Assessment of Marketplace Emergence and Potential Benefits of Hybrid Systems with Solar, Storage and Combined Heat and Power (CHP)

Final Report

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NYSERDA Contract 136600 December 2019

Notice

Assessment of Marketplace Emergence and Potential Benefits of Hybrid Systems with Solar, Storage and Combined Heat and Power (CHP)

This is the first of a series of two whitepapers. This paper assesses the value proposition of hybrid systems consisting of Solar+Storage+CHP and provides examples of how hybrid systems with solar PV, energy storage, and CHP can work together to maximize energy resilience for critical operations while minimizing fossil fuel requirements. ***The next paper*** *examines potential frameworks for a successful hybrid CHP system incentive program.*

Executive Summary

Businesses, institutions, and multifamily residential tenants are showing an increased desire for both renewable and resilient energy, while acknowledging that traditional diesel emergency generators can be unreliable[1]. Solar PV systems paired with battery energy storage (referred to as Solar+Storage) are being deployed to deliver some of this functionality with a renewable energy solution. However, for certain customer sites with resource and space limitations, maximizing Solar+Storage will deliver only a fraction of the magnitude and duration of resiliency that the customer may deem necessary. Based on their personal needs and circumstances, some customers may find short-duration (on the order of one day) resilience to be sufficient, while others may require long-duration resilience. Some customers may also place higher value on a 100% renewable solution (Solar+Storage) compared to a solution that incorporates gas-fired generation such as CHP to improve the magnitude, duration, and availability of resilient on-site power..

Heretofore, purveyors of Solar+Storage solutions have not offered supplemental CHP installations, and likewise purveyors of CHP solutions have not offered supplemental Solar+Storage. While some energy service companies may offer custom microgrid projects to larger customers, smaller customers are left to seek two separate installations via contracts with two separate solution providers while taking on associated integration risks. However, most customers (especially smaller customers) would prefer to contract for a single turnkey solution. Currently, if they want a resilient/renewable solution but cannot afford a custom microgrid project they are likely to default to either the Solar+Storage option with insufficient resiliency or the CHP option which lacks renewables.

Fortunately, we are witnessing the emergence of turnkey solution providers offering hybrid Solar+Storage+CHP systems intended to work together in a single coordinated effort, designing the hybrid system to maximize the available renewable energy resources and minimize the required fossil fuel use (and associated emissions). An enabler for accelerating this emergence would be the facilitation of team formations working towards standardized, replicable designs. A well-crafted incentive program could help drive this outcome.

This paper analyzes the current market status and assesses the value proposition of Solar+Storage+CHP systems, with examples for applicability and sizing using both modeled and actual building data. The findings show that if these hybrid options were available in the marketplace, the size of the supplemental CHP within the hybrid system could be downsized relative to -- and with the hybrid system

[1] It's normal for backup generators to fail https://boingboing.net/2012/11/02/in-backup-generators-we-trust.html "In fact, they *won't* work something like 20%-to-30% of the time… Most of the time, these generators just sit around, doing nothing. It might seem like you're keeping them safe, but it's actually a pretty rough way to treat a mechanical system … if you don't burn diesel fuel sitting in the tank, it will start to degrade and clog the fuel filters. Things that don't get used tend to fail."

still achieving the same level of resilience as -- the CHP-only option. The resulting hybrid Solar+Storage+CHP systems would achieve maximum resilience with minimal carbon emissions.

Introduction

Hurricanes, heatwaves, and other weather events across the U.S. have exposed weaknesses in the resiliency of the electric grid, resulting in multi-day power outages impacting critical facilities and vulnerable populations[2] in New York and other states. These events have led to increased research and development, incentives, and deployments for resilient on-site power solutions that allow critical operations and shelter-in-place to continue during extended utility outages. As customers seek solutions, utilities and government regulators are beginning to recognize the potential benefits that distributed energy resources (DERs) and microgrids can provide, including grid support services, load relief, and improved system reliability.

The recent push for resilient power solutions has coincided with technical advancements and cost reductions for renewable energy, battery storage, and microgrid control technologies. At the same time, climate awareness has created a drive to reduce carbon emissions and move towards a renewable and sustainable energy future. Utility customers desire power solutions that are both resilient and renewable, but there are certain situations where renewables may not provide the desired level of resilience, and the currently-available next-best alternative (i.e., fuel-based DERs) may have an undesirable emissions impact. In those cases, a hybrid design (consisting of some renewables paired with some fuel-based DER) can serve as a bridge while resilient renewable technologies continue to improve. Additionally, for any given project, the flexibility to iteratively revise its dispatch guidelines (for example, evolving from operating two prime movers simultaneously to typically running only one at any given time while bidding the capacity of the other into a demand response program) softens the concern over technology lock-in.

Many buildings in New York will require innovative and integrated power solutions capable of supporting both long-duration resilience needs and state and local greenhouse gas reduction goals. In those situations where solar photovoltaics (PV) and battery energy storage can meet only a portion of on-site resilience needs (for example, where space for solar panels is limited, or critical load requirements demand a need for more continuous power), in order to champion appropriate solutions for these situations, the New York State Energy Research and Development Authority (NYSERDA) is

Different Approaches to Resilience in Multifamily Buildings

The desired level of resilience (magnitude and duration) can help to determine the most applicable DER technologies.

Short-term sheltering: Maycroft Apartments in Washington, DC and Marcus Garvey Apartments in Brooklyn, NY recently installed Solar+Storage systems to provide power to community rooms with centralized amenities for up to 3 days and 12 hours, respectively

Unlimited sheltering: The Brevoort in Greenwhish Village, NY and South Oaks Hospital in Amityville, NY use CHP systems to continue critical building operations indefinitely during extended utility outages. Both were able to provide power to tenants during Superstorm Sandy and associated power outages

[2] Vulnerable populations are those needing to shelter-in-place because they are substantially unable to evacuate/self-rescue during an emergency/grid outage, include those with medical needs such as patients at hospitals and nursing homes, and those typically lacking a personal vehicle readily at hand such as occupants of multi-family residences, hotels, and colleges/universities.

interested in assessing the viability of hybrid systems that combine resilient CHP technologies with solar PV and energy storage.

CHP is one of the most efficient ways to produce electricity and thermal energy, and it has reliably proven[3] to be a resilient technology, maintaining operation and providing power to facilities during extended utility outages. CHP has traditionally offered significant carbon emissions savings compared to separate heat and utility-supplied power. As utilities retire coal plants and employ more renewable energy resources, single-technology CHP systems fueled by natural gas will no longer produce those historic levels of reductions. However, when Solar+Storage needs to be supplemented, an optimized combination of solar, storage, and CHP can provide solid, long-duration on-site energy for sites with high resilience needs with the least possible carbon emissions.

Current Hybrid System Offerings

BrightPower offers a "Resilient Power Hub" consisting of integrated 140kW CHP + 73kW Solar PV + 250kW Battery Storage. The Resilient Power Hub was first installed at a 100% affordable housing complex, Archer Green Apartments, in Queens, NY with groundbreaking in September 2018.

GE participated in a team in 2015 that installed a Solar+Storage+CHP system at a commercial facility to explore adaptability and scalability.

Centrica has acquired separate divisions for solar, storage, and CHP, and has established Centrica Business Solutions to market integrated/optimized solutions to customers.

The ability for the market to deliver solar paired with storage, and single-technology CHP is strong. However, there is currently only a fledgling alignment of market actors positioned to deliver integrated Solar+Storage+CHP solutions. For example, most microgrid solutions to date have been constructed piecemeal, starting with existing DERs and adding more generation equipment and advanced controls to manage resources and allow islanding from the grid. Now, with the experience gained from these initial installations, there is an opportunity to transform the market and shift project development towards coordinated efforts where purveyors of these different sub-systems can work collaboratively to deliver hybrid system solutions. These systems can be designed to strike an appropriate balance between optimizing for economics and sustainability for the overwhelming majority of days when the utility grid is available while also being able to serve needed resiliency for those rare days when the utility grid is down.

Renewable solar output can be maximized based on available space. Energy storage can "firm" the intermittent solar to create value when the system is running grid-parallel as well as during island-mode, shift loads to evening or morning hours when solar energy is not available, and facilitate a down-sized CHP system's accommodation of in-rush currents during island-mode operation. CHP can improve the economics of the overall hybrid system during normal days, and during grid outages can be used as a resilient source of power to fill in the gaps that cannot be served with solar and storage. With renewable output maximized, the required size (and corresponding fossil fuel consumption) for CHP would be reduced compared to a single-technology CHP installation, resulting in lower greenhouse gas (GHG) emissions. Modeling shows that hybridizing unlocks the ability to meaningfully downsize the CHP

[3] How CHP Stepped Up When the Power Went Out During Hurricane Sandy https://aceee.org/blog/2012/12/how-chp-stepped-when-power-went-out-d

system and its emissions by between 10 and 33 percent, and thus a hybrid system could be designed to provide maximum resiliency with a minimal emissions impact.

Current Status of Hybrid Systems

CHP is often used as a resilient baseload anchor for microgrids, which can operate independently of the larger utility grid during extended outages. Currently, there are 242 operating and 138 planned microgrids in the U.S. that provide services additional to backup power, and CHP is included as one of the technologies in 68 and 36 of these microgrids, respectively.[4] Microgrids without CHP tend to include backup diesel generators and hope for resiliency during power outages, but CHP typically operates 24/7 and can provide improved resiliency benefits and economics compared to utility power and backup diesel generators.

To date, most microgrids have been built in phases over time, rather than as a single coordinated effort. For example, a microgrid may start with an existing CHP system, later incorporating PV as rooftop panels are installed, and then adding energy storage and a central controller. Designing a resilient microgrid as a single hybrid system could allow end users to maximize renewable utilization (and minimize GHG emissions) while sizing efficient gas-fueled CHP systems to cover critical loads during utility power outages.

The combination of a controllable source of generation, such as CHP, along with energy storage and other variable DERs can provide more power resilience and operational flexibility compared to a single-technology installation. In 2018, the U.S. Department of Energy published a Distributed Energy Resources Disaster Matrix issue brief, which ranks major DER technologies on their vulnerability to major types of natural disaster outage events. The brief noted that CHP fueled by natural gas is one of the least vulnerable technologies, and that there are resiliency benefits associated with combining various DER technologies.[5]

Examining the attributes of current operational and planned microgrids can help to inform the characteristics and design considerations of future coordinated hybrid installations. When examining Solar+CHP microgrids, both operational and planned, there are 47 total microgrids across the U.S.[6] Of these, 19 do not include energy storage, while 28 include some form of storage. The primary driver for development of nearly all of these microgrids is resiliency and reliability.

When energy storage is included in a microgrid, CHP is typically sized smaller and solar is sized larger, compared to microgrids that do not incorporate storage. Energy storage enables PV to be sized larger, as excess power from peak daytime loads can be shifted to provide power at other times. Similarly, microgrids with energy storage may allow smaller CHP capacities, as storage can be used to fill out daytime and evening loads. The difference in CHP and solar sizing in microgrids with (portfolio has 28 sites) and without (portfolio has 19 sites) energy storage can be seen in Figure 1.

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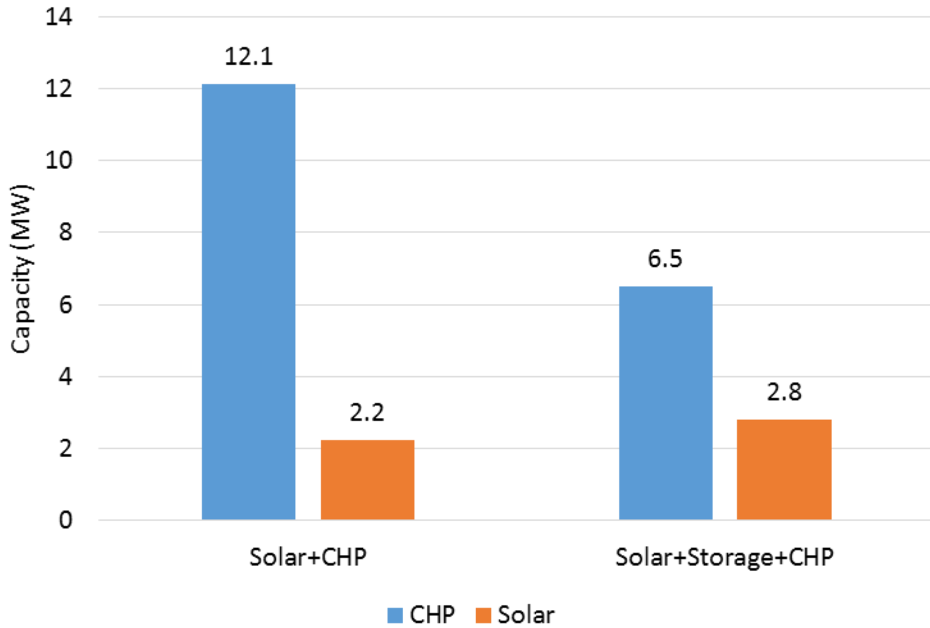
[4] ICF Microgrid Database, October 2019.
[5] U.S. Department of Energy, Better Buildings, Issue Brief: Distributed Energy Resources Disaster Matrix, https://betterbuildingsinitiative.energy.gov/sites/default/files/attachments/DER_Disaster_Impacts_Issue%20Brief.pdf
[6] ICF Microgrid Database, October 2019.

Figure 1. Average Capacity (MW) of Technology by Microgrid



While energy storage can provide benefits when paired with CHP, and some CHP developers are incorporating energy storage or "integration-ready" features in new CHP models, it is interesting to note that there are not currently any planned or operational microgrids that include CHP and storage without also including a solar component.

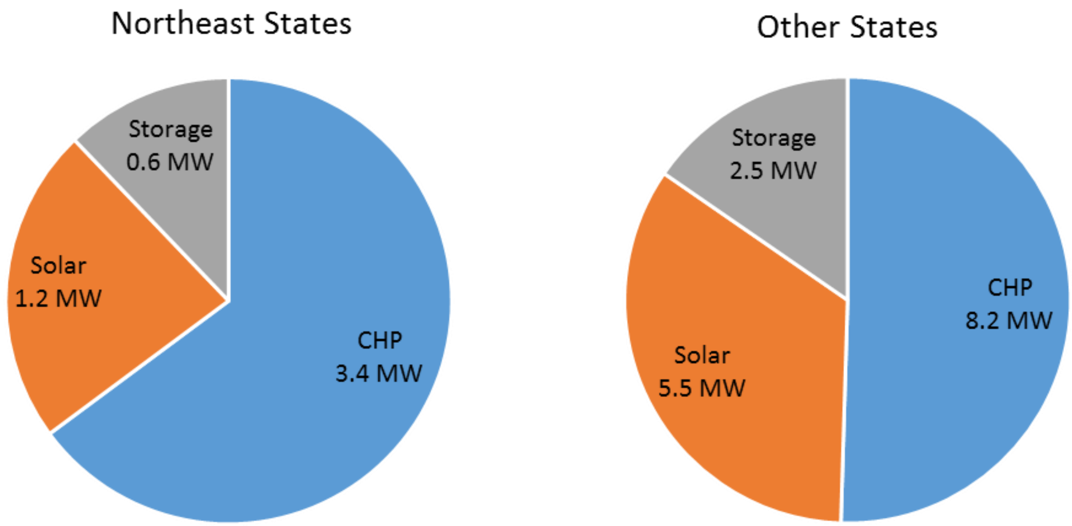
Focusing on just Solar+Storage+CHP microgrids, more than one third of planned and operational systems are located in New York. The breakdown by state and technology is shown in Table 1.

Table 1. Solar+Storage+CHP Microgrids by State and Technology Capacity (MW)

State	Sites	Total On-Site	CHP	Solar	Storage
Arizona	1	39.0	9.0	16.0	6.0
California	6	122.8	52.9	26.4	11.9
Connecticut	3	6.0	4	1.4	0.6
Georgia	1	Unknown	-	-	-
Maryland	2	20.5	14.0	5.5	1.0
Massachusetts	1	Unknown	-	-	-
Minnesota	1	2.4	0.6	0.2	0.1
New Jersey	1	7.9	3.0	2.0	2.0
New York	12	88.0	52.9	7.8	3.6
Total	**28**	**287**	**136**	**59**	**25**

Typical sizing by technology varies considerably according to region. States in the Southwest, such as Arizona and California, are more likely to size solar PV to encompass a larger percentage of microgrid capacity. Meanwhile, states in the Northeast, including New York, are more likely to size CHP relatively larger than the solar and storage components. The breakdown of average technology capacity by region for these 28 sites is shown in Figure 2.

Figure 2. Average Technology Capacity by Region in Solar+Storage+CHP Microgrids



The sizing of solar PV largely depends on available space, which can be constrained in the Northeast. Hybrid system design should ideally start with maximizing renewable output by determining the maximum potential PV capacity and sizing CHP and storage requirements accordingly.

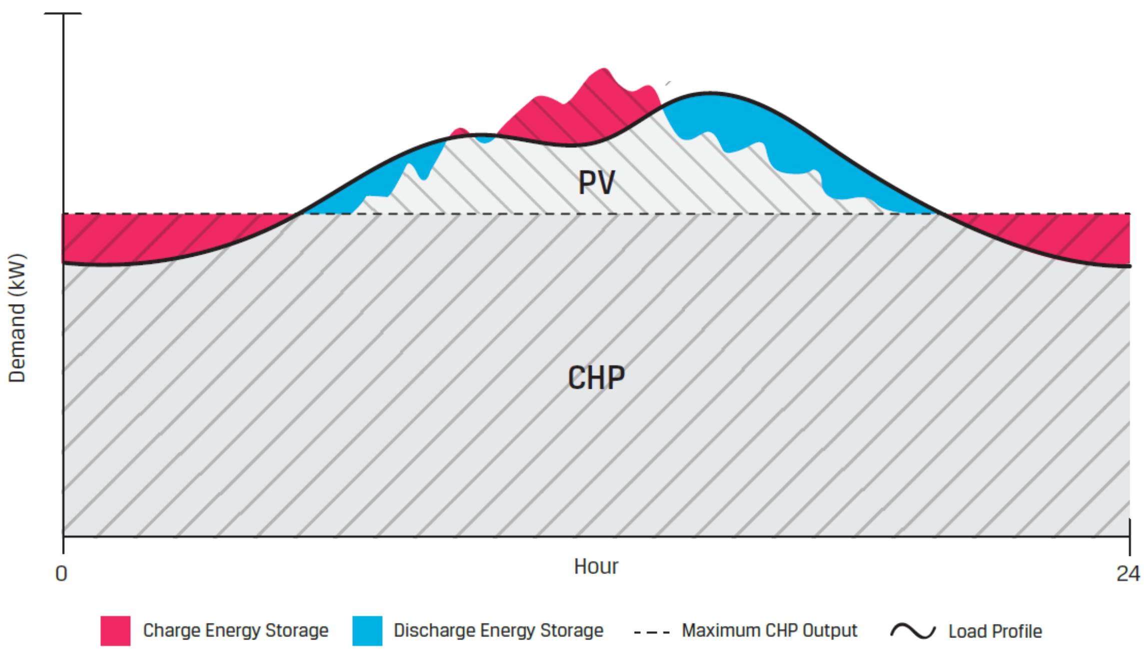
Solar+Storage+CHP Value Proposition

The development of a hybrid Solar+Storage+CHP system allows for the flexibility and optimization of operation of each of the technologies. An individual technology can deliver a successful on-site power solution, but performance gaps can limit the ability for a single-technology solution of solar or storage or CHP to fully capture all potential benefits. A hybrid approach can offer the opportunity for one technology to complement another, offering extra value.

Each technology brings its own set of benefits that, when strategically combined to respond to the needs of end-users, produce stacked values. Combining solar, storage, and CHP in an integrated system can expand the roles of each asset, providing better economics and resilience for the end-user. Leveraging their respective technology characteristics can also provide grid services and support increased deployment and integration of renewables. A standardized, replicable microgrid approach consisting of Solar+Storage+CHP could enable resiliency at substantially more facilities than is affordable based on current microgrid development practices.

In a hybrid system, optimally-sized CHP can be used as efficient and resilient baseload power, reducing the impact of intermittency and short output duration from solar and storage, respectively. When paired with CHP, solar and storage can more effectively provide benefits, with solar reducing grid demand and related emissions in peak hours and storage flexibly charging and discharging, helping to “firm” the solar to meet peak site loads and avoid high demand or time-of-use charges. In the example hybrid system shown in Figure 3, solar, storage, and CHP all work together to fully serve critical facility loads during a utility power outage. During normal operation, the facility would use utility electricity to power non-critical loads (not shown in the chart).

Figure 3. Example of Optimized Hybrid Solar+Storage+CHP System Serving Critical Loads during an Extended Utility Power Outage (ICF)



ICF assessed the viability of this type of hybrid system using actual load profile data to determine the potential for Solar+Storage+CHP systems to maximize critical load resiliency while minimizing emissions and fossil fuel requirements. ICF’s findings, described below, are reinforced by modeling performed by NREL and presented at the ACEEE Summer Study in August 2019. NREL conducted modeling using their ReOPT tool to analyze for a large hospital in California the economic and emission impacts of the CHP-only option, the Solar+Storage option, and the Solar+Storage+CHP option. The results indicate that the integrated hybrid option had a 7% lower life cycle cost than CHP-only, and a 22% lower life cycle cost than Solar+Storage. **The life cycle emissions for the hybrid Solar+Storage+CHP option resulted in a 24% reduction compared to the CHP-only scenario**, and a 17% increase in emissions over Solar+Storage. NREL’s results align with this paper’s thesis that if Solar+Storage is sufficient to meet the site’s resiliency requirement it is the most-desirable option, but when Solar+Storage is insufficient to meet resiliency then the hybrid Solar+Storage+CHP configuration is preferable over the CHP-only option.

Examples of Hybrid System Design and Operation

The Solar+Storage+ CHP value proposition was tested with modeled load profiles and actual 24/7 building data. Two different building types were evaluated: multifamily buildings and hospitals. U.S. Department of Energy (DOE) commercial reference building models in EnergyPlus were used to estimate typical energy end-use loads and critical loads. For multifamily buildings, all common area loads were considered critical, such as tenant common areas, hallways, elevators, etc. Individual tenant loads (with the exception of hot water, served by CHP thermal energy) were not categorized as critical for this analysis. For hospitals, it was assumed that all end-use loads are considered critical to continue normal operations in the event of a grid outage.

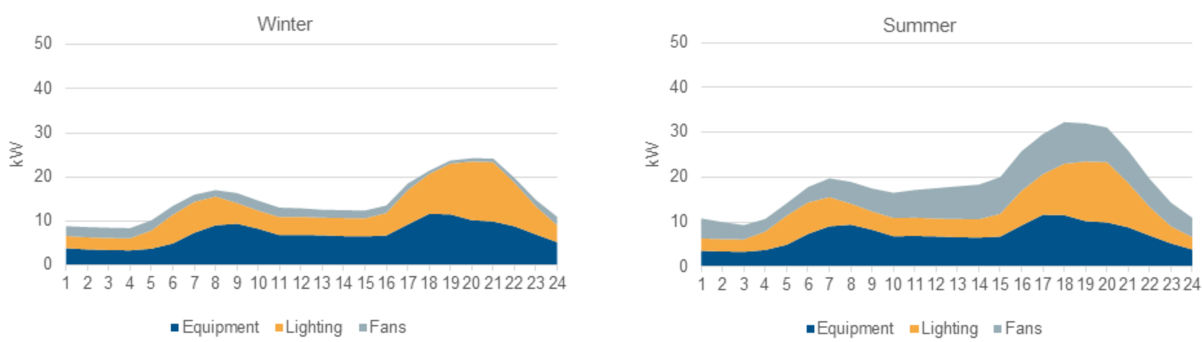
Multifamily Buildings

Modeled Building Loads

The modeled multifamily commercial reference building annual load shapes were used to calculate an average weekday profile for both summer and winter. Both average winter and summer daily load profiles are shown in order to illustrate seasonal differences in peak loads and end-use loads.

Load shapes for the modeled multifamily building are shown below. Tenant loads were removed from the load profile and the resulting critical common area loads for the modeled multifamily building were much smaller in size, with a peak of only 32 kW. Average winter and summer load profiles are broken down by end-use in Figure 4. Load shapes for the summer and winter were relatively similar, with peaks in the morning and evening hours coinciding with tenant activity. The primary difference is the amount of fan operation that would be required in summer.

Figure 4. Modeled Critical (Common Area) Multifamily Load Shapes by Energy End-Use



Hybrid System Analysis for Modeled Buildings

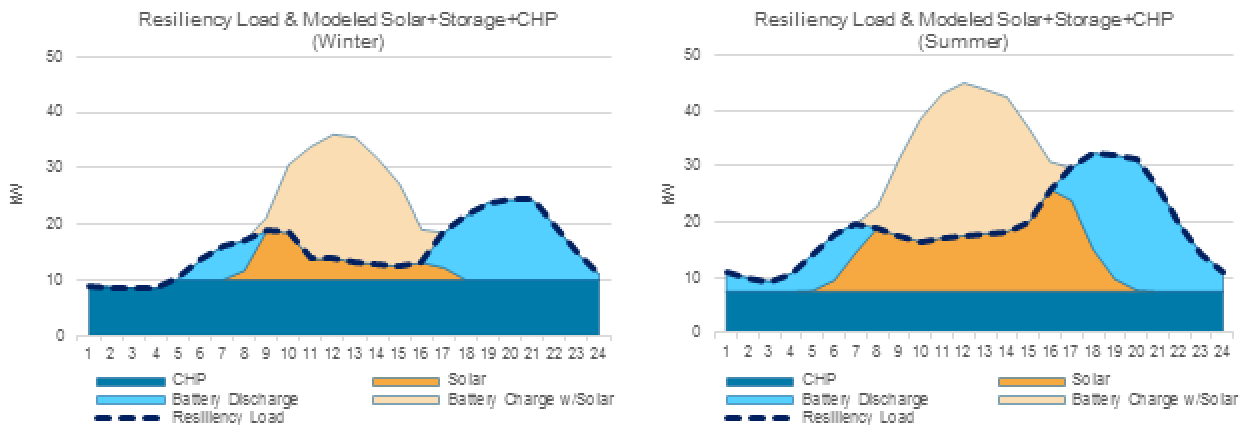
Using the load shapes developed above and reference building model assumptions for rooftop space, we determined the potential rooftop size for solar PV[7] and simulated the solar output for the average winter and summer day for each modeled building using System Advisor Model (SAM).[8] This helped to determine the minimally-sized CHP system for each building which in conjunction with electricity from solar PV and storage/discharge from the battery enables the system to cover critical loads in both winter and summer during a utility grid outage, assuming average cloud coverage. Energy storage incorporated into the building models also helped to address morning and evening loads as needed and maximize solar PV utilization.

The modeled multifamily building was able to accommodate a meaningful amount of solar PV relative to critical building loads. Compared to a CHP system sized for full resiliency requirements (covering all common area loads), the addition of solar PV and storage allowed the CHP system size to be reduced by ~70%. In addition, the size of the CHP system in the hybrid configuration is similar to a CHP system

[7] Rooftop area available for solar PV was calculated using the building rooftop area, multiplying by a PV coverage factor developed by the City University of New York (CUNY), and incorporating an additional sizing factor estimated by NREL's PVWatts.
[8] https://sam.nrel.gov/

efficiently sized to cover the building's hot water requirements. The results for the modeled multifamily building with Solar+Storage+CHP utilization are shown in Figure 5.

Figure 5. Modeled Critical (Common Area) Multifamily Solar+Storage+CHP Load Shapes



The modeled multifamily building includes a hybrid CHP size of 10 kW, compared to 65 kW of solar PV and a 200 kWh battery. Thermal output from the hybrid CHP system was found to match the average modeled summer hot water requirements. Note that multifamily buildings in New York can have significantly higher loads than the reference building model, often supporting CHP systems over 100 kW.

In addition to modeled building load profiles, ICF evaluated the potential use of hybrid CHP systems for several multifamily buildings in New York using actual metered load data, which reinforced the premise that hybrid systems can deliver resiliency at meaningfully reduced fossil fuel consumption.

Hybrid System Analysis with New York Building Data

Metered building data for current New York multifamily buildings with CHP was used to estimate the critical loads that could be served by Solar+Storage+CHP, providing real-world examples of hybrid system applicability. The data was gathered from NYSERDA's DER Integrated Data System[9], with 15-minute load data supplied by Frontier Energy. It included historical electric load data and CHP output, including thermal utilization, for more than ten multifamily buildings in New York. For each building, critical loads were estimated either based directly on monitored common loads or based on synthesized common loads computed via the ratios of common area and tenant loads for the multifamily reference building model. The following are two examples of actual multifamily building cases.

Example 1: Central Park West Towers

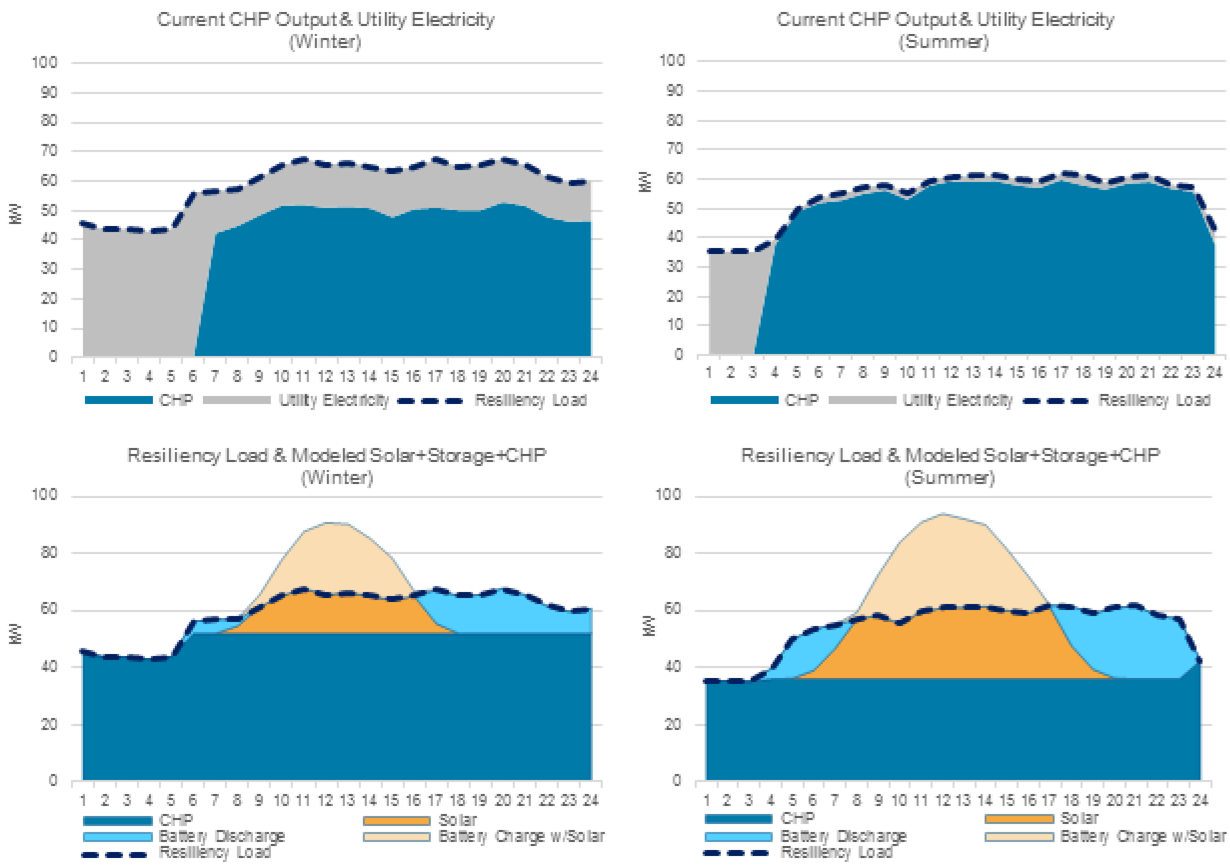
Central Park West (CPW) Towers, located at 400 Central Park West, currently utilizes a 100 kW CHP system. The system is load-following and is rarely operated above 60 kW, but as with several other recent multifamily CHP installations, the system has been sized larger than typical load requirements. The building is direct-metered, which means utility electric loads only cover common areas, and electricity output from the CHP system is also limited to common area loads.

The resilient sizing approach described for modeled buildings was used to size the Solar+Storage+CHP system at CPW. This approach maximized solar output and minimized CHP requirements while also

[9] NYSERDA. Distributed Energy Resources (DER) Integrated Data System. Available at: https://der.nyserda.ny.gov/data/

ensuring critical loads are served on a typical winter and summer day in the event of a utility grid outage. The result of the analysis showed that 85 kW of solar PV could be supported with rooftop space, and combining such solar PV with storage and a 55 kW CHP system could cover all critical building loads on a typical day.   Historical CHP output and utility electricity at CPW for both winter and summer are shown (Figure 6), compared to modeled Solar+Storage+CHP output.

Figure 6. Current CHP Output Operation and Solar+Storage+CHP Output for CPW Towers



A hybrid CHP system would allow for more efficient use of fossil fuels for on-site power. During the summer, CHP could operate at less than 40 kW, compared to the current 50-60 kW range. During winter, the system would operate near the full 55 kW capacity for most of the day. In both Winter and Summer, close to 100 percent of the recovered heat from the CHP unit could be fully utilized for hot water loads. Compared to the CHP size required for full critical operation (~70 kW), the required size for CHP in a hybrid system is reduced by approximately 20 percent.

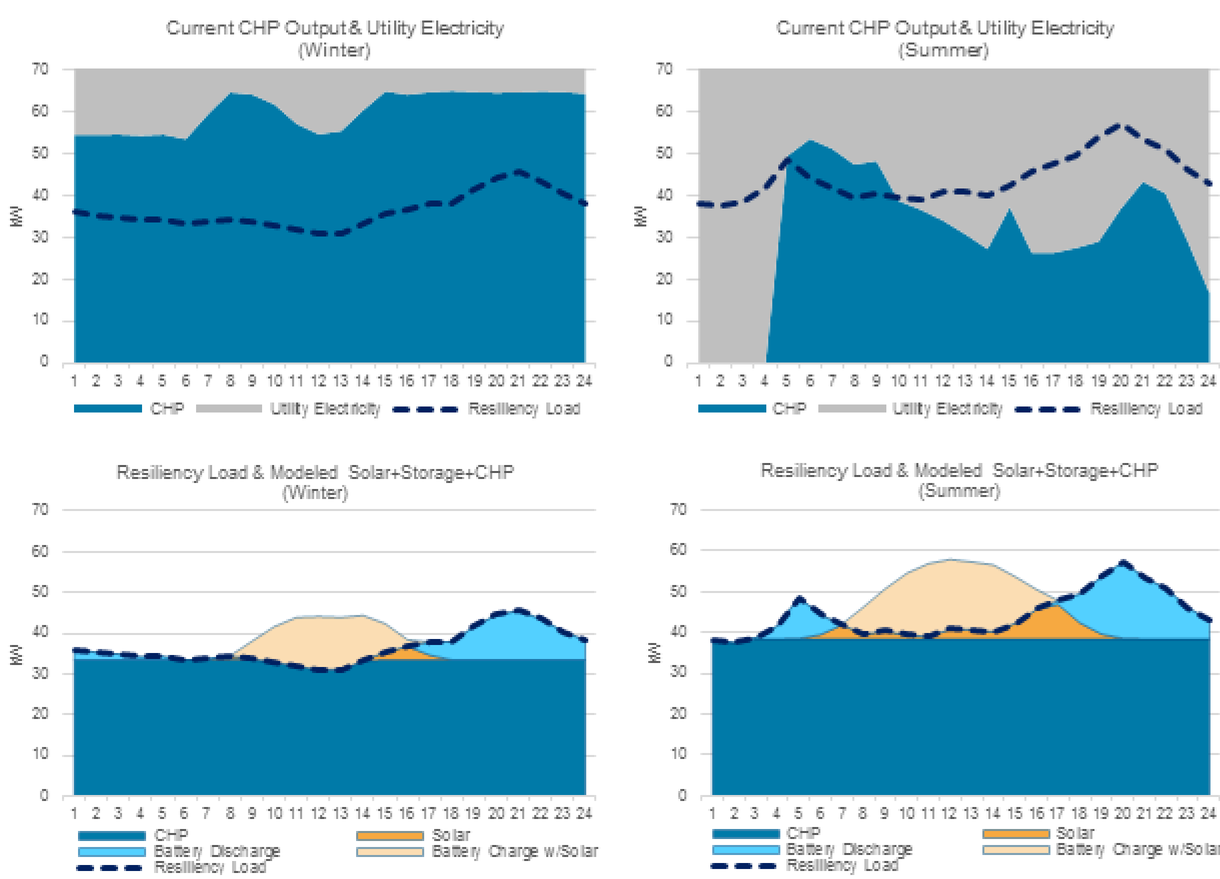
Example 2: Dorado Apartments

Dorado Apartments, a master-metered apartment building in Yonkers, currently uses a 75 kW CHP system for baseload heat and power, primarily covering the building's common area loads. Because the Dorado building is master-metered, electric load data covers both common area and tenant loads. In order to estimate the critical common area loads for resilient operation, ratios from the modeled multifamily building were applied to the total Dorado hourly load data.

The current CHP system can cover all of the common area loads during an outage, but during normal conditions the system operates at less than full capacity in a thermal load following mode, with variable output that depends on the building's hot water loads. In winter, the system operates with close to 70 kW electric output, but in summer the average output is reduced to about 35 kW, less than half of the system's capacity. A smaller CHP system, combined with PV and storage, could operate more efficiently while still covering critical common area loads.

ICF evaluated potential sizing options for Dorado Apartments when maximizing rooftop space for solar PV and incorporating energy storage. Using the same sizing approach, we determined that the Dorado building could support a hybrid system with 33 kW of rooftop PV with a 150 kWh battery, which would support a smaller CHP size of 40 kW. A single-technology CHP system sized to cover critical loads would require a capacity of 60 kW, so the required size for CHP in a hybrid system is reduced by approximately 33 percent.

Figure 7. Current CHP Output Operation and Solar+Storage+CHP Output for Dorado Apartments

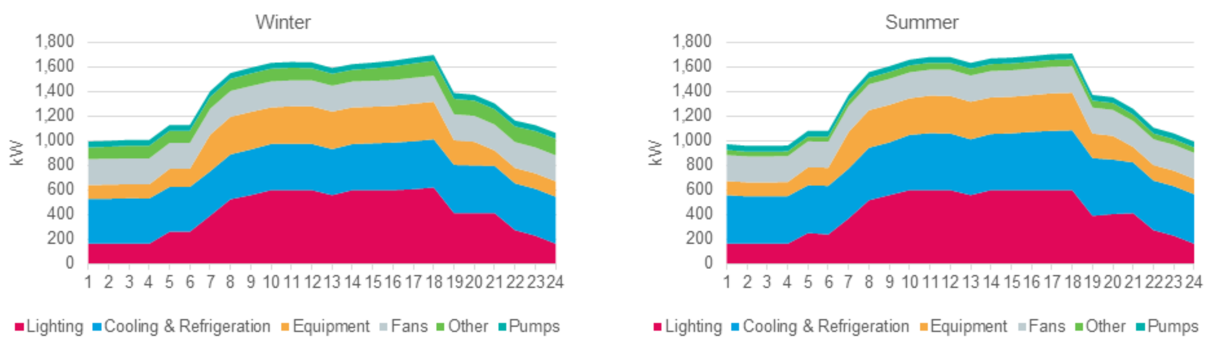


Hospitals

Modeled Building Loads

The modeled hospital reference building annual load shapes were used to calculate an average weekday profile for both summer and winter. The results for the hospital analysis are shown below, with hourly electric loads broken down by energy end-use, assuming that gas is used for heating applications. Both average winter and summer daily load profiles are shown in order to illustrate seasonal differences in peak loads and end-use loads. The modeled hospital in this analysis had a peak load of 1.72 MW, and daily load shapes and end-use loads were relatively consistent throughout the year, with a steady peak throughout the middle of the day. Modeled summer energy shapes required slightly more cooling, refrigeration and fan use.

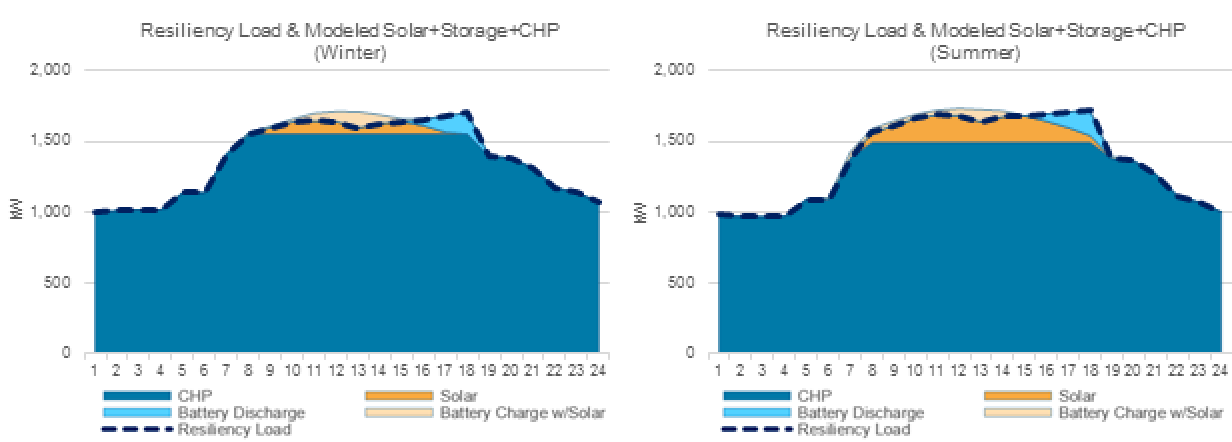
Figure 8. Modeled Hospital Electric Load Shapes by Energy End-Use



Hybrid System Analysis for Modeled Buildings

As explained above, we used the System Advisor Model (SAM) to determine the minimally-sized CHP system for each building, while allowing the building to fully utilize electricity from solar PV to cover critical loads in both winter and summer, and assess energy storage. Solar+Storage+CHP results for the modeled hospital are shown in Figure 9.

Figure 9. Modeled Hospital Solar+Storage+CHP Load Shapes



The modeled hospital was estimated to be large enough to support 390 kW of solar PV. With a peak of 1.72 MW, the CHP system was sized to 1.55 MW, with 390 kW of solar PV and a 460 kWh battery to cover the remaining loads.[10] Because hospital critical load requirements are presumed to include all building loads, and hospitals have a relatively high energy intensity, solar PV output from available rooftop space is small in comparison to total building loads/critical loads. However, incorporating solar and storage into the hybrid CHP system allowed CHP to be sized ~10% less while covering full resilience requirements with the hybrid system.

Summary of Hybrid System Evaluation

In all of the cases evaluated, when hybrid CHP systems are sized for resiliency, adding solar PV and storage allows CHP to be sized smaller, minimizing fossil fuel usage at the site while also preserving the ability to serve critical building loads during power outages. The percentage difference for CHP sizing to cover only critical loads in multifamily buildings can be significant. When sizing a hybrid system for critical loads, nearly a 70% reduction in CHP size was achieved in the modeled multifamily building, whereas a reduction of 20-33% was achieved using actual New York building data. For the modeled hospital, our modeling showed roughly a 10% reduction in CHP size was achieved when rooftop space is used for PV and backed up with battery storage. Meanwhile NREL's modeling showed that the life cycle emissions for Solar+Storage+CHP at a hospital would result in a 24% reduction compared to the CHP-only scenario.

Currently, hybrid systems including solar PV, energy storage and CHP are rarely installed through coordinated efforts. However, there is a chance that well-crafted incentive programs can induce project developers for these different technologies to work together for hybrid system installations that will provide maximum resilience with minimal GHG emissions.

The value proposition of Solar+Storage+CHP was demonstrated with several examples for multifamily buildings and hospitals. For these facilities, the combination of solar and storage, designed to utilize the maximum available space for solar PV, allowed for a significant reduction in the necessary CHP size for resiliency requirements. The hybrid systems would lower fossil fuel use and reduce emissions while providing reliable, resilient power for facilities with critical load requirements.

Next Steps

Hybrid systems will require the formation of teams of installers and coordinated efforts between project developers. NYSERDA has already taken steps to foster these relationships, most recently with the June 2019 *On-Site Resilient Power Conference*. In a follow-up to this white paper, we will explore options for a program that incentivizes Solar+Storage+CHP projects, requiring the formation of developer teams for new hybrid system installations.

[10] The required battery size was estimated at 120 percent of the size necessary to distribute PV loads in a manner that would cover all critical loads with a minimally-sized CHP system.