CADMUS

DRAFT Virtual Power Plant Potential Assessment

CONCORD, MA

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Prepared for:

The Town of Concord, MA &
Concord Municipal Light and Power

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CADMUS

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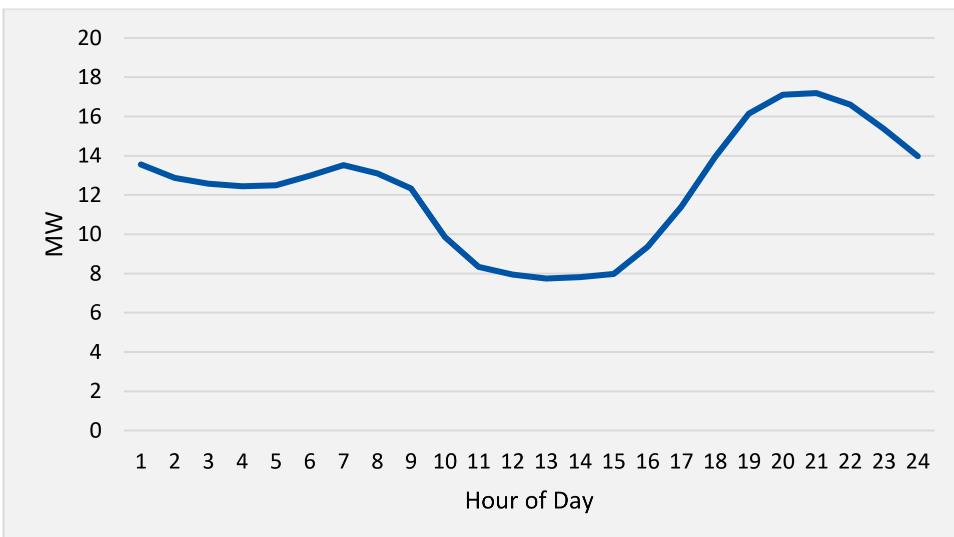
Introduction

The Cadmus Group (Cadmus) has prepared this report for The Town of Concord (herein referred to as "the Town") and the Concord Municipal Light and Power (CMLP) to assess key considerations and best practices for a virtual power plant (VPP) solution that could utilize existing and future excess photovoltaic (PV) generation to support grid stability and facilitate a fully renewable electric grid by 2030. This report contains the results of this assessment, a discussion of VPP program options, and financing and ownership models available to the Town.

Background

As of early 2020, CMLP has 9.6 MW of solar generation installed throughout the Town, 2. This generation comes from two large solar arrays and over 300 residential PV systems. In the future the substantial energy export from the solar arrays to the CMLP grid threatens to reach saturation for existing CMLP infrastructure. Currently, PV generation is such that during shoulder seasons CMLP could risk sending power backwards to the larger grid in the near future, which would damage the substation that connects the CMLP territory to the larger grid. Additionally, PV saturation has dramatically shifted peak observed load by CMLP, from 2:30-4 PM to 6-8 PM daily. This new load shape is clearly seen on May 11th, 2019 during a sunny spring day.

Figure 1: 2019 Minimum System Load Observed on 5/11/19 at 13:00



The Town is considering installation of a VPP network with distributed battery storage with the following goals:

- Provide "solar soaking", charging energy storage assets during peak generation times
- Provide "peak shaving", reducing 10-12 transmission peaks per year
- Increase resiliency in the CMLP network
- Demonstrate viability of using distributed storage to help decarbonize electric generation by "leading by example."

- (Optional) Provide frequency demand response functionality, which could provide a new revenue source for CMLP

A VPP could help CMLP and the Town achieve all these goals. Additionally, the town could integrate its public EV chargers and an its electrified school bus fleet. Additionally, CMLP already has over 1,000 AMI[1] units supplied by NextGrid, which are integrated into iTron meters and can record data at a sampling period of down to seven seconds.

Current CMLP Electricity Load

The Concord Municipal Light Plant provided hourly load data at the Eversource substation. This substation serves electricity to the majority of CMLP's 8,200 customer meters. The monthly energy consumption ranges from a low of 11,165 MWh in April to a high of 16,262 MWh in July as shown in Figure 2. The minimum hourly demand for the year is in May while the Maximum hourly demand is in July as shown in Figure 3.

Figure 2. CMLP 2019 Load at substation

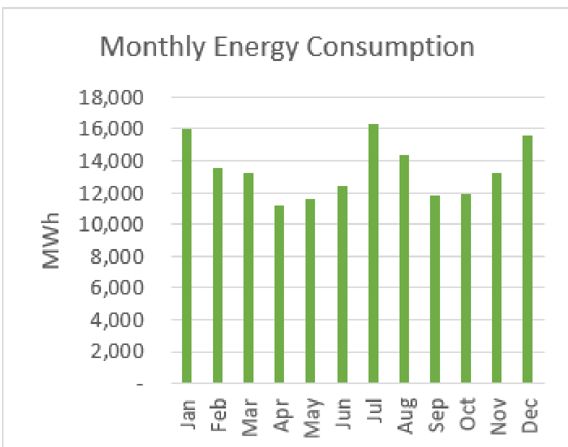
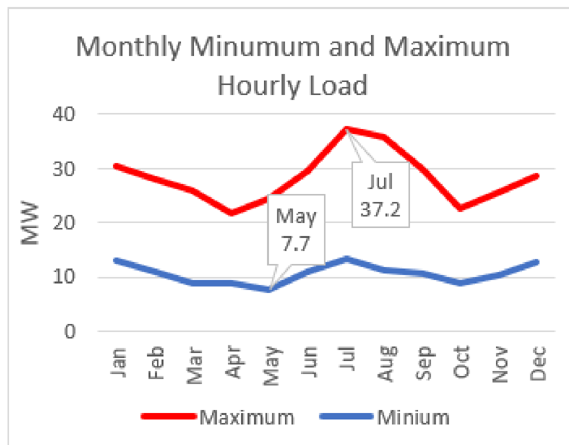


Figure 3. CMLP Minimum and Maximum Monthly Load



Concord's daily load shapes are highly influenced by the nearly 10MW of solar currently installed in the town. The hour of the year with the minimum load occurred on Saturday May 11th at 12pm, a mostly sunny spring day with average temperatures between 55- and 70-degrees Fahrenheit. On this day, PV electrical generation production was high, electric heating use was minimal and air conditioning use was also minimal. The hour with the minimum load matched the hour with the highest PV electric generation. Figure 4 shows the hour by hour net load on May 11th, 2019, the estimated demand is in grey.

[1] AMI: advanced metering infrastructure

Figure 4. 2019 Load Shape on day with Lowest Demand

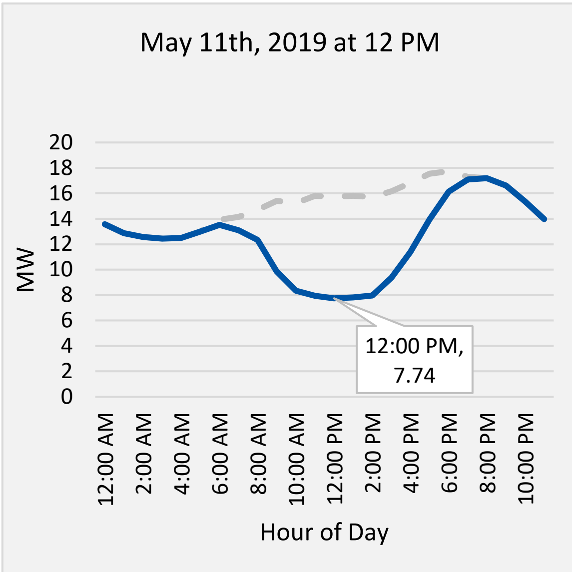
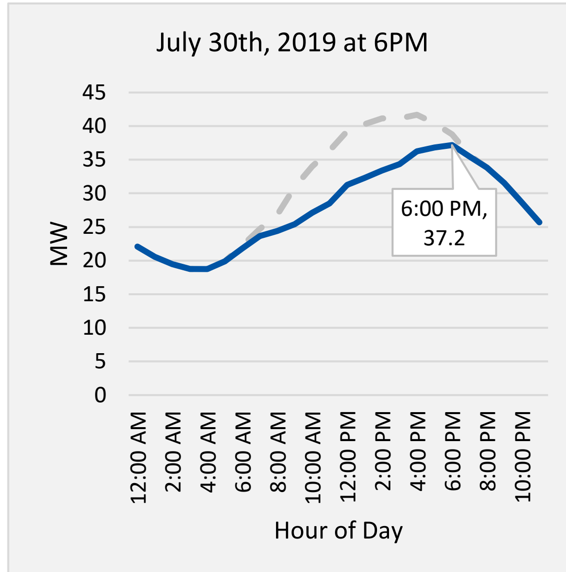


Figure 5. 2019 Load Shape on day with Highest Demand

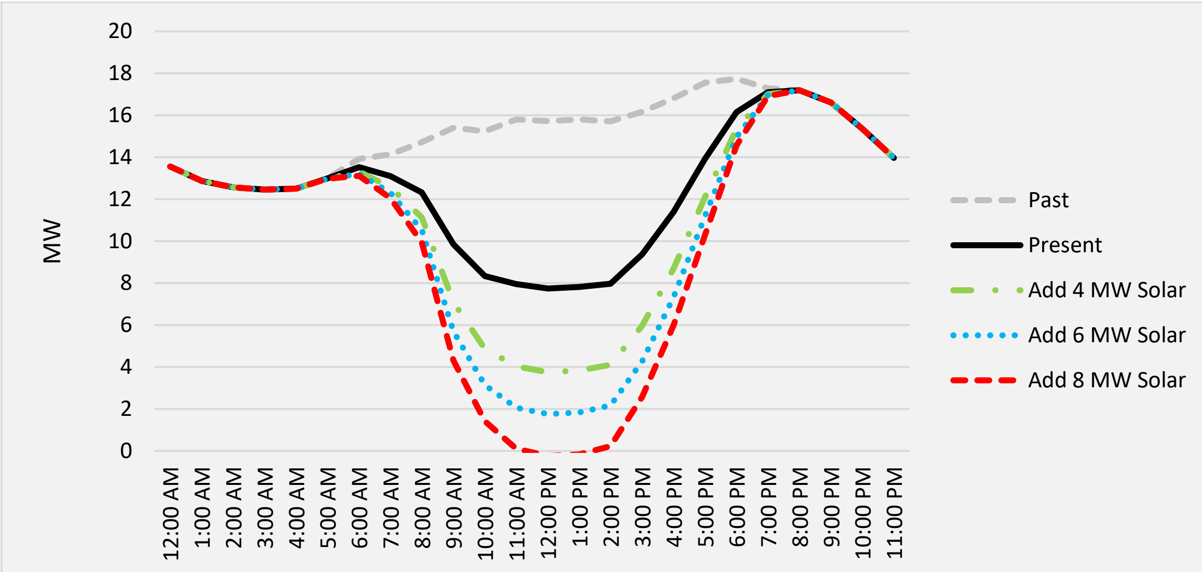


Solar generation has also impacted the load shape on the day with peak demand. Peak demand occurred on Tuesday July 30th at 6pm, shown in Figure 5. Without distributed solar generation it is estimated that peak load would have been 4 MW higher and 2 hours earlier then the observed peak.

Future CMLP Impacts

Increasing intown generation of solar will continue to alter the hourly load shape at the CMLP substation. Assuming minimal changes to the community's electricity demand, it is estimated that town can safely add up to 6 MW of additional distributed PV. Once an estimated 8 MW of additional Solar Capacity are installed the load at the substation will periodically reach 0 MW. Figure 6 shows the projected minimum load in spring with 4, 6 and 8 additional MW (AC Inverter Nameplate) worth of distributed solar installations in the town.

Figure 6. Projected Minimum Load in Spring with Additional Distributed Solar Generation



Utility-Scale Battery Energy Storage System Considerations

In addition to a distributed VPP, energy storage systems paired with an existing utility-scale solar array can provide additional economic benefits to CMLP through avoided capacity costs, avoided transmission costs, and energy cost arbitrage. However, cost-effectiveness of energy storage also depends on the cost of batteries, which vary by size, capacity, and manufacturer. The design of a BESS is influenced by the underling economics and a utilities ability to forecast their coincident peak load. Batteries are sized based on both energy stored (kWh), and output power (kW). The energy storage capacity (kWh) of the battery will depend on the amount of storage material in the battery, while the power rating of the BESS will depend largely on the size of the inverter (kW) that is paired with the battery.

If a utility can predict the coincident peak load of its system within a 2-hour window, then a 2:1 (2 hour) kWh to kW ratio might be optimal. However, if the prediction is not as good a cheaper 4:1 (4 hour) kWh to kW ratio may be a better option.

For analysis throughout this report, we use the following parameters:

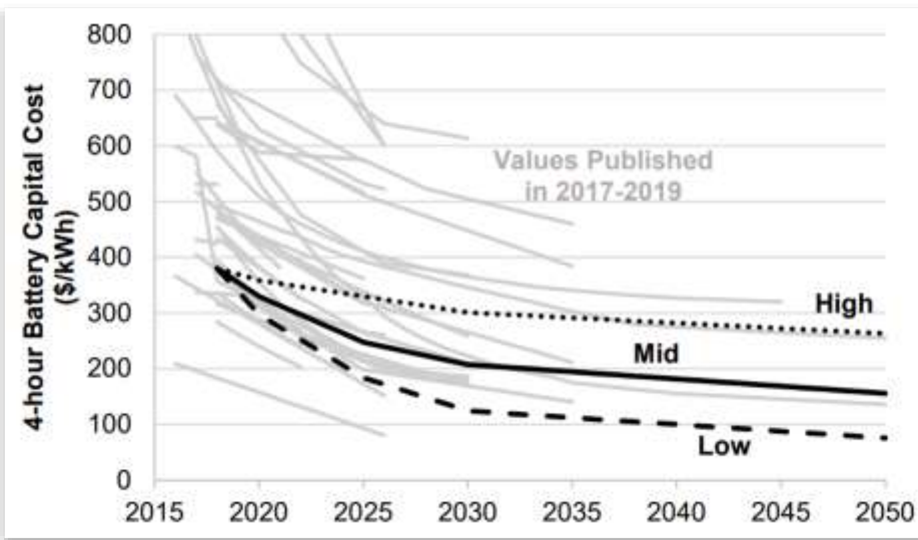
- 2019 Hourly load at substation, includes 9.6 MW of installed distributed solar
- 1.34% Discount Rate
- Energy cost: ISO NE Spot Price of energy for Northeastern Massachusetts (NEMABOST)
- Capacity costs: $64/kW coincident to ISO NE peak load
- Transmission costs: $120/kW coincident to ISO NE peak load
- Installed costs lithium ion batteries: Variable
- 20% minimum for Charge Battery Energy Storage System (BESS)
- Batteries Ratios by: Usable kWh to AC kW
- Battery Costs by nominal kWh

Table 1. BESS Financial Analysis

	4:1 BESS 800kWh / 200 kW	2:1 BESS 800kWh / 400 kW
O&M annual	$1,500	$2,502
Avoided Capacity Charges (Year 1)	$12,800	$25,600
Avoided Transmission Charges (Year 1)	$24,000	$48,000
Energy Arbitrage Savings (Year 1)	$3,363	$5,698
Net Savings (Year 1)	**$38,663**	**$76,796**
Savings per BESS kWh	$38.66	$76.80
Savings per BESS KW	$193.32	$191.99

Battery costs continue to rapidly fall. The current estimate of a 4-hour grid scale battery overall capital costs is estimated to be $330/kWh in 2020 as shown in Figure 7. 2-hour batteries with the same amount of energy storage will be more expensive as will residential batteries.

Figure 7. NREL Cost Projections of 4-hr Lithium Ion Grid Scale Batteries[2]



Virtual Power Plant Considerations

There are several ways to mitigate the impacts of additional solar on the Town's grid through energy storage. These include demand response programs, solar curtailment, central grid-scale batteries, and distributed batteries utilized as a virtual power plant (VPP). For this analysis we look at the ability of lithium-ion batteries, in a distributed configuration, may have to mitigate the impacts of increased solar generation.

[2] Cole, Wesley J, and Allister Frazier. "Cost Projections for Utility-Scale Battery Storage." NREL, June 19, 2019. https://www.nrel.gov/docs/fy19osti/73222.pdf.

First, we reviewed existing VPP programs that CMLP may use as a basis for their own program. After summarizing the programs that have already been implemented, we reviewed the various hardware and software options that are available to CMLP if they were to pursue a VPP solution, and the benefits and drawbacks of each. Once we established the vendors that most directly aligned with CMLP's current goals, we conducted interviews to obtain a deeper understanding of the operating parameters and constraints each vendor offered, and we provided a summary of each discussion. The results of this investigation are provided for CMLP to review, along with a high-level cost estimate for potential distributed energy storage systems, both in a VPP and grid-scale large battery configuration.

Existing Virtual Power Plant Programs

To provide CMLP and the Town with an overview of the current applications of VPPs, we reviewed several currently operating programs, conducting a literature review of each, and interviewed representatives of each program to discuss the strengths and weaknesses of their respective programs.

ConnectedSolutions: National Grid & Eversource

Overview of Program

The ConnectedSolutions energy storage program covers the majority of the Commonwealth of Massachusetts and involves cooperation from all electric utilities in the state, including National Grid and Eversource Energy. The program aims to utilize distributed energy storage assets from residential, commercial, and industrial customers for grid-wide demand response and peak shaving. Control systems were selected to allow for expanding functionality, including frequency response, fast-ramping, and voltage and current regulation.[3] Electric service in much of Massachusetts is relatively reliable, therefore blackout and brownout management and islanding are of lower priority compared to grid peak-shaving, which offers the greatest ability to reduce utility operational costs. In the ConnectedSolution program, customers, not utilities, are the owners of the energy storage systems.

Program Design & Incentives

For commercial and industrial (C&I) customers, there are three separate programs within the ConnectedSolutions umbrella: targeted dispatch, winter dispatch, and summer dispatch. Participants in each program receive day-ahead notice of "events," (no longer than three hours) in which customers must reduce load (for targeted dispatch) or utilize energy storage and load reduction (for winter and summer dispatch). The incentive is calculated based on average instantaneous load reduction (in kW) throughout the duration of all events. Day-ahead notice is provided to the curtailment service provider and/or directly to the customer by email. There is no penalty for not participating in a single event other than the reduction in incentives based on average kilowatts dispatched.

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[3] **Frequency Response**: Using battery storage to compensate for fluctuations of frequency in delivered alternating-current power

Fast-Ramping: Using battery storage to respond to changes in grid electric load that occur too quickly for conventional generation to respond to

Voltage and Current Regulation: Using battery storage to compensate for fluctuations of voltage and current in distribution lines and outlets

Table 2. ConnectedSolutions Battery Incentives

	Targeted Dispatch	Winter Dispatch	Summer Dispatch
Program focus	Demand response	Demand response and energy storage	Demand response and energy storage
Incentive per kilowatt-season	$35/kW-season	$25/kW-season	$200/kW-season
Season	June, July, August, September	December, January, February, March	June, July, August, September
Number of events	2-8	~5	30-60
Event duration	3 Hours	3 Hours	2-3 Hours

For residential customers, the ConnectedSolutions program offers a modest networked thermostat incentive and a more valuable networked battery incentive, which are both dependent on smart home products connected to the grid via the internet. For the thermostat incentive, electric utilities interface with Wi-Fi thermostats across eight brands[4] to reduce cooling load during grid peaks. Before each three-hour event, the utility dispatches thermostats to pre-cool customer buildings by 3°F below setpoint, and then during the event, the thermostats are set to 4°F above setpoint. Similar to C&I customers, the incentive is calculated based on average kilowatt reduction throughout the duration of all events.

The residential ConnectedSolutions program is typically enrolled in next to applications for other rebates like SMART[5]. National Grid claimed that if a residential customer installed a solar-storage system and received a rebate from federal battery investment, the SMART program, and ConnectedSolutions, the payback for the battery would be 4-5 years.

Table 3. ConnectedSolutions Networked Thermostats Incentives

	Winter Dispatch	Summer Dispatch
Incentive per kilowatt-season	$50/kW-season	$225/kW-season
Season	December, January, February, March	June, July, August, September
Event Times	2 PM – 7 PM	2 PM – 7 PM
Max number of events	5	60
Max event duration	3 Hours	3 Hours

Outreach

For the thermostat program, it was found that the only reliable method of marketing ConnectedSolutions was to request the thermostat manufacturer provide marketing materials as part of

[4] Eligible thermostat brands are Building36, ecobee, Emerson, Honeywell/Lyric, Lux, Nest, Radio Thermostat, and vivint.SmartHome.

[5] SMART (Solar Massachusetts Renewable Target) rebates are a Massachusetts solar rebate program that offers rebates based on kWh of solar energy produced. It is paired with ConnectedSolutions as a rebate program for solar-storage installations.

their standard business operations. Once the networked thermostat was installed in the customer's building, the manufacturer would provide information about participation in the ConnectedSolutions program directly to the customer. Similarly, marketing the battery program was done in partnership with battery storage installers, pairing the ConnectedSolutions incentives with SMART incentives[6] and MassSave HEAT Loans[7] to create a single savings package available to customers. National Grid estimates that when ConnectedSolutions participation is combined with SMART incentives, the customer payback of the battery system is 4-5 years.

Technical Operation

Operation of a residential battery system managed by the EnergyHub distributed energy resources management software (DERMS) suite (for both National Grid and Eversource), which interfaces with other battery systems that otherwise may not all use the same communication protocol.[8] EnergyHub allows for control of other distributed energy resources, including networked thermostats and appliances. Eversource also decided to use Enbala[9] as a central control platform for the system, which allows for expansion into further functionalities, like voltage regulation and EV charging integration. National Grid, meanwhile, uses the Enel X platform for central control. The software systems were installed by the vendors under supervision of the utilities, and cybersecurity continues to be the responsibility of software vendors. Utilities only send scheduling data (which is not information that could identify customers) to the DERMS platform, so if a cybersecurity threat compromises a customer battery unit, there is no way for the threat to directly extend to the utilities.

Cost-Effectiveness

The statewide cost of ConnectedSolutions is approximately $6-7 million per year, with 90% of the cost going towards rebates. National Grid can dispatch 4 MW of capacity from C&I customers, and has 150 residential batteries, each providing 5.5 kW during dispatch events, for combined customer dispatch total of approximately 5.6 MW during events. Eversource did not disclose the capacity of battery storage on their network.

Funding for ConnectedSolutions comes from the energy efficiency tariff placed on electricity bills, and currently, the program is working as planned. Expansion is plateauing, because the largest C&I customers have already signed on for both National Grid and Eversource. Eversource's program had an initially slower rate of residential outreach, but they believe that there is still room to increase the number of customers participating in the program.

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[6] The Solar Massachusetts Renewable Target (SMART) program incentives installation of photovoltaic power, but it includes adders for installation of energy storage in the same project.

[7] The MassSave HEAT Loan offers 0% interest loans of up to $25,000 for home performance improvements, including energy storage.

[8] Example communication protocols include OpenADR and SCADA

[9] Enbala is a VPP software system: https://www.enbala.com/technology/the-enbala-engine/

Takeaways

- Eversource suggests focusing battery integration on *customer* objectives to increase the share of customers integrating battery storage, which may not be the same as utility objectives.
- Eversource is focused on increasing reliability primarily, but because Concord has a large ratio of solar generation to grid load, a potential program should focus more on soaking solar and managing internal grid constraints.
- National Grid suggested starting with C&I customers where applicable, because the largest economy-of-scale benefits will arise from the largest customers in the service area.
- National Grid suggested emulating the workflow of the larger ConnectedSolutions program, including vendor choice, noting that adapting an existing chain of software will require less integration time than building a new suite of software tools with no baseline example to build upon.

Resilient Homes: Green Mountain Power

Background of Program

The Resilient Homes program implemented by Green Mountain Power (GMP) is a residential-focused[10] battery storage program designed and marketed as a means of offering suburban and rural customers a backup power source to replace traditional generators, piloted in 2016-2017 as one of the first distributed storage networks in the United States.

The scale of solar generation exported to the GMP grid is such that it can occasionally reach the limits of distribution infrastructure, and installation of storage capacity allows for "solar soaking, reducing the net power sent through distribution assets. This provides GMP an option for reducing peak loads on their grid during critical periods, although GMP specifies that reducing outages for customers takes priority over reducing peak loads.

Program Design & Incentives

The GMP Resilient Homes program consists of offering customers two Tesla PowerWall units, typically installed as two-unit packs in residential and small commercial buildings, although the program is expanding to allow for other battery manufacturers.[11] A significant proportion of participants are rural customers, who are at greater risk of outages.

Batteries are owned by GMP and leased to customers for a flat rate of $30 per month.[12] The lease covers approximately half of the lifetime cost of the battery, and the rest of the cost is recouped through savings from peak shaving. Participants are not required to have photovoltaic (PV) solar panels

[10] Some small commercial customers are also included in the program.

[11] Eligible battery manufacturers include Pika Energy, Sunverge, and Sonnen. Tesla PowerWalls were selected for the 2016 pilot largely because there were not many other options at that time.

[12] The customer pays $15 per battery per month, but almost all customers install two batteries.

installed, but approximately half of customers do. These participants can set their PV panels to directly charge their battery systems, potentially being able to sit out multi-day power outages if operating only critical loads.

Outreach

The program was not heavily marketed in the pilot stages, but outreach has focused on the resiliency benefits of the batteries. The Resilient Homes program offers *no* rebates to customers; instead, customers pay no upfront battery costs through the Resilient Homes program.

Technical Operation

Tesla batteries have their own automated system managed entirely by Tesla and backed by a performance guarantee. GMP has indicated good performance from the automated Tesla system, with respect to battery control and optimization. Cybersecurity for the Tesla systems is handled entirely by Tesla, and because Tesla handles scheduling of the PowerWalls, there is no avenue for a cybersecurity threat from a compromised PowerWall to GMP.

Non-Tesla batteries in the Resilient Homes program, as well as other DER equipment like EV chargers and thermostats, are controlled through the Virtual Peaker DERMS system, using SCADA as a communication protocol for DER equipment. Scheduling through the Virtual Peaker DERMS system is done manually by GMP.

Takeaways

- The Resilient Homes program is functioning as anticipated and expanding.
- With respect to the town of Concord’s goals of installing a virtual power plant in Concord, GMP stressed the importance of setting up a small-scale hardware pilot, noting that despite the additional risk, there is no substitute to a physical pilot.
- Concord may need to consider a different selling point rather than resiliency and backup power, as outages in Concord are more uncommon compared to rural Vermont.
- GMP stressed the importance of customer service. The Town should consider who is running the program, and who will perform maintenance and customer service, whether that be the storage manufacturer or CMLP.

Hardware Review for VPP Systems

A series of battery storage manufacturers were reviewed for viability of integration within a VPP. Manufacturers were evaluated for breadth of options, battery and inverter specifications, PV compatibility DC-DC efficiency (efficiency between charge and discharge of DC power), inverter efficiency, and estimated system operation life.

The manufacturers span a wide set of battery configurations, from residential-scale batteries to megawatt-scale utility batteries. However, there is little overlap between manufacturers that produce residential batteries and manufacturers that sell commercial- and utility-level batteries.

Information for hardware systems is very inconsistent between manufacturers, making comparison between systems difficult—only Tesla provides any pricing information for products, and only Sonnen and SolarEdge provide any information about the rated lifetime of products. Cadmus was unable to secure interviews regarding hardware systems for this study.

An interview with software vendor Sunverge (detailed below on page 16) suggests that many residential-scale battery manufacturers (outside of Tesla) use batteries manufactured by LG Chem. If that is the case, then the primary differentiators between residential-scale lithium battery systems are:

- Integration into software platforms
- Inverter efficiency
- Warranty quality
- Price per unit

A detailed feature matrix for hardware systems is provided in 0.

Software Vendors

Key Program Design Considerations

An important aspect of selecting software vendors for the Concord Municipal Light Plant (CMLP) VPP program is clarifying design priorities for levels of system automation; ownership of assets and data; organization of incentives to participating customers; and managing responsibility for outreach, enrollment, and installation. We investigated the following considerations as part of our software vendor review.

Literature Review

Prior to conducting interviews, Cadmus conducted a review of commercially available VPP software systems, evaluating systems based on a feature requirements list provided by CMLP. Like with hardware systems, software vendors do not publicly provide detailed feature lists—and during interviews with selected software vendors, those feature lists were treated as confidential information. Therefore, the feature lists given are unlikely to be comprehensive.

The VPP software systems evaluated all appear capable of providing basic functionality of monitoring and dispatch of battery systems, instead, differentiation comes from more advanced features like automated optimization tools, integration with home energy management tools, voltage and frequency regulation, and forecasting based on weather or market conditions.

Figure 8 summarizes our literature review of software vendors. The three vendors that provided solutions that most closely aligned with CMLP's goals were interviewed: Sunverge, AutoGrid, and Tesla.

Software Input Options

The control system for a VPP can be controlled through multiple input options, including:

- Manual operation through a user interface (UI)
- Custom operation through an application program interface (API), allowing the operator to write custom scripts to integrate with the control system
- A fully automated system operated by the software vendor, which, depending on the software vendor, may or may not allow for input from the operator

Different software systems may have different strengths in each of these input options.

Asset Ownership

Which entities own batteries—and where those batteries are installed—will have significant effects on what a control system would need to optimize for, depending on where costs and benefits are allocated. Options for ownership include:

- A single utility-owned battery
- A network of utility-owned batteries, which customers lease or receive incentives to install in their buildings

- A network of customer-owned batteries subsidized by the utility

Customer Incentive

Battery installation incentives provided to customers will affect optimization priorities for batteries, cost-effectiveness to the utility, and uptake from customers. Options for customer incentivization include:

- Providing an upfront discount or rebate for installation
- Providing a recurring payment or reduced lease cost
- An optimization or simplification of electric rate costs to increase the value of stored electricity

Outreach and Enrollment

The entities and brands designated to manage marketing and outreach, enrollment, and billing for the VPP program has a significant effect on uptake, as uptake depends partially on whether customers trust the entities acting as the “face” of the program. Entities who could potentially manage outreach, enrollment, and installation include:

- Local battery installation companies
- Software or hardware vendors
- The utility or local government
- Volunteer organizations

Figure 8. Software Vendor Literature Review Matrix

CMLP Operational Requirements		Sonnen	Sunverge	Next Kraftwerke	Enbala	AutoGrid	AMS	Tiko Energy	Tesla
Aggregate DER assets	Must have	x	x	x		x		x	x
Monitor DER assets	Must have		x	x	x	x		x	x
Real-time DER dispatch	Must have	x	x	x	x	x		x	x
Demand Response	Must have		x		x	x			x
Peak reduction	Must have		x			x			x
Peak shifting	Must have		x		x	x			x
Backup power	Must have	x	x		x	x	x		x
Home Energy Management	Nice to have					x			
Frequency regulation	Nice to have		x						
Voltage regulation	Nice to have		x		x				
EV charging integration	Nice to have					x			
Automated control	Nice to have			x					
Smart inverter management	Not important					x			
Market-based optimization	Not important			x			x		x
Weather-based optimization	Not important	x		x					x
Forecasted optimization	Not important						x		
Machine learning	Not important						x		

Vendor Interview: Sunverge

For Cadmus's interview with the VPP software vendor Sunverge, the research team spoke with the CEO, Martin Milani, who provided a summary of the feature set of the Sunverge software suite. These include a broad set of features and they can provide a turnkey storage solution with hardware also provided by the company.

The software suite allows for real time aggregation and control of DER assets like batteries, PV, networked home appliances and thermostats, and EV charging infrastructure. This control includes load forecasting, peak reduction, peak shifting, and backup power maintenance. The system can also account for broader utility parameters like load forecasting, stability analysis, wholesale market analysis, and grid infrastructure improvements like transmission and distribution non-wire alternatives. Notably, the system calls out capacity to bid excess supply to the larger ISO, if possible, with existing infrastructure.

Integration

The Sunverge software system is a partially-cloud-based system that connects to DER assets through gateway boxes that can attach to batteries. The platform comes with an operator-controllable UI, and it can integrate with DERMS[13], ADMS[14], and SCADA[15] systems. These gateways collect load data at 4-second intervals, can disaggregate home loads, and Sunverge claims they provide accurate enough data to use as networked electricity meters, though accuracy requirements will vary from utility to utility. These gateways can connect to the internet using a cellular radio or home Wi-Fi connection, although Sunverge recommends the former in order to facilitate maintenance without requiring contractors to enter customers' buildings.

Sunverge gateways are compatible with most non-Tesla battery systems—in particular, the gateways can integrate with batteries from LG Chem, which many hardware manufacturers adapt for their own battery modules. Sunverge also sells their own hardware systems, allowing for the company to offer fully turnkey installation of a distributed VPP system.

Notably, Sunverge found that customers are more likely to sign up for battery installation programs if the utility bulk-buys batteries. This arrangement hides the high upfront cost of batteries, which can be a significant barrier for customer participation. This was the approach taken by Green Mountain Power for their VPP program.

The platform does not account for the MA SMART solar rebate program offered for solar-storage systems, but Sunverge would be willing to integrate SMART incentives into optimization tools.

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[13] DERMS: Distributed energy resource management system. Virtual Peaker is a DERMS platform

[14] ADMS: Advanced distribution management system

[15] SCADA: Supervisory control and data acquisition

Pricing

Sunverge hardware is priced per-unit, with installation and maintenance costs passed directly to local installers, and an additional per-unit and monthly cost for adding cell modems to hardware gateways. The software is priced on a tiered model allowing for discounts at scale. Sunverge did not disclose specific prices, potentially because those prices are dependent on a per-quote basis.

Sunverge shares collected data only with its utility client and considers it the property of the utility.

Vendor Interview: AutoGrid

For Cadmus's interview with the VPP software vendor AutoGrid, the research team spoke with Clive Thomas and Rahul Kaur, who described the capabilities of the AutoGrid Flex platform as a software suite with a narrower set of features than Sunverge but with high ratings in industry testing.

The AutoGrid Flex system can be used to aggregate and control DER assets from an operator-controlled UI, although there is an automated optimization system and several APIs for custom control. This platform allows for load forecasting, peak reduction, peak shifting, and backup power maintenance and it can operate to the level of individual meters, networked inverters, and smart home technologies like networked thermostats. The AutoGrid Flex platform has tools for EV charger integration and frequency regulation, but it does *not* have support for voltage regulation.

The AutoGrid representatives claimed that their system can scale down to 50-unit pilot programs easily (and that AutoGrid has done so before), and that a Navigant study rated the AutoGrid Flex platform highest in the industry.[16] They also claimed that by the end of 2020, the Flex platform will be managing 10,000 residential batteries in VPP networks in states including California, Hawai'i, New York, and Massachusetts.

Integration

AutoGrid does not sell hardware compatible with its software platform, but the system is hardware-agnostic and compatible with older inverters, and the company can partner with a hardware partner to install storage infrastructure. The system is OpenADR-compliant, which allows connection with VPP networks like ConnectedSolutions in Massachusetts and can work with DERMS tools like Virtual Peaker.

Pricing

The AutoGrid platform is billed on a software-as-service (SaS) model, with pricing dependent on the use case. Pilot programs are billed at a discount, with clear parameters for how prices scale with the network. AutoGrid did not disclose specific prices, potentially because those prices are dependent on a per-quote basis.

AutoGrid shares collected data with utility clients and considers it property of the utilities.

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[16] https://www.giiresearch.com/report/nav931272-navigant-research-leaderboard-report-vpp-virtual.html

Vendor Interview: Tesla

For Cadmus' interview with the VPP software vendor Tesla, the research team spoke with Caleb Patrick, who provided a summary of the Tesla hardware and software system. The Tesla VPP product options are more restricted than other vendor options, although with a much higher brand recognition and total integration than other vendors.

The Tesla VPP system allows for real-time battery network management, including backup power and solar self-consumption, peak shaving and load shifting, demand response and voltage regulation, and broader grid services, although the system has no support for frequency regulation. The system can be operated through an operator-controlled UI and an API system that can connect to a DERMS platform, but the primary focus of the system appears to be the automated optimization system.

Green Mountain Power uses the Tesla VPP package and relies on the automated optimization system. GMP noted strong performance with little input required on their part.

Integration

The Tesla VPP system is operated completely by Tesla using almost exclusively Tesla hardware, including Tesla batteries and EV chargers. As a result, the system does not integrate with smart home technologies that Tesla does not sell, like networked thermostats. The batteries have a networked electricity meter that is not revenue-grade, although Green Mountain Power was willing to use the battery-collected data for metering purposes.

Outreach and installation can be done through Tesla's existing sales team, who are briefed on all available battery rebate programs in a customer's area. Installation can also be handled through Tesla's network of battery installers.

Pricing

Tesla did not provide pricing information about their system, although their customer-facing website suggests that residential batteries would cost approximately $7,500 per 13.5 kWh unit. Tesla noted that customer uptake is higher when the utility takes on some or all upfront cost of the battery units. Tesla did not disclose specific prices, potentially because those prices are dependent on a per-quote basis.

Tesla was much less clear than other vendors about willingness to share user data with utilities.

Analysis and Conclusion

The Town is committed to a clean energy future with an energy goal of reducing its emissions to 80% of 2008 emissions by 2050. In order to reduce carbon emission, the town will need to continue to reduce use of fossil fuels in transportation and buildings by transitioning these energy needs to 100% clean electricity which they aim to do by 2030.

To meet these targets, the town and Concord Municipal Light Plant will need to continue to adopt new technology to prepare for an energy future that looks starkly different than it does today.

The Town has already made progress toward these goals. Currently there are nearly 10 MW of solar installed in the town, including over 300 residences. The town is investing in electric vehicles infrastructure and was one of the first Massachusetts towns to add electric school buses to its school bus fleet. Additionally, the community has shown interest in expanding in-town solar generation. Pursuit of a VPP program will allow the Concord Municipal Light Plant to progress into the new energy landscape.

Concord VPP Technical Analysis

To understand the real battery energy storage systems (BESS) hardware need required to prevent solar from feeding backwards into the grid, Cadmus modeled the town loads with additional solar installation and an energy storage system that could prevent the system from back feeding onto the grid.

For this analysis we use the following parameters:

- 2019 Hourly load at substation, includes 9.6 MW of currently installed distributed solar
- Solar curtailment: not allowed
- TMY weather data for Concord, MA
- 20% minimum charge for Battery Energy Storage System (BESS)

Table 4 shows the results of this analysis, describing the minimum energy storage requirements (and recommended installed BESS capacity) for the Town as additional solar resources are installed.

Table 4. Sizing storage to additional Solar Installations in Concord, MA

Total Installed Solar Capacity	Minimum Energy Storage		Recommended BESS
(kW AC)	(kWh)	(kW)	Nominal (kW)
9,000	100	500	625
10,000	300	1,500	1,875
11,000	1,000	2,500	3,125
12,000	3,700	3,500	4,375
13,000	7,600	4,500	5,625

When additional solar capacity first threatens to back feed on to the grid, storage-supplied power (kW) can be dispatched for short periods of time to handle the relatively rare events. As additional installed solar increases the duration of events increases, this will require the Energy to Power Ratio (kWh:kW) to shift toward energy.

The effects of additional solar installation can also be mitigated by building demand management programs like preheating or cooling buildings and preheating hot water tanks, as well as with BESS installation.

VPP Install Cost Projection

While the economic benefits of a distributed VPP program is difficult to model at this early stage of investigation, we were able to project potential installation costs associated with a residential VPP program. Table 5 compares the economics of battery systems at different installation cost levels for 4:1 and 2:1 battery. The exact costs will depend on contracts with battery installers and manufactures.

Table 5. Installed Cost Comparison

kWh:kW	Installed Cost $/kWh	IRR	Simple Payback (years)	CAPEX for 1MWh BESS	Net Savings BESS 1 MWh (Year 1)	Savings per kWh	Savings per KW
4:1	200	13%	5.2	$200,000	$38,663	$39	$193
	300	9.6%	7.7	$300,000			
	400	5.0%	10	$400,000			
	500	1.5%	13	$500,000			
	600	-	-	$600,000			
2:1	400	17%	5.2	$400,000	$76,798	$77	$192
	500	13%	6.6	$500,000			
	600	9.1%	7.9	$600,000			
	700	6.5%	9.3	$700,000			
	800	4.4%	11	$800,000			
	900	2.8%	12	$900,000			

VPP Program Design

The existing VPP programs in the Northeast, ConnectedSolutions and the Green Mountain Power Resilience Homes program, function quite differently from each other owing to differing priorities and ownership structures.

Interviews suggest that VPP programs have higher uptake from customers when the utility owns the energy storage systems (and thus pays the upfront costs). This upfront cost can be offset by a lease program for the customers, but this requires a selling point for the customers. For Green Mountain Power, batteries were marketed on the promise of backup power in suburban and rural service territory. However, given the strong reliability of power in the Town, another marketing promise is suggested—potentially an option for customers to sign up for a flat-rate electric bill or receive extra rebates.

Additionally, it is important that the Town start VPP implementation with a small pilot of less than 100 customers.

Vendor Selection

Each vendor option provides a different set of benefits and tradeoffs depending on what configuration CMLP prefers for deployment, summarized in Table 6.

Table 6. VPP Vendor Benefit Summary

<table>
<tr><th>Vendor</th><th>Findings</th></tr>
<tr><td>Sunverge</td><td>Largest feature set out of the vendors interviewed for the memo
High capacity for integration, as Sunverge sells their own hardware options
This higher level of integration may reduce issues in deployment and reliability
Successfully deployed VPP system in a Kentucky municipal utility as of 2016</td></tr>
<tr><td>AutoGrid</td><td>Smaller set of value-add features (ie frequency regulation) compared to other vendors
More robust system than competitors with a significant toolset for automation
Experience with pilot programs of 50-100 customers, as well as with larger networks</td></tr>
<tr><td>Tesla</td><td>Highest integration and the lowest potential CMLP staff overhead to operate
Vendor can operate VPP completely with a performance guarantee
Only works with Tesla hardware
Cannot integrate with thermostats or water heaters
Cannot integrate with AMI or EV charging infrastructure not sold by Tesla</td></tr>
</table>

With regards to battery selection, it appears that the major consideration is compatibility with the software vendor, which has less to do with specific hardware or software limitations as it does agreements between vendors.

It also appears that each software vendor has their own approach to metering, which may not be compatible with existing hardware installed in the Town. Depending on the vendor, the software provider may be amenable to adapting their platform for existing infrastructure and rebate programs.

If CMLP aims to implement a VPP with a broad integration of energy storage, thermostats, EV chargers, and other distributed energy assets, then a Sunverge or AutoGrid system would be recommended. The AutoGrid system will likely provide more robust automation tools, whereas the Sunverge system would offer a broader feature set that offers more options for further VPP development and flexibility.

By contrast, a Tesla system would work very well in the Town if broader distributed energy integration was not a concern. Tesla already has a robust installer and sales network that could be deployed for outreach, and once installed, the VPP system could function effectively without significant involvement from CMLP. However, broader integration—or integration with any non-Tesla products—will be severely limited.

Appendix A. Hardware Decision Matrix

Parameters	***Pika Energy***	***Sonnen***	***SolarEdge***
Size of Company (US vs International)	Based in Westbrook, ME Has ~25 employees	Based in Germany Has 300 international employees Has offices in San Jose and Atlanta	Based in Israel Has ~1700 international employees Has office in Fremont CA for USA
Consumer Product Sizes	8.6kWh/3.4kW, 11.4kWh/4.5kW, 14.3kWh/5.6kW, 17.1kWh/6.7kW	**ecoLinx**: 10kWh/8kW, 20kWh/8kW (7kW on-grid) **eco**: 5kWh-15kWh/3kW-8kW	**No in-house battery,** uses LG Chem RESU 10H: 9.8kWh/5kW (1 or 2 units)
Commercial Product Sizes	14kWh/8kW	N/A	N/A
Grid-scale Product Sizes	N/A	N/A	N/A
Works with PV?	Pika PV Link	Claimed; no details given	PV-compatible SolarEdge only makes inverters/management systems/communication software, not panels
Comes with PV?	No	No	No
Comes with Inverter?	Separate: X7600 or X11400	Built-in	They only sell the inverter
Inverter Specs	120/240 VAC, 8kW for backup. 7.6kW or 11.4kW for grid-tie. Input is 380VDC, like Harbor battery	N/A	3.8kW or 7.6kW output grid. 5kW output for backup. 240/120VAC output, 21A output.
Inverter Efficiency	97%	93%	97.50%
Notes	DC-DC efficiency of at least 96.5%	eco batteries have warranty for 10,000 cycles / 10 years ecoLinx batteries have warranty for 15,000 cycles / 15 years	LG Chem RESU 10H batteries are rated for 6,500 cycles

Parameters	***Sunrun***	***SunPower***	***Sunverge***
Size of Company (US vs International)	Based in San Francisco Estimated 1,000-5,000 employees	Based in San Jose Estimated 5,000-10,000 employees	Based in San Francisco Has ~75 employees
Consumer Product Sizes	**No in-house battery,** uses LG Chem RESU 10H: 9.8kWh/5kW (1 or 2 units)	Equinox: 6.5 kWh/4.2kW, 13 kWh/6.8kW	7.7kWh, 11.6kWh, 15.5kWh, 19.4kWh All output to 6kW or 4.5kW
Commercial Product Sizes	N/A	N/A	N/A
Grid-scale Product Sizes	N/A	N/A	N/A
Works with PV?	Yes	Yes	Yes
Comes with PV?	Sold separately	Equinox is PV-Storage as a single package. Helix appears to be a turnkey PV-Storage system	No
Comes with Inverter?	Unknown	Unknown	Yes
Inverter Specs	N/A	N/A	120/240VAC Split phase, 6kW or 4.5kW output Input: 48-140VDC or 195-510VDC
Inverter Efficiency	N/A	N/A	95.7% peak
Notes	Website advertises demand response capabilities in CA and AZ		Interviewed Hardware system has optional heater for outdoor mounting

Parameters	***Tesla***	***BYD***	***Samsung SDI***
Size of Company (US vs International)	Based in Palo Alto Has 45,000 employees. Unclear how many work on ESS	Based in Shenzhen, China Has US office in Los Angeles. Has 750 employees in USA.	Samsung SDI division based in San Jose SDI has 8401 employees
Consumer Product Sizes	13.5kWh/5kW (up to 10 units)	N/A	N/A
Commercial Product Sizes	210kWh (AC)/50kW	40kWh/40kW	8.8kWh, 2 hours, 38.4-49.8V. Can stack into racks for higher voltages
Grid-scale Product Sizes	N/A	1 MWh/240kW, 1 MWh/500kW, 1MWh/1MW, 800kWh/1.8MWh	256 kWh
Works with PV?	Yes	Yes	Yes
Comes with PV?	Sold separately	No	No
Comes with Inverter?	Powerwall doesn't specify inverter. Powerpack specifies inverters between 50kW to 625kW (480V)	Yes, in the commercial system. Sold separately in utility ESS system	Unclear
Inverter Specs	N/A	Commercial: 10kW, 400V 3-phase 50Hz Utility: 500/650 kW, 480VAC 60Hz/360-440VAC 50Hz	N/A
Inverter Efficiency	N/A	97.50%	N/A
Notes	Powerwall has 90% DC-DC efficiency. Powerwall costs $6,500 USD per unit + $1,100 fixed cost	Commercial system seems designed for indoor use Utility system has fire protection and heating/AC system for outdoor use	Unclear

Parameters	RES	LG	ESS Inc.
Size of Company (US vs International)	Five offices in USA: in CO, CA, CT, MN, TX Estimated 1,000-5,000 employees	US office based in Englewood Cliffs, NJ	Based in Wilsonville OR Estimated 11-50 employees
Consumer Product Sizes	N/A	No mention of residential RESU 10H systems	N/A
Commercial Product Sizes	Turnkey custom system	250kW 500kW 750kW 1MW No capacity values given	400kWH/100kW, 100kWh/50kW
Grid-scale Product Sizes	Turnkey custom system	N/A	N/A
Works with PV?	If needed	Unspecified	Unspecified
Comes with PV?	If needed	No	Unspecified
Comes with Inverter?	Unknown	Sold separately: SR "PCS" series	Unspecified
Inverter Specs		250-1067VAC and 515-1868 A, depending on model 50 or 60 Hz	Output 400-480VAC 3 phase 50 or 60 Hz
Inverter Efficiency	N/A	98.7 - 99.13%, depending on model	N/A
Notes	RES seems to offer completely turnkey systems	ESS Systems have DC-DC efficiency of over 98%	ESS sells *liquid flow batteries*, not Lithium ion systems