilience Hub sites, this facility has legacy diesel generators (one for each of the two building phases). In Normal Mode, the HyRS is primarily tasked with reducing operating expense as a result of the solar PV generation, as well as additional benefit from the reduction of peak demand provided by the battery. From an operational perspective, the HyRS offers the added benefit of reducing fuel consumption, extending the duration until re-fueling for the generator system, or serving additional load beyond the critical load served by the generators.

Load Profile: The entire site is served by Eversource on their Rate B7 NEMA Large General TOU service with monthly demand. The load profile has some interesting features. The summer months, particularly July and August, have variable spiky loads compared to the rest of the year. These summer peaks are six standard deviations above the annual average. The load pattern is inconsistent from week to week; an anomaly often found in sites such as this. These anomalies can be quite helpful as they often point to other issues with operations or functionality of building equipment, the resolution of which may lead to reduced energy costs.

Figure 11. Annual load profile for Boston senior housing facility including two electric meters (represented in blue and yellow).



Immediately, the "peaky" load profile points to the potential of the energy storage system to reduce demand charges.

Tariff Considerations: While the utility tariff and rate class are always critical factors in the design and analysis of a HyRS, they are particularly important in this case. First, this utility rate tariff is dominated by high demand charges, especially in the summer. This will enhance the benefit that onsite energy storage can bring. Second, under the new Massachusetts SMART plan, the value of solar and storage solutions increases. (see p. xx for a description).

Solar PV: A preliminary PV design provided by the client and using Helioscope indicates the capacity for a roof-mounted 116 kW array using ballasted racking. For the analysis, the system was apportioned to each meter based in proportion to the total load of each.

Battery: The analysis evaluated a variety of battery configurations to be coupled with the planned solar and assumed to be charged only by solar to enable ITC, SMART adder, and MACRS tax benefits.

Generator: The facility has two emergency diesel generators, both Consolidated Power 135-kW (3 phase, 165KVA) serving critical load functions. Coleman maintains three days of fuel on site. The generators power first floor lighting, a portion of first-floor outlets and one elevator in each building. This analysis defines these as Coleman's critical loads.

Results: The HyRS solution provides added operational, financial, environmental and social benefits. Based on the provided assumptions, modelling shows that a solar+storage solution meets the operational and financial goals for the facility while provided significant environmental and social benefits to the community. Increasing the battery size, however, does not necessarily increase the value of the system. The larger battery does not appreciably reduce the peak demand issue, nor does it provide increased environmental benefit except in the case of an extended power outage.

Case 3: Coleman House

SCENARIO	BASE CASE *(meter 12)*	SOLAR ONLY *(meter 12)*	SOLAR + STORAGE *(meter 12)*	BASE CASE *(meter 13)*	PV13	PVBatt13
PV Size [kW]		89	89		27	27
Battery Power [kW]			53			23
Battery Energy [kWh]			211			79
Generator	135	135	135	135	135	135
Operations						
Hours of Backup Power *(Critical Load = 15%)*	72	72	72	72	72	72
Additional Hours From Solar + Storage	0	0.0	14		0	20
Financial Metrics						
Utility Bill Savings						
Monthly Demand Savings		$1,109	$13,576		$326	$6,324
Avoided Energy Charges		$14,235	$13,773		$4,318	$4,133
Total Utility Bill Savings 1st Year		$15,343	$27,349		$4,644	$10,457
NPV		$201,506	$387,162		$60,966	$142,510
IRR		15.6%	19.0%		15.5%	20.2%
Sustainability						
Solar Energy Production Year 1 (kWh)		113,749	113,749		34,508	34,508

Forecast SMART incentive						
SMART Solar Incentive		$0.155	$0.155		$0.155	$0.155
Smart Storage Adder			$0.065			$0.064
Total SMART Incentive		$0.155	$0.220		$0.155	$0.219
Total SMART 1st Year Comp		$17,620	$25,059		$5,345	$7,554
Total 1st Year Revenue		$32,963	$52,408		$9,989	$18,011

Note that resilient energy hours are dependent upon the supported load. In this case, the analysis assumed that sufficient loads would be shed such that only 15% of nominal load would need to be supported.

Case 4: Mixed-Use Redevelopment in Buffalo

Background: PUSH Buffalo's School 77 project is a renovation of a former public school building into multi-family housing and a community center in Buffalo, NY. The project serves a variety of functions for the surrounding community. Planners at the site sought to incorporate a HyRS for economic reasons and, at the time of analysis, solar PV was already planned. The analysis fixed the planned solar and was optimized for economic benefits.

Load Profile: As the facility had been vacant for a long period of time and the new use of the new facility changed significantly, actual interval data was not available. Instead, the analysis used U.S. Department of Energy commercial reference buildings and climate zone 5A to synthesize an hourly interval load profile given the annual load forecast. Since this is a mixed-use building, we used different reference buildings to synthesize the shape, based on the amount of expected usage of the building. In this case, we used 50% mid-size apartment, 30% small office and 20% warehouse. This profile had an average demand of 36 kW and a peak demand of 91.5 kW.

Meters: As designed, the facility included one meter for common areas and individual meters for each of the 30 residential units.

Utility Rates: In this project, the evolution of New York's VDER "value stack" program, played a considerable role in the design and analysis of the system. The meter configuration created an immediate challenge for a HyRS as the system must sit behind a single meter. It could either serve the common areas under the National Grid Small General (SC2) service tariff, or the residential meters (if they were aggregated behind a single "master meter"). The latter option is subject to a more complicated set of considerations. Value stack compensation for Community Distributed Generation (CDG) solar is expected to have a maximum value of $.117 per kWh (when all electricity is used to offset small commercial load SC-2) which should yield an IRR for the project of 13.9%.

Generator: 60-kilowatt, natural-gas fired generator configured for Life Safety and backup to some of the common area loads.

PV: 64.4kW, roof mount.

Energy Storage: 8kW/14kWh lithium ion battery (behind the meter).

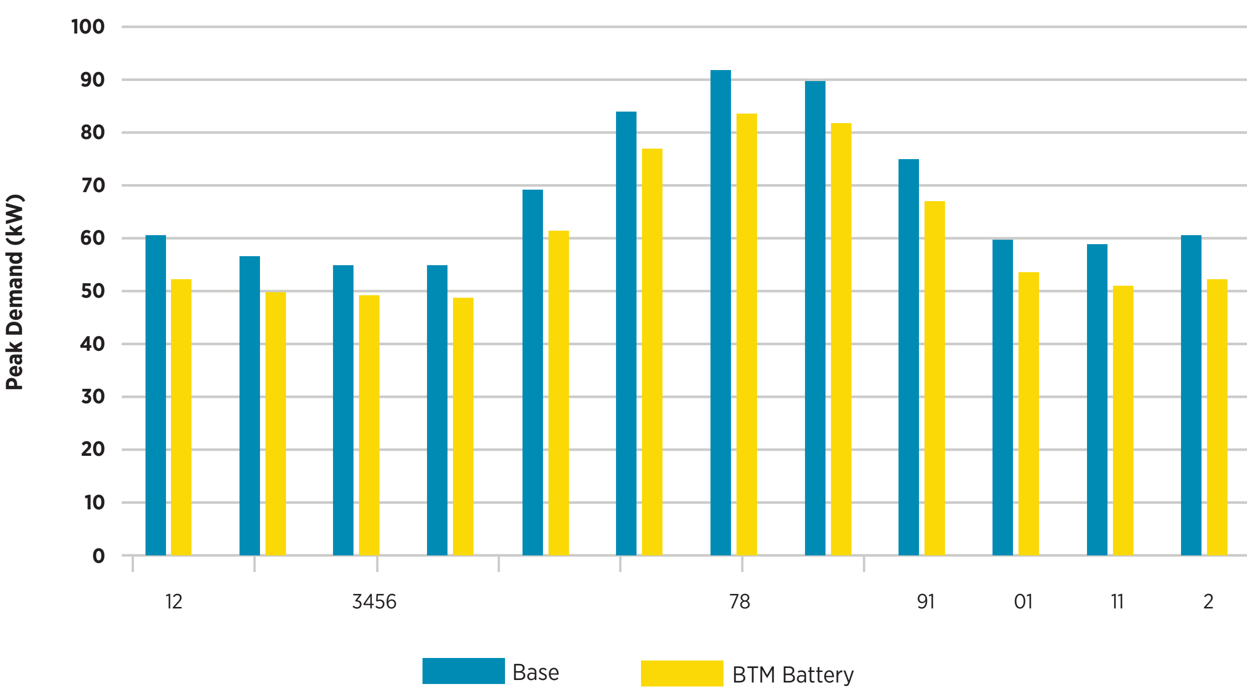
Results: Due to project timing issues, the planners opted for the benefits community solar option instead of the solar+storage solution. By putting the solar behind a meter separate from building loads, this precludes the system from contributing to resilience during outage mode. While some potential strategies to overcome this condition were explored, they presented significant cost, engineering and regulatory hurdles that made them unfeasible. However, the analysis also found that, a modestly sized behind-the-meter battery could provide some economic benefit to the facility as well. While community solar prevented a PV-coupled battery, the model identified that a battery may be economically viable if installed on the main building load, even without solar, used for peak shaving. This system would also receive very modest Value Stack compensation under the proposed VDER regulations. Since solar would not be installed, the system would not receive the ITC. This is based on our modeled interval load profile behind a single meter on the SC-2 tariff. An 8kW/14kWh battery could provide up to 1-hour of resilience to critical load comprised of 50% of the normal load and have a 7.8% IRR due to peak shaving. In this case, the solution met environmental (offsetting more than 66,231 kWh of grid-supplied energy).

Case 4: PUSH Buffalo School 77

SCENARIO	BASE CASE	COMMUNITY SOLAR ONLY	BTM BATTERY ONLY
PV Size [kW]		64.4	0
Battery Power [kW]			8
Battery Energy [kWh]			14
Generator	NA	NA	NA
Operations			
Hours of Backup Power	0.0	0.0	0.3
Financial			
Capital Cost		$128,750	$10,600
Life Cycle Cost	$376,885		$375,095
NPV		$21,173	$1,790
IRR		11.7%	7.8%
Utility Bill Savings			
Monthly Demand Savings		$ –	$1,013
Avoided Energy Charges		$ –	$(17)
Total Utility Bill Savings 1st Year		$ –	$996

Forecast Value Stack Revenue[45]			
Value Stack Solar		$7,775	
Value Stack Storage		$ –	$42
Total Value Stack		$7,775	$42
Value Stack Per kWh		$0.117	
Total First Year Revenue		$7,775	$1,038
Sustainability			
Solar Energy Production Year 1 (kWh)		$66,231	
NYSUN Solar Incentive		$41,300	

Figure 12. Demand Reduction from a Standalone Battery



[45] Analysis based on VDER Value Stack data available as of February, 2018.

Next Steps: Installation & Operations

Next Steps: Installation & Operations

Once a feasibility analysis is complete and the organization has moved forward with a decision to pursue the project, Resilience Hub planners will convert the preliminary design into a fully engineered system. Procurement processes will vary with each organization's policies, a detailed discussion of which is outside of the scope here. However, given the size of most systems, a turnkey project will be the best value. In a turnkey project, a vendor will provide a complete solution that includes not only the materials and installation, but also the final design, engineering and permitting. Some vendors will offer finance as part of the package either directly through captive finance programs, or by helping the Resilience Hub team put together a package of sources that may equity, debt and grants.

The process will begin with finding the right team to take your preliminary designs and convert them into a buildable, fully-engineered and permitted projects. Finding the right expert team here is critical. Depending on your procurement practices, Resilience Hub planners may select a partner through a normal bidding process or may seek a sole source provider. One good way to get a sense of the options out there is to research projects similar in size, scale and mission to your own. Industry publications like GTM www.greentechmedia.com, Navigant Resesarch www.navigantresearch.com and Microgrid Knowledge www.microgridknowledge.com provide regular coverage of a wide range of projects. Non-profit Clean Energy Group www.cleanergyrgroup.com has a database of case studies for resilient power projects. The Solar Energy Industries Association www.seia.org has news and information about a wide range of projects as does the Energy Storage Association, www.energystorage.org. Trade publications, like Solar Power World publish annual lists of EPCs www.solarworldpowerworldonline.com.

- **Engineering, Procurement & Construction Firms (EPCs):** Include a wide range of local, national and specialists. They may also work as developers, installers, and electricians. Finding qualified Solar EPCs is relatively easy. Finding EPCs with legitimate energy storage system experience at the commercial level is more difficult as this industry is still relatively young. Major systems suppliers will often recommend local EPC contractors who can install both solar and storage solutions. Installers who specialize in small-scale residential systems may not be familiar with the requirements of larger scale commercial systems.
- **Systems Integrators:** Systems integrators are firms with expertise in engineering and project management that combine components from manufactures to create resilient power systems. Many Resilience Hubs sites will be too small for the kind of projects on which Systems Integrators focus. However, microgrid specialists at these firms may be useful resources in the initial phases.
- **Solutions Providers:** These firms manufacture or sell components used in the HyRS. Typically they provide these to systems integrators who then re-sell them to the client. However, a number of solutions providers have developed in-house resources to provide EPC services (and, in some cases, finance). Again, the small scale of many of these projects may prove challenging and the solution provider will connect the Resilience Hub with a certified installer.
- **Developers:** Developers are firms who specialize in operating and owning assets from which they earn a financial return over time. Some developers offer "turnkey services" whereby they handle the details and either handoff a full functioning system or the services from one. These firms seek to build, own and operate assets. Some developers are interested in early stages (working with a host to bring a project from concept to ready to build) or in long-term ownership and operations. For Resilience Hub HyRS, the challenge for developers is often scale. The systems are typically too small and the fixed costs too high to meet the requirements of their business models.

- **Installers:** These firms specialize in the design and installation of solar PV systems and, more uncommonly, storage systems. Installers typically do not have the resources and tools that developers and EPCs do.
- **Electricians:** Licensed electricians will be part of the installation team, typically as subcontractors. While invaluable in many phases of the project, they are typically not equipped to provide design or feasibility services.

Lessons Learned

Lessons Learned

While the Resilience Hub model and the HyRS power solution models are relatively young, we have gathered some common themes or lessons learned as a result of the work.

- **Commit to Resilience Early:** Investing in resilient power solutions involve a series of tradeoffs not only in cost but also performance. Prioritizing goals must be done early in the design process. Attempting to phase in HyRS components to a project under-way creates additional challenges and limitations. Some design decisions (such as the configuration of meters, electrical panels and switch gear) may make later modifications more difficult. Project teams must decide where in their own value stack resilience fits, and accept the tradeoffs associated.
- **Enable Optionality:** If you anticipate that you may retrofit a system with additional functionality later, consider enabling designs with room to grow. As we have seen, some new construction includes the ability to incorporate HyRS components in later phases. However, retrofits and additions typically carry higher costs and may constrain options more than including HyRS features early.
- **Newer is Better:** Newer buildings tend to have modern, code-compliant electrical systems. Older systems can include old, out-of-compliance wiring, inefficient appliances (that require oversizing equipment to serve) and a patchwork of meters and panels. Moreover, efficiently modelling these buildings can be difficult as drawings and load data are seldom available. This, of course, is not always the case.
- **Start with Energy Efficiency & Demand Management:** The most effective use of limited resources is to start by ensuring the building envelope is as efficient as economically possible. Before sizing a HyRS to serve a certain level of load, attempt to reduce that load through greater efficiency.
- **Get Everyone Onboard:** Whether new construction, a renovation or retrofitting a current facility, make sure the design team (architects, engineers, vendors, stakeholders, and building users) have a shared understanding of the project’s goals and limitations. Likewise, carefully vet the design team to understand their approach and philosophy about integrating hybrid systems as opposed to conventional backup generation.
- **Manage Expectations:** Solar PV, battery storage and firm generation offer a range of benefits but also have important limitations. Be sure that all stakeholders are aware of those and do not simply assume that the presence of any one of these components meets their needs. Articulate all goals early (operational, financial, environmental and social), demonstrate how the HyRS meets those (and, when possible, how single-component solutions do not) and address concerns upfront.
- **Practice Resilience:** Resilience assets alone have limited use unless they are properly maintained. Too often failure in critical situations results from problems that ongoing maintenance can prevent. Likewise, ensure that key Resilience Hub staff understand how to use these systems. Training, desktop exercises and hands-on drills are critical to ensure that the HyRS supports the Resilience Hub’s mission.

Appendix A: Resilience Hub HyRS Framework Checklist

Project Launch

- ☐ Select a HyRS Project Team as part of your Resilience Hub Team
- ☐ Set both Resilience and Economic goals for the project (Note: These may change during the process, so be sure to have firm limits on what may or may not be included).
- ☐ Identify Subject Matter Experts (e.g., through USDN and its partners) who can provide support and tools
- ☐ Identify the assumptions that will be used to evaluate a HyRS
- ☐ Establish a budget as well as a project budget
- ☐ Set a project timeline with key milestones for decisions

Feasibility & Planning

- ☐ Identify Critical Loads
- ☐ Collect As-Built Drawings for the facility (particularly electrical)
- ☐ Collect Utility Bills (12-24 months).
- ☐ Identify all the meters that serve the building and the rate class under which they are billed.
- ☐ Collect Interval Data (hourly or 15-minute) if available
- ☐ Conduct a Load Study and Energy Audit
- ☐ If new construction, collect Load Forecasts produced by the engineer
- ☐ Identify a key contact at the local utility to serve as a reference

Design & Engineering

- ☐ Select a consulting engineer who will assist in analyzing proposals
- ☐ Review your facility's capital improvement plan? What in it (like HVAC upgrades) might impact the design and engineering of the HyRS?
- ☐ What space constraints does the facility have?
- ☐ Identify all local permitting requirements (building codes, fire codes, utility interconnection)

Legal & Finance

- ☐ Identify both the property owner and form of property ownership
- ☐ Identify the utility account holder and those authorized to access utility data
- ☐ Evaluate finance strategies. Will you pay for and own the system or will you seek a third-party owner operator? Lease or buy?
- ☐ Review the installation contract to ensure it includes ongoing operations and maintenance, warranties and support after installation

Installation & Commissioning

- [ ] Require updated As-Built Drawings of the system and Single-Line Drawings after the system is installed
- [ ] Require O&M manuals and training (these are typically included with larger projects, but may be overlooked with smaller ones.
- [ ] Require training for key operational staff in the operation of the system

Operations & Maintenance

- [ ] Consider an Operations & Maintenance Contract for the system

Appendix B: Glossary

Alternating Current (AC): The electrical current delivered by the main power grid in which electrical current that reverses direction periodically. Solar PV produces Direct Current (DC) which must be converted to AC for use by most appliances.

Ancillary Services: Services in addition to the delivery of energy that help stabilize the grid and that can include such as voltage and frequency regulations.

Anti-Islanding: Strategies and components used during grid outages to disconnect distributed generation (like solar PV) from the grid both for safety (preventing injury to lineworkers by feeding power back onto the grid) and damage to equipment. Distributed generators must detect islanding and immediately disconnect from the circuit.

Behind the Meter (BTM): A system that produces power primarily for on-site use that may export excess generation to the grid but is not intended to provide solely to the grid.

Authority Having Jurisdiction (AHJ): Entities that enforce codes and standards regulating aspects of power system including planning & zoning, building departments, fire departments, utilities, environmental agencies and others.

Battery Chemistry: The combination of chemicals present in an electrochemical battery; common battery chemistries used for commercial-scale energy storage include: lead-acid, Li-ion, and vanadium redox flow batteries.

Charge Controller: A device that regulates electric current flowing to or from a battery.

Combined Heat and Power (also Cogeneration): Onsite power architectures designed to optimize efficiency by providing both electricity and useful heat.

Combiner Box: A feature of PV systems that combine wiring from array strings.

Critical Load: Electrical loads including appliance, lights and devices that a property owner deems vital to a building during an outage

Direct Current: Electricity that flows in a single direction such as that produced by batteries or solar PV systems.

Demand Charge: A component of an electric rate tariff bill (typically for commercial customers) that charges variable and are based on the peak rate at which energy is consumed during any single period during the month – consuming a lot of energy in a short period of time will result in a high peak demand charge even if very little energy is consumed during other times.

Demand Management: Strategies used to reduce or control peak energy demand.

Demand Response: The practice of reducing the amount of electricity drawn from the grid in response to requests from the utility typically during peak

Direct Ownership: A structure in which the facility that hosts a system also owns the system and receives the benefits from it.

Distributed Generation: Power generation typically located at the site where it is consumed and thus not centralized like most power plants.

Dual Inverters (also "Grid-Forming Inverters"): Inverters that allow operation whether the system is connected or disconnected from the grid.

Energy: The capacity to do work measured in Joules or kilowatt hours.

Grid-Tied: A solar, storage or Resilient Power system that connects back to the power grid.

Grid-Tied Inverter: An inverter that must be tied to the grid in order to function.

Host: The facility or property on which a distributed generation system is located. Depending on the ownership model, the Host need not be the system Owner nor the Offtaker.

Internal Rate of Return: A metric to evaluate an investment over time and that reflects the discount rate required to make the net present value of an investment equal zero.

Islanding: When an onsite power system continues to provide power during a power outage potentially creating safety hazards and damage to equipment unless measures are in place to isolate it from the grid.

Inverter: A device that converts direct current to alternating current.

Kilowatt (kW): 1,000 watts of electrical power.

Kilowatt Hour (KWh): 1,000 watts of electrical power delivered over 1 hour.

Megawatt: 1,000,000 watts of electrical power

Microgrid: "A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode." [U.S. Department of Energy definition]

Microinverters: Inverters that connect directly to solar panels for the purpose of converting DC to AC .

Offtaker: The buyer of power produced from a distributed generation system.

Peak Shaving: A strategy of shifting demand for energy from peak times to other times of day in order to reduce cost.

Power Grid: An interconnected network that links electricity generators and consumers

Power: Rate at which work is done or the amount of energy transferred per unit time.

Power Purchase Agreement: A financial agreement between the owner of a distributed generation system and the entity that purchases the power.

Resilience: The ability to anticipate, accommodate and positively adapt to or thrive amidst changing climate conditions, while enhancing quality of life, reliable systems, economic vitality and conservation of resources. Resilience differs by setting, facility and community.

Resilient Power: Power systems that offer the ability not only to provide critical power to essential facilities and services during a power outage, but also to provide economic benefits throughout the year, by reducing power bills and generating revenue through providing services to utilities and grid operators.

Round trip efficiency: ....

Stand-Alone Inverters: Inverters designed for off-grid applications in which the PV array charges batteries before the inverter converts to AC power for use.

Third-Party Owned: A form of asset ownership used in distributed generation systems where the Host does not own the system on its property, and instead a separate party owns the asset often because the Host cannot take advantage of tax incentives that a third-party can.

Virtual Microgrid: A strategy to coordinate operations and resilient power systems in multiple buildings located in a localized geographic area to approximate the economic and resilience benefits of a microgrid.

Appendix C: Resilience Hub HyRS Development Phases

The following summarizes the phases of a HyRS development project. Each of the Tasks listed below is comprised of multiple subtasks and each deliverable is the compilation of many individual components. Duration and budget allocations will vary widely depending on the complexity of each project.

PHASE	STAGE	TASKS	DELIVERABLES
Development	Launch	Establish project goals Select project team Conduct research, audits & data collection Produce schedule, budgets, finance, construction & operations strategies	Project Team Roster Project Goals & Constraints Project Plan & Timeline (Preliminary)
	Feasibility & Modeling	Complete research Produce technical feasibility analysis Produce financial feasibility analysis	Project Design (Final) Project Plan & Timeline (Final)
	Energy Efficiency & Demand Reduction	Optimize retail energy procurement Identify & install energy efficiency measures Identify & install demand reduction measures	Energy Supply Contracts Load Study Energy Audit Energy Efficiency Upgrades Demand Reduction Upgrades
	Finance & Contracting	Produce finance, construction, procurement & logistics strategies, execute contracts	Finance Package Executed Contracts

PHASE	STAGE	TASKS	DELIVERABLES
Milestone: Financial Close & Notice to Proceed (NTP)			
Construction	**Design & Engineering**	Design & engineer generation, distribution, gas supply and all related civil and MEP	Design & Engineering Package Permits & Licenses
	Construction & Commissioning	Provide construction management, site preparation, full installation, construction, commissioning	Installed System Utility Interconnection
Milestone: Commercial Operation Date (COD)			
Operations & Maintenance	**Operations & Maintenance**	Fuel supply System monitoring Service & maintenance Capital improvements	
	Evaluation	Performance review Production verification	
	Training	Training & Drills	

Appendix D: Resilience Hub HyRS Project Team

Each HyRS team will vary in its membership with the size, complexity and budget both of the host and the project. The following represent key players and skill sets that will be important.

ROLE	RESPONSIBILITIES	SKILL SET	SOURCE
Team Lead	Charter Project Manage Team Manage Deliverables	Project Management	Staff
Consulting Engineer	Develop Deliverables Collect Data Conduct Analyses Manage Subcontractors	Microgrid Design Microgrid Finance Engineering Construction Operations & Maintenance	Microgrid development or engineering firm
Facilities Operations	System operations System maintenance	MEP Operations Familiarity with existing plant	
Finance	Municipal Lead Hub Site Stakeholders	Financial Analysis Accounting Project Finance	CFO (staff, board or both)
Resilience	Emergency Operations Processes	Emergency Operations & Planning, Sustainability	Staff
Construction	Design, Engineer, Procure & Construct Project Manage Subcontractors Procure Permits & Licenses	Engineering Construction	EPC Firm