CADMUS

Solar and Energy Storage Feasibility Assessment

CONCORD, MA

May 22, 2020

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The Town of Concord, MA

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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 evaluate the feasibility of solar and storage at selected town properties. This report contains the results of this assessment, a discussion of PV and storage technology basics, and financing and ownership models available to the Town.

The specific town properties analyzed are the Concord-Carlisle High School (CCHS), the Beede Swim & Fitness Center, the Free Public Library and the Harvey Wheeler Community Center. A desktop analysis of the solar and storage potential for each of these sites was performed using satellite images and monthly utility bills provided by the Town.

Cadmus created seven preliminary solar photovoltaic (PV) array designs for several municipal sites throughout Concord, MA. The designs illustrate configuration and electricity production potential based on publicly available satellite images, and additional information provided by the Town. The estimated annual production offered in this analysis can be used to project annual energy savings for the Town across all potential PV arrays. We would expect site specific energy savings to continue over a 25-year timeline with minimal (approximately 0.5%) annual performance degradation. With the savings and energy production from Cadmus' site findings and preliminary design, we populated our economic pro-forma to project 25-year financial savings for each preliminary array to provide the Town with an overview of what to expect from each site.

Solar and Energy Storage Benefits

Solar Only

PV systems provided significant opportunities for the Town to produce its own energy and lower utility bills at all Town properties studied. Solar PV-only systems can reduce energy charges on electricity bills and depending on the energy use profile at individual sites and interconnection type, solar PV systems are also able to reduce demand charges.

Integrating Solar and Storage

Integrating storage systems with solar PV provides added benefits including augmented demand charge savings, added resilience, and environmental benefits. Generally, solar PV will alter a facility load shape from a broad mid-day peak to a narrower late-afternoon peak. Energy storage can be discharged during the narrower peak to achieve greater demand charge savings. Solar and storage resources can provide power for emergency loads during longer grid disruptions. Additionally, storage systems can be utilized to reduce grid export from PV systems. Finally, stakeholders may value the environmental benefits of charging the storage system from an on-site renewable energy source, rather than the electric grid. To maximize energy savings and revenue generation potential, storage developers try to deploy systems with multiple use cases.

Demand Charge Reductions

Solar PV and storage systems can reduce the demand charges for monthly peak energy consumption.

Depending on level of consumption and utility rate structure, demand charges can be as much as 70% of a building's electric bill. Based on the provided utility bills, CMLP's demand charges range from $9.88/kW at to $10.85/kW.

Energy Resilience

Solar PV systems can provide buildings with alternative energy generation options during grid interruptions. When combined, solar PV and storage can effectively provide backup power for critical facility functions during power outages. Storage increases the resiliency of a facility's power supply and can enable continuity of critical electric services in cases of power failure. Critical services might include heating and cooling, emergency lighting, and elevators, and can be determined on a per-facility basis.

Energy Arbitrage

Property owners subject to variable electricity pricing can leverage price gaps with the use of behind-the-meter energy storage to reduce their electric bill. By charging the storage system when utility electricity prices are low and discharging when prices are high, facilities can shift consumption to lower-cost electricity periods. CMLP's current rate structure does not differentiate between on peak and off-peak times for the selected sites. However, the marginal cost of purchasing energy from the ISO-NE grid is tied to the variable ISO-NE spot price of energy for Northeastern Massachusetts.

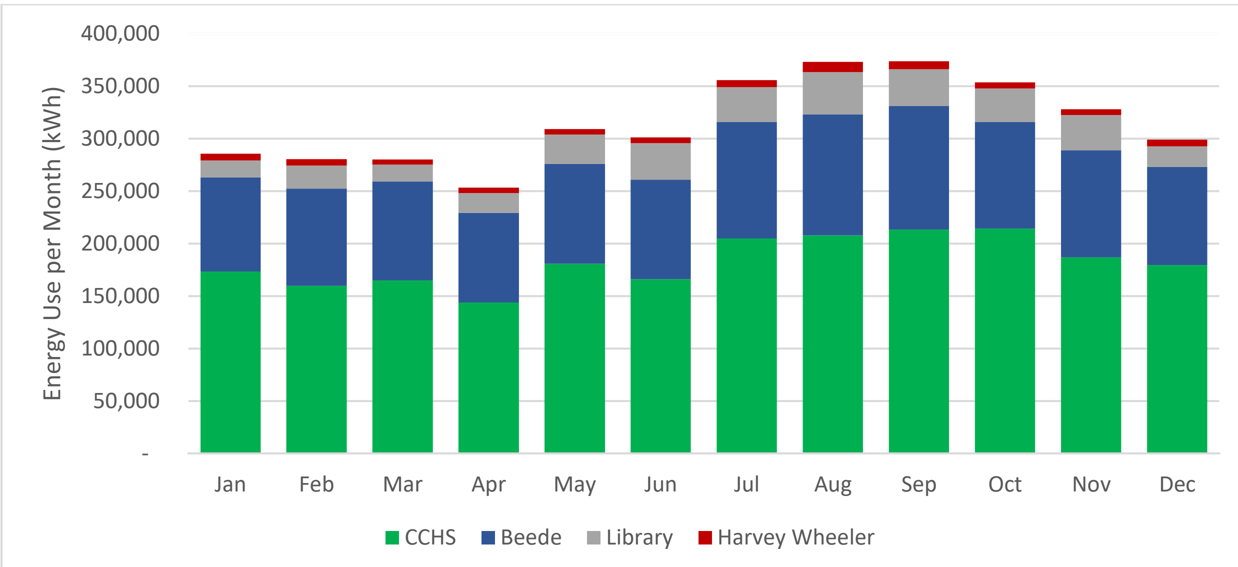
Participation in Demand Response Programs

Demand response (DR) programs compensate participants for energy they can export to the utility grid when utility-wide demand is high and system reliability is at risk. Demand response programs are one way for a utility to provide strong incentives for storage systems to help reduce system peak demand. Storage systems can enable owners to strategically manage energy usage to participate in these programs. CMLP currently has a voluntary demand response program but does not offer any monetary compensation for responding to DR events.

Summary of Selected Town Building Energy Usage

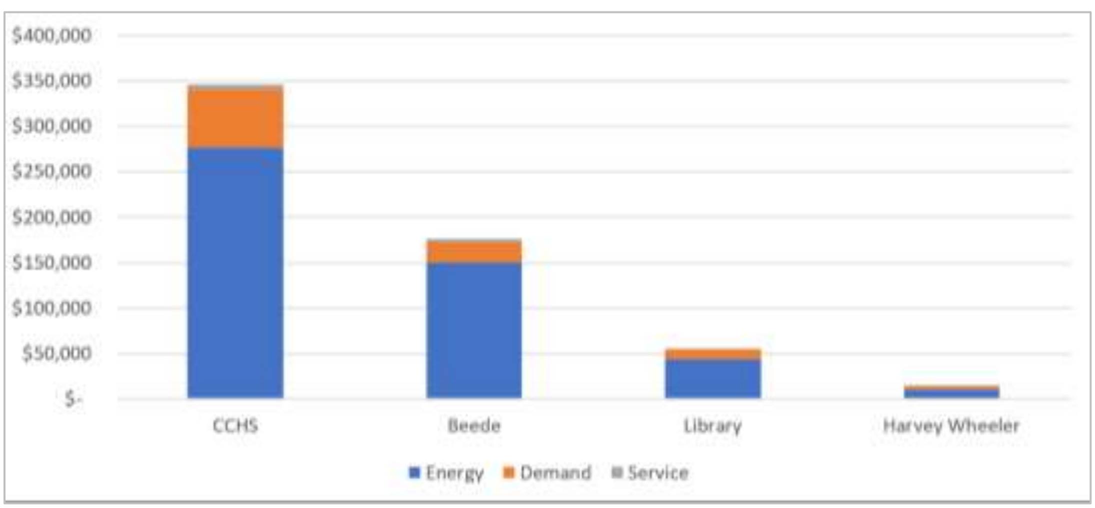
The Town of Concord provided electricity bills from 2019 for the Concord- Carlisle High School (CCHS), the Beede Swim and Fitness Center, the Free Public Library and the Harvey Wheeler Community Center. All sites have both energy and demand charges on their electricity bills. Figure 1 shows the monthly electric energy usage of each of the selected sites.

Figure 1: 2019 Electricity Usage at Selected Town Facilities



The total cost of electricity service for the four buildings in 2019 was $1.2 million. Figure 2 shows the annual bill at each of the sites with component energy, demand and customer service charges. This study will focus most of its analysis on CCHS and the Beede Swim & Fitness Center as the have the largest electricity bills and the largest capacity for potential for solar installations.

Figure 2: Annual Electricity Bills at Selected Town Facilities



Summary of Solar Feasibility

The specific sites analyzed for solar technical and economic feasibility, and their estimated system capacities and annual productions, are listed in Table 1. Locations 1-6 are all located at the campus of the Concord-Carlisle High School (CCHS) and Beede Swim and Fitness Center, approximately 1.3 miles from the Town center. The Free Public Library is located in the Town center and the Harvey Wheeler Community Center is located in West Concord. Based on these initial results, locations 1 and 3 could be developed immediately.

Table 1: Solar Feasibility

Location	Type	Nameplate kW DC	Annual Production MWh	# Panels	Tree Removal
1 - CCHS	Rooftop	365	443,000	1000	No
2 - CCHS	Carport	323	425,000	885	Yes
3 - Beede Swim	Rooftop	90	111,200	247	No
4 - Beede Swim	Carport	167	222,200	484	Yes
5 - CCHS east field	Ground	236	308,000	684	No
6 - CCHS center field	Ground	354	479,000	970	Yes
7 - Library	Rooftop	9	11,300	32	No
8 - Harvey Wheeler	Rooftop	13	16,600	37	No
Total		**1557**	**1,988,400**	**4,339**	

Summary of Storage Feasibility

Battery energy storage systems (BESS) provide limited economic benefits to the individual sites under the current CMLP site specific tariffs. Introducing a Demand Response Program would greatly increase the economic feasibility of Battery Storage across all the sites studied. Additionally, Battery Prices are expected to continue to decline so the economic feasibility may change in the not too distant future.

We reviewed satellite photos and Google street view images to assess the physical feasibility of installing BESS at each of the selected sites. We found that the CCHS campus has ample space to accommodate a large outdoor battery installation while the library does not have an obvious location for an outdoor battery storage system, but it is believed a small battery could be mounted to an exterior wall on the west side of the building. The Harvey Wheeler community center could have an outdoor battery system installed in the rear parking lot. Large lithium ion batteries are not currently recommended for indoor installations per Fire Department standards.

Table 2: Storage Feasibility

Building	Nameplate kWh	Technical Feasibility	Site Specific Financial Benefit	Site Specific Financial Benefit with DR
CCHS & Beede Campus	290 - 1900	High	Low	Medium
Library	16	Medium	Medium	Medium
Harvey Wheeler	10	Medium	Low	Medium

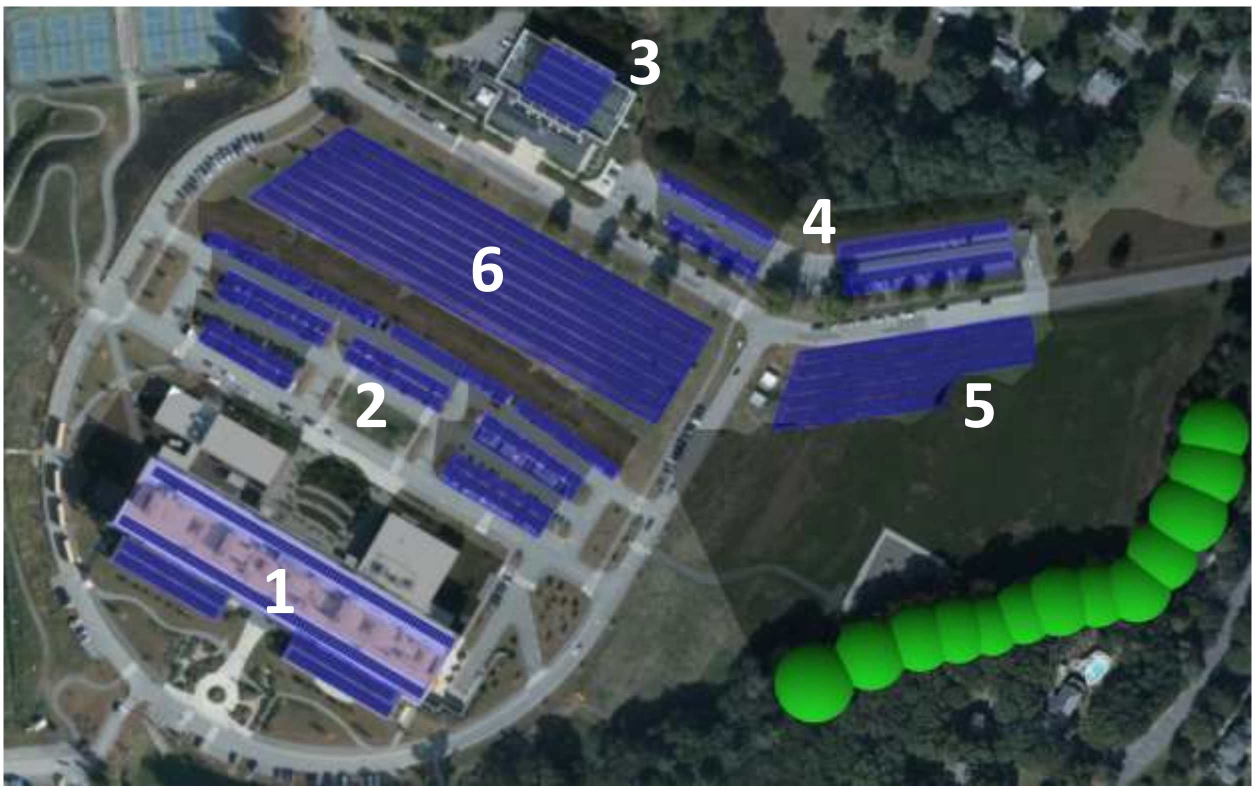
CCHS and Beede Campus Solar and Storage Technical Feasibility

Solar Feasibility

A preliminary site assessment was performed to identify where solar panels could be installed on the Concord-Carlisle High School and Beede Swim & Fitness Center campus. Sport fields were not considered for solar installations; however, two empty fields were considered.

The maximum solar potential for the entire campus was modeled. The maximum potential does consider the impact of shading from trees on the property but does not consider the shading impact of trees on the property's perimeter. Figure 3 shows the solar potential for the entire property. The individual solar arrays are numbered one through six as identified in Figure 3.

Figure 3: Maximum Site Potential



These solar PV arrays would be able to generate approximately 87% of the electricity consumed by the high school and Beede. This initial analysis represents what is the maximum solar potential of the site, no considerations have been made for aesthetics, landscaping, slope. Additionally, the central and east lots are assumed to be fully acceptable for consideration of carport construction. This model has a name plate capacity of 2.3 MW and annual production of 2.9 GWh.

Solar Shading Analysis

Next, we performed a shading analysis to determine how the campus's tree population impacts the production potential of the solar arrays. The high school opened in 2015 and much of the initial landscaping and tree planting was performed around the same time. Figure 4 shows a photograph of the parking lot with a tree next to a van for scale. These trees could be removed in exchange for other landscaping options if solar carport structures are pursued.

Figure 4: Trees in the Parking lot of CCHS

The parking lot of Beede (5) has several large mature trees, including the ones pictured in Figure 5, that shade parking lot. These trees would need to be removed to consider this site for development.

Figure 5: Trees in the Parking lot of Beede

Additionally, the perimeter of the campus has large mature trees on top of a hill shown in Figure 6. These trees limit the size of an array on the east field of campus.

Figure 6: Trees on the SE Parameter of the Campus

When shading is considered, only about half of the solar PV panels identified in the maximum site potential analysis should be installed without tree removal.

Figure 7: Site Shading Analysis

The impact of the shading analysis on the feasibility of solar for the campus are discussed below.

1. The roofs of the high school are the best candidates for solar, and together could host 365 kW nameplate of PV modules. The roofs are free of significant shading from trees.
2. The central parking lot of the high school could host solar parking canopies that would support a 323-kW array. However, there are currently several trees within the parking lot that would have to be replaced with smaller vegetation for these solar canopies to be economically feasible.
3. The roof at Beede is an excellent candidate for solar, and together could host 90 kW nameplate of PV modules. The roof is free of significant shading from trees.
4. The parking lot at Beede has several large trees that would dramatically shade the parking PV array. This site is not recommended without significant tree removal. If these trees were replaced with shorter vegetation, this parking lot would provide space for a 167-kW array.
5. On the east side of the campus there is another large field that could host a PV array. However, the trees on the southeast corner of the property shade a substantial portion of the lot. Our preliminary desktop shading analysis indicates that 236 kW could be installed, which would still effectively produce energy year-round.
6. There is a large field in the central campus that is currently serving as stormwater management for runoff from the central parking lot. This field could potentially host a 350 kW PV array. The field has a row of young trees on the southern border with the parking lot which will grow to create more significant solar obstructions over time. If these trees were replaced with shorter shrubs or grasses then the array could be as large as 910 kW.

Solar Recommendations

Table 3 shows a summary of each of the solar arrays discussed above with the size of the recommended array size for each location. Additionally, information about each of these arrays is provided in Appendix A: Details of Individual Solar Installations on page 22.

Table 3: Summary of Solar Feasibility for CCHS and Beede

Building	Type	Nameplate kW DC	Annual Production MWh	# Panels	Tree Removal
1 - CCHS	Rooftop	365	443,000	1000	No
2 - CCHS	Carport	323	425,000	885	Yes
3 - Beede Swim	Rooftop	90	111,200	247	No
4 - Beede Swim	Carport	167	222,200	484	Yes
5 - CCHS east field	Ground Mount	236	308,000	684	No
6 - CCHS center field	Ground Mount	354	479,000	970	Yes
Total		**1535**	**1,988,400**	**4,270**	

Tree removal is a delicate subject for many stakeholders. Trees provided many benefits to the community. They create an aesthetically pleasing campus and provide shade in the summer, while allowing light through in the winter. This report does not attempt to quantify the value of the tree population on the campus, other than to say that the carbon reduction benefits of solar PV are greater than the carbon sequestration of trees, and thus tree removal and replacement with solar PV and shrubs would provide a net benefit for the Town's carbon reduction goals.

There are substantial solar PV opportunities with the current tree population, and the two best sites, the roofs of the CCHS and Beede, do not require any tree removal. Table 4, shows the site potential with and without tree removal.

Table 4: Solar PV Feasibility Complete Campus

	Site Potential with Tree Removal	Site Potential without Tree Removal
DC Nameplate	1.5 MW	1.2 MW
Inverter AC Nameplate	1.2 MW	1.0 MW
Annual Production	1.9 GWh	1.6 GWh
Performance Ratio	84%	84%

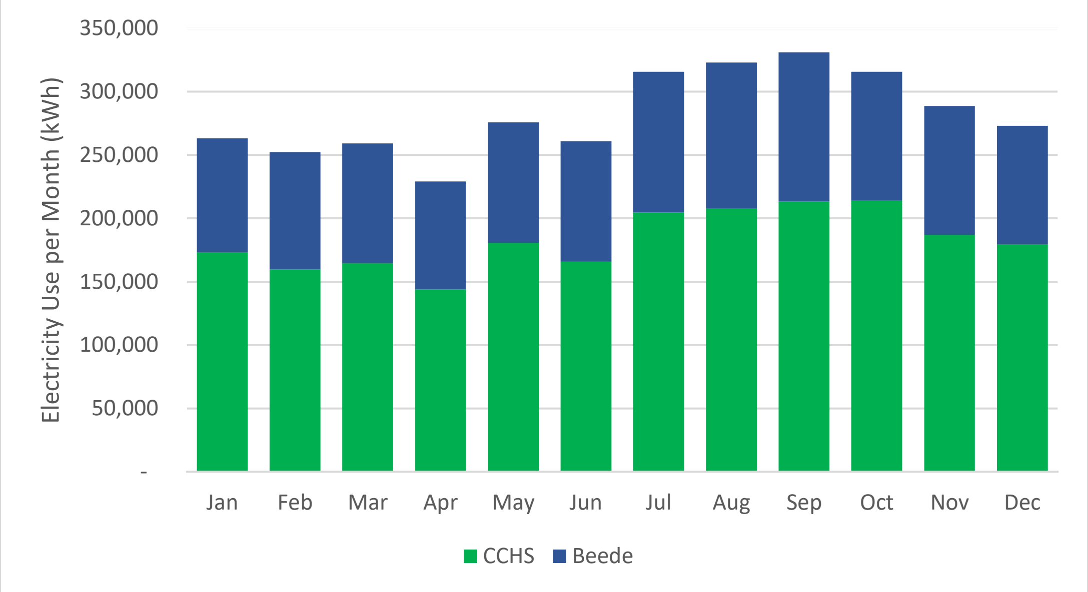
Storage Feasibility

There is ample space for storage to be located on the property of the high school and the Beede center. Both facilities have space around the buildings where large outdoor energy storage systems could be installed.

Optimization Analysis

The CCHS and Beede Campus has been modeled together for the purposes of analyzing the financial benefits of solar and storage systems. Figure 8 shows the combined monthly energy consumption of the CCHS and Beede Swim & Fitness Center.

Figure 8: CCHS and Beede Electricity Use



Both facilities are subject to CLMP's LGS rate which includes a $9.97/kW demand charge, and a flat $0.126/kWh energy charge. The Town spends approximately $522,000 per year for electricity service at these sites. The electricity consumed at these sites is responsible for an estimated 1,470 tons of CO2e emissions per year[1].

A model was used to find the optimal size and configuration of solar PV projects paired with energy storage. There are many inputs to the model, including hourly generation from the preliminary design solar PV arrays, estimated costs of the solar PV arrays, estimated battery costs, and current utility rate. Additionally, the site was modeled with and without a social cost of carbon and a demand response program. A full list of the modeling assumption can be found in Appendix B: Optimization Modeling Assumptions on page 25.

The systems that create the most savings for the campus over a 25-year period were determined using the optimization model. This determination is made through a net present cost calculation. Table 5 shows a summary of the best performing systems for each combination of solar PV and storage.

[1]EPA Emissions & Generation Resource Integrated Database (eGRID) 2018

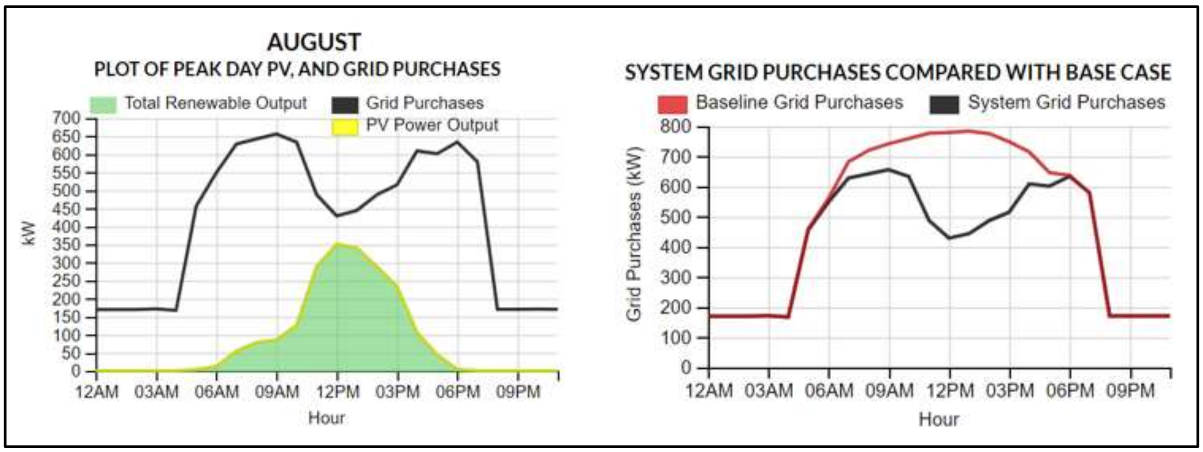
Table 5: Financial Summary CCHS and Beede

CCHS and Beede	Solar Size (kW DC)	Battery Size (kWh)	Operating Costs ($/year)	Net Present Costs (25 year)	Capital Cost	IRR	Payback (years)
Current Incentives							
Base	0	0	$522,000	$9.97 M	$0	0%	0
Solar PV	450	0	$442,000	$12,020,000	$1.00 M	6.1%	13

Under the current CMPL tariff, the best performing system is the 450 kW solar PV-only system, which would consist of a rooftop array at CCHS and at the Beede Swim & Fitness Center. At current prices and under the current tariff, energy storage systems provide no added financial benefit to the campus. An estimated 97% of the electricity produced by the 450 kW system would be consumed onsite.

In this configuration the solar PV array is sized so that it rarely exceeds the campus' energy demand. Figure 9 shows the grid purchases and solar generation of the Campus with a 450 kW DC solar system. We see clearly that the system grid purchases dip significantly with solar production but stay positive throughout the day.

Figure 9: CCHS Campus Energy Use – 450 kW DC Solar



There are hours of the year where the PV arrays would generate more electricity than the campus uses. There are also hours of the year when the local distribution system cannot accommodate for electricity export to the grid from the PV Arrays. To accommodate for when these two periods overlap, a solar only system would need to curtail its output or have a large enough battery to store all excess PV production to prevent grid exports. Solar curtailment is much more cost effective then adding battery storage for this application.

There are several changes that would alter this finacial analysis. The changes include:

- Changes to the tariff and incentive structure which could include time varient energy prices, demand response programs, and changes to the calulation of peak demand

- Declining battery costs
- Measured hourly or 15 minute energy use at the facility
- Including a Cost associated with Carbon emissions.

In the next sections we introduce demand response programs and consider a price on carbon. These programs help to capture additional benefits that solar and storage systems providesociety that are not considered by the current CMLP tarrif.

Demand Response

A Demand Response Program can create the economic incentives needed to make Battery Storage cost effective. When a Demand Response program is included in the financial analysis, the system that performs best is a solar PV and storage system. We modeled two demand response programs with 10 events annually. One program has a three hour event length and the other has a two hour event length. In both programs the battery energy systems were awarded $300/kW of average kW reduction across all event hours. The length of DR events should be partially determined by how accurately future system peaks can be predicted. Table 6 shows the optimal system under both Demand Response programs.

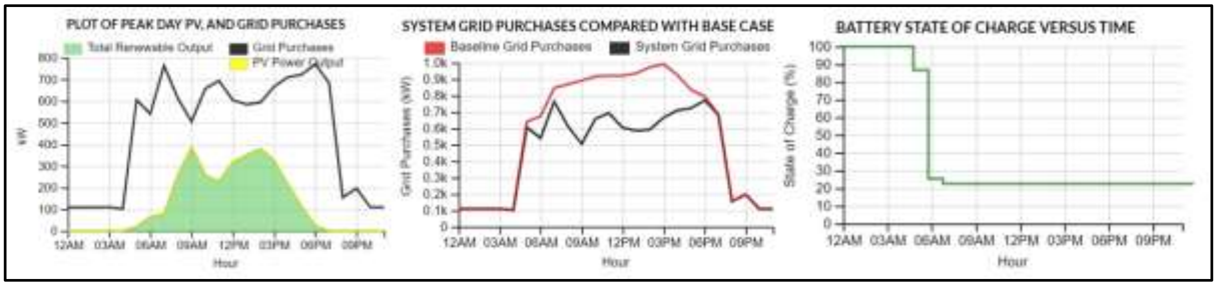
Table 6: Financial Summary CCHS and Beede with DR Program

CCHS and Beede	Solar Size (kW DC)	Battery Size (kWh)	Potential Costs ($/year)	Net Present Costs (25 year)	Capital Cost	IRR	Payback (years)
Base	0	0	$522,000	$9.97 M	$0	0%	0
3-hr DR Program with 10 events							
Solar PV and Storage	638	125	$392,000	$9.24 M	$1.69 M	5.8%	13
2-hr DR Program with 10 events							
Solar PV and Storage	762	260	$344,000	$8.84 M	$2.19 M	6.4%	12

Battery energy storage systems are more cost effective under a shorter event window. Additionally, they are able to store excess solar which allows for a larger solar installation. However, solar curtailment will still need to occur as it is not cost-effective to size the battery to be large enough to avoid all grid exports during critical system periods.

The energy load on the peak day in July is shown in Figure 10 for the 638 kW PV array with a 125 kWh battery.

Figure 10: CCHS Campus Energy Use. 638 kW Solar and 125 kWh Storage



Carbon Reduction

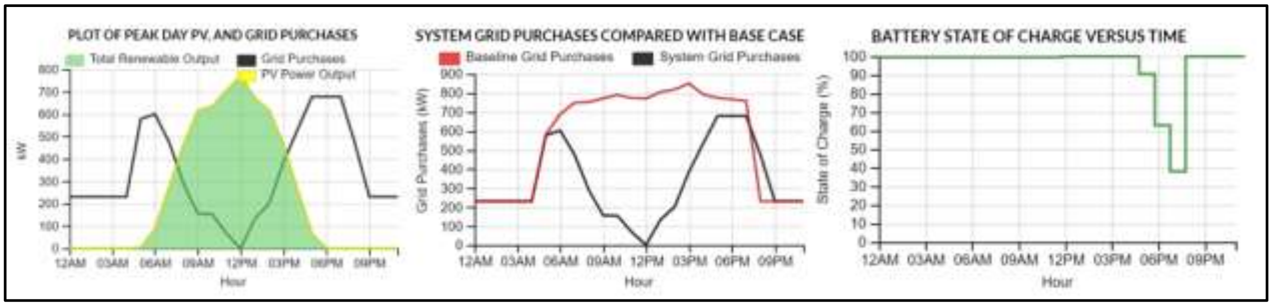
The town has a goal of reaching 100% carbon free electricity by 2030. A sensitivity analysis was performed on the price of carbon dioxide emissions to see the impacts on the sizing of solar PV and battery storage systems. We considered a price of $68/ton Carbon Dioxide equivalence (CO_2e) and $100/ton CO_2e. These prices on carbon emissions are used only to help size the system and are not reflected in the operating costs shown in the table below. Table 7 shows the expected operating costs of different system configurations. Additionally, Table 7 shows the largest recommended system that could be installed that would have a payback period of under 25 years.

Table 7: Financial Summary CCHS and Beede with DR and Social Cost of Carbon Consideration

CCHS and Beede	Solar Size (kW DC)	Battery Size (kWh)	Operating Costs ($/year)	Net Present Costs (25 year)	Capital Cost	IRR	Payback (years)
Base	0	0	$522,000	$9.97 M	$0	0%	0
Includes: 2-hr DR Program with 10 events Solar PV and Battery Energy Storage Systems (PV+BESS)							
PV+BESS ($68/ton)	930	400	$312,000	$8.88 M	$2.84 M	5.4%	13
PV+BESS ($100/ton)	1000	350	$305,000	$8.90 M	$3.01 M	5.2%	13
PV+BESS Max Rec.	1535	1900	$246,000	$11.1 M	$5.97 M	0.76%	24

Our analysis shows that solar PV and storage are both technicaly and economicly feasible on the campus of the CCHS and Beede Swim & Fitness Center if a Demand Response program is introduced, and that the sizing of the solar and storage system is flexible. The sizing of the solar and storage system could be adjusted to help meet the town's emissions reduction goals and still provide finacial benefits. The maximum recommended system would develop the campus's full solar potnetial and pair it with a 1,900 kWh battery. This system would break even over a 25 year period. This study should not be used to identify an exact sizing of solar and storage as the exact size combination of solar and battery is sensitive to the assumed capital costs of solar and storage sytems, which are declining rapidly year over year.

Figure 11: CCHS Campus Energy Use. 1,000 kW Solar and 350 kWh Storage



Resiliency Analysis

A large battery system could provide other valuable benefits to the Town. CMLP provides reliable energy to the campus, outages are generally few and of short duration. However, in the event of a natural disaster, a large battery, when combined with the high school's gas generator, could provide continuous energy for a prolonged time period, without grid-sourced energy.

Our resiliency analysis focuses on the high school's use as an emergency shelter. The high school currently has a Kohler Gas Generator that is estimated to be able to produce 150 kW. Combined with a battery system, it could provide power to the campus continually.

Figure 12: CCHS's 150 kW Generator

Based on utility bills provided by the Town, the high school has an annual peak load of approximately 667 kW in December. The average monthly peak is 530 kW. For this analysis we assume that a typical day has a peak near 500kW.

The current gas generator is only rated for 150 kW so there is a substantial portion of the load that would not be met during an emergency. Adding solar and energy storage would be able to provide continuous power to the high school typical operating levels continuously.

Table 13 compares the length of time that different systems could provide the high school during an emergency event.

Table 13: Resiliency Analysis

High School	Min Load of High School (63kW)	Moderate Load (200kW)	Full Load of High School (max 500 kW)
1900 kWh battery	24 hours	7.5 hours	3 hours
150 kW Gas generator	Indefinitely	Cannot meet	Cannot meet
Battery and generator	Indefinitely	30 hours	4.2 hours
Battery, generator, and Solar PV.	Indefinitely	Indefinitely	Week+

Library Solar and Storage Technical Feasibility

The Concord Free Public Library is currently on CMLP's Medium General Service tariff and uses approximately 329,000 kWh of electricity per year. In 2019 the Library used the most monthly energy in August, which likely corresponds with Increased electricity use for Air conditioning, however the library's peak hourly load in 2019 was in November. The operating hours of the library are generally weekdays between 9 am and 9 pm and limited weekend hours. The daily load profile of the library was modeled to peak in the evening.

The Library has the potential for a rooftop solar PV array. However, the library is surrounded by trees that will require a site visit to confirm the feasibility. During our analysis, tree heights were estimated to be 30 feet, but if tree height is closer to 40 ft at time of installation, then the PV array on the SW facing roof would likely be too shaded to be economically beneficial without trimming trees.

Figure 14: Google Street View of Concord Free Public Library

Based on our analysis, and review of the 2017 Solar Feasibility Assessment of the Concord Free Public Library, Cadmus estimates that the Concord Free Public Library would benefit from a solar PV array of up 17 kW DC. The 2017 Solar Feasibility Assessment included PV on two of the lower flat roofs of the library, however our analysis of the shading on site leads us to not recommend these locations. The array of this capacity would generate 21,700 kWh annually, which would supply 8% of the energy usage of the building.

Figure 15: Conceptual PV Design Library

DC Capacity (kW)	17.6
AC Capacity (kW)	15.1
No. Modules	63
PV Module	LG, LG365N2W-B3 (365W)
Inverter	Enphase Micro Inverter
Est. Annual Solar Production (kWh)	21,700

The solar installation would reduce the midday load of the library but would not significantly alter the library's load shape and are not able to reduce the libraies estimated peak monthly demand. Battery energy storage systems are able to effectivly reduce the peak demand of the Library.

The solar installation would benefit from being paired with a 16 kWh battery energy storage system. This paired system would be able to reduce the Library's monthly energy and demand charges.

Figure 16: Base Load - Peak Day

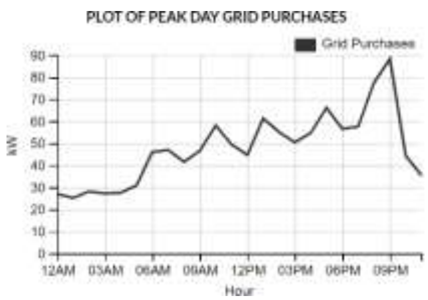


Figure 17: Solar Production

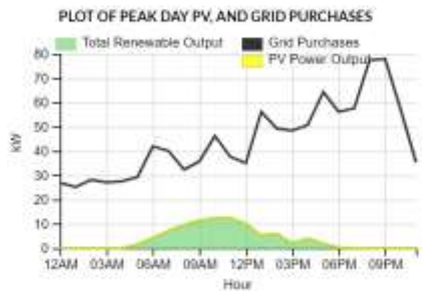
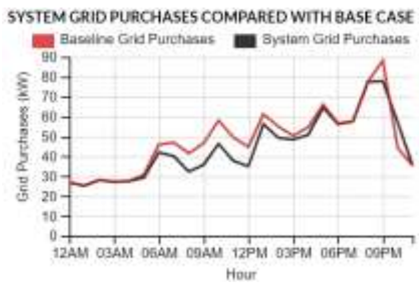


Figure 18: Solar and Storage



Our financial analysis indicates that the solar and the solar and storage system generate an internal rate of return of about 2.3% and 2.6% respectively. Table 8 presents more details of our financial analysis for the Library.

Table 8: Financial Analysis Library

Library	Solar Size (kW DC)	Battery Size (kWh)	Annual Electric Costs	Net Present Costs (25 year)	Capital Cost	IRR	Payback (years)
Base	0	0	$52,100	$1.10 M	$0	0	0
Solar	17	0	$49,300	$1.10 M	$15,200	2.3%	19
Storage	0	16	$51,202	$1.10 M	$52,900	3.9%	12
Solar and Storage	17	16	$48,400	$1.09 M	$68,100	2.6%	20

The are several changes thought would alter this finacial analysis, these include:

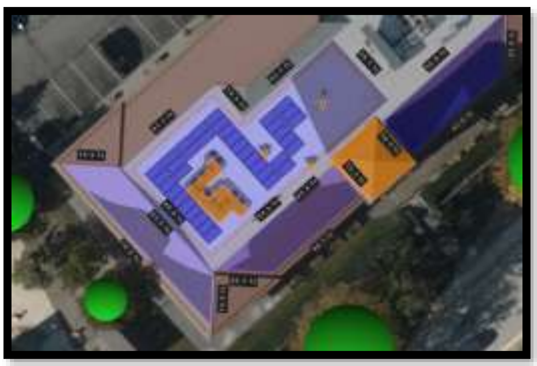
- Changes to the tariff and incentive structure which could include time varient energy prices, demand response programs, and changes to the calulation of peak demand.
- Declining battery costs
- Measured hourly or 15 minute energy use at the facility

Harvey Wheeler Solar and Storage Technical Feasibility

The Harvey Wheeler Community Center uses 75,000 kWh of energy each year. In 2019 both the highest monthly load and the peak hourly load for the Harvey Wheeler Community Center occurred in August. This is likely due to air-conditioning load. The Community Center is generally open weekdays from 8:30 am to 4:30 pm. The daily load was modeled to peak between 12 pm and 3 pm.

The Harvey Wheeler Community Center is surrounded by trees on the SE and SW sides. Additionally, part of the roof is composed of clay tile, which would increase cost for a solar installation. The flat central roof is suitable for a limited fixed tilt array. Rooftop HVAC equipment, and other structures limits the potential size of the array. Additionally, shading from trees would have to be further assed. Based on our preliminary analysis Cadmus estimates that this building may support a PV array of approximately 14 kW DC. An array of this capacity would generate 16,600 kWh annually.

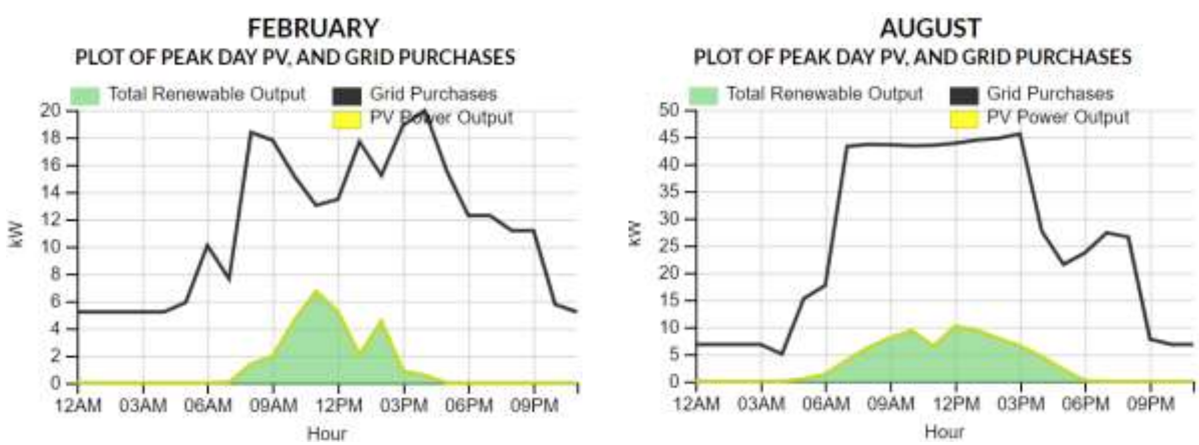
Figure 19: Conceptual PV Design Harvey Wheeler



DC Capacity (kW)	14
AC Capacity (kW)	12
No. Modules	37
PV Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	16,600

The solar installation would reduce the midday load at the Harvey Wheeler Community Center and may help reduce the peak load. Figure 20 shows the solar production and resulting grid purchases when a 14 kW PV installation is added to the building on the peak day of February and August.

Figure 20: Harvey Wheeler Solar Production



The Solar PV system is able to reduce both the energy and demand requirments of the Community Center as shown in Figure 22. Based on our estimates of the load shape of the Harvey Wheeler Community Center, battery energy storage systems are not currently economically beneficial for the Harvey Wheeler Community Center. Using measured hourly load may alter the results.

Figure 21: Base Load - Peak Day

Figure 22: PV Solar

Our financial analysis indicates that a solar only system provides the most financial benefit to the facility and would generate a 3.3% return under a direct ownership model. Table 9 presents more details of our financial analysis for the Harvey Wheeler Community Center.

Table 9: Financial Summary Harvey Wheeler

Harvey Wheeler	Solar Size (kW DC)	Battery Size (kWh)	Annual Electric Costs	Net Present Costs (25 year)	Capital Cost	IRR	Payback (years)
Base	0	0	$16,149	$341,240	$0	-	-
Solar	14	0	$14,144	$332,657	$33,773	3.3%	17
Storage	0	10	$15,885	$345,173	$9,511	-	-
Solar and Storage	14	10	$13,717	$333,157	$43,273	2.8%	19

The are several changes that would alter this finacial analysis, these include:

- Changes to the tariff and incentive structure which could include time varient energy prices, demand response programs, and changes to the calulation of peak demand
- Declining battery costs
- Measured hourly or 15 minute energy use at the facility

Appendix A: Details of Individual Solar Installations

Concord-Carlisle High School Rooftop

There are several rooftops at the Concord-Carlisle High School that are suitable for solar. Based on our preliminary analysis, Cadmus estimates that the high school can support PV arrays of approximately 365 kW DC. An array of this capacity would generate 438,000 kWh annually.

Figure 23: Conceptual PV Design CCHS Rooftop

DC Capacity (kW)	365
AC Capacity (kW)	300
No. Modules	1000
PV Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	443,000

Beede Swim & Fitness Center

The Beede Swim & Fitness Center has a flat roof that is suitable for rack mounted solar. The parking lots in the southeast section of the parcel could be suitable for potential solar PV parking canopy array development, however there are several large, 50ft+ trees that would dramatically shade the solar PV arrays. Cadmus estimates that the Beede Swim & Fitness Center can support solar PV arrays of approximately 90 kW DC. An array of this capacity would generate 111,200 kWh annually.

Figure 24: Conceptual PV Design Beede Rooftop

DC Capacity (kW)	90.2
AC Capacity (kW)	59.3
No. Modules	247
Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	111,200

CCHS Central Field

There is also a large field in between Beede and the high school. This field serves as a stormwater runoff catchment basin for the parking lot. There are several small trees on the south side of the lot that will eventually grow to shade the lot, the initial array modeled by Cadmus for a ground mount array accounts for a max tree height of 25 feet. If the trees were replaced with smaller shrubs, this array would approximately double in size. However, if these trees are planned to grow to 40+ feet, this lot would not be appropriate for ground mount solar.

Figure 25: Conceptual PV Design 1 Ground Mount CCHS Central Field

DC Capacity (kW)	354
AC Capacity (kW)	325
No. Modules	970
PV Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	479,000

Alternate orientation that account for the grade of the field. Will generate more energy in the afternoon, but less energy overall.

Figure 26: Conceptual PV Design 2 Ground Mount CCHS Central Field

CCHS Solar Carport

There is opportunity for solar canopies over the parking lot areas at the high school. Future growth of small trees will need to be considered for feasibility.

Figure 27: Conceptual PV Design CCHS Solar Carport

DC Capacity (kW)	323
AC Capacity (kW)	270
No. Modules	885
PV Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	425,000

CCHS East Field

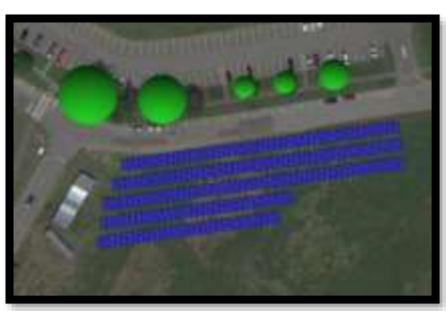
There is also an opportunity to develop ground mounted solar on a large lot to the West of the School.

Figure 28: Conceptual PV Design 1 CCHS East Field

DC Capacity (kW)	236
AC Capacity (kW)	195
No. Modules	648
PV Module	LG, LG365N2W-B3 (365W)
Inverter	XGI 1000-65/65-Solectria
Est. Annual Solar Production (kWh)	308,000

Alternate Orientation, running parallel with the road. This array would generate more energy in the morning but less overall.

Figure 29: Conceptual PV Design 2 CCHS East Field



Appendix B: Optimization Modeling Assumptions

Cadmus uses a net present costs calculation to determine the best size of energy storage to be paired with the solar arrays. As part of these calculation several assumptions are needed to complete the modeling of future costs. These assumptions Include:

- Preliminary PV designs energy output
- Typical Meteorological Year from NASA Worldwide Energy Resource Data Base
- Building energy usage matched to 2019 building utility bills
- Simulated hourly electric load based on supplied town information.
- Real discount rate: 1.34%
- Project lifetime: 25 years
- Battery replacement: 10-15 years at 80% current cost
- Annual utility charge escalator: 2%
- Estimates for Battery Costs and Solar Costs from Cadmus's Massachusetts market insights
- Social Cost of Carbon: $68/ton of CO_2 and $100/ton of CO_2
- Direct purchase assumed
- Modeled with CMLP Net Metering credit of 0.029/kWh[2]
- Investment Tax Credit: Not eligible
- CMLP Large General Service (Rate G-3) and Medium General Service (Rate G-2) tariffs
- No value added for resiliency
- Basic Demand Response Program ($30/kW reduction for ten 3-hour events between June 1st to July 30th 12 - 6 pm)

Concord currently has a voluntary demand response program. Cadmus believes that modeling a basic demand response (DR) program is important to the Town and has created a simple DR program that will help to optimize the battery selection.

> *"Thirty percent of your electric bill is directly related to the amount of electricity Concord uses for just one hour during the entire year. That one hour, the peak demand hour, occurs on a hot weekday afternoon during the summer months from June 1st to September 15th typically between the hours of 12PM – 6PM." (CMLP)*

[2] 12-Month Average CMLP Solar Net Metering Credit