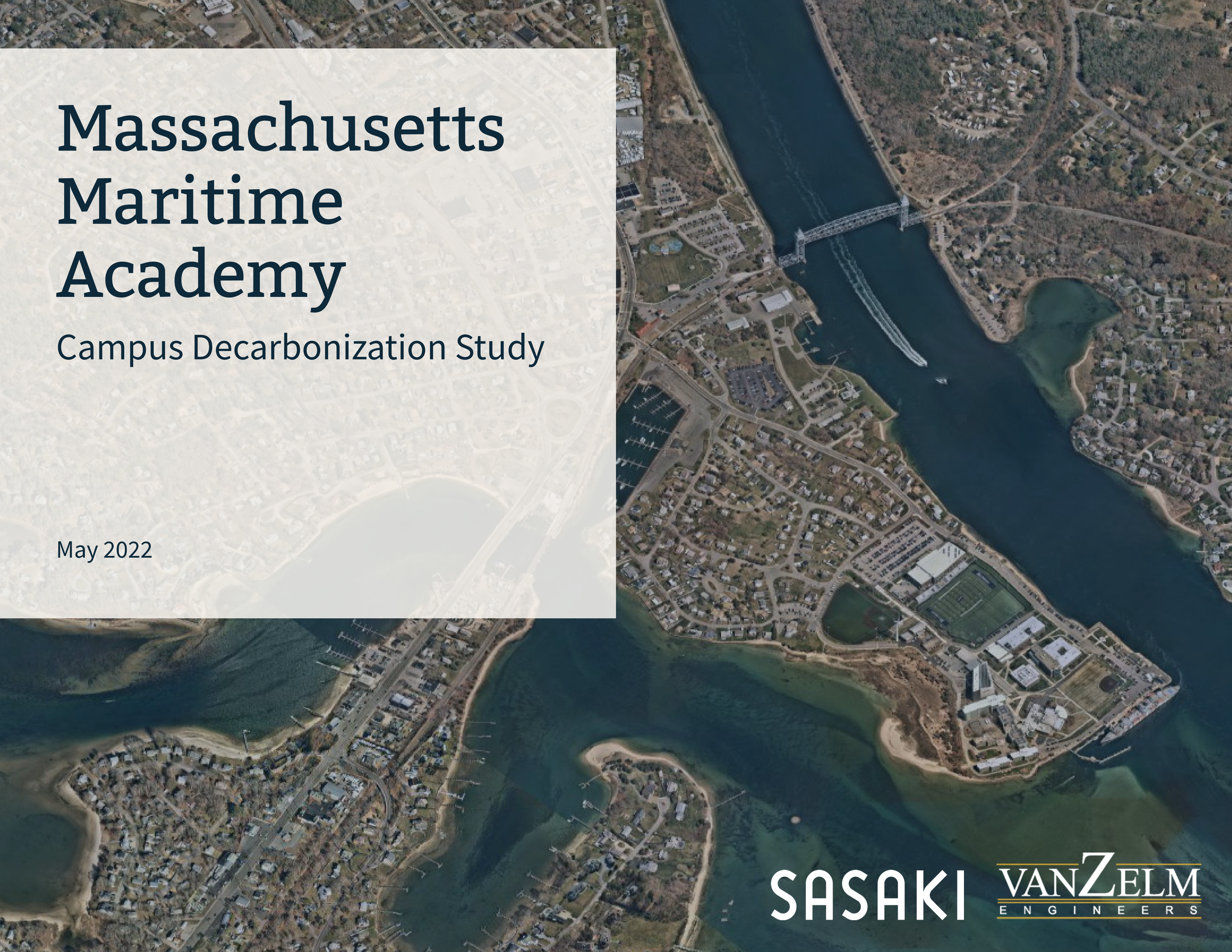

Massachusetts Maritime Academy

Campus Decarbonization Study

May 2022

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VANZELM ENGINEERS

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Executive Summary

This Campus Decarbonization Study is a roadmap for Massachusetts Maritime Academy ("the Academy") to achieve the ambitious goals of Executive Order 594 and to contribute to meeting the requirements of the 2021 Massachusetts Climate Act, with the goal of 95% carbon neutrality by 2050.

The phased plan combines extensive energy efficiency with an energy loop, geothermal wells, and building-based heat pumps, in coordination with anticipated carbon intensity reductions of the region's electrical grid, to achieve these goals[1]. This plan will renew the campus heating and cooling infrastructure, increase its resilience, and demonstrate leadership of the Academy in addressing the pressing climate change challenge.

The Decarbonization Study was developed in conjunction with the Academy's Campus Master Plan that details expansion to accommodate an additional 400 students with a proposed Company 8 Residence Hall as well as a new Science, Technology, Engineering & Mathematics (STEM) building and several building additions.

Today, the Academy heats more than 600,000 square feet with natural gas-fueled cogeneration and combustion boilers, distributing hot water within most buildings. A large on-site wind turbine supplies electricity to the grid. Grid-sourced electricity is supplemented by a solar thermal installation and several photovoltaic installations. The newest building on campus features a ground source geothermal loop, PV and all electric heat pumps that have operated successfully for over a decade.

The Decarbonization Plan proposes phased implementation representing the most cost-effective approach to achieving carbon neutrality. The plan results in a reduction of operational carbon from current levels of approximately 3500 MTCOe/yr to less than 500 MTCOe/year with the following major steps:

1. DECARBONIZING THE FUEL SOURCE

- Develop the Energy Transfer Loop and geothermal well capacity for first ten years of Master Plan, with expansion and utilization of other heat addition/rejection technologies beyond ten years.
- Use water source heat pumps connected to Energy Loop for heating and cooling of all buildings.
- Optimize onsite solar PV.

2. NEW CONSTRUCTION SUSTAINABILITY STANDARDS

- Water source heat pumps connect to Energy Loop, rooftop PV
- EUI (Energy Use Intensity) targets are provided for each project.
- Prescriptive targets for building envelope: Insulation, WWR (Window to Wall Ratio)

3. EXISTING BUILDING UPGRADES

- As soon as possible, implement short-term energy conservation measures with early payback in all buildings.
- Phase the implementation of deep energy retrofits for envelope and systems, including upgrade for low-temperature hot water.
- Include deep energy retrofits in every building addition or programmatic renovation.

4. IMPROVE RESILIENCE TO SEA LEVEL RISE, STORM SURGES AND EXTREME HEAT

- Raise critical building infrastructure above flood levels
- Design building areas below flood levels for wet-floodproofing
- Maintain gas boiler plants for back-up heating resiliency
- Provide cooling for additional spaces

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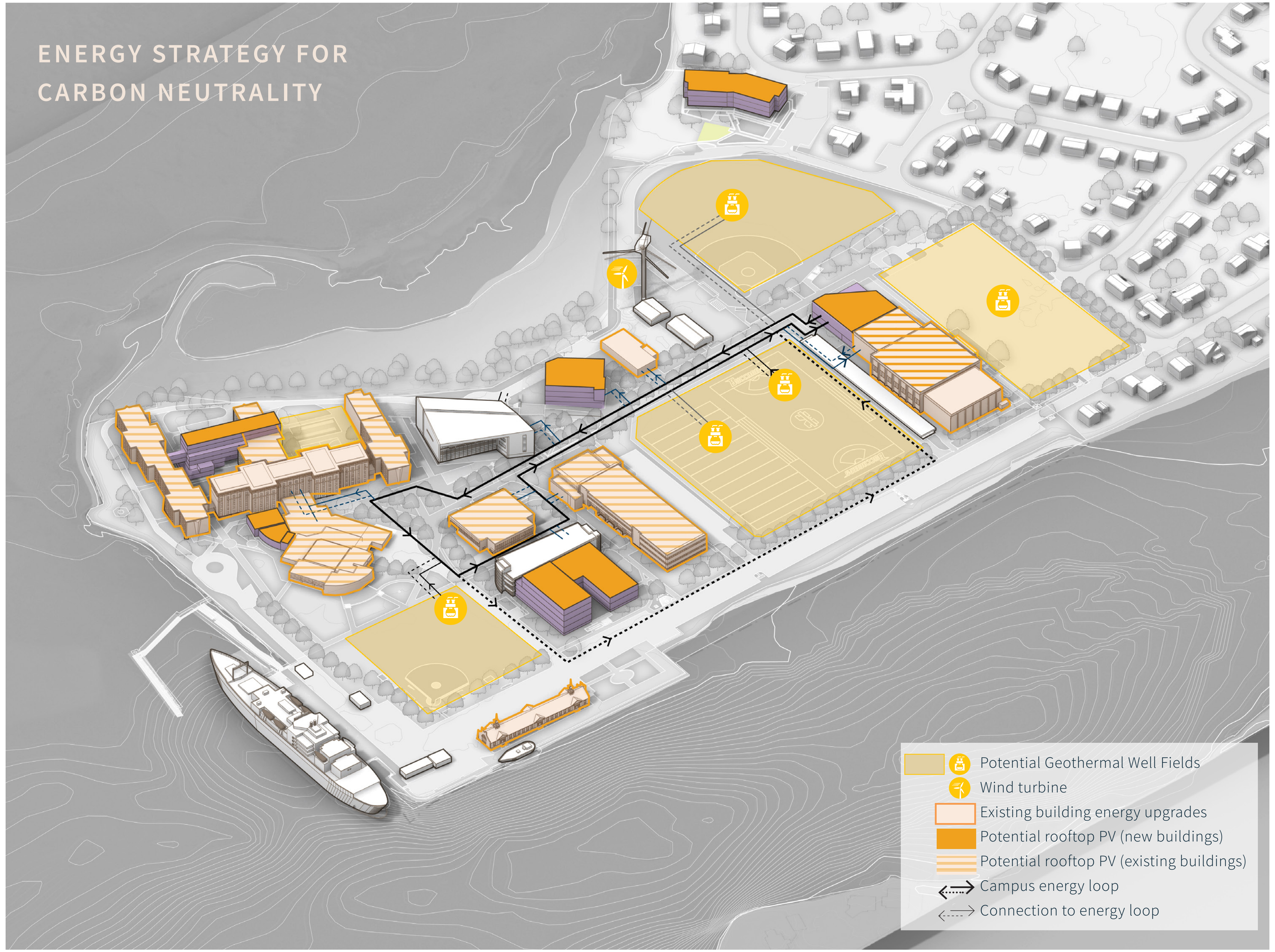
1 This study addresses only main "core" campus facilities and does not include the energy impact or carbon footprint of the existing training ship or the implications of the new training ship scheduled to be introduced in 2024.

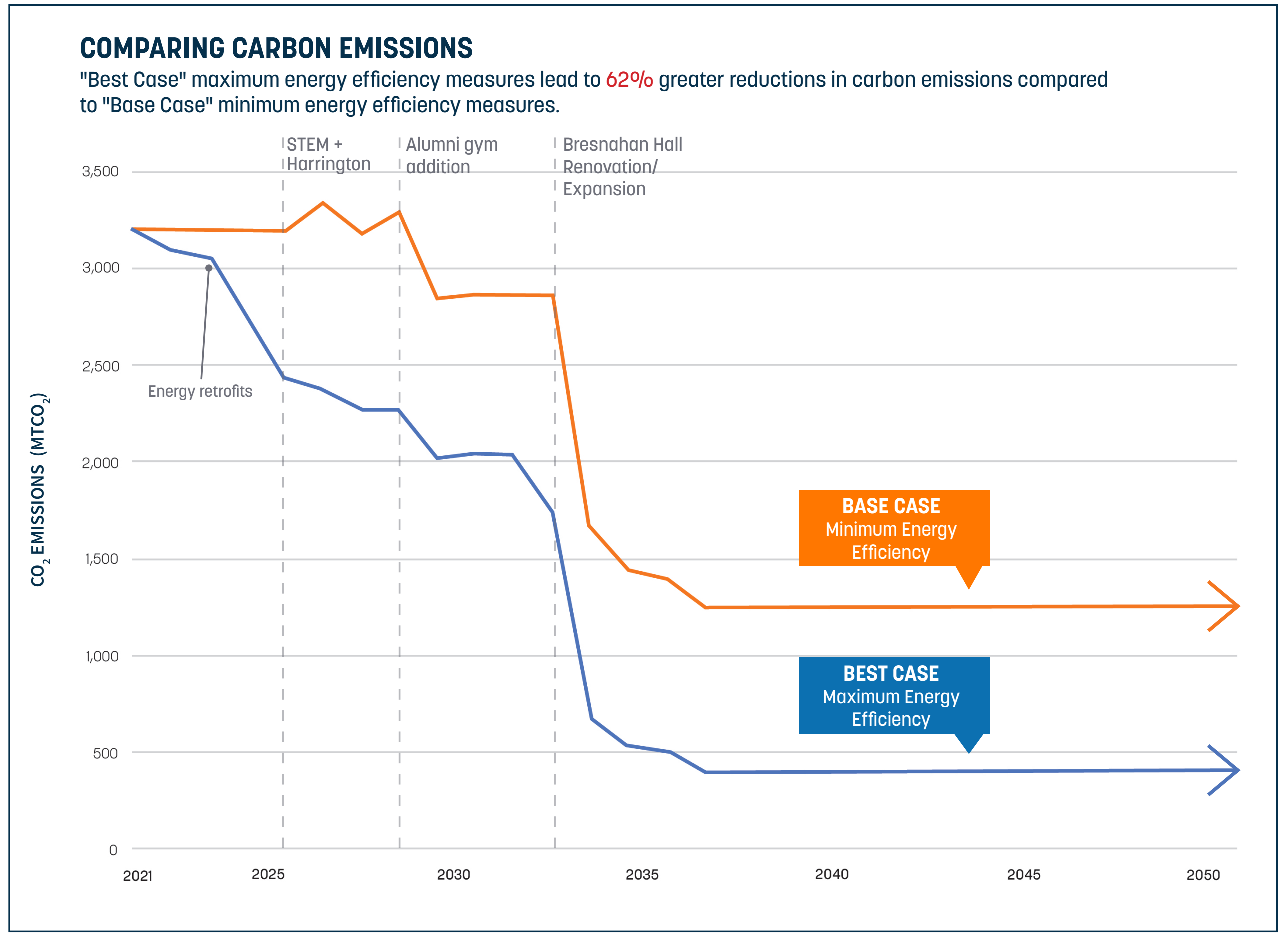


The plan has a number of economic and operational benefits, including:

- Substantial reductions in energy use, energy costs and carbon emissions
- Reduced peak heating, cooling and electrical loads
- High level of flexibility for integrating new energy sources in future
- Improved occupant comfort from new terminal heating equipment and envelope improvements
- Improved balance between heating and cooling loads
- High level of resiliency with elevation of critical building infrastructure
- Increased passive survivability (e.g. extreme heat or cold from power interruptions).

The plan demonstrates that this combination of strategies is the most cost-effective approach to reducing emissions. Implementation of only the energy loop (source) without load reduction (efficiency) would have increased capital and operating costs.

In summary, this study has concluded that it is both economically desirable and environmentally sensible for the Academy to undertake the steps outlined here to achieve the stated goal of 95% carbon neutrality by 2050.



	BASE CASE	BEST CASE
NPV of Cash Flows	($72,612,931)	($64,664,718)
Best Case benefit over Base Case in today's dollars		$7,948,213

LIST OF ABBREVIATIONS

AHU: Air Handling Unit
BAU: Business As Usual
Btu: British Thermal Unit
ChW: Chilled Water
CPP: Central Power Plant
DHW: Domestic Hot Water
EUI: Energy Use Intensity (kBTU/sf/year)
HAWT: Horizontal Axis Wind Turbine
HP: Heat Pump
HVAC: Heating, Ventilating and Air Conditioning
Lb/hr: pounds per hour
MTCO2e: Metric tons of Carbon Dioxide Equivalent
RFO: Renewable Fuel Oil
SCH: Schedule
VAV: Variable Air Volume
CHP: Combined Heat and Power
COP: Co-efficient of Performance
CUH: Cabinet Unit Heaters
DX: Direct Expansion
FCU: Fan Coil Units
HHW: Heating hot water
HRU: Heat Recovery Unit
HW: Hot Water
kV: kilo Volt
lb: pounds of mass
PRV: Pressure Reducing Valve
SAP: Sustainability Action Plan
SE: Service Entrance
VAWT: Vertical Axis Wind Turbine

Introduction

Objectives

The purpose of this study is to create a roadmap that integrates decarbonization of building systems with the concurrent Campus Master Plan at Massachusetts Maritime Academy ("The Academy"). The roadmap defines and prioritizes projects that meet future energy demands at The Academy and meet the Commonwealth's mandated targets for renewable energy, energy conservation, and greenhouse gas emissions. The roadmap outlines a variety of strategies that The Academy can take in the short, medium, and long term to achieve campus carbon neutrality.

This study comes at an important time in the Commonwealth's path toward carbon neutrality. In April of 2021 Governor Baker signed Executive Order 594, "Leading by Example: Decarbonizing and Minimizing Environmental Impacts of State Government." EO594 requires state buildings to reduce fossil fuels by 95% by 2050 from a 2004 baseline. As a public institution, facilities at Mass Maritime are therefore part of the portfolio of buildings that collectively must reduce reliance on fossil fuels.

The Massachusetts Maritime Academy Decarbonization Study reflects an approach to campus decarbonization that integrates carbon neutrality goals with campus master planning. Weaving together the master plan and decarbonization study ensures that future campus projects connect to broader climate goals. It considers how the campus can grow and meet planning objectives while eliminating reliance on fossil fuels.

The Academy is uniquely suited to serve as a demonstration project for campus decarbonization in the Commonwealth. With an existing on-campus wind turbine, new offerings related to offshore wind,d and degree programs in emergency management and energy systems, Marine Engineering and Facilities Engineering, the Academy is a living laboratory for exploring innovative decarbonization strategies. As a coastal campus vulnerable to flooding, The Academy also demonstrates the need to couple decarbonization strategies with resilience in mind.

Project Scope and Planning Objectives

The focus of the Decarbonization Study is on reducing carbon emissions on campus over the next 30 years. To accomplish this, the study focuses on small- and large-scale retrofits to existing buildings, capital improvement projects proposed in the campus master plan, and overall campus energy infrastructure. Addressing carbon emissions related to other aspects of the campus, such as transportation, waste, and the training ship, are outside of the scope of this study.

The scope of decarbonization strategies varies between existing and proposed buildings. In existing campus buildings, the study focuses on renovations and retrofits that reduce energy use, convert to all-electric systems, and increase capacity for on-site energy generation. In proposed campus projects, the study presents sustainable design guidelines for facilities that use minimal energy with all-electric HVAC systems, generate renewable energy on-site, and minimize embodied carbon in building and landscape materials. Both existing and proposed buildings can connect to a proposed decentralized campus energy loop system with ground source heat pumps located below permanent open spaces on campus.

With the project scope in mind, the following planning objectives were developed to guide the decarbonization study:

- Evaluate the campus energy use and carbon footprint
- Understand proposed campus needs and future energy demands
- Assess the existing and future energy infrastructure capacity to meet these needs
- Evaluate the resilience of the campus infrastructure
- Model proposed capital improvement projects for energy use and embodied carbon emissions
- Develop practical implementation strategies for decarbonization
- Integrate the proposed implementation strategies

Approach and Methodology

The Decarbonization Study followed a careful approach that allowed the design and engineering teams to gather information, test different approaches to campus decarbonization, define a phased decarbonization roadmap that aligns with the campus master plan, and understand the environmental and economic impact of proposed strategies. The approach is summarized below and described in more detail in the following sections.

1. Reviewed overall campus energy use, source energy/fuel, grid mix electric, renewably sourced electric, and existing carbon footprint.
2. Reviewed primary campus energy conversion and distribution systems, and analyzed options to transition to and/or replace systems with those utilizing renewable energy sources (supply side analysis).
3. Reviewed individual building energy use and analyzed opportunities to reduce energy use and/or transition to building systems utilizing or compatible with renewable energy (demand side analysis).
4. Reviewed proposed campus expansions and discussed implications of campus expansion initiatives on energy consumption and carbon emissions.
5. Integrated proposed carbon neutrality road map with the campus master plan

OVERALL CAMPUS ENERGY AND CARBON FOOTPRINT ANALYSIS

1. Met with key stakeholders to develop and document goals and objectives for this effort (vision/charter).
2. Obtained, reviewed, and summarized information on all campus facilities included within the scope of work. Categorized by building type, age, energy and program use.
3. Obtained and reviewed energy use information for all campus facilities. Develop a summary of energy use by fuel type for campus as a whole, and develop an overall Energy Use Index (EUI) for on-site and source energy.
4. Obtained any information developed to date by the Academy regarding carbon footprint associated with campus energy use. Summarized building (excluding transportation) emissions to develop a baseline for carbon emissions.
5. Conducted benchmarking to compare campus and building EUI and carbon emissions to buildings with similar use in the vicinity.
6. Developed a summary of various renewable energy sources and conversion/utilization technologies (presently available and anticipated future technologies). Reviewed implications of utilization of these technologies for meeting the energy needs of the campus.
7. Summarized possible reduction in campus energy use and carbon emissions based on implementation of short, medium, and long term recommendations.
8. Worked with the Academy/DCAMM to develop base economic parameters to be used for assessing the value of energy sources, carbon emissions reductions, system capacity and future escalation.
9. Developed a summary of overall recommendations, with associated capital and operating costs, which will lead to a carbon free and/or renewable energy scenario for the ACademy. Recommendations included development of metrics for future building construction and future renovation.
10. Developed a final report and PowerPoint presentation summarizing work undertaken and recommendations; presented to the Academy and DCAMM staff.

CAMPUS ENERGY INFRASTRUCTURE ASSESSMENT (SUPPLY SIDE ANALYSIS)

1. Obtained and reviewed all salient information relating to the campus energy conversion and distribution systems including boiler plant(s), chiller plant(s), co-generation, Solar PV, ground source heat pumps, and electrical distribution systems.
2. Analyzed equipment and systems, then developed peak and average annual effective conversion and distribution efficiencies.
3. Developed and analyzed short term measures to improve efficiency of existing equipment/systems.
4. Reviewed and analyzed options for renewable fuel sources which may be utilized to satisfy short, medium, and long terms goals for campus carbon neutrality.
5. Developed and analyzed long term options to convert campus energy infrastructure from fossil fuel based to renewable/carbon neutral energy-based options. Evaluated options included:
    - Fully centralized systems, with low temperature hot water and chilled water provided by central ground source (or other thermal storage) heat pumps, air source heat pumps, and/or biomass boilers/ cogeneration.
    - Semi-distributed systems, with central heating and cooling equipment working in conjunction with distributed building heat pump systems.
    - Fully distributed systems, with local ground source heat pump and/or biomass systems providing heating and cooling at each building.
6. Reviewed projected long term campus development plans and projected impacts of building energy conservation efforts to determine future loads for renewable energy systems.
7. Analyzed capital costs for conversion of campus infrastructure from fossil fuel based to renewable fuel based for each time frame (short, medium, and long term), and estimate projected operating costs.
8. Reviewed options to provide resiliency for proposed renewably fueled campus energy infrastructure including microgrid and battery storage options.
9. Developed recommendations for phased implementation of system upgrades/new technology to reduce/eliminate carbon emissions over time, categorized into short, medium, and long term actions, with implementation and operating costs for each.

BUILDING ENERGY CONSERVATION/ CONVERSION ASSESSMENTS (DEMAND SIDE ANALYSIS)

This aspect included a high-level energy efficiency assessment for all campus facilities and a review of existing building systems for compatibility with renewable energy sources. The following scope of work was undertaken for each building within our charter:

1. Reviewed information on building systems and energy consumption for existing buildings provided by The Academy for our use in developing an Energy Use Index (EUI) for each building.
2. Compared the Energy Use Index (EUI) and the Energy Cost Index (ECI) for the various building types with buildings that have similar characteristics in the same geographical vicinity. Comparisons were also made with publicly available energy indices of similar buildings in similar climates such as CBECS and ENERGY STAR.
3. Compared the energy and cost savings if the building were to reach the target EUI. Considered anticipated peak load reductions possible if target EUI figures were achieved.
4. Performed a walk-through survey of each facility to become familiar with its construction, equipment,

operation, and maintenance.

5. Met with The Academy operations staff to learn of special problems or needs of each individual building and the campus as a whole to determine if any maintenance problems and/or equipment age/condition may affect efficiency.
6. Identified and listed low-cost improvements to the facility or to operating and maintenance procedures and estimated the savings that will result from these changes.
7. Identified and listed potential energy conservation measures for further study and developed preliminary estimates of potential costs and savings.
8. Projected total energy and demand savings associated with the implementation of recommended energy conservation measures.
9. Created a summary of any special problems or needs identified during the walk-through survey, including possible revisions to operating and maintenance procedures.
10. Commented on the modifications to building systems required to integrate with possible local or campus-wide renewable energy systems.
11. Commented on the impact of developed measures as it pertains to resiliency.
12. Synchronized all of the above with concurrent Campus Master Planning effort.

Existing Campus Energy Analysis

Campus Overview

EXISTING BUILDINGS

The following table summarizes major energy consuming and continually occupied buildings.

All of the buildings are heated. However, most of the buildings, including the Companies, are not currently cooled. Some buildings are cooled partially (such as Pande Dining Hall and Student Union, Flanagan Hall, Bresnahan Hall, Clean Harbors Athletics Center), while others such as ABS Information Commons and Kurz Hall are fully air conditioned. The total conditioned square footage for existing buildings included in this study is approximately 602,000 square feet. At the time of this report, Beachmoor Hall was being reconstructed and Company 1 was in design for a major MEP retrofit.

BUILDING NAME	BLDG TYPE	GSF
Pande Dining Hall And Student Union	Dining Hall	24,500
Clean Harbors Athletic Center	Athletics	80,000
Gerhard E. Kurz Hall	Classroom/Office/Retail	26,800
Power Plant	Facilities	4,900
Flanagan Hall	Classroom/Office	8,000
Bresnahan Building	Classroom/Office	54,100
American Bureau of Shipping Information Commons	Classroom/Library	41,740
The Beachmoor	Conference Center	7,823
Harrington Building	Classroom/Office	74,000

BUILDING NAME	BLDG TYPE	GSF
Company 1 (Gray Hall)	Residence/Dormitory	45,450
Company 2 (Bassett Hall)	Residence/Dormitory	45,450
Company 3 (Wilson Hall)	Residence/Dormitory	29,760
Company 4 & 7 (Thompson Hall)	Residence/Dormitory	64,235
Company 5 (Limouze Hall)	Residence/Dormitory	34,206
Company 6 (Abele Hall)	Residence/Dormitory	35,057
Waste Water Treatment Plant	Sewage Treatment Plant	2,000

Sources: 2020 CAMIS Building Detail by Location and 2021 MSCBA Building List with Values, for the Companies

MASTER PLAN PROJECTS

The Decarbonization Study took place concurrently with the latest campus master planning effort. This enabled the master plan and decarbonization study to form a holistic set of recommendations that lead the campus toward a robust, sustainable future.

The 2021 Campus Master Plan Update identified key investments to address deferred maintenance, better address the needs of current campus users, and to accommodate growth and change in academic and student life programs. The master plan proposes development, additions, and renovations within the buildable land area on campus. This includes the projects included in the table to the right.

While some of these additions will increase energy consumption due to new building construction and additional occupancies, the proposed renovations will decrease the energy consumption due to improvements in technology and relevant Code compliance criteria. Sustainable design guidelines included in this report ensure that future construction on campus integrates strategies to maximize energy use efficiency and minimize the carbon footprint. This will facilitate the construction of all electric high efficiency buildings on campus which can then be integrated into the proposed energy transfer loop. The prediction of future campus energy use and carbon emission footprints have included these above criteria.

BUILDING	PROGRAM TYPE	PROJECT TYPE	GSF
Beachmoor	Housing	New construction *(in progress)*	26,057
Housing addition	Housing	New construction	38,500
Fantail expansion	Dining	New construction *(in progress)*	7,011
Alumni gym	Athletics/Rec	New construction (addition) and comprehensive modernization	37,400
Bresnahan pt 1 (existing)	Academic	Comprehensive modernization	30,000
Bresnahan pt 1 (new program)	Academic	New Construction	6,000
Bresnahan pt 2	Academic	New construction	24,000
STEM Building	Academic	New construction	32,380
Harrington Hall	Academic	Comprehensive modernization	6,540
Power Plant	Academic	Comprehensive modernization	5,055
Dock Renovation	Infrastructure	Electrical and Infrastructure Upgrade	
HARDSCAPE/ SOFTSCAPE	**PROGRAM TYPE**		**GSF OR LF**
Hardscape	New paths		2,860.00
Hardscape	New roads		1,040.00
Softscape	Formal Quad landscape		120,555.80
Softscape	Informal Landscape		491,910.70
Softscape	Native edge landscape		153,923.920

Campus Energy Use and Emissions

EXISTING ENERGY SOURCES AND SYSTEMS

The campus currently utilizes a mixture of renewable technologies and fossil fuels to meet its energy needs. Energy is primarily utilized for:

- Heating (natural gas & electrical energy)
- Cooling (electrical energy)
- Ventilation (electrical energy)
- Miscellaneous loads such lighting and charging cell phones and other computing devices (electrical energy)
- Domestic hot water (natural gas and electrical energy)
- Other uses.

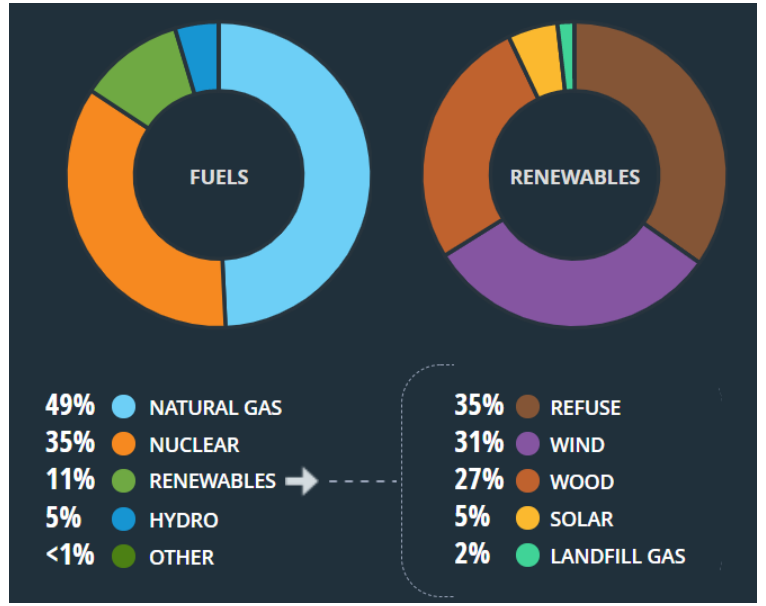
Electrical power is primarily sourced from:

- Electrical Grid
- 178 kW total solar PV system on the Companies and information commons
- 195 kW combined heat and power (CHP) system in the Companies
- Solar PV lamps on pathways

On site 660 kW wind turbine supplies electricity to the grid.

CHP System in Companies

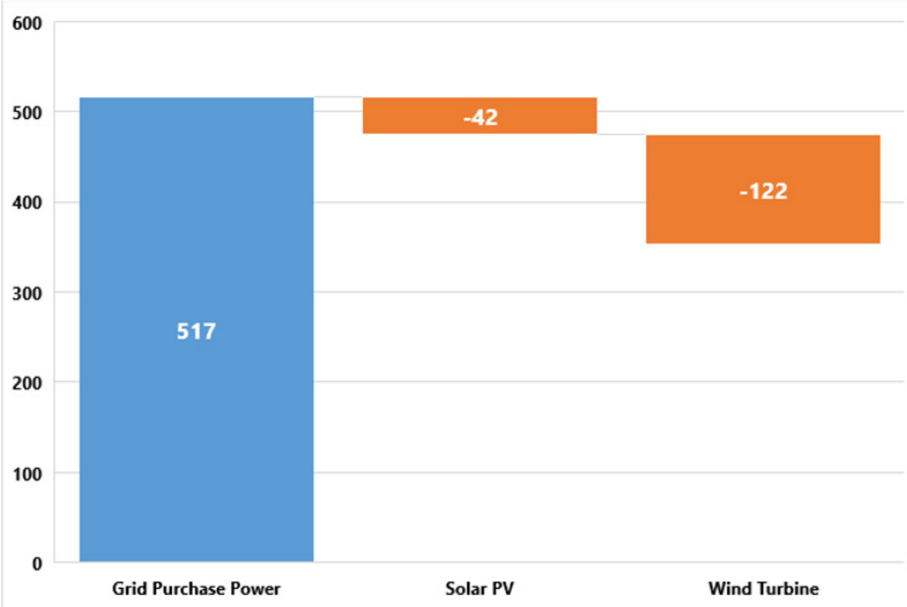
Solar PV Lamps on Pathways



NEW ENGLAND FUEL MIX

Electrical power in New England tends to be a clean source of energy. It lends itself to achieving carbon neutrality by further electrification of heating and by conversion of other campus infrastructure elements. The chart[1] above denotes a snap shot of the electrical power sourced from the New England electrical grid on a typical work day during working hours:

- Approximately 16% of electrical power sourced from the grid is from renewable sources
- Approximately 35% of electrical power sourced from the grid is generated by nuclear reactors. While nuclear power has low carbon emissions, it does create other environmental concerns
- Almost 50% (~49%)of the electrical power sourced from the grid is obtained from natural gas i.e. a carbon intensive fuel
- Unlike other parts of the country, the electrical generation from coal or oil is negligible
- Every kWh sourced from the grid results in an emission of 0.0002045 MTCO2e approximately. This number can vary hourly based on the availability of energy sources.
- Emissions from grid purchased electricity are estimated to be approximately 517 MTCO2e for buildings currently in our scope.



CAMPUS ELECTRICAL EMISSIONS/OFFSETS BY SOURCE

The figure above denotes the benefit of solar PV and Wind power generation based on the current New England grid mix. By generating a portion of their own electrical energy sustainably for over a decade, The Academy is at the forefront of the sustainability movement .

1 (ISO New England (iso-ne.com))

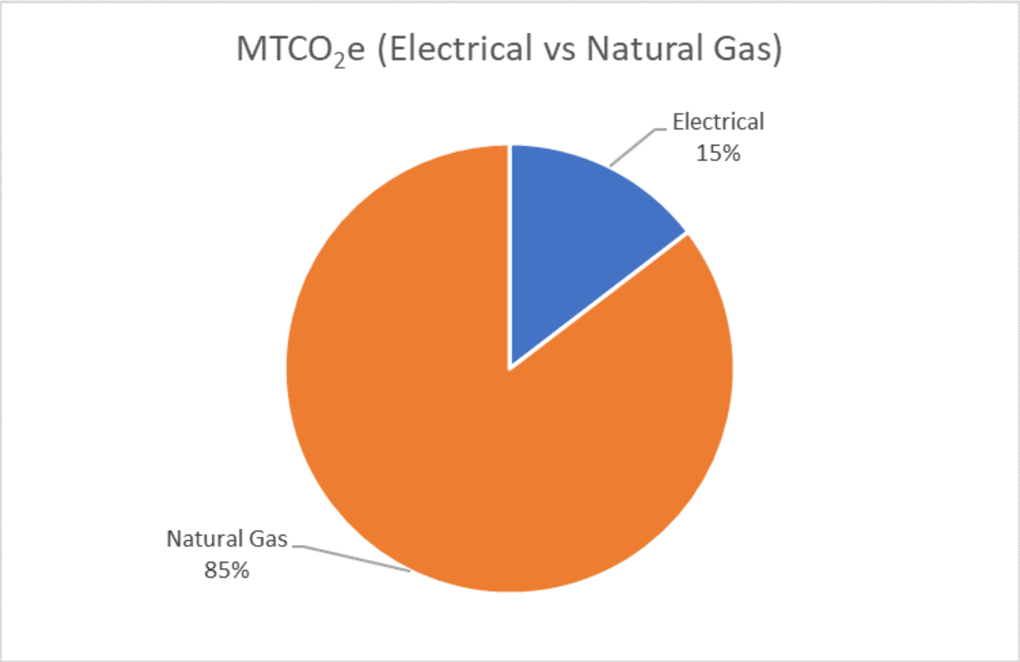
NATURAL GAS

Natural gas is utilized on campus to provide heating hot water as well as running the cogeneration systems when the building temperature calls for it. While natural gas is cleaner than most other fossil fuels, it still contributes significantly to the carbon emissions on campus. The Global Warming Potential (GWP) of natural gas is estimated to be 21 times that of CO2. Total annual natural gas utilization on campus is estimated to be 57,059 MMBtu.

Every MMBtu of natural gas combusted on site contributes 0.053 MTCO2e. The natural gas consumption on site results in 3,024 MTCO2e. Utilizing natural gas in a cogeneration plant reduces the carbon footprint due to concurrent utilization of thermal and electricity, however there are still significant carbon emissions.

The chart to the right summarizes the carbon emissions from electrical energy vs natural gas. Natural gas consumption and thermal loads result in over 75% of the campus carbon footprint. This can be primarily attributed to:

- Heavy campus utilization during the heating season
- Relatively energy inefficient buildings
- Significant Domestic Hot Water (DHW) Loads
- Utilization of a cogeneration system to generate power and hot water on site
- Comparatively clean New England Grid
- Utilization efficiencies of electrical equipment vs thermal equipment
- Partially cooled buildings result in a load imbalance between heating and cooling loads; heating loads use thermal energy while cooling loads use electrical power



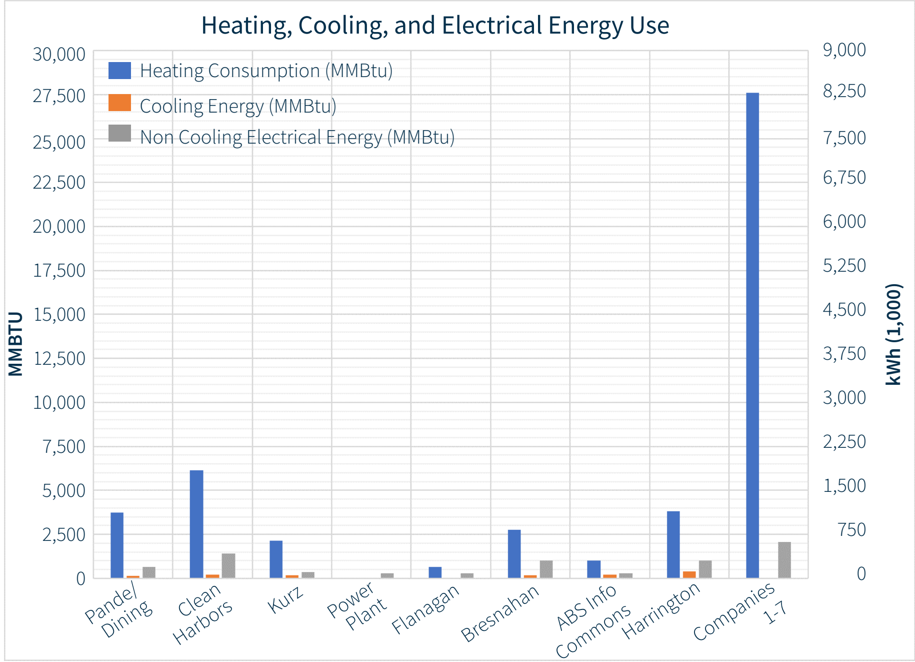
Carbon emissions from purchased electricity can be eliminated by purchasing “green” power. Eliminating carbon emissions from natural gas for heating represents a greater challenge.

Energy Use by Building

BUILDING ENERGY USE

Company buildings consume the most electrical as well as thermal energy. They however also have the highest square footage and are not currently cooled. The Power plant and Flanagan Hall consume the least amount of energy but also occupy the smallest square footage. A portion (~25%) of the thermal energy listed under Company 1 - 7 is used for producing electrical power while the remainder is utilized for heating. The facility is net metered and receives a quarterly credit for the electrical energy generated on site from cogeneration, Solar PV and the Wind Turbine.

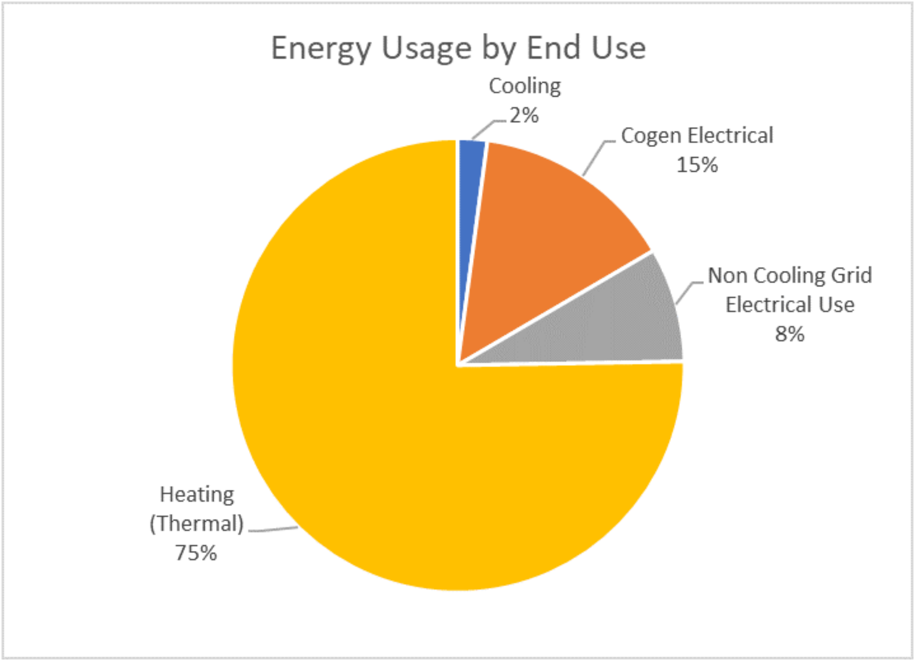
BUILDING NAME	SQ FT	PEAK (kW)	ELECTRICAL ENERGY CONSUMED (kWh)	MMBtu (THERMAL)	UTILITY COST ($)	$MTCO_2e$
Pande Dining Hall And Student Union	24,500	54	225,406	3,738	$ 74,929	244
Clean Harbors Athletic Center	80,000	178	472,823	6,146	$ 138,529	422
Gerhard E. Kurz Hall	26,800	98	158,376	2,122	$ 47,098	145
Power Plant	4,900	78	84,051	41	$ 13,062	19
Flanagan Hall	8,000	32	90,349	634	$ 20,526	52
Bresnahan Building	54,099	112	346,889	2,767	$ 82,467	218
ABS Info Commons	41,741	148	139,744	1,010	$ 32,072	82
Harrington Building	74,500	109	404,193	3,810	$ 102,539	285
Company 1 - 7	277,900	634	607,676	36,791	$ 495,852	2,074
Total	**592,440**		**2,529,507**	**57,059**	**$1,007,076**	**3,542**



ENERGY USE PERCENTAGE BY END USE

The heating energy consumption for the dormitories (the Companies) is significantly higher than any other energy consumption. This can be attributed to:

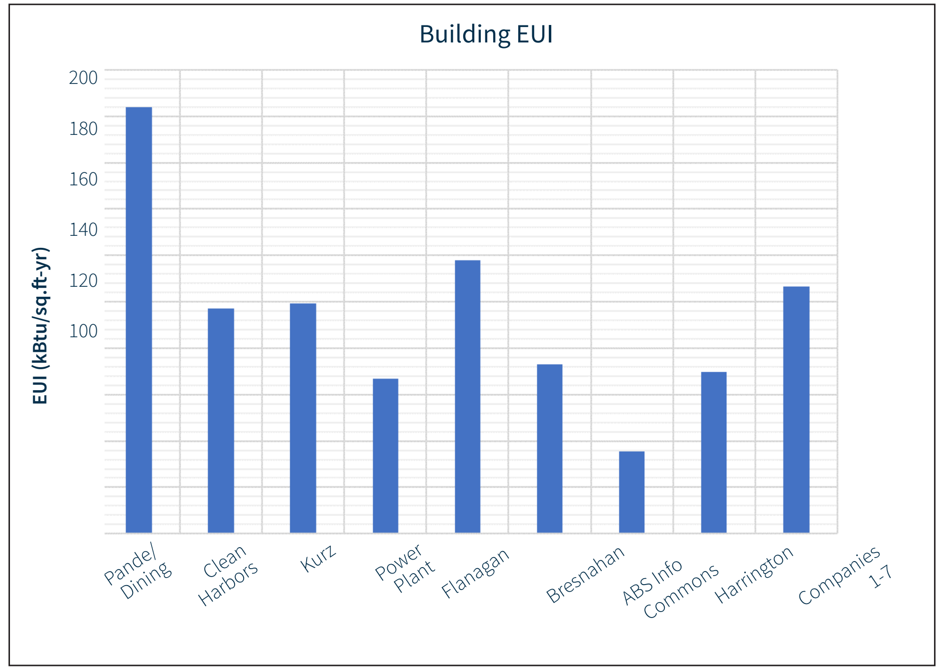
- Approximately 47% of the total square footage under consideration can be allocated to the Companies
- The lack of cooling in most buildings results in an imbalance between the heating load and the cooling loads.
- The non-cooling energy consumption on an educational campus (i.e. miscellaneous loads) tends to be lower than in an office space
- Heating consumption for Pande Hall includes energy spent on cooking and dish washing
- ABS Info Commons is a relatively new building with high efficiency building systems and has a lower energy footprint than other buildings on campus
- Clean Harbors has a large floor area and high ceilings resulting in a large volume of air that needs to be conditioned



BUILDING ENERGY USAGE

Most of the energy consumed on site is used for heating. This can be primarily attributed to the predominantly heating weather pattern. The cooling use on campus is minimal because most buildings on campus are not currently cooled. Buildings that are cooled, such as ABS Information Commons, are extremely energy efficient and hence consume a low amount of energy.

Campus scheduling results in some buildings being only partially occupied during the cooling season and thus resulting in reduced cooling loads and cooling energy consumption



EXISTING BUILDING EUI

In order to compare the relative energy performance of each building, the annual energy consumption should be compared on a per square foot basis. This metric is also called the Energy Use Intensity (EUI) of a building. EUI can also be used to compare facilities of similar use, size, and climate.

Even though they have the highest occupied square footage, the energy consumption per square foot of the Companies is not the highest. This can be attributed to the lack of cooling in the Companies. This implies that most of the energy expended in the Companies is for heating. Energy efficiency measures should be undertaken to reduce this consumption. ABS Information Commons has the lowest EUI per square foot as shown above due to an efficient design and compliance with a more stringent energy efficiency code.

COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY

The Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures). Commercial buildings include all buildings in which at least half of the floorspace is used for a purpose that is not residential, industrial, or agricultural. By this definition, CBECS includes building types that might not traditionally be considered commercial, such as schools, hospitals, correctional institutions, and buildings used for religious worship, in addition to traditional commercial buildings such as stores, restaurants, warehouses, and office buildings.[2]

CBECS is conducted in two phases. Phase 1 is the Buildings Survey, which collects building characteristics (such as building size and use, structural characteristics, energy sources and uses, and energy-using equipment) and energy usage data (annual consumption and costs) from a respondent at the building, either by an interviewer or using a web questionnaire.

Phase 2 is the Energy Supplier Survey (ESS), which is a follow-up survey of the energy providers for buildings that responded in Phase 1. Providers of electricity, natural gas, heating oil (which includes fuel oil, kerosene, and diesel), and district heat (steam or hot water) supply monthly energy usage data for each building. The energy data are collected using a secure website that offers several reporting options designed to minimize reporting burden.

The first CBECS was conducted in 1979; the following numbers denote updated data commercially available from Calendar Year 2018.

Building Name	Utilization Type	Actual	CBECS - 25TH PERCENTILE (lowest)	CBECS - Median	CBECS - 75TH PERCENTILE (highest)
		EUI (kBtu/sq ft)			
Pande Dining Hall And Student Union	Mixed	184	76	179	340
Clean Harbors Athletic Center	Sports	97	25	51	96
Gerhard E. Kurz Hall	Mixed	99	29	51	75
Power Plant	Utility	67	15	34	76
Flanagan Hall	Mixed	118	40	64	92
Bresnahan Building	Classroom	73	22	44	81
American Bureau of Shipping Information Commons	Library	36	41	65	89
Harrington Building	Classroom	70	46	73	105
Company 1-6	Dorm	107	24	58	84

** Color format based on Median values*

Most of the buildings on campus consume significantly more energy than the buildings at the 25th CBECS percentile or even the CBECS median. This implies that most of these buildings could benefit from short term as well as long term energy efficiency measures. Implementing energy efficiency measures leads to a significant decrease in capital investment required for implementing future campus carbon neutrality projects. This is discussed in further detail later in the report.

2 Energy Information Administration (EIA)- About the Commercial Buildings Energy Consumption Survey (CBECS)

Carbon Footprint

The carbon footprint of the Academy can be defined as the total greenhouse gas emissions (GHG) caused by the campus expressed as CO_2 equivalents in metric tons. A carbon dioxide equivalent, abbreviated as CO_2e, is a metric used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming.

This study focuses only the carbon footprint as it pertains to on-site building energy use. To estimate the carbon footprint of all energy use sources on site, extensive analysis was conducted to accurately estimate the carbon footprint per unit of all energy sources burnt on site. The following information was developed and utilized to develop energy and carbon footprint metrics.

All emissions on site are primarily composed of two sources:

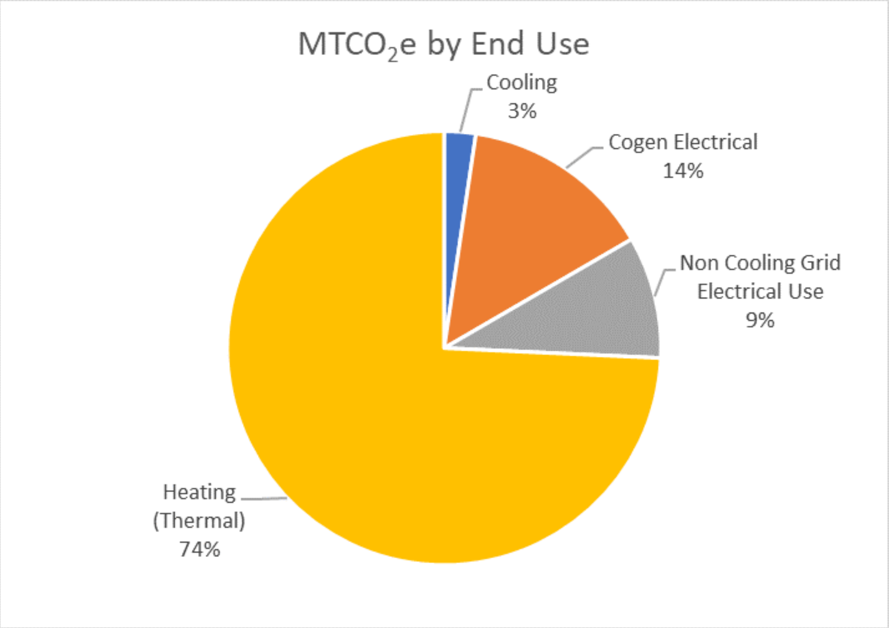
1. **Electrical power and energy consumption** for lighting, cooling, miscellaneous loads, fan power, pumping energy
2. **Natural gas consumption** for heating individual buildings using boilers / cogeneration units, operating the cogeneration plant in the Companies to meet heating loads while recovering electrical power as a by product, and domestic hot water when required.

The Solar PV systems and wind turbines on site do not contribute to the operational carbon footprint on campus.

To estimate the electrical energy consumption per kWh, published data from ISO-NE were analyzed. Based on available information it was determined that one kWh emits approximately 0.0002 $MTCO_2e$.

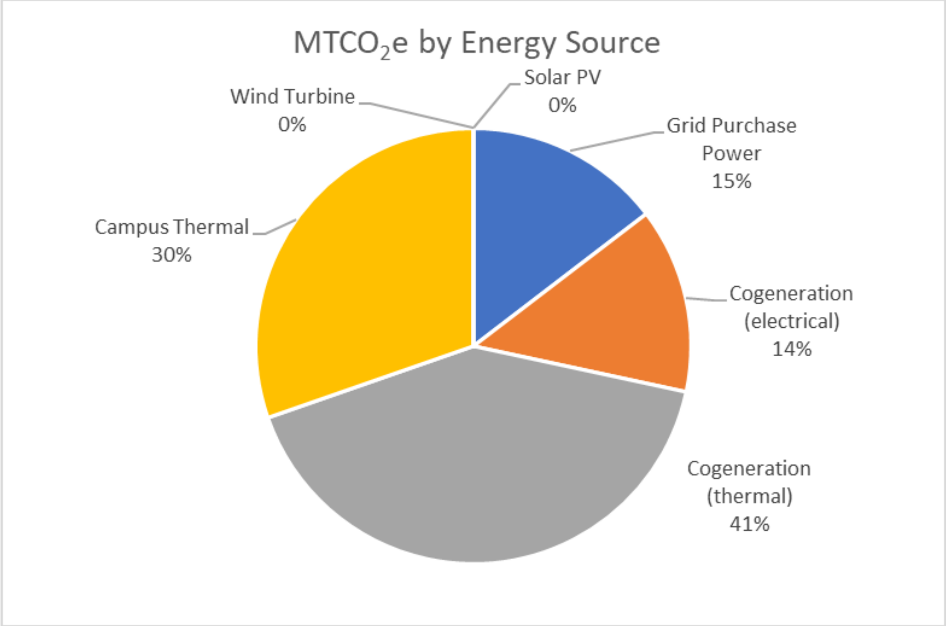
The United States Department of Energy's metrics were utilized to assess the carbon footprint resulting from the natural gas energy consumption on site. Every MMBtu of natural gas combusted on site results in approximately 0.053 MTCO2e being emitted.

The Academy's campus is located in an area served by the Independent System Operator – New England (ISO-NE). Over the last two decades, ISO-NE has taken significant steps in reducing its own power generation carbon footprint. This has resulted in the New England Grid being one of the cleanest grids in the country This can play a significant role in minimizing the amount of green power or carbon offsets required to be purchased by the Academy after the campus has been completely electrified.



CO_2 EMISSIONS BY END USE

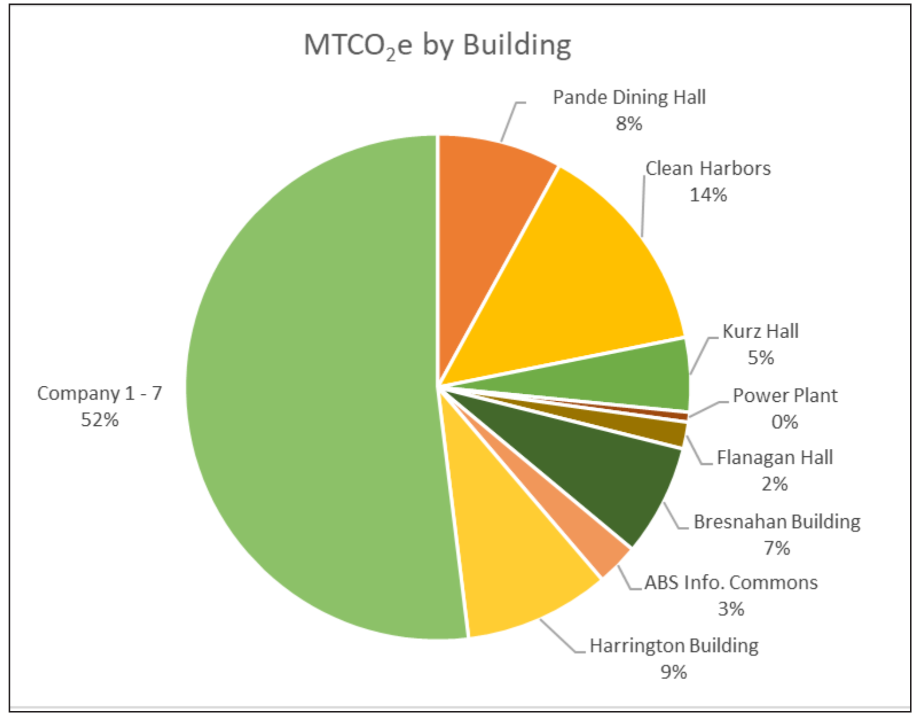
Most of the carbon emissions on site can be allocated to heating. This can be attributed not only to the fact that natural gas is predominantly utilized for heating currently, but also to the fact that it is a dirtier fuel. A key step towards achieving carbon neutrality and sustainability is the elimination of all fossil fuel consumption from the Academy's campus, including natural gas.



CO_2 EMISSIONS BY ENERGY SOURCE

In order to understand the carbon footprint by energy source a little bit better, the above chart was developed. It allocates the carbon footprint by percentage into the following categories: Campus Thermal, Wind Turbine, Solar PV, Grid Purchased Power, Cogeneration (Electrical), and Cogeneration (thermal)

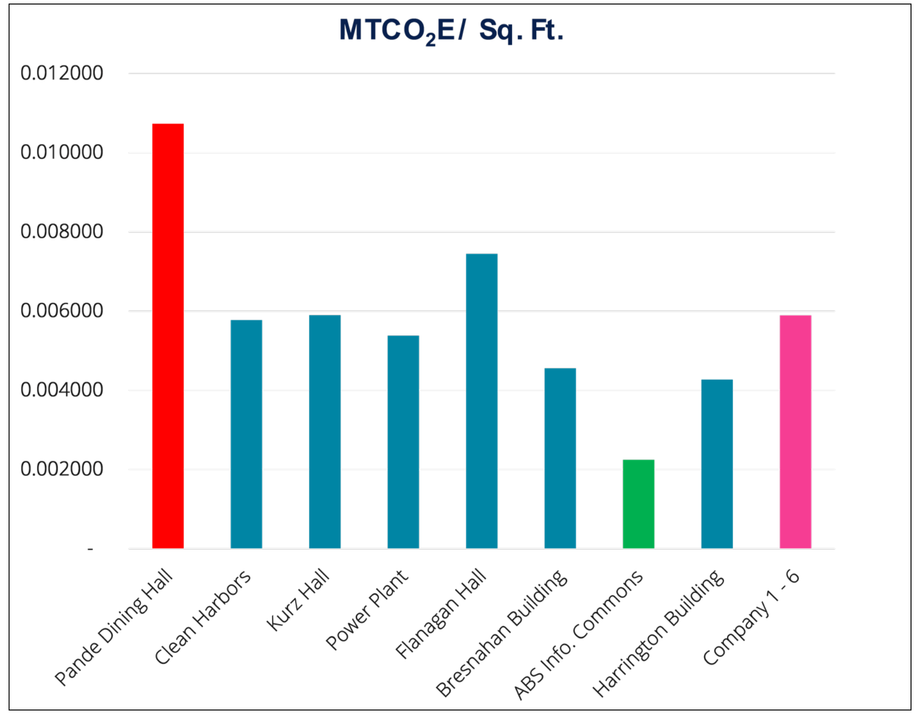
Solar PV and the Wind Turbine have zero operational emissions. We commend the Academy staff on being pro-active and having installed these sustainable power generating sources over a decade ago.



CO_2 EMISSIONS BY BUILDING

To better assess the carbon emissions from each building, the energy consumption and resulting carbon emissions associated with each building were estimated and isolated.

The Companies have the highest total carbon footprint. This can be attributed in part to the fact that they occupy almost 50% of total floor area on campus. ABS Information Commons is a significantly smaller and more energy efficient building and hence has the lowest total carbon emissions.



CO_2 EMISSIONS PER SQUARE FOOT

Just as with energy consumption, it is imperative to evaluate the carbon footprint of each building per square foot. Pande dining has a very high carbon footprint which can be attributed to dining activities. The Companies have a high carbon footprint that can be attributed to heating. The lack of cooling in the Companies suggests that the heating system utilized is extremely carbon intensive. ABS Information Commons has a low carbon footprint due to the utilization of energy and carbon efficient heating and cooling systems on site.

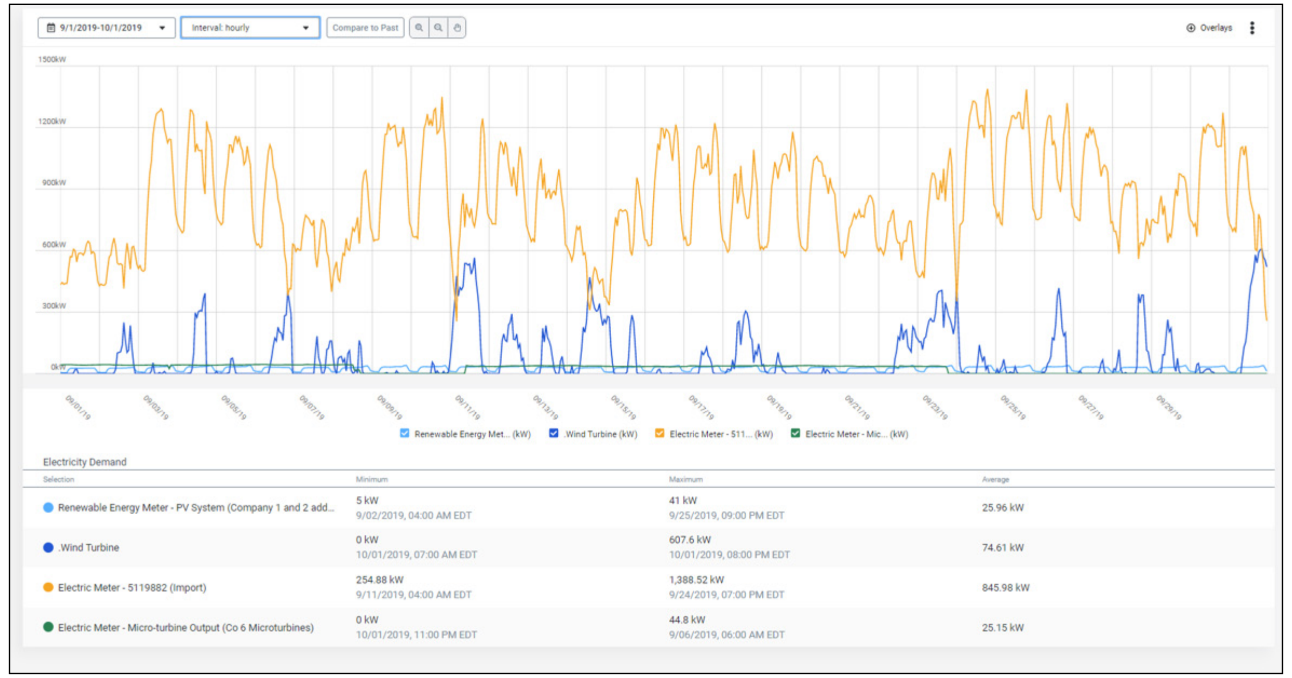
Existing Campus Energy Systems

CAMPUS ELECTRICAL DISTRIBUTION SYSTEM

The Academy is served with a single underground primary feeder from Eversource at 25 kV. This feeds a 2,500 KVA pad mounted transformer adjacent to the newly constructed campus electric service building. Campus electrical consumption is metered on the primary service. The secondary of the service transformer provides a campus incoming service at 4,160V and feeds a single ended switchgear lineup located in an elevated room for flood protection. The 4,160V switchgear was recently installed in 2020 as part of the relocation of the campus service from the old power plant building.

From the 4,160V switchgear there are 5 radial feeders that distribute across the campus underground. Each radial feeder serves one or several buildings. Most buildings have indoor unit substations consisting of incoming switch, transformer, step-down transformer and building distribution section. There are a few exterior pad mounted transformers serving select buildings.

RADIAL FEEDER #	BUILDING	SERVICE TYPE	BUILDING TRANSFORMER RATING
1	Clean Harbors Athletic Center	Indoor Unit Substation	500 KVA
2	Harrington Building	Indoor Unit Substation	500 KVA
2	ABS/Information Commons	Indoor Unit Substation – Penthouse	500 KVA
3	Kurz Building	Indoor Unit Substation	300 KVA
3	Bresnehan Building	Indoor Unit Substation	500 KVA
3	Dining/Student Union/Dormitory Building	Indoor Unit Substation	750 KVA
4	Flannigan	Outdoor Pad Mount Transformer	300 KVA
4	Rectifier Building	Indoor Unit Substation	1,500 KVA
4	Rectifier/Dock Boiler Room	Outdoor Pad Mount Transformer	500 KVA
5	Power Plant / Water Treatment Plant	Indoor Unit Substation - Elevated	500 KVA



Metered Electricity Usage (Source: Mass Maritime Hatch Database)

ELECTRICAL GENERATION SYSTEMS

DCAMM and the Academy have taken a proactive approach towards sustainability. A key component of reducing carbon footprint is to minimize the utilization of fossil fuels and grid-imported power on site and maximizing the utilization of renewable energy sources on site. Towards this end the Academy and DCAMM have installed multiple sources of renewable power which can be summarized as follows:

- 660 kW wind turbine located on site
- 75 kW rooftop array on Companies 1-6 (designed, but condition is degrading with falling output and system nearing the end of life)
- 103 kW rooftop solar PV array on the ABS Information Commons building
- 70 kW solar thermal rooftop array on the natatorium
- 195 kW combined heat and power system in the dormitory
- 120 ton geothermal ground source heat pump system near the information commons
- Solar PV and battery storage lighting pathway

Existing Buildings and Energy Conservation Upgrades

Overview

The campus had a steam distribution loop to heat buildings that was de-commissioned approximately 15 years ago. Currently, each building has its own boiler plant for heating. The Companies utilize a cogeneration system that primarily tracks the heating load requirement, and the electrical power is utilized for electrical loads within the Companies. The heating and cooling systems for each building are described in the following sections.

Energy Conservation Opportunities - Summary

The energy conservation and efficiency measures recommended in the following sections can be described as short term and long term measures.

SHORT TERM MEASURES

The short term measures are relativity inexpensive and non-disruptive to building occupants. Examples of short term measures are listed below.

Retro-commissioning

- Identify operational deficiencies and improve system efficiencies

Demand Control Ventilation (DCV) / Occupancy & CO_2 Sensors

- Limit ventilation to minimum required for occupied spaces
- Reduce volume of outdoor air that requires conditioning

Energy recovery

- Retrofitting heat recovery wheels, cores, etc. to air handler units
- Duct-mounted heat recovery devices
- Piped sensible only heat recovery or Adiabatic (Konvekta™) heat recovery for lab buildings

Lighting upgrades / controls

- Upgrade to LED lighting
- Occupancy controls
- Daylighting & controls

Control Optimization

- Optimized Scheduling / Reset
- Improved Sequence of Operations
- Hardware and metering upgrades

LONG TERM MEASURES

Long term measures generally include major mechanical system renovations, replacement and envelope upgrades. These renovations are expensive and largely disruptive to the building occupants. Some of the recommended long term mechanical changes include the following:

- Design and implement low temperature hot water (up to 120°F) heating systems.
- Design and implement a dual temperature chilled water system using low temperature chilled water (44°F) for dehumidification in air handler units that cascades into non-condensing terminal equipment (chilled beams, radiant panels, etc.) that uses medium temperature chilled water (58°F).
- Design and implement high efficiency ventilation systems to minimize the quantity of outdoor air required, with a combination of the following technologies:
    - A Dedicated Outdoor Air System (DOAS), which supplies 100% outdoor air.
    - Displacement ventilation diffusers that provide fresh air at low levels in a space that then rises vertically to provide each occupant with fresh air and displaces any contaminants to above the occupied zone from where they can be exhausted. (This strategy allows for up to a 20% decrease in code required ventilation.)
    - Demand control ventilation, which uses a

combination of occupancy and CO2 sensors to limit the airflow to the quantity required by space occupancy, and high efficiency heat recovery, such as a total energy or enthalpy wheel, to recover as much energy as possible and reduce the total heating and cooling required.
    - Low static pressure air delivery systems.
- Design and implement natural and mixed mode ventilation systems where possible by encouraging occupants to open windows during periods of mild weather and using installed fans to draw air through the windows and up through the building to reduce the need for mechanical cooling.
- Install ceiling fans, particularly high volume, low speed (HVLS) fans, to extend the thermal comfort window and allow for higher cooling setpoints and lower heating setpoints.
    - Note that it is typically not appropriate to combine ceiling fans with displacement ventilation as fans are used to mix (de-stratify) the air in a space and displacement ventilation relies on air stratification
- Design and implement LED based lighting systems with power densities not to exceed 0.8 W / sq. ft.
- Update Building Automation Systems (BAS) with new state of the art control and metering systems.

Building Systems and Recommended Upgrades: Harrington Hall

OVERVIEW

Harrington Hall is a 74,000 sf building, built in 1979, used as an office and classroom building. Harrington has not received a substantial renovation in its life with the exception of updates to the Admiral Hall Auditorium in 2014 and the Emergency Operations Training Center (EOTC) in 2020. The building is brick and concrete with near continuous rows of windows on each floor. The northern portion has floor to ceiling windows on the East and West sides on the ground level near the entrances. The southern half of the building contains office space, and the northern half contains classroom space. The building operates on a 6:00 AM – 5:00 PM daily schedule.

EXISTING MEP SYSTEMS

The mechanical room is in the northern portion of the ground level and contains the building's heating boilers, domestic hot water heater, evaporative fluid cooler, pumps, fire service, and emergency generator.

Three natural gas boilers, HydroTherm KN-20 with 1,853,99 BTU output each, installed within the past 10 years, feed the building's unit ventilators and cabinet unit heaters directly as well temper the building's condenser water loop via a pair of shell-and-tube heat exchangers. The boilers operate between a supply temperature 135°F and 180°F. A condensing gas fired hot water heating system, PowerVent VT, 399,000 Btu 125 gallon, provides hot water for the building.

The evaporative fluid cooler made by Baltimore Aircoil Company (Model F1743-MM) was installed about 20 years ago and cools the building condenser water loop directly. It operates as a dry cooler in the swing season.

The building was originally served by a pneumatic control system, however this system now only serves the equipment in the mechanical room. The rest of the building has been outfitted with individual space controls.

The 75-kW emergency diesel generator is elevated in the mechanical room with an adjacent 80 gallon day tank and an outdoor 500 gallon fuel tank next to the building. The fuel oil pumps are located on the ground level of the mechanical room adjacent to the other building pumps. The generator provides backup power to the heating system, safety lighting, and critical IT equipment. The load is near its maximum capacity. Harrington's HVAC systems vary by zone type – office, classroom, Admiral Hall, and EOTC.

BUILDING USE(S)	Office and Classroom	AREA (SF)	74,000	NAT.GAS USE (MMBTU)	3,810
		YEAR CONSTRUCTED	1979	CARBON EMISSIONS ($MTCO_2e$)	318
		RENOVATIONS	N/A	EUI (kBTU/SQFT/YR)	70

Harrington Hall At a Glance

The office areas use a combination of unit ventilator and above-ceiling ducted water-to-air heat pumps served by an 80°F condenser water loop. The condenser water loop switches its heating / cooling source between the natural gas boilers paired to shell-and-tube heat exchangers and an evaporative fluid cooler depending on the load. The condenser water loop is served by pumps #P-6 and #P-7. A majority, about 85, of the water-to-air heat pumps have been replaced, however there are ~10 that are original to the building.

The classrooms are served by perimeter radiation and heating-only unit ventilators. Nearly all the unit ventilators are original to the building. The unit ventilators are served by three pumps, P-3, P-4, and P-5, two of which operate to serve the load while the third is redundant.

Admiral Hall Auditorium is served by an AAON rooftop unit with gas heating and DX cooling. There are two cabinet unit heaters in the hallway adjacent to auditorium that feed hot water from the buildings boilers. There are two pumps, P-1 and P-2 that exclusively serve these cabinet unit heaters.

The Emergency Operations Training Center is served by a Mitsubishi VRF system that provides heating and cooling. Additionally, there are multiple heat pumps that serve individual spaces, such as a pair of IT spaces. The air supplied to building is exhausted by several roof exhaust fans and three fume hood exhaust fans.

SHORT TERM MEP UPGRADES

Retro-commissioning of the building systems provides an opportunity to identify operational deficiencies and improve system efficiency. Adding demand control ventilation by integrating occupancy sensors and adding CO2 sensors in multi-occupant spaces to limit the amount of outdoor air results in significant energy savings. Adding heat recovery to the ventilation/exhaust systems will also result in energy savings. Heat recovery can be added as air handlers are replaced or as duct mounted devices are added to duct mains.

The unit ventilators serving the classrooms are original to the building and are past their useful life. The unit ventilator outdoor air dampers do not close, which results in unnecessary heating when the classrooms are unoccupied. These units can be replaced with newer, fully functional models sized for a lower hot water temperature.

There are several heat pumps serving the office area that are original to the building. Replacing these units will decrease energy use in these spaces and will likely have a beneficial effect to space acoustics. The facilities team has been actively replacing these units when possible.

Elevating the fuel oil pumps, which are currently on the ground level, will benefit building resiliency, but will not have an energy impact.

LONG TERM MEP UPGRADES

The long term upgrades that will result in the largest energy savings include replacing most mechanical systems and terminal devices in the building in order to be fully compatible with a heat pump system and campus energy loop. The existing boilers can be left in place and connected to the building's heating system to serve as a backup system. These changes would include the following:

- Add heat pumps to integrate with campus energy loop.
- Replace rooftop units with a dedicated outdoor-air air handler units with total energy recovery, a hot water coil, and chilled water coil.
- Install radiant ceiling panels or chilled beams in occupied spaces.
- Install fan coil units to serve in vestibule/entry areas.

- Update Building Automation Systems

Lighting systems have been upgraded in portions of the building, however there are additional spaces to upgrade to LED lighting from fluorescents. Daylighting controls may be beneficial in the portions of the building with significant glazed areas. Additionally, use of occupancy sensors with a “manual on, vacancy off” control strategy may represent additional energy savings.

The building was not originally insulated well and although some spaces have been insulated during renovations, a majority of the spaces have not. Upgrading to triple-glazed windows, increasing insulation, and reducing infiltration will provide energy benefits, especially in heating.


Harrington Hall Mechanical Room Exterior at Grade Level


Lighting Fixtures


Mechanical Room Pumps


Condensing Gas Fired Domestic Hot Water Heater

Building Systems and Recommended Upgrades: Bresnahan Hall

OVERVIEW

Bresnahan Hall is a 54,100-sf building, originally built in 1968 with a sizable addition in the late 70’s/early 80’s and another in 2004. The original building is used as office and classroom space. The first addition is used as classrooms, lab space and office space for the campus police station. The 2004 addition is used as lab and classroom space. The original building and first addition are brick buildings with large, glazed areas on each side. The 2004 addition is a large brick building with several windows in each space and curtain walls along the northeast and southwest sides.

EXISTING MEP SYSTEMS

The building’s main mechanical room is in the northeast portion of the ground floor and contains the building’s boilers, hot water pumps, fuel oil tank, fuel pumps, and fire service. The building’s gas-fired domestic water heater is in a smaller mechanical room near the main mechanical room.

Three natural gas boilers, installed within the past 10 years, feed the building’s perimeter radiation, reheat coils, radiant floor, and air handler coils. The boilers operate between 135°F and 180°F.

The 3-kW emergency diesel generator is on the roof near the northeast corner of the original building and has a 200-gallon day tank. The 285-gallon fuel tank and fuel oil pumps are located on the ground level of the mechanical room.

The original building is served by perimeter radiation, a 20–25-year-old Mitsubishi split system and an energy recovery ventilator (ERV) with a hot water coil. There are also small air handler units with hot water coils serving the machine shop and welding lab, respectively.

The first addition is served by perimeter radiation, an energy recovery ventilator with a hot water coil, and heat pumps to cool individual spaces. There are several supply and exhaust fans that serve individual spaces.

The 2004 addition is primarily served by perimeter radiation and rooftop units with hot water coils and DX cooling. The labs on the first level are heated by perimeter radiation with ventilation air provided by a rooftop unit with a hot water coil. One lab on the first floor has radiant floor heating.

Labs on the second and third level are served by a rooftop unit with hot water coil and DX coil with additional heating from a VAV box reheat coil. The atrium is served by a rooftop unit with hot water coil and DX coil and smoke exhaust fans. Restrooms on each floor are exhausted through a common exhaust fan.

BUILDING USE(S)	Office, Classroom, Laboratory, etc	AREA (SF)	54,100	NAT.GAS USE (MMBTU)	2,767
		YEAR CONSTRUCTED	1968	CARBON EMISSIONS ($MTCO_2e$)	246
		RENOVATIONS	Late 70s/Early 80s, 2004	EUI (kBTU/SQFT/YR)	73

Bresnahan Hall At a Glance

SHORT TERM MEP UPGRADES

Retro-commissioning of the building systems provides an opportunity to identify operational deficiencies and improve system efficiency. Adding demand control ventilation by integrating occupancy sensors adding CO2 sensors in multi-occupant spaces to limit the amount of outdoor air results in significant energy savings. Adding heat recovery to the ventilation/exhaust systems will also result in energy savings. Heat recovery can be added as air handlers are replaced or as duct mounted devices are added to duct mains.

The Mitsubishi system serving the original portion is near the end of its useful life. Replacing this system with a VRF system will result in energy savings from improved equipment efficiencies. This system can also be extended into other portions of the building that do not have cooling with minimally disruptive renovations.

Elevating the fuel oil pumps, which are currently on the ground level, will benefit building resiliency, but will not have an energy impact.

LONG TERM MEP UPGRADES

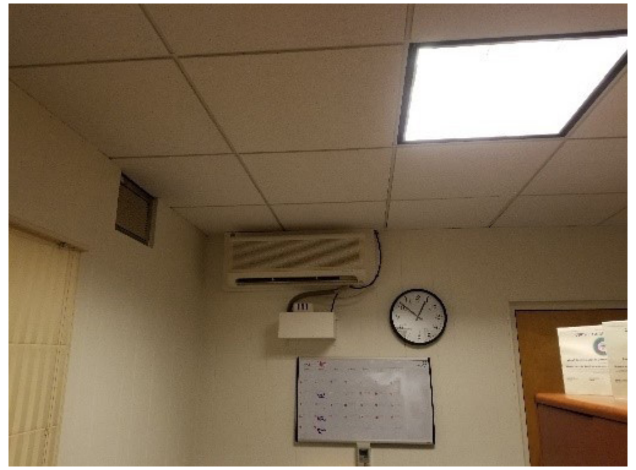
The long term upgrades that will result in the largest energy savings include replacing the majority of mechanical systems and terminal devices in the building in order to be fully compatible with a heat pump system and campus energy loop. The existing boilers can be left in place and connected to the building's heating system to serve as a backup system. These changes would include the following:

- Add air-source and/or water-source heat pumps to produce hot and/or chilled water and integrate with campus condenser water loop.
- Replace rooftop units with a dedicated outdoor-air air handler unit with total energy recovery, a hot water coil, and chilled water coil.
- Install radiant ceiling panels or chilled beams in occupied spaces.
- Install fan coil units served to hot water and low temperature chilled water in vestibule/entry areas.
- Update Building Automation Systems

Lighting systems have been upgraded in portions of the building, however, there are additional spaces to upgrade to LED lighting from fluorescents. Daylighting controls may be beneficial in the portions of the building with significant glazed areas. Additionally, use of occupancy sensors with a "manual on, vacancy off" control strategy may represent additional energy savings

The envelope of the building varies given the difference in age in each building section. Based on previous energy codes and the observed construction it is likely that the older sections of the building have an insulation of R-4 or below while the 2004 addition likely has an insulation value of R-8 to R-12. The original and first addition will benefit from increasing insulation and reducing air infiltration.

Bresnahan Hall Mechanical Equipment in Mechanical Room



Lighting in Office Space

Lighting Fixture and Roof Vent

Electrical Equipment

Building Systems and Recommended Upgrades: Gerhard E Kurz Hall

OVERVIEW

Gerhard E Kurz Hall is a 26,800 sf, brick and concrete building with near continuous rows of windows on each floor. The building was originally used as a library but was renovated in 2014 and is now used as office space and a bookstore.

EXISTING MEP SYSTEMS

The building is served by two rooftop units with DX and hot water coils that provide conditioned air to each space and a pair of natural gas boilers that were installed as part of the campus heating decentralization project prior to the Kurz Hall renovation. The boilers also provide hot water to VAV box reheat coils, perimeter radiation, and a couple cabinet unit heaters.

The rooftop units produce a loud, low-to-mid frequency noise that can be heard in the areas surrounding the building. The facilities team reported that there have been noise complaints and that the units' fans were lowered to 80% speed.

SHORT TERM MEP UPGRADES

Retro-commissioning of the building systems provides an opportunity to identify operational deficiencies and improve system efficiency as this building shows particularly high energy usage for this program/building type. Adding demand control ventilation by integrating occupancy sensors and adding CO2 sensors in multi-occupant spaces to limit the amount of outdoor air results in significant energy savings. Adding heat recovery to the ventilation/exhaust systems will also result in energy savings. Heat recovery can be added as air handlers are replaced or as duct mounted devices are added to duct mains.

LONG TERM MEP UPGRADES

The long term upgrades that will result in the largest energy savings include replacing most mechanical systems and terminal devices in the building in order to be fully compatible with a heat pump system and campus condenser water loop. The existing boilers can be relocated to a higher elevation (or replaced) and

BUILDING USE(S)	Office and Bookstore	AREA (SF)	26,800	NAT.GAS USE (MMBTU)	2,122
		YEAR CONSTRUCTED	1969	CARBON EMISSIONS ($MTCO_2e$)	158
		RENOVATIONS	2014	EUI (kBTU/SQFT/YR)	99

Kurz Hall At a Glance

connected to the building's heating system to serve as a backup system. These changes would include the following:

- Add air-source and/or water-source heat pumps to produce hot and/or chilled water and integrate with campus condenser water loop.
- Replace rooftop units with a dedicated outdoor-air air handler unit with total energy recovery, a hot water coil, and chilled water coil.
- Install radiant ceiling panels or chilled beams in occupied spaces.
- Install fan coil units served to hot water and low temperature chilled water in vestibule/entry areas.
- Update Building Automation Systems.

The lighting systems were upgraded as part of the 2014 renovation and contain a mix of fluorescent and LED fixtures. The fluorescent fixtures can be upgraded LED fixtures. Daylighting controls may be beneficial in the portions of the building with significant glazed areas. Additionally, use of occupancy sensors with a "manual on, vacancy off" control strategy may represent additional energy savings.

The building was insulated and fitted with double-glazed windows in the 2014 renovation. Upgrading to triple-glazed windows, increasing insulation, and reducing infiltration will provide energy benefits, especially in heating.

Building Systems and Recommended Upgrades: Clean Harbors Athletic Center

OVERVIEW

The Clean Harbors Athletic Center is an 80,000 sf building originally built in 1971 with minor renovations such as mechanical system renovations 12 years ago and a window and roof insulation replacement in 2020-2021.

The electric, gas, and water utilities serving Clean Harbors are located in the Level 1 Electrical Room, the North side of the building exterior, and Pool Mechanical Room, respectively. The Pool Mechanical room also houses the pool chemicals, which are monitored by a hazardous material alarm system.

EXISTING MEP SYSTEMS

The Clean Harbors Athletic Center has 8 major single zone air handlers that serve various areas for ventilation. Most of these air handlers are about 12 years old and are located within mechanical rooms. The air handling units that serve the gym are also located in the gym. There are a number of exhaust fans that serve several areas in the building. The units that provide ventilation do not include heat recovery or demand-controlled ventilation (DCV).

The hot water heating system is served by 4 gas-fired HydroTherm KN-30 boilers from the boiler plant which is located above grade in the mezzanine. The hot water heating system serves the AHU coils, perimeter radiation, reheat coils, and unit heaters. Most of these hot water terminal units are designed for a 200-degree Fahrenheit hot water temperature.

Most areas of the Clean Harbors Athletic Center are not air conditioned except for the Health Services department and some offices. There is also an existing solar hot water heating system that serves the pool and the domestic hot water system and has the capability for expansion.

SHORT TERM HVAC UPGRADES

Retro-commissioning of the building systems provides an opportunity to identify operational deficiencies and improve system efficiency. Adding demand control ventilation by integrating occupancy sensors adding CO2 sensors in multi-occupant spaces to limit the amount of outdoor air results in significant energy savings. Adding heat recovery to the ventilation/exhaust systems will also result in energy savings. Heat recovery can be added as air handlers are replaced or as duct mounted devices are added to duct mains. The installation of destratification fans in gymnasiums and other large spaces would be beneficial. The existing lighting conditions are currently a mix between LEDs and Fluorescent lighting with a value of 1.2 W/f2. Replacing the remaining fluorescent fixtures and adding lighting controls for occupancy and daylighting will provide energy savings.

BUILDING USE(S)	Athletics and Recreation	AREA (SF)	80,000	NAT.GAS USE (MMBTU)	6,146
		YEAR CONSTRUCTED	1971	CARBON EMISSIONS ($MTCO_2e$)	462
		RENOVATIONS	2020-2021	EUI (kBTU/SQFT/YR)	97

Athletic Center At a Glance

LONG TERM MEP UPGRADES

A new water source heat pump plant should be added at or near the location of the existing boilers. Existing boilers can be maintained to provide back-up heat, as they are located well above the flood level. The Athletic Center is currently in the process of replacing the windows and could benefit from more extensive energy efficiency upgrades to the building envelope. The building suffers from overheating during warm weather, and full air conditioning would be beneficial. This should be combined with an effective natural ventilation system to reduce the annual cooling energy required. Most of the existing Athletics Center is not air conditioned, is served by 8 major single zone air handlers that serve multiple areas, or the air is exhausted by one of the numerous exhaust fans. Long term HVAC upgrades to the Clean Harbors Athletic Center would be to fully air condition the building by replacing the 8 air handlers and numerous exhaust fans with one capable air handler that includes heat recovery and demand-controlled ventilation (DCV). Supplemental radiant heat would reduce stratification and eliminate the need to operate air handling units for heating during unoccupied periods.

Elevated Location for Mechanical Equipment

Athletic Center Mechanical / Boiler Room

Lighting

Building Systems and Recommended Upgrades: Pande Dining Hall & Student Union

OVERVIEW

Pande Dining Hall is a one-story, brick veneer building and it is located at the southern end of the campus. The dining services handle over 1,200 students with three meals served per day. The dining hall is open from 6:00 am until 8:00 pm every day. The existing lighting conditions are currently a mix between LEDs and Fluorescent lighting with a value of 1.2 W/ft2 so the Pande Dining Hall and Student Union could benefit from a lighting upgrade.

The insulation in the Pande Dining Hall and Student Union is overall in good shape. The building needs an insulation upgrade, however, the insulation in this building is not as bad as the current insulation conditions compared to some of the other buildings on campus.

There is a current project underway for an addition to the Pande Dining Hall. As part of this design process, Sasaki and Van Zelm did a peer review of the Design Development Drawings to suggest that the decarbonization recommendations be incorporated into the design.

EXISTING MEP SYSTEMS

The Dining Hall and Student Union is served by 7 roof-top units, roof-top kitchen exhaust fans and perimeter hot water heating. Five of the seven rooftop units serve seating areas and have DX cooling and gas heat; the other two serve as kitchen make up air and have gas heating only. The roof-top units are in good condition but have relatively low energy efficiency.

The roof-top kitchen exhaust fans use a variable flow hood exhaust system for ventilation but do not have any heat recovery capabilities. The perimeter hot water heating is served by the boiler plant located at the Company 1 building. The perimeter hot water heating system provides heat through fin tube radiation and radiant ceiling panels with a design hot water temperature of 170 degrees Fahrenheit. The boiler plant for the Dining Hall and Student Union is located on grade.

SHORT TERM HVAC UPGRADES

A balancing contractor should be contracted to balance all equipment in the Dining Hall. The manufacturer of the dishwasher recommends that 500 CFM be exhausted from the load end of the dishwasher and that 1,000 CFM be exhausted from the unload end. The servery area needs a review to confirm that sufficient airflow is being returned to the roof top units (RTUs) and that adequate make-up air is being provided to the kitchen dishwashing area. The air from the janitor's closet with stored chemicals should be exhausted through the roof.

LONG TERM HVAC UPGRADES

The building HVAC systems serving kitchen and dining areas should be replaced when they reach the end of their useful life, or at time of next major renovation. When replacement is warranted, the rooftop air handling systems should be consolidated and integrated between the dining and kitchen areas such that ventilation and cooling airflow delivered to the dining area serves as make-up air to the kitchen exhaust hoods. The units should be fit with a heat recovery system to reduce the conditioning required for the kitchen make-up air and hydronic heating and cooling coils to ensure compatibility with heat pump systems. Additionally, all heating components should be sized to use low temperature hot water (120F-140F).

BUILDING USE(S)	Dining, Student Life	AREA (SF)	24,500	NAT.GAS USE (MMBTU)	3,738
		YEAR CONSTRUCTED	1971	CARBON EMISSIONS ($MTCO_2e$)	263
		RENOVATIONS	2011	EUI (kBTU/SQFT/YR)	184

Pande Dining Hall & Student Union At A Glance

In addition:

- Natural gas use should be eliminated at all air handlers. Low temperature hot water/glycol should be used for pre-heating outside air.
- Hot water in greater capacity should be provided from the future heat pump plant in The Company buildings.
- Variable flow kitchen hoods with a heat recovery exhaust system should be provided to reduce energy use and peak heating loads.
- Chilled water should be provided from the heat pump plant in The Company buildings to satisfy cooling requirements.

Pande Dining Hall

Mechanical Equipment Located on Roof

RTU-2

Mechanical Equipment Located on Roof

Building Systems and Recommended Upgrades: Company Halls, 1-7

OVERVIEW

The Company 1-7 buildings are due for an insulation upgrade. The current EUI value for this building (107 kBTU/ft2) is almost double the median EUI value (58 kBTU/ft2) which makes insulation one of the top priorities for this building's envelope upgrades. Other building envelope upgrades that the dorms would benefit from are utilizing a revolving door at the Company building entrances instead of using the existing wide doors because this would decrease infiltration in the high traffic entrances.

EXISTING MEP SYSTEMS

The Company 1 through 7 Dorm buildings have heating hot water and domestic hot water systems produced by three 65 kW Capstone Micro turbines. The central hot water loop serves all Companies and the Dining Hall with a design hot water temperature of 170 degrees Fahrenheit. The gas-fired boiler plant is used as a backup and to help meet the peak loads. The turbines stage to meet hot water load, electrical output follows, and no supplementary heat rejection is provided.

There is no air conditioning (only heating) in the Companies and most heating to the dorms is provided by perimeter radiation. There are roof-top heat recovery ventilation units that provide bathroom exhaust and make-up air to the corridors. There is also no ventilation for the dorm rooms. There is an existing 74 kW Photovoltaic system located on the roof of the Companies that currently has issues with bird damage and the boiler plant is located on grade.

SHORT TERM HVAC UPGRADES

The Companies short term upgrades to help the Academy reach decarbonization would be replacing the perimeter heating radiation with the heating source utilizing low temperature hot water (120-140°F). Since the building does not have air conditioning, ventilation could be used to cool the dorms. There are roof-top heat recovery ventilation units that exhaust air from the bathrooms and provide make-up air to the corridors. These same units could be used to improve conditions during warm weather by increasing exhaust airflow to provide more airflow through operable windows.

LONG TERM HVAC UPGRADES

The Academy is in the process of upgrading/replacing the heating system throughout to Company buildings. The first building was completed and individual room temperature control was provided, but the system design was based on higher temperature hot water (180°F) that would not be compatible with future heat pumps. Subsequent renovations should include building envelope upgrades and perimeter heating systems that can utilize low temperature (120-140°F) hot water.

When the heating systems for all buildings have been converted to low temperature hot water, the existing cogeneration plant should be replaced with a new ground source heat pump plant connected to the energy transfer loop. This plant would be sized to provide hot water for The Company buildings as well as the Pande Dining building. The new plant should be located at the roof level, with gas fired condensing hot water boilers for back-up purposes. Additionally, the roof-top heat recovery ventilation units that serve the bathrooms and provide make-up air to the corridors should be replaced with roof-top heat recovery ventilation units that are sized to handle the ventilation loads of the bathrooms and dorm rooms, with ventilation air provided to the dorm rooms and transferred to the bathrooms for make-up.

BUILDING USE(S)	Housing	AREA (SF)	254,158	NAT.GAS USE (MMBTU)	27,593
		YEAR CONSTRUCTED	1971	$MTCO_2e$	1,637
		RENOVATIONS	2004	EUI (kBTU/SQFT/YR)	107

Companies 1-7 At A Glance


Companies 1-7


Mechanical Room (2)


Mechanical Room


Mechanical Room (3)

Building Systems and Recommended Upgrades: ABS Commons

OVERVIEW

The ABS Commons building is a relatively new library facility constructed to modern standards for high efficiency buildings. The building achieve LEED Platinum certification, indicative of the high level of sustainability and energy efficiency. The ABS Information Commons building envelope has good insulation values; the median EUI for this building is 65 kBTU/ft2 and the building's actual EUI is 36 kBTU/ ft2.

In many ways, ABS is the model for sustainable systems for future capital improvement projects. The proposed Campus Energy Loop can connect the ABS building and its geowells with future developments on campus.

EXISTING MEP SYSTEMS

The building is fully air conditioned throughout and all of the HVAC equipment serving the building is located in the mechanical penthouse. There is an energy recovery unit used for ventilating the building and there are 2 air handling units to cool the building. Chilled beams are supplemented into the office spaces and conference rooms. The building uses a ground source heat pump system with 3 water to water heat pumps and each heat pump can provide heating or cooling. There are approximately twenty 400-foot closed loop geo-wells for the ground source heat pump system. For heating, the hot water supply temperature is 100-degrees Fahrenheit and is served through the radiant floor, chilled beams, AHU coils, and perimeter radiation.

In addition to the system components described above, there is also a 104 kW Photovoltaic system on the roof of the building and the boiler plant for the ABS building is located above grade. The HVAC system for the ABS Information Commons building serves as a good conceptual example for future renovations and new construction to come.

SHORT TERM HVAC UPGRADES

The ABS Information Commons building is a relatively new building that is conceptually a good HVAC system example for future renovations and new construction.

LONG TERM HVAC UPGRADES

There are 3 existing water to water ground source heat pumps and each heat pump can provide heating or cooling. An upgrade to this current system could be implementing 3 water to water ground source heat pumps that can provide heating and cooling simultaneously. As part of the development of the campus-wide geo-exchange and energy transfer loop (ETL) system, the dedicated well field for the building should be tied into the ETL in a configuration consistent with all other buildings.


ABS Commons Mechanical Room


Light Fixtures in Conference Room


Lighting

BUILDING USE(S)	Library	AREA (SF)	41,741	NAT.GAS USE (MMBTU)	1,010
		YEAR CONSTRUCTED	2011	MTCO$_2$e	94
		RENOVATIONS	N/A	EUI (kBTU/SQFT/YR)	36

ABS Information Commons At A Glance

Building Systems and Recommended Upgrades: Flanagan Hall

OVERVIEW

Flanagan Hall is an 8,000-sf building, built in 1938, used as admissions offices and classrooms. Flanagan received a major renovation in 2002 with architectural, structural and MEP updates. Another renovation is currently underway to add cooling coils to the existing air handler units. Flanagan is a brick building with a continuous row of windows along each wall. The building is occupied on the ground level and has a large attic space that serves as the mechanical room for the building. The admissions office occupies about half of the building with classrooms in the remainder.

EXISTING MEP SYSTEMS

The building is served by perimeter radiation and small air handlers with heating coils fed by two natural gas boilers. Domestic hot water is provided by a natural gas hot water heater with a storage tank. The building has seen recent upgrades to the HVAC system to provide AC throughout all occupied areas.

The air handlers serving the offices provides cooled and heated outdoor air, the air handler serving the Sea-lab classroom provides heated outdoor air in the winter and unconditioned air in the summer, and the air handlers serving the classrooms, lobby and conference room provide unconditioned outdoor air mixed with return air from the spaces they serve.

The facilities team reported that there are control issues between the heating provided by the perimeter radiation and the air handlers where the heat provided by the air handlers satisfies the thermostat setpoint but does not adequately heat the space. The problem is particularly noticeable in the Sea-lab classroom.

SHORT TERM MEP UPGRADES

Building energy use is quite high for a building of this type, so retro-commissioning of the building systems provides an opportunity to identify operational deficiencies and improve system efficiency. Adding demand control ventilation will limit the amount of outdoor air to the minimum required for the space, thus resulting in significant energy savings. Adding heat recovery to the ventilation/exhaust systems will also result in energy savings. Heat recovery can be added as air handlers are replaced or as duct mounted devices added to duct mains.

LONG TERM MEP UPGRADES

The long term upgrades that will result in the largest energy savings include replacing most mechanical systems and terminal devices in the building in order to be fully compatible with a heat pump system and campus condenser water loop. These changes would include the following:

- Adding air-source and/or water-source heat pumps to produce hot and/or chilled water and integrate with campus energy transfer loop.
- Replacing air handling units with a dedicated outdoor-air air handler unit with total energy recovery, a hot water coil, and chilled water coil.
- Installing radiant ceiling panels or chilled beams in occupied spaces.
- Installing fan coil units served to hot water and low temperature chilled water in vestibule/entry areas.

The lighting systems are fluorescent fixtures from the 2002 renovation and will provide an energy reduction

BUILDING USE(S)	Office and Classroom	AREA (SF)	8,000	NAT.GAS USE (MMBTU)	634
		YEAR CONSTRUCTED	1938	MTCO$_2$e	60
		RENOVATIONS	2002	EUI (kBTU/SQFT/YR)	118

Flanagan Hall At a Glance

if upgraded to LED lighting. Daylighting controls may be beneficial in the portions of the building with significant glazed areas. Additionally, use of occupancy sensors with a "manual on, vacancy off" control strategy may represent additional energy savings.

The building was insulated and fitted with double-glazed windows in the 2002 renovation. Upgrading to triple-glazed windows, increasing insulation, and reducing infiltration will provide energy benefits, especially in heating.


Flanagan Hall Outdoor Mechanical Equipment


Attic Mechanical Equipment


Lighting

Building Systems and Recommended Upgrades: Kelly Power Plant

OVERVIEW

The Kelly Power Plant is a 4,900-sf building that is currently being used as facilities' offices and workshop with a space cordoned off for academic use. The building previously housed three high pressure steam boilers that served the campus. These boilers were removed as part of a campus heating decentralization that was completed in 2014. The building is an open two-story, brick and CMU construction with groups of large windows along each side.

EXISTING MEP SYSTEMS

The building is served by a natural gas boilers feeding unit heaters that are evenly spaced around the open area portion of the building with cabinet unit heaters in the other spaces in the building. Domestic hot water is provided by an electric resistance hot water heater.

SHORT TERM MEP UPGRADES

Adding a destratification fan(s) will improve heating efficiency by forcing heated air into the occupied zone. Destratification fans can also add a degree of cooling.

LONG TERM MEP UPGRADES

Lighting systems should be upgraded to LED lighting from fluorescents/HID. Daylighting controls may be beneficial in the portions of the building with significant glazed areas. Use of occupancy sensors with a "manual on, vacancy off" control strategy may represent additional energy savings.

The building will be studied for possible renovation and program change after the proposed new Science Building is completed.

Major portions of the building are uninsulated. Upgrading windows, adding insulation, and reducing infiltration will provide energy benefits, and should be done as part of the renovations.

Complete new HVAC systems should be provided as appropriate for the proposed building program and should include:

- New water to water heat pumps to satisfy building heating and cooling requirements.
- New Dedicated Outside Air System with heat recovery for ventilation.
- New zone level heating/cooling provided by radiant ceiling panels or chilled beams.

BUILDING USE(S)	Utility, Lab	AREA (SF)	4,900	NAT.GAS USE (MMBTU)	41
		YEAR CONSTRUCTED	1969	$MTCO_2e$	26
		RENOVATIONS	2014	EUI (kBTU/SQFT/YR)	67

Kelly Power Plant At a Glance


Kelly Power Plant Mechanical Equipment


Light Fixtures


Light Fixtures and Mechanical Piping

Proposed Projects: Sustainable Design Guidelines

Decarbonization Strategies for Projects Proposed in Campus Master Plan

Along with a study of existing campus structures, the decarbonization study proposes strategies for projects proposed in the campus master plan. The following sections outline some of these strategies, including passive strategies, low energy systems, and embodied carbon reduction strategies.

PASSIVE STRATEGIES IN FUTURE BUILDINGS

The decarbonization study recommends that new facilities embrace passive design strategies that can contribute to significant reductions in heating and cooling loads. Most broadly, optimal solar orientation – in which long facades face the South and North to the greatest degree possible - can improve the Whole Building EUI of new buildings. Solar shading of South facing windows can block summer passive solar heat gain. East and West glazing should be minimized, and vertical louvers should be added where possible. Optimizing access to natural light and ventilation throughout buildings is encouraged.

Sustainable envelope design strategies lead to significant energy savings and are recommended in future building design. WWR of 35-40% is recommended, which is in line with upcoming Building Code based on IECC 2021 with anticipated MA amendments. Roof, wall, and glazing insulation of at least 25% greater than code is recommended, as well as new construction airtightness of 0.1 CFM/ft2 of gross envelope area at 75 Pa.

LOW ENERGY SYSTEMS IN NEW CONSTRUCTION AND ADDITIONS

Low energy systems in proposed buildings are similar to the systems suggested in deep energy retrofits of existing buildings. This includes high efficiency water to water heat pumps, hydronic heating and cooling systems, Dedicated Outside Air Systems (DOAS), displacement ventilation, high efficiency heat recovery (sensible and latent), non-condensing cooling/radiant heating systems, natural and mixed mode ventilation, and use of ceiling fans.

EMBODIED CARBON

Along with operational carbon, building and infrastructure materials contribute to embodied carbon. With the goal to reduce embodied carbon from campus materials, the decarbonization study used the Carbon Conscious app, developed by Sasaki, to estimate the potential for carbon emissions, carbon storage, and carbon sequestration for design alternatives of proposed building and landscape projects. The Carbon Conscious app allowed the design team to compare design options, test alternate land uses, structural systems, and landscape and façade materials and see the impact of those choices.

To understand the carbon impact of different structural and façade systems for proposed buildings, the team tested design options in Carbon Conscious. The table on the next page compares estimated embodied carbon for each building based on different combinations of structural and façade systems.

To reduce embodied carbon from buildings, sustainable building materials guidelines were developed based on the understanding gathered through Carbon Conscious. A key factor in minimizing embodied carbon is prioritizing the reuse and repurposing of existing structures and material over new structures. When using new material in façade systems, wood should be prioritized, followed by brick, then metal panel. When using new materials in structural systems, wood should be prioritized, then steel, then concrete. Cement should be minimized in concrete mixes; Supplementary Cementing Materials (SCM) can be substituted for concrete. It is important to note that concrete structures will be required in the flood plain. Structures can be steel or wood above flood levels.

To reduce embodied carbon from landscape materials, softscape and planted materials should be prioritized over hardscape. Native grasses, meadow shrubs, and trees should be prioritized over turf grass where possible.

BUILDING	EMBODIED CARBON (TCO2/FT2)			
	WOOD STRUCTURE, WOOD CLADDING	STEEL STRUCTURE, WOOD CLADDING	STEEL STRUCTURE, BRICK CLADDING	STEEL STRUCTURE, METAL RAINSCREEN
STEM Building	140 - 290	190 – 490	210 – 530	220 – 560
Bresnahan		190 – 490	210 – 530	220 – 560
Housing Addition		290 – 720	315 – 770	340 – 530
Gym Addition		160 – 690	180 – 750	190 – 780
Harrington Reno		190 – 490	210 – 530	220 – 560
Power Plant Reno		160 – 690	180 – 750	190 – 780

LAND USE	AREA (HA)	CATEGORY / MATERIALS	CARBON (TCO2/FT2)		
			EMBODIED CARBON	CARBON SEQUESTERED	CARBON STORED
Turf	3.01	Turf	0 – 0	- 3.20	0.50
Informal Landscape	4.57	Low intensity perennial grasses and forb landscape, prairie garden, amended soil no irrigation	2.37 – 4.74	- 12.00	0
Native Edge Landscape	1.43	Restoration/Ecosystem restoration. Temperate continental forest.	1.20 – 3.02	- 24.60	0
Formal Quad Landscape	1.12	Sod turf over amended soil with irrigation	18.78 – 30.55	-4.80	0
New paths	1.29	CIP vehicular concrete hardscape. Mostly flatwork, some walls, limited drain structures and light furnishings	79.41 – 124.51	0	0.82

Resilience Considerations

This report evaluates resilience from a high level and only evaluates resiliency as it pertains to Carbon Neutrality. The Campus Master Plan summarizes the recommended resiliency approach.

The following are key recommendations to ensure resilience in conjunction with sustainability on the Academy's campus:

- Elevate Critical Building infrastructure such as boiler rooms and switch gear rooms
- Reinforce the coastal edge
- Implement wet and dry floodproofing
- Select landscapes that are flood resistant
- Optimize tree planting to prevent soil erosion and flood plain shifting

BOILER PLANTS

As shown in the chart on the following page, the following boiler plants are located below the 100 year flood plain and should be relocated:

- Bresnahan Building
- Companies
- Kurz Hall
- Harrington Hall
- Kelly Power Plant
- Dock Boiler

It is recommended that these existing boiler plants be relocated or replaced in association with the development of new heat pump plants at each building, and be utilized for back-up heating purposes only.

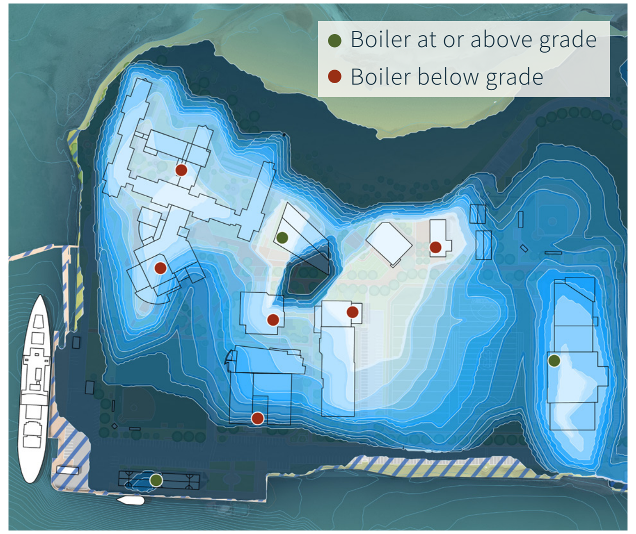
ELECTRICAL SYSTEMS

As shown in the chart to the right, the following electrical switchgear and generator rooms are located below the 100 year flood plain and should be relocated:

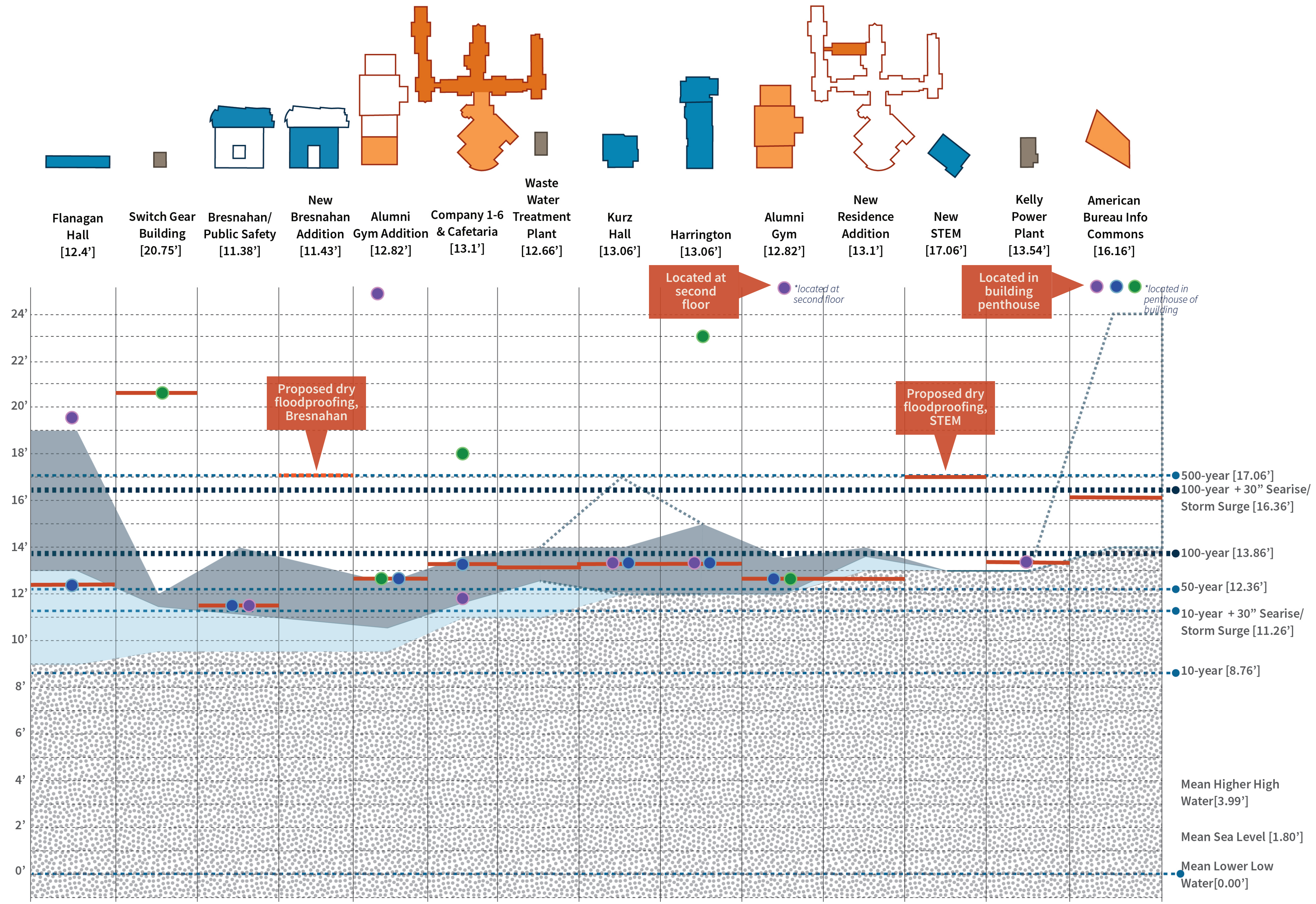
- Alumni Gym Addition
- Companies (Switchgear only)
- Kurz Hall (Switchgear only)
- Harrington Hall (Switchgear only)
- Alumni Gymnasium (Generator Only)

WINDOW RESILIENCE

The Academy is located in a region identified as hurricane prone. Most buildings on the Academy's campus fall under Occupancy Category three[1]. As such, triple pane windows capable of withstanding up to 47 pounds per square foot of force and winds of up to 130 mph should be included in any window upgrade.



First floor level
Boiler plant location
Switchgear location
Generator Location
Minimum flood depth below building footprint during a present day 1% storm event
Minimum flood depth below building footprint during a present day 1% storm event
Average elevation below building footprint



Sources: 2015 MMA Resiliency Study Book, Woods Hole Group, email communication with Paul O'Keefe on September 21, 2021

Renewable Energy/Decarbonization Technologies

To determine the optimal combination of technologies for the Academy to achieve carbon neutrality, several renewable energy and decarbonization technologies were evaluated.

The following technologies were deemed to be feasible for addition or expansion on the campus:

- Ground Source Heat Pumps
- Air Source Heat Pumps
- Solar Thermal
- Solar PV
- On Site Electrical Storage

Some of the most feasible and a few non feasible technologies have been discussed in further sections.

Technology / Fuel Source	Further Consideration	Comments
Ground Source Heat Pumps	Yes	Highest Efficiency, but High Cost, Site Disruption
Air Source Heat Pumps	Yes	Ongoing Advances in Technology/Efficiency
Solar Thermal – DHW/Pool Heating	Yes	Consider for Facilities with Significant DHW Loads or Pool Heating
Solar PV	Yes	Consider On & Off Campus Deployment, Power Purchase
On-Site Electrical Storage	Yes	Future Consideration based on Technology Development and Electrical Rate Structure
Hydropower - Remote	Yes	Potential Remote Source of Green Power
Wind Energy	Possible	Consider Off Campus Deployment, Power Purchase
Hydropower - Tidal	Possible	Investigate Potential for Future Local Development
Seawater Source Heat Pumps	Possible	Water Temp too cold in Winter, Application Challenges, gas boiler backup required
Biomass – Gaseous BioFuels	Possible	May Investigate Remote Gas Purchase, but High Cost
Microturbine Based Cogeneration	Possible	Retain/Replace existing, evaluate Bio-gas Availability
Solar Thermal – Space Heating/Cooling	No	Energy Storage Requirements, Complexity, Poor Economics
Biomass – Wood Chips/Pellets	No	Material Handling, Space Requirements, Resiliency Issues
Biomass – Liquid BioFuels	No	Equipment Compatibility, Availability, Cost
Hydrogen	No	High Cost, Limited Availability
Fuel Cell Based Cogeneration	No	High Equipment Cost, Limited and Costly Renewable Fuels

A NOTE ON CONSERVATION

In addition to identifying and eliminating emissions from generation sources and distribution sources on campus, The Academy can take significant steps towards carbon neutrality by implementing energy conservation measures at several of its largest as well as worst performing (highest energy use intensity) facilities identified in preceding sections of this report.

Solar Photo Voltaic (PV) Systems

The Academy already employs a significant amount of solar generation on its campus (75 kW on the Company Buildings and 103 kW on the American Bureau of Shipping Information Commons). Not only does this significantly offset its grid electrical utility consumption and cost, but also represents a significant step in going carbon neutral.

Photovoltaic energy harvesting is accomplished with photovoltaic cells composed of two types of semiconductors. The cell is hit by photons from the sun, and if a photon is energetic enough it will cause a flow of electrons, creating an electrical current. The electricity generated from photovoltaics is in the form of direct current, so inverters are required to convert to alternating current. The amount of energy that can be harvested in a given location is proportional to how well the panels are aligned to receive sunlight and to the area receiving the sunlight. PV systems generate no carbon emissions and can significantly offset the emissions due to grid purchased electricity, or cogenerated electricity. However, using this resource to heat facilities on campus will involve using heat pumps, or electric resistance heating or heat pumps chillers etc. All of these technologies in turn will increase the electrical demand on campus. Over the last decade, PV collector efficiency has increased by about 30%, while system costs have reduced dramatically (50-70%). Currently, solar PV arrays can be installed for approximately $1.80 / W[4].

Photovoltaic systems represent the best approach to generating renewable energy on the Academy's campus. The decarbonization study evaluated the potential for the installation of additional solar PV panels on campus, summarized in the table below.

A significant amount of solar PV sourced electrical energy can be generated on campus. This can be done via a Power Purchase agreement (PPA) to avoid the initial capital outlay associated with the development, design, procurement and installation of a PV system and subcomponents.

If the Academy and DCAMM can finance ownership of the solar PV panels, they can reap higher long term benefits for campus operations.

BUILDING NAME	ADDITIONAL PV POTENTIAL (kW)	PV ENERGY (kWH)
Pande Dining Hall	96	119,438
Clean Harbors	351	438,750
Kurz Hall	105	130,650
Power Plant	57	71,663
Bresnahan Building	140	175,500
Harrington Building	218	272,391
Company 1 - 6	75	93,750
Company 7	82	102,375
New Science Building	88	109,688
New Beachmoor	70	87,750
Total	**1,328**	**1,660,453**

4 https://www.costofsolar.com/mit-confirms-future-value-todays-solar-pv/

Solar Thermal

Active solar thermal applications collect the incident radiation from the sun and use it to provide heat to a working fluid such as water or a glycol mixture. Two of the most common types are flat-plate collectors and concentrating collectors. Flat-plate collectors have a dark material as a receiver plate with embedded piping for fluid circulation and a glazing. Solar radiation travels through the glazing and is absorbed by the receiver plate, which in turn heats the fluid circulating within the pipes. Flat-plate collectors are commonly used in residential, commercial, and industrial buildings for domestic hot water and space heating. In concentrating solar collectors, a curved mirror surface is used to reflect incident sunlight onto a pipe with fluid circulating through it. These collectors often include a tracking module to ensure the maximum amount of sunlight is reflected to the surface of the pipe. Concentrating collectors provide higher temperatures than flat-plate collectors, and are more commonly seen in industrial, commercial, and institutional applications.

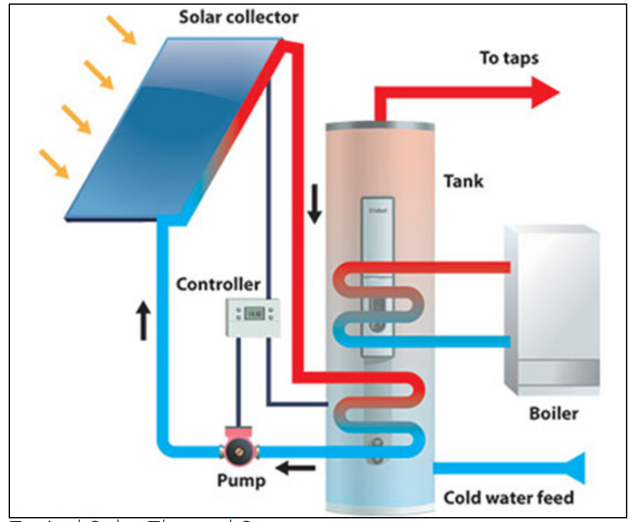
Solar thermal collector efficiency is highly sensitive to the differential between fluid temperature and ambient temperature, and output is a function of solar intensity and duration. As such, a solar system will produce roughly three times as much energy on a typical summer day than on a typical winter day.

For this reason, solar thermal systems are most cost effective when applied to low temperature heating loads which exist year-round, such as domestic hot water in dorms and pool heating

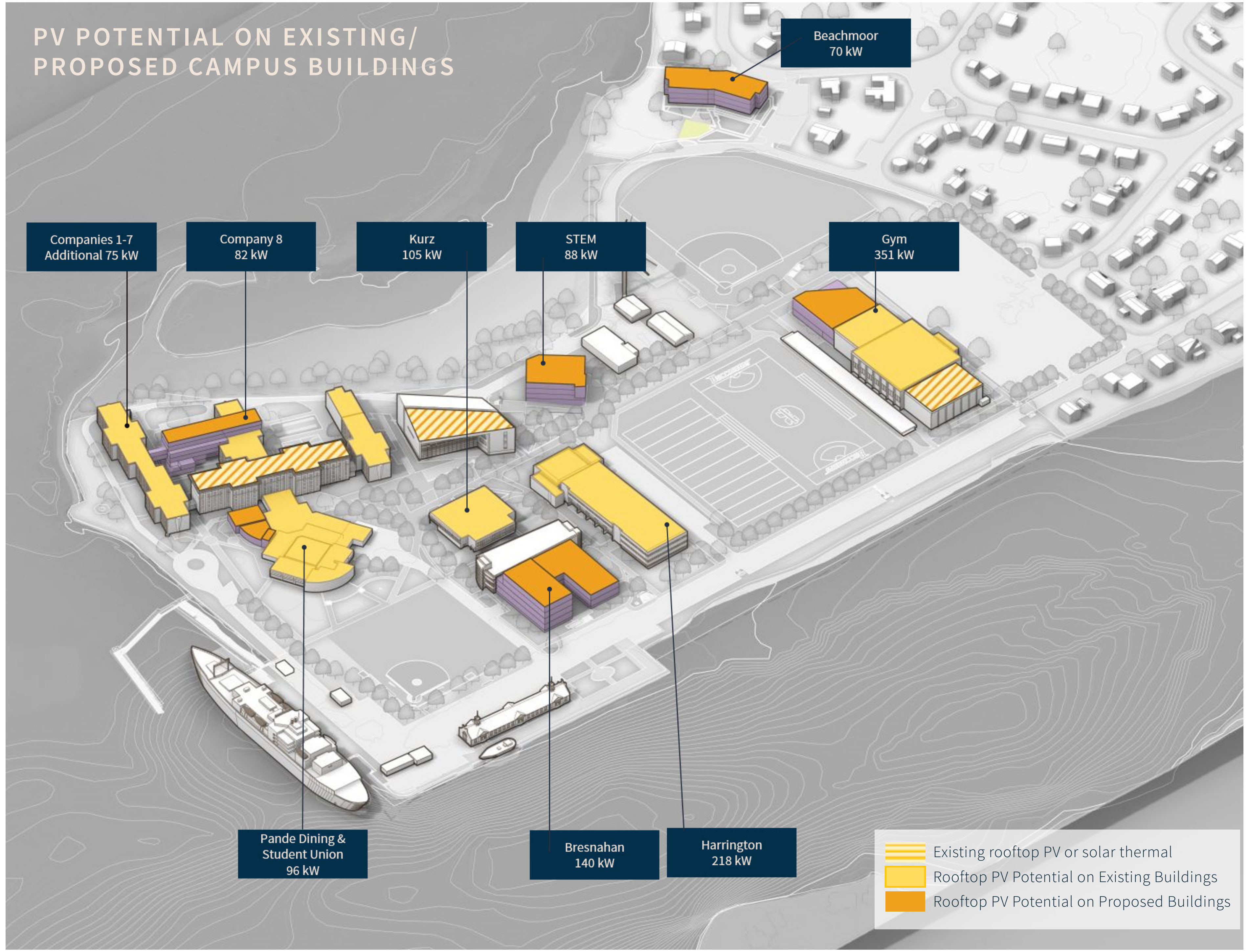
A major downside of using solar thermal to offset campus space heating loads is that the heating requirements are highest when the output and efficiency of solar thermal systems are at their lowest. In addition, substantial thermal storage is required, as greatest heat loads are at night when solar thermal energy is not available. Interseasonal energy storage (storing solar thermal energy generated throughout the year for use in the winter) has seen some limited applications in Europe and Canada, but such storage is costly and not presently competitive with other renewable energy heating approaches.

Solar thermal energy is effective for offsetting the utilization of natural gas for heating pool and domestic hot water loads. A solar hot water heating system is in place to serve the pool and domestic water loads at the Clean Harbors Athletic Center.

This system works well and has the capability to be expanded to provide a greater portion of the heating loads. Solar Thermal domestic hot water systems can complement ground source heat pumps systems where a heating imbalance exists (as will be the case at the Academy when the Companies come online), but the light summer occupancy on campus - when the greatest thermal output is available - makes this less attractive for residence halls at the Academy.



Typical Solar Thermal System



Wind Energy[5 6]

Wind energy harvesting is accomplished with a wind turbine rotating due to the forces the wind exerts on the blades. Devices to harvest wind energy come in many possible configurations, such as Vertical-Axis Wind Turbines (VAWTs) and Horizontal-Axis Wind Turbines (HAWTs), with the latter being more common. To keep HAWTs pointed in the direction of the wind, they require a yaw control. HAWTs can have different blade configurations and can be positioned either upwind or downwind. To convert the wind energy to electricity, the rotor is connected to a generator, either by a gearbox or by using a direct-drive generator. The controller for the turbine limits the operation of the wind turbine to a range between what is called the cut-in speed and the cut-out speed. This prevents the turbine from spinning in times of very high wind speeds like powerful storms. In unobstructed areas, more power can be harvested with higher hub heights.

Currently, the Academy has an operational 660 kW wind turbine on campus. This turbine outputs approximately 902,000 kWh annually and offsets approximately 185 MTCO2e of carbon emissions that would otherwise have been incurred. The local utility company credits the Academy for any PV or Wind Power exported into the grid, by the Academy. There is a wind turbine interconnection to the Electrical systems on campus. Wind is typically an efficient renewable energy source, especially near the water. However, noise and space concerns are often a perceived downside of wind turbines.

We commend the Academy for being at the forefront of sustainability and installing this wind turbine a decade ago. We do not currently recommend installing any additional wind turbines on site as a part of this study.

Hydro Power [7]

Conventional hydropower uses the difference in depth on two sides of a dam as a driving pressure gradient. This pressure gradient creates flow from one side of the dam to the other. A turbine is inserted into this flow to generate electricity from the kinetic energy of the water. The difference in depth and therefore the flow speed through the turbine can be modulated through the opening and closing valves on either side of the dam, allowing more water to pool in the reservoir before opening the valve and allowing flow through the turbine. This method of electricity generation requires damming a river, which is site-specific and has its own inherent environmental impacts, but the operation of the system requires no combustion.

There is no opportunity to develop hydro power facilities on or near campus. Currently, although the Academy does not purchase hydro power directly from a third-party vendor, the ISO-NE grid supplying the Academy does include a significant component of hydro-electricity.

Biomass/Biofuels

Biomass used for energy production involves the use of organic materials of biological origin as fuels for combustion. These organic chemical fuels come in various forms. Solid fuel exists in the form of wood pellets. Liquid and gaseous fuels exist in the forms of methanol, ethanol, and biodiesel. Part of the attraction of biomass is the fact that biomass can potentially be CO2-neutral. CO2-neutral biomass fuel is generated when the combustion of the fuel is balanced by the CO2 expended by photosynthesis during the growth process. The implication then is that the CO2 produced in harvesting and combusting the biomass would be completely offset by growth of the biomass. This balance is difficult to achieve. Another environmental concern of biomass is that combustion can produce a diverse variety of pollutants, including CO, nitrogen oxides, and ash/soot particulates. These bio-fuels can come from various feedstocks, including agricultural crops, woods, and their residues.

5 http://greenfieldspenrith.com/renewable-energy-cumbria/solar-thermal/

6 http://archive.boston.com/news/local/articles/2008/03/05/wind_turbines_propel_logans_energy_efforts/

7 https://www.hydroworld.com/articles/2015/12/northwestern-submits-final-filing-for-194-mw-kerr-hydropower-project.html

In terms of application to the Academy's campus, the most applicable forms of biomass fuel would be wood chips or liquid bio-fuels to meet some or all of the campus heating loads, and possibly produce some portion of the electrical or chilled water loads. Wood chips are used as a primary heating source at a number of campuses, generally throughout northern New England and other northern states/Canada. Use of wood chips for heating requires very high volumes of storage and transport compared to traditional oil or gas fired sources.

Liquid bio-fuels can be derived from sources such as waste cooking oil and soy beans, or generated from wood chip feed stock, such as Renewable Fuel Oil (RFO).

Biogas can also be derived from a variety of bio-feed stock or from landfill, and if of the proper quality could be used in the present cogeneration system. However, there is no local source for bio-gas so it could not be piped to the site, and other transportation methods are not feasible. Remotely generated bio-gas can be purchased and transported via natural gas distribution systems, but the cost if very high.

While biomass in all forms represents a renewable source of energy, it can have significant negative impacts when used on a large-scale basis due to environmental impacts of the very large volumes of feedstock required to meet current energy needs along with the emissions associated with combustion. Development of bio-fuels with reduced environmental impact, such as algae grown in the ocean, is still in early stages and commercial viability is uncertain. the Academy is not located near reasonable sources of sustainably harvested stock for wood chips or other bio-fuels, and the required transport/storage would be problematic at the site of the boiler plant. As such, bio fuels are not a recommended choice for a renewable energy fuel source at the Academy.

Ground Source Heat Pumps

Conventional heat pumps operate by rejecting heat to the atmosphere in the summer and extracting heat from the atmosphere in the winter by utilizing a refrigeration cycle. Ground source heat pumps use the same principle, but rather than using the atmosphere as the source in winter and the sink in summer, ground source heat pump systems use the ground, which stays at a near constant temperature annually. This can be done in several different configurations, including horizontal closed loop, vertical closed loop, lake/pond closed loop, and open loop systems. In closed loop systems regardless of configuration, a working fluid such as water or a glycol mixture circulates in a closed piping network between the ground and the heat pump system. In horizontal configurations, pipes are placed in a helical coil or “slinky” arrangement at the bottom of a trench between 4 and 6 feet deep. Vertical systems require 4inch diameter boreholes from 400-600 ft deep spaced 20-25 ft apart. Within each borehole, piping carries the fluid down the borehole and back up to the heat pump with a u-shaped bend at the bottom. In systems where a lake or pond with a depth of at least 8 feet is present, the helical arrangement of piping can be sunk to the bottom of the body of water, and the heat exchange occurs between the lake or pond and the working fluid. Open loop systems circulate water from a well or pond to the heat pump, and then that water is discharged either to the same source or to another “recharge” well located nearby.

Open loop well systems (known as “standing column” wells) are typically deeper – up to 1,500 ft. deep, and can produce high capacity with the right hydrogeological conditions, but can be subject to operational problems due to water quality and other issues.

Ground source heat pumps can be installed at a large scale to satisfy the heating and cooling loads of a campus such as the Academy and represent a highly efficient way to meet the heating and cooling loads of the campus using renewably generated electrical power; either locally generated through PV systems or purchased from the grid. As the size and cost of geothermal well fields are directly proportional to the loads served and represent the largest cost component of a carbon neutral campus heating system, reducing peak campus heating/cooling loads can produce substantial savings in the development of a campus ground source heat pump system. Additionally, as buildings are retrofitted for energy conservation heating hot water temperatures can be reduced, allowing lower hot water distribution temperatures and increasing efficiency of the campus hot water system. This report recommends this approach and further details can be found in the following sections.

Other considerations with ground source heat pumps include:

- High efficiency.
- Unobtrusive system once it is fully installed.
- High capital cost.
- Balancing heating and cooling loads.

Each well requires 400-500SF. Through the decarbonization study, potential wellfield locations were identified (see the following page). These locations are below permanent open space or parking lots. Based on this analysis, there is a potential for more than 1,000 GeoWells on the Academy campus.

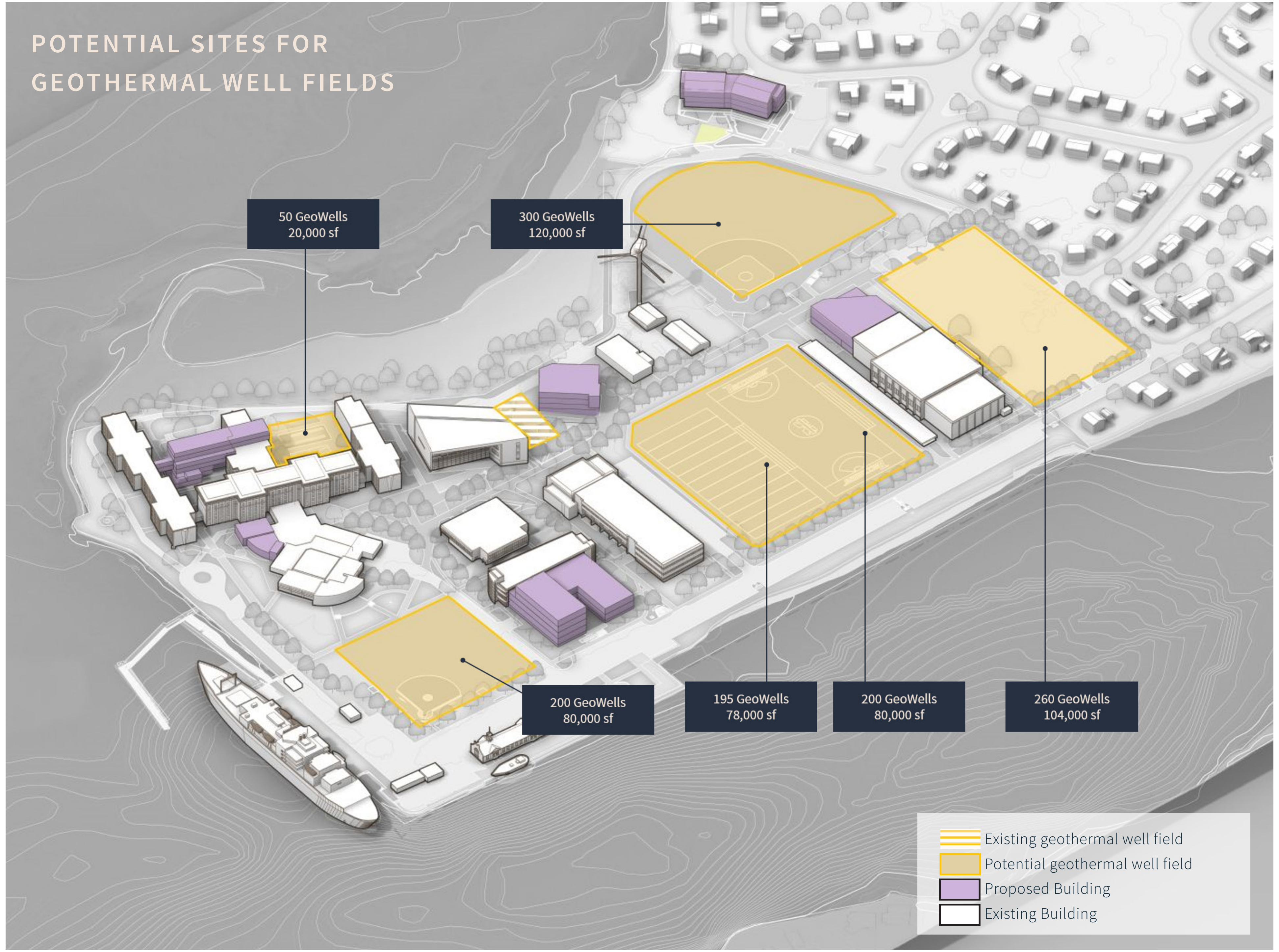
Heat Recovery Heat Pumps

A significant component of decarbonization of a university campus such as the Academy's involves the elimination of natural gas, diesel, bio-diesel or any other fossil fuel from being combusted in the onsite boiler or cogeneration plants. Achieving carbon neutrality requires switching those heating, cooling and energy sources to electrical power sourced from environmentally friendly, non-emitting sources.

When concurrent heating and cooling loads exist, a heat pump chiller can be used to transfer energy between the chilled and hot water systems. Water Source heat pumps integrated with a geo-exchange system can function in this manner very efficiently when concurrent heating and cooling loads exist.

Heat pumps operating in a heat recovery mode can have a Coefficient of Performance (COP) as high as 7. This makes them a significantly better option than conventional air source heat pumps, since they use significantly lower electrical power than air source heat pumps. Additionally, heating and cooling energy can be transferred within a single loop by these heat pumps resulting in re-utilization of existing cooling or heating energy rather than obtaining this energy by consuming another resource.

When dedicated outside air systems with hydronic heating/cooling terminals are implemented, concurrent heating and cooling loads are typically developed. They can also be developed by eliminating economizer operation on recirculating air handling units once heat pump systems are in place.



Air Source Heat Pumps

Air Source Heat Pumps (ASHP) extract heat from the outside air using the mechanical refrigeration cycle. They transfer heat into buildings to provide heating and hot water without burning fossil fuels. The types of heat pump systems are Air-to-Water, Air-to-Air, and Variable Refrigerant Flow (VRF). The Coefficient of Performance (COP) of an ASHP is typically about 3.0 on an annual basis. The pros and cons of ASHP's can be found in the figure below.

ASHP's should be considered as a part of the future growth of the Academy 's campus because of ongoing advances in technology and efficiency. The design and construction of a campus loop should be flexible to accomodate future and existing equipment.

	Air to Air	VRF	Air to Water
Pros	• **Can run in reverse and provide cooling with a high ambient outdoor temperature.** • Installation is simple. • Moderate investment costs compared to energy savings.	• **Can operate simultaneously in heating and cooling.** • Heat recovery can be very energy efficient. • Minimal space required in the building or in the ceiling.	• **Low carbon footprint.** • Eligible for RHI. • Both heating and cooling. • Used for space heating and domestic hot water. • Works in low temperatures. • High SCOP. • Easy installation process. • Low maintenance. • Long lifespan. • No fuel storage needed.
Cons	• **Lowest COP when heating needs are greatest.** • Dependent on placement. • Need for extra heat is greater than other methods. • Defrosting is necessary. • Air filter must be maintained regularly. • High humidity can shorten the life of the heat pump.	• **Costly.** • Manufacturer driven (If the system is provided by manufacturer A, then components from manufacturer B cannot be used). • Refrigerant capacity.	• **Have a lower heat supply than boilers.** • Extra spending to install underfloor heating. • Low efficiency below 0°C. • Lower savings compared to low price mains gas. • Electricity needed . • Noisy.

VANZELM ENGINEERS

Fuel Cells[8]

Similar to batteries, fuel cells produce direct current from an electrochemical process in the absence of direct combustion of a fuel source. The DC power is then converted to AC for use in buildings, and the waste heat can be captured for heating use as well. A fuel cell consists of an anode, an electrolyte, and a cathode. The anode splits the hydrogen fuel into cations and electrons via a catalytic reaction. After this split, the cations then travel through the electrolyte and to the cathode. The electrons meanwhile are traveling to the load in the form of current. When the electrons return to the cathode, they recombine with the cations and with oxygen, and are rejected as water carrying waste heat. While hydrogen gas is the fuel used by the cell, a fuel cell system typically uses methane in the form of natural gas to produce that hydrogen gas. As such, while fuel cells offer the promise of high conversion efficiencies, using natural gas as the fuel source still produces significant carbon emissions. Hydrogen can be produced renewably through electrolysis, but this requires the use of renewably generated electricity and is a fairly inefficient process, leading to a high cost for hydrogen as a fuel.

Due to the very high cost of fuel cells and the high cost and limited availability of hydrogen, fuel cells are not recommended as a primary energy source for the Academy's campus.

8 https://www.scania.com/group/en/hydrogen-a-fuel-of-the-future/

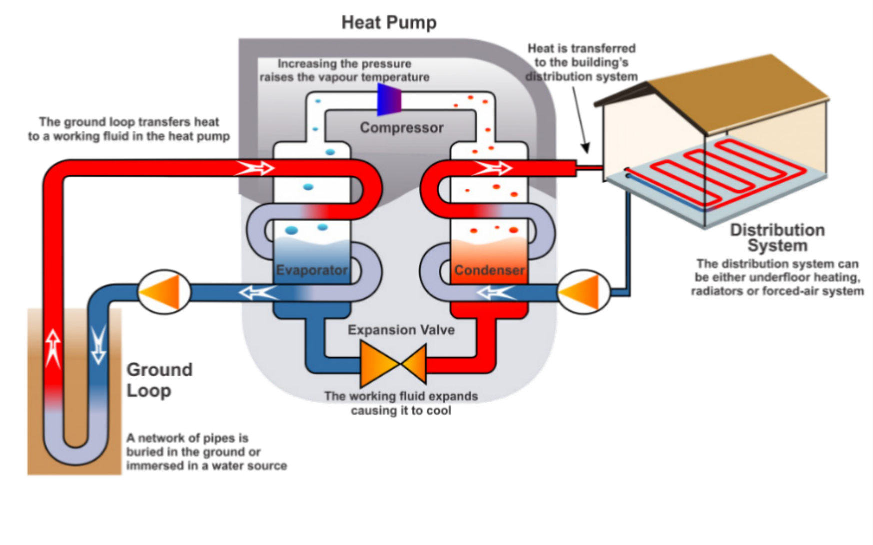
Seawater Source Heat Pumps

Water source heat pumps can use any fluid with the proper temperature and energy capacity characteristics as source to extract heat from or reject heat to. The heat pumps would operate the same as ground source heat pumps, but would use an open loop heat exchanger to extract heat from the fluid source.

The campus location directly adjacent to the ocean makes seawater an attractive source for heat pumps, but there are issues that need to be addressed:

- Environmental permitting to extract/discharge water from the ocean.
- Heat exchanger fouling due to biological growth.
- Low water temperatures in winter.

The first two issues can be resolved, but the third represents a significant problem for the use of seawater as a primary heating source, as minimum winter seawater temperatures can be too cold to allow the system to operate without freeze-up (see chart below). Water temperatures below 36-38°F are problematic for winter heating. Seawater could be used as a supplementary source if other sources are available when seawater temperatures are too low.



Seawater/Wastewater Source Heat Pumps

Cape Cod Water Temperature by Month over the past 10 years

Month	Average (F)	Minimum (F)	Maximum (F)
January	41	36.7	46.9
February	38.3	32.9	42.8
March	39	33.6	46.4
April	43.3	36.9	49.8
May	51.1	44.4	62.2
June	59.7	51.8	68.4
July	67.6	60.1	76.1
August	68.7	62.8	75.9
September	64.9	60.3	71.6
October	58.5	52.2	65.3
November	51.1	45.1	56.8
December	45.5	40.6	50.5

Ocean Thermal or Tidal Energy

Ocean energy can be broken down into three major types: ocean thermal energy conversion (OTEC), tidal energy, and marine and hydrokinetic (MHK) energy conversion. OTEC is made possible from the temperature difference between surface water and deeper ocean water. This temperature gradient is used to operate a thermodynamic cycle similar to a Rankine cycle, but using a substance like ammonia or propane as the working fluid. Generally speaking, OTEC systems are only considered economically feasible if the temperature gradient between the surface and deep ocean water is greater than 20 degrees Celsius. This kind of energy conversion is being investigated mostly in equatorial and tropical regions. Tidal energy uses the rise and fall of the tides to indirectly generate electricity.

the Academy is located on the Cape Cod Canal which experiences very high tidal flows that can be used as a source of tidal energy for electrical generation. Even though the Academy's geographic location would make this technology applicable, developing and permitting this technology is an arduous process. Additionally, since this technology is in its infancy, the associated operational efficiencies tend to be low. We do not think this is a feasible option for energy generation for the Academy at this time. The scale and complexity of implementing this technology makes it a better candidate for development by a third party entity.

Additionally, the sea water temperature and water salinity can cause limitations. Other important items to consider are:

- Infinite capacity, modest efficiency, low capital cost.
- Dirty source: particulates, general crud, and bio-fouling Reliability issues due to fouling.

On-Site Electrical Storage

The electric power grid balances fluctuations in electricity supply (generation) and demand (consumer use) by storing electricity during times where high electricity is produced and the demand is relatively low. This provides an efficient way to provide electricity back into the electric power grid when production is low and the demand is higher.

Electricity storage can provide reliable, economic, and environmental benefits in multiple ways. Some of the most efficient ways to store energy are by:

- Pumped hydroelectric
- Compressed air
- Flywheels
- Batteries
- Thermal Energy Storage (TES)

On-Site Electrical Storage should be considered in the future for the Academy Campus based on the types of technology developed in the future and the respective impacts of the electrical rate to generate and store the electrical energy. Developing technologies that the Academy can consider in the future include flow batteries, supercapacitors, and superconducting magnetic energy storage.

Analysis and Recommended Approach

Eliminating carbon emissions from a university campus such as the Academy's involves the implementation of peak and average heating and cooling load reductions and the development of complementary renewable energy technologies. Several renewable energy sources are available to minimize the use of fossil fuels to ultimately eliminate all emissions resulting from energy consumption. The following steps should be undertaken to achieve carbon neutrality.

Conservation and Its Impact on Campus Loads/Well Field Sizing

The Academy's campus has an average Energy Use Intensity (EUI) of 111 kBtu/sq.ft-yr of conditioned space. This number is on par with campuses of similar use and age in the Northeast, but much higher than state-of-the-art new buildings. A significant percentage of the campus area is not cooled, but if they were to become cooled this number would be even higher. This relatively high EUI figure represents a significant opportunity for energy conservation efforts.

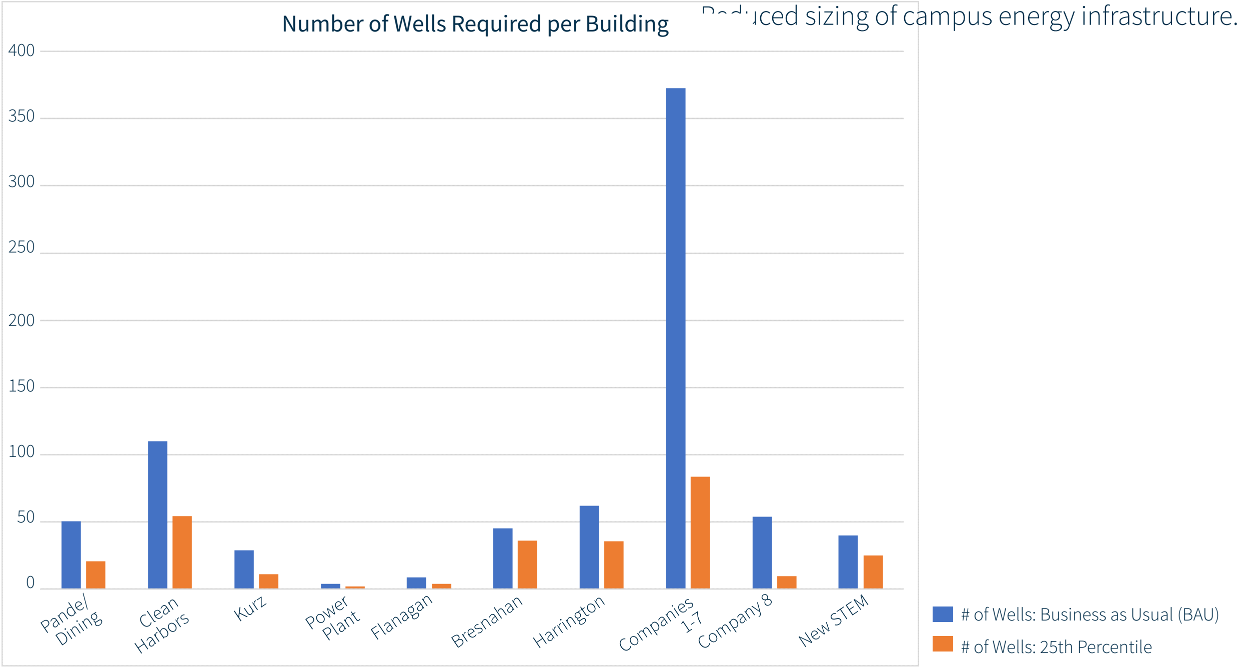
Improving the energy use efficiency of individual buildings across campus has been discussed in the preceding sections of this report.

Aggressive implementation of envelope upgrades and measures recommended previously will bring the buildings closer to the CBECS 25th percentile, resulting in a significant decrease in the number of geothermal wells that will need to be installed.

The chart below summarizes the potential reduction in the number of wells that could be obtained if the conversion to ground source heat systems were implemented in association with a “Deep Energy Retrofit” of each building.

The difference in number of wells directly translates to the cost associated with installing the wells as well as the area required. We recommend that the Academy commission detailed envelope and energy efficiency improvement studies for all of its most intense and largest energy consuming facilities across campus. Continuing to implement the energy efficiency measures recommended in the study will also decrease the peak heating and cooling loads thus resulting in:

- Lower utility demand charges.
- Downsizing (or right sizing) of mechanical and electrical systems in buildings.
- Reduced sizing of campus energy infrastructure.



Applicable Renewable Energy Generation Technologies

ELECTRICAL

Solar Photo Voltaic (Solar PV) continues to be the primary technology for generating carbon emission free electricity. Technology advances over have significantly improved the efficiencies of solar panels. Solar PV can be installed at several additional locations at the Academy which has been elaborated upon in the preceding sections.

HEATING INCLUDING GEOTHERMAL

Combustion of natural gas for heating purposes represents the largest component of carbon emissions by the Academy's campus. The most effective way to meet campus heating loads is to shift heating loads away from fossil fuels and use renewably generated electricity. Electricity is an expensive fuel source for heating on a unit energy basis, but if used to power a ground source heat pump system it results in an efficient and cost-effective solution. This is especially true when combined with low temperature hot water and chilled water distribution systems. We have reviewed the existing and future campus heating/cooling loads and determined that it is possible to meet the campus loads with geothermal well fields installed in selected open areas of the campus.

Central ground source heat pump systems are quickly becoming the preferred approach for campuses around the country to meet their goals for carbon neutrality.

COOLING INCLUDING GEOTHERMAL

Ground source heat pump systems can be utilized for cooling as well, since the ground temperature is lower than the ambient air temperature during the summer months. Ground source heat pump systems have been successfully installed at many locations across New England. Additionally, green power through virtual power purchase agreements can be used to reduce emissions of electricity used for equipment.

As discussed previously, the decarbonization study identified locations and sizes for these well fields. There is enough potential for well field installation on campus to meet the projected loads under the Best Case scenario.

Renewable Energy Campus Infrastructure

CENTRALIZED VS DISTRIBUTED SYSTEMS

Centralized generation of power, steam, hot water, chilled water or other utilities refers to energy that is generated in a central location and distributed across campus using steam lines, hot water / chilled water lines and other distribution networks. Central plants can provide better economies of scale, and higher generation efficiencies. However, as the generation and distribution systems deteriorate over the years, it can result in distribution losses, more than offsetting any gains from economies of scale and higher generation efficiencies. This is especially true in the case of central steam generating plants and distribution networks. This is why the campus steam plant and distribution system at the Academy was abandoned in the past. Additionally, with no existing central plant or distribution systems in place on the Academy's campus, the development of centralized campus energy systems offer a number of potential problems, including:

- High initial cost for development of central plant and distribution systems.
- Difficulty in phasing the development of plant/distribution infrastructure over time to satisfy ongoing projects.
- Space required for a central plant facility on a campus with very limited available space. Any space used for a plant would take away from space available for academic, housing, or athletic facilities.
- Resiliency concerns and need to elevate plant above flood levels, increasing cost aesthetic concerns.

With these issues in mind, the development of a new central plant and energy distribution system is not recommended for the Academy.

While we do not feel that fully centralized campus heating/cooling systems represent the best approach for the Academy's campus, there are a number of problems with fully distributed systems (independent system for each building), including:

- Development of local geo-exchange systems for each building is problematic, as available space does not exist in close proximity to many buildings.
- Without some means of sharing energy between buildings, diversity of heating/cooling cannot be used to improve system generation and efficiency, resulting in larger overall well fields and increased associated cost.
- Inability to utilize potential future sources of heat transfer energy, such as seawater or wastewater treatment discharge.

To address the preceding issues, the decarbonization study recommends a “semi-distributed” campus heating/cooling system in which each building or group of buildings is provided with a ground source heat pump plant with water source heat pumps to meet the heating and cooling needs of each building. These plants would be connected by an “Energy Transfer Loop” (ETL) which would connect to all heat pump plants and energy transfer systems, which would consist initially of geo-exchange well fields and in the future could include seawater heat exchangers, air source heat pumps, or solar thermal systems. Operation of this system will be described in greater detail later in this report.

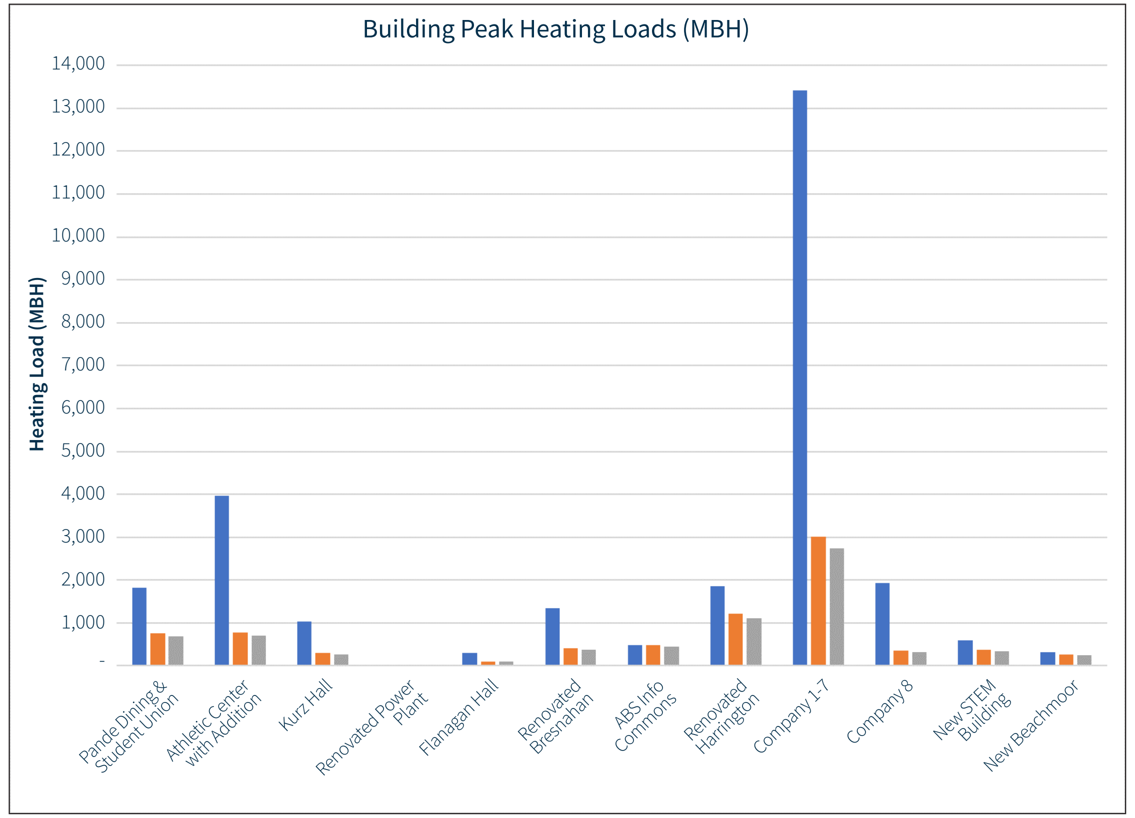
Campus Growth and Projected Upgrades

Unless aggressive energy efficiency measures are incorporated across campus and in new building design, Master Plan projects will result in an increase of the energy consumption on campus and the carbon footprint.

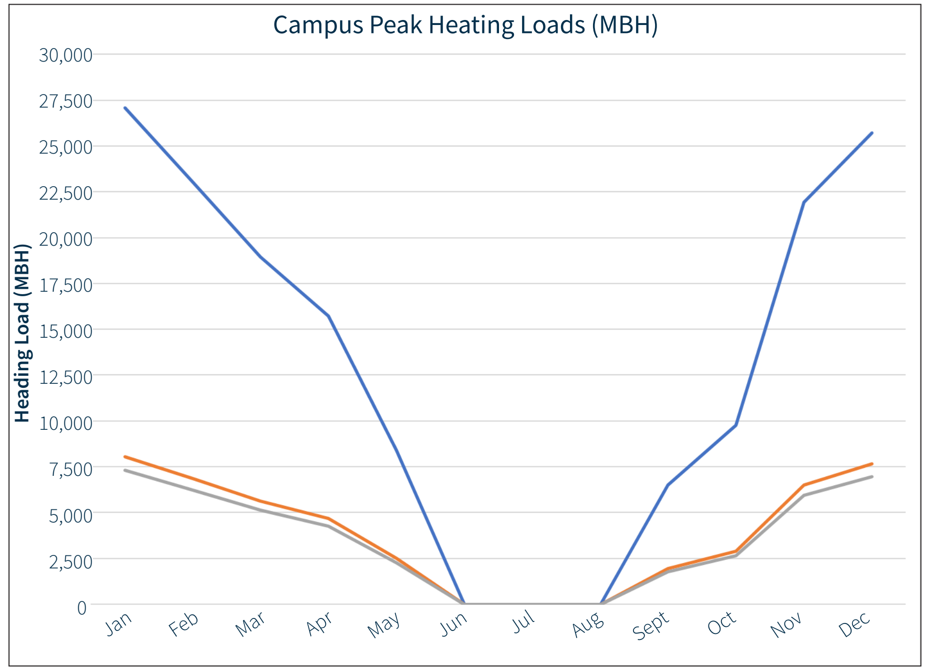
Projected Energy Use

BUILDING PEAK HEATING LOADS

The chart to the right summarizes the peak heating loads between existing as well as efficient buildings located at both the 25th and the 10th percentile on the CBECS scale. Decreasing the peak heating loads is paramount to achieving carbon neutrality on the Academy's campus since most of the existing carbon emissions are a resultant of fossil fuel combustion to meet these loads. In an electrified future, these uncontrolled large heating loads will result in the tripling of the well field size, in addition to consuming significantly more pumping power which in turn will result in the need to purchase more green energy. Thus, not only will the capital expense be higher the operational expense to meet the heating loads will be higher as well.



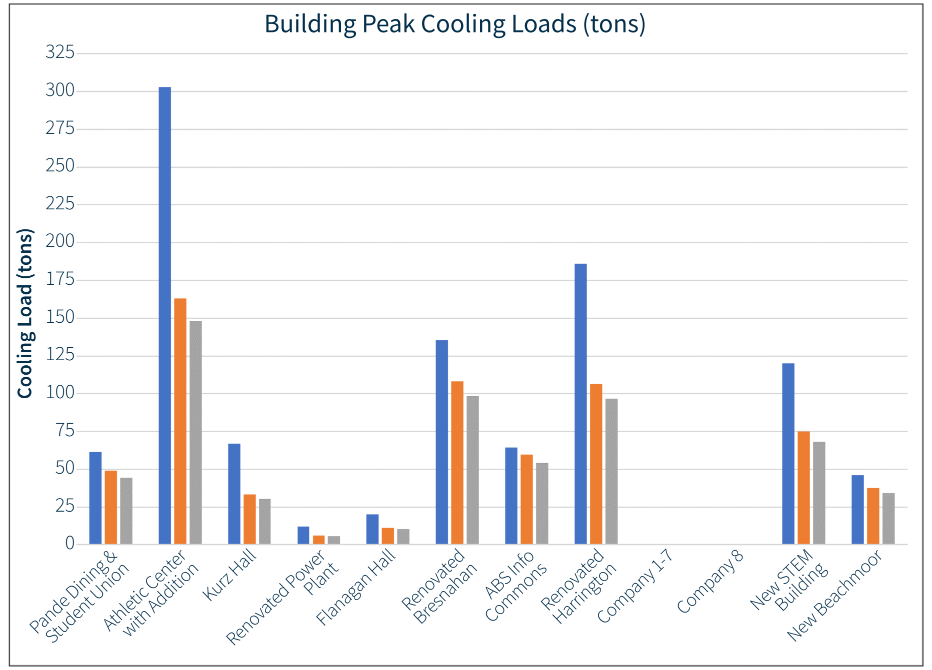
Peak Heating Load BAU (MBh)
Peak Heating Loads at 25th Percentile (MBh)
Peak Heating Loads at 10th Percentile (MBh)



CAMPUS PEAK HEATING LOADS

The chart above summarizes the difference in energy consumption between the Existing buildings and those that are significantly more efficient as per the CBECS scale. As discussed on the previous page, reducing the heating load is critical to achieving carbon neutrality.

Cooling Load BAU (tons)
Cooling Loads at 25th Percentile (tons)
Cooling Loads at 10th Percentile (tons)



BUILDING PEAK COOLING LOADS

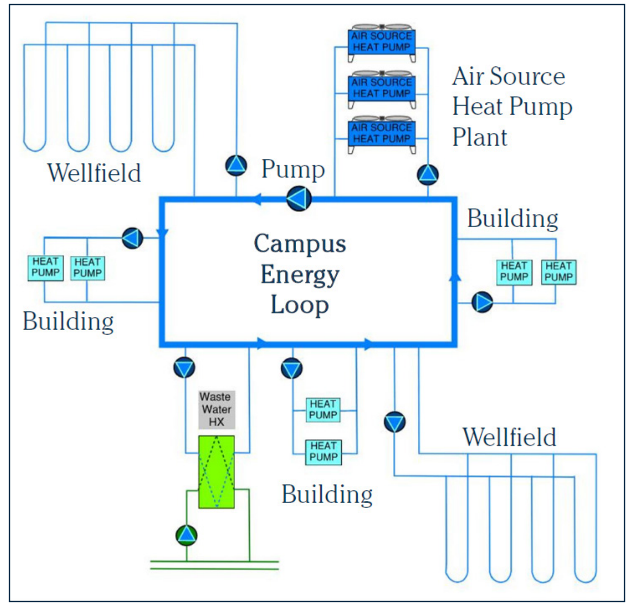
Similarly, even though most buildings on campus are not cooled and the campus is located in a predominantly heating climate, the cooling loads and cooling energy consumption can be decreased further by implementing energy efficiency measures. The chart above denotes this.

Heating Loads BAU (MBh)
Heating Loads at 25th Percentile (Mbh)
Heating Loads at 10th Percentile (Mbh)

Recommended Strategy and Projected Costs

Primary Campus Energy System

The proposed primary heating and cooling system on campus will consist of individual water source heat pump plants in each building or group of buildings, all connected by an Energy Transfer Loop. The Energy Transfer Loop allows all building plants to utilize common, campus-wide heat gain/rejection systems such as geo-exchange systems (well fields), air source heat pumps, and seawater heat exchangers as indicated in the diagram below and on the following page.



This loop will consist of:

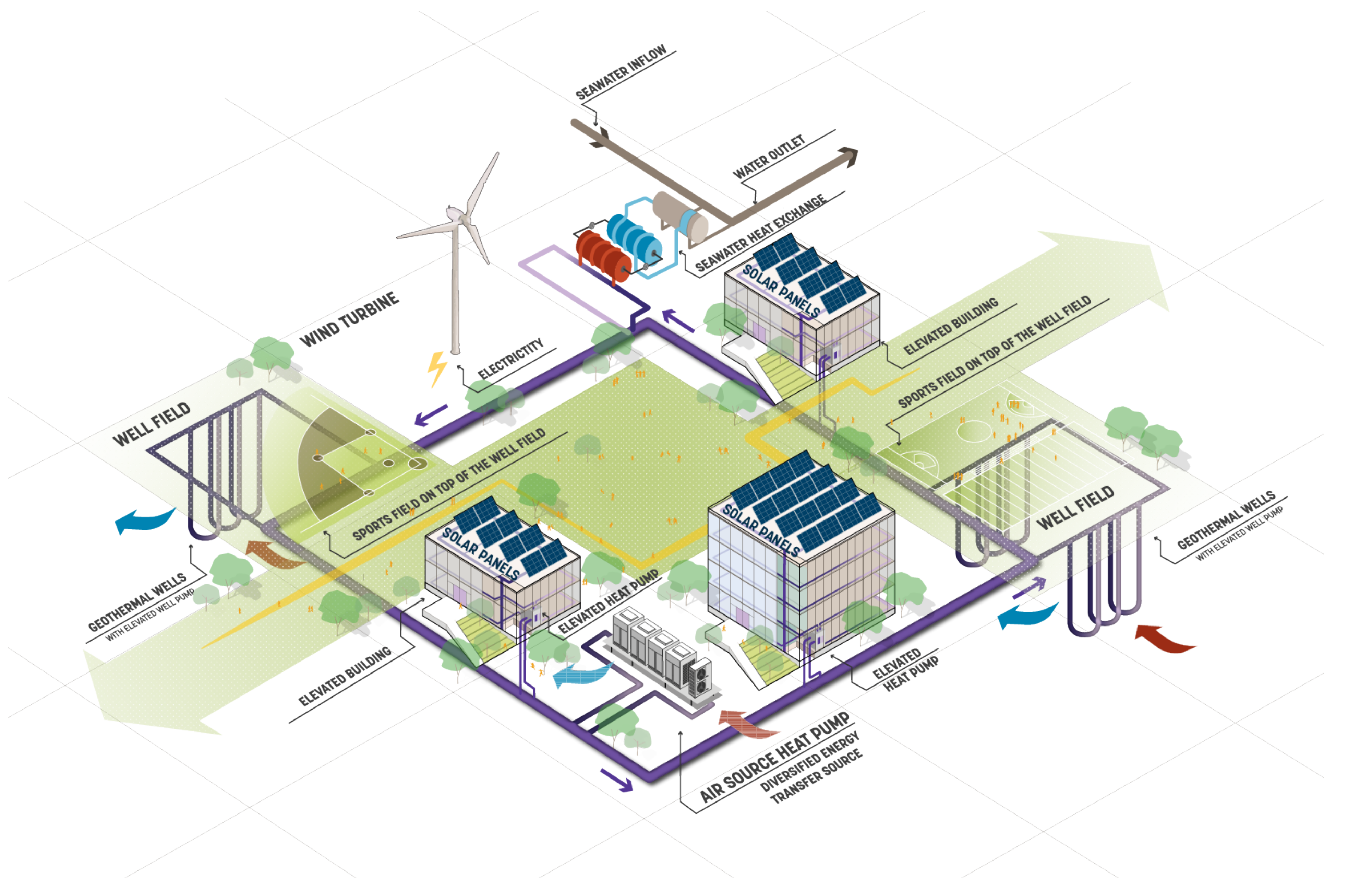
- A piping and heat exchange loop with supply and return piping to each building (inexpensive, uninsulated high density polyethyele – HDPE).
- A wellfield to facilitate heat exchange between the buildings and the ground.
- Pumping stations with Variable frequency Drives to pump the water within the loop. Other potential systems add or reject heat to/from the loop.
- Heat pumps located within each building.
- Control valves and devices located as needed.

The system will operate as follows:

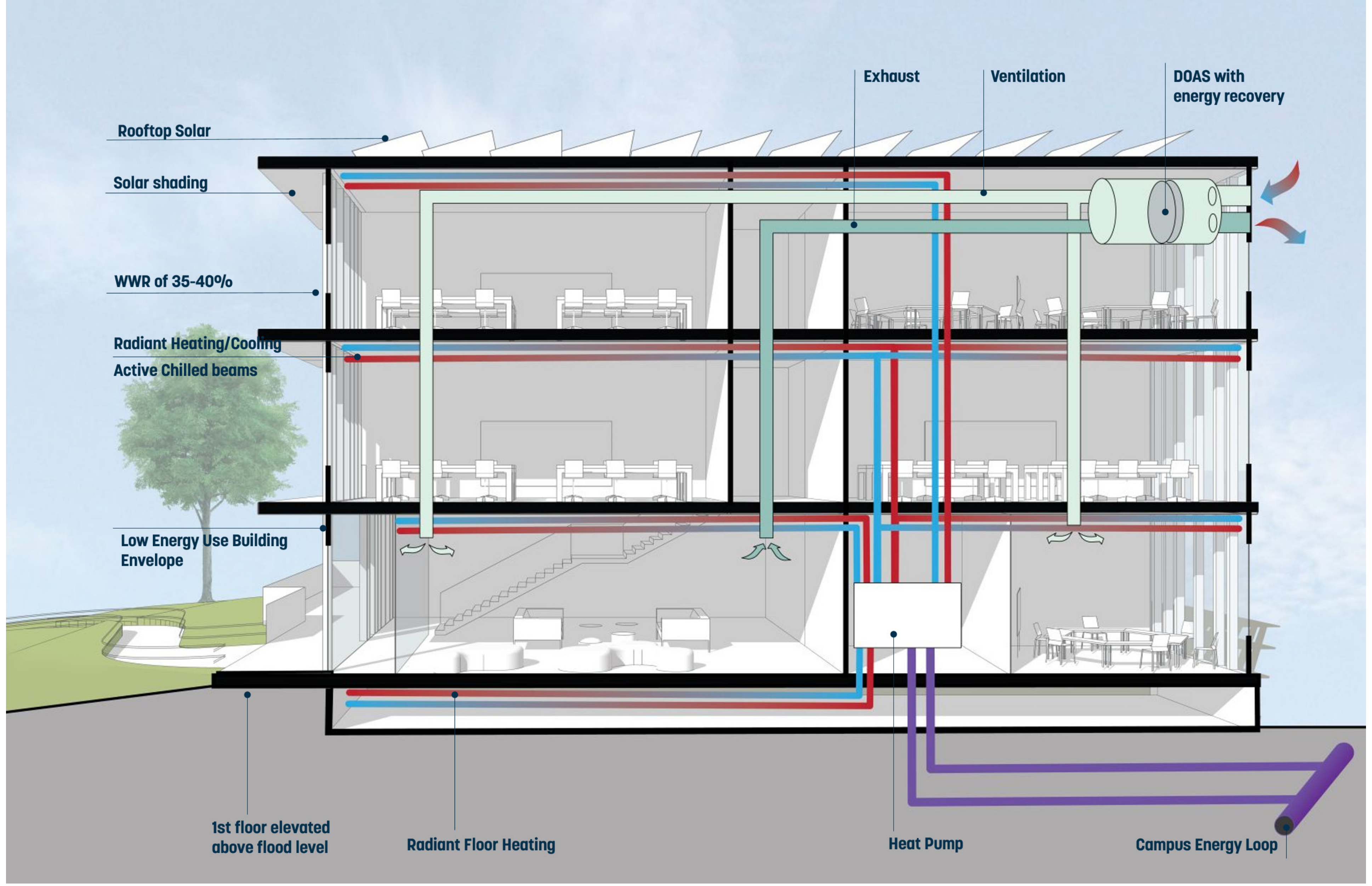
- Water (not glycol/water) will be circulated around the loop in a "one-pipe" distribution fashion.
- Water source heat pumps will be provided in each building. These would typically be water to water heat pumps, but could also be water to air or VRF, depending on the program and HVAC approach for the building.
- Each building heat pump plant will be controlled to satisfy the heating/cooling loads in each building. In doing so, each will either draw heat from the loop (heating mode) or reject heat to the loop (cooling mode).
- The loop temperature will float between a minimum of 40-45°F and a maximum of 80-85°F.
- Energy will be either rejected from or added to the loop, primarily by circulating water through the geo-exchange systems.
- Other methods of balancing loop temperature may be added in the future, as the technology or heating/cooling sources become available to minimize required well field area/cost or as needed to balance heating/cooling loads on the loop.
- Based on the proposed timeline for implementation (described later), relatively balanced heating/cooling loads will exist for the first 10 years or so. After that, when The Company buildings (dorms) are added to the loop, a heating imbalance will exist since the dorms will not be cooled. This will result in loop temperatures getting too low, so methods of adding heat to the loop should be implemented, which may consist of air source heat pumps, wastewater heat exchangers, seawater heat exchangers, or solar thermal collectors.

The diagrams on the following pages illustrate the proposed system arrangement.

ILLUSTRATIVE CONCEPTUAL DIAGRAM OF PROPOSED CAMPUS ENERGY LOOP



CONCEPTUAL DRAWING OF BUILDING LEVEL ENERGY TRANSFER LOOP



Additional Electrical Loads

The conversion of campus heating systems from fossil fuel based (natural gas) to carbon free electrically fueled systems, along with the addition of cooling to a number of buildings, will increase the load on the campus electrical service and primary distribution system. We have analyzed the impact of these increased loads to determine if the existing systems will support the additional loads or if additional electrical service/distribution capacity will be required. This analysis is summarized to the right. We have assumed that short term energy conservation measures will have an effect of reducing electrical demand by 10%.

Present campus planning involves removing the existing training ship from the electrical distribution system and bringing a new, dedicated utility feed to campus to feed the new training ship (with much higher electrical loads than the existing ship). Assuming the existing ship load is removed from the campus distribution system, the additional heat pump loads can be comfortably accommodated with no required modifications to the campus primary electrical distribution system.

Campus Demand	1,566 kW	
Safety Factor (10%)	+ 157	
Sub-total	1,723 kW	
Conservation Target (10%)	- 172	
Sub-total	1,551 kW	
New Construction/Addition	+ 231	
Adj Campus Demand		1,782 kW

Addition of Heat Pumps:

HP Connected Load: *(Circuit breaker size)*	1,078 kW	HP Demand Load: *(Actual electrical consumption)*	539 kW
	2,860 kW		2,321 kW
Remove Training Ship from Campus Distribution	- 300 kW		-300 kW
	2,560 kW		2,021 kW
0.90 pf	2,844 kVA		2,246 kVA

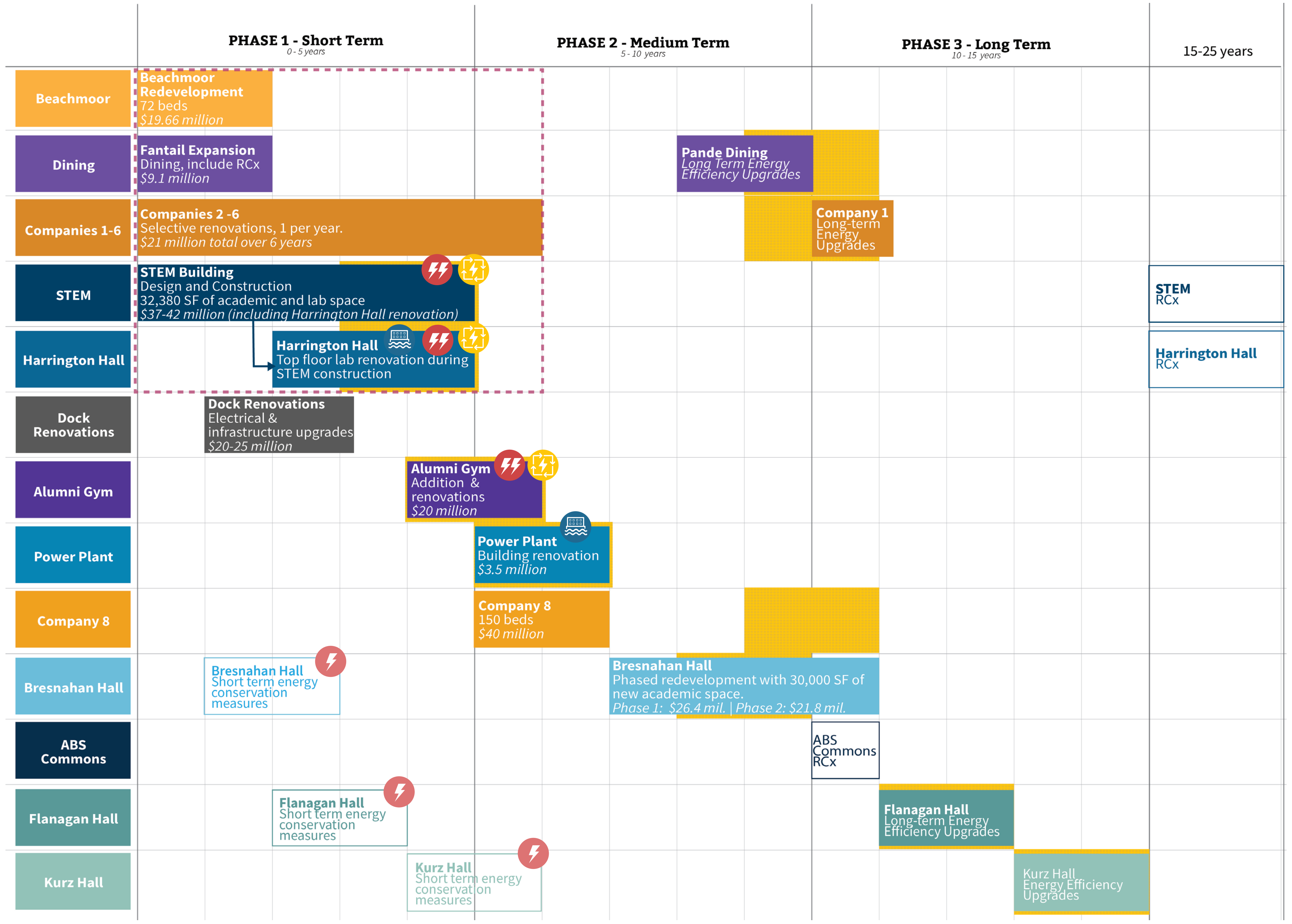
Campus Service Transformer is 2,500 kVA

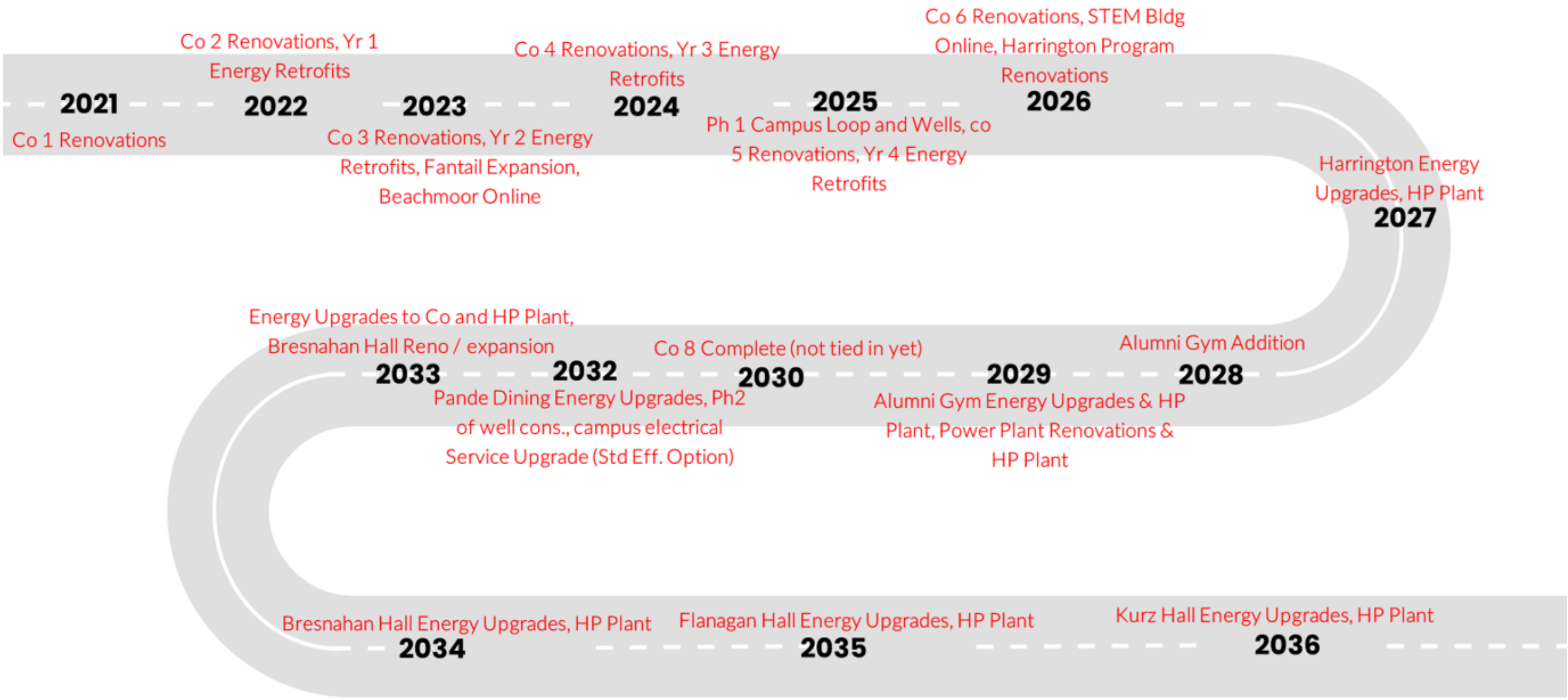
Campus Electrical Load Analysis

Project Phasing

The following graphic and chart summarizes our recommended approach towards achieving carbon neutrality.

It is recommended that the building upgrades and development of new campus infrastructure be done in a phased manner coordinated with implementation of the campus master plan projects. The development of a separate campus infrastructure project consisting of the energy loop and initial well field capacity to handle the first 10 years of projects is recommended to simplify and minimize cost for each individual project. In general, when any program-driven new construction or major renovation project is undertaken, it is recommended that the building undergo a “deep energy retrofit” consisting of building envelope upgrades to meet present building standards and the installation of new HVAC systems designed for maximum energy efficiency. The proposed carbon neutrality implementation approach carried out in association with the master plan projects is illustrated in the following graphics.





Proposed Carbon Neutrality Roadmap

- Funded projects
- Floodproofing during renovation
- Short term energy upgrade during renovation
- Long term energy upgrade during renovation
- Connection to energy loop

Economic Analysis

To determine the economic feasibility of the proposed **Best Case - Carbon Neutrality Project,** the decarbonization study estimated the annual expenditure for investments, energy costs, maintenance costs and labor costs for both the **Base Case** and the **Best Case** over 30 years between 2021-2050. This methodology accounts for the annual costs for either option and provides their "life cycle" costs over the time period stipulated. The Option with the lowest Life Cycle Cost, and correspondingly the lowest Net Present Value (NPV) of the Life Cycle Costs, is the best option. The following data inputs were utilized to determine the NPV of Life Cycle Costs.

- A blended electrical energy cost of $0.15 / kWh
- A blended natural gas cost of $11/MCF
- An annual inflation rate of 3%
    - For all costs including utility, maintenance etc.
- A discount rate of 4%
- A potential carbon tax of $50/MTCO2e per year
- 18 W/ sq. ft. of solar PV production
- 1,250 kWh of AC power generated for each kW dc of Solar PV installed
- $18/sq.ft of Base Case costs for renovations
- $42 - $60 / sq. ft. of Best Case costs for renovations and upgrades
- $20,000 per installed well
- $2,000 per ton for the installation of heat pumps
- Purchased carbon offsets have not been evaluated in either case

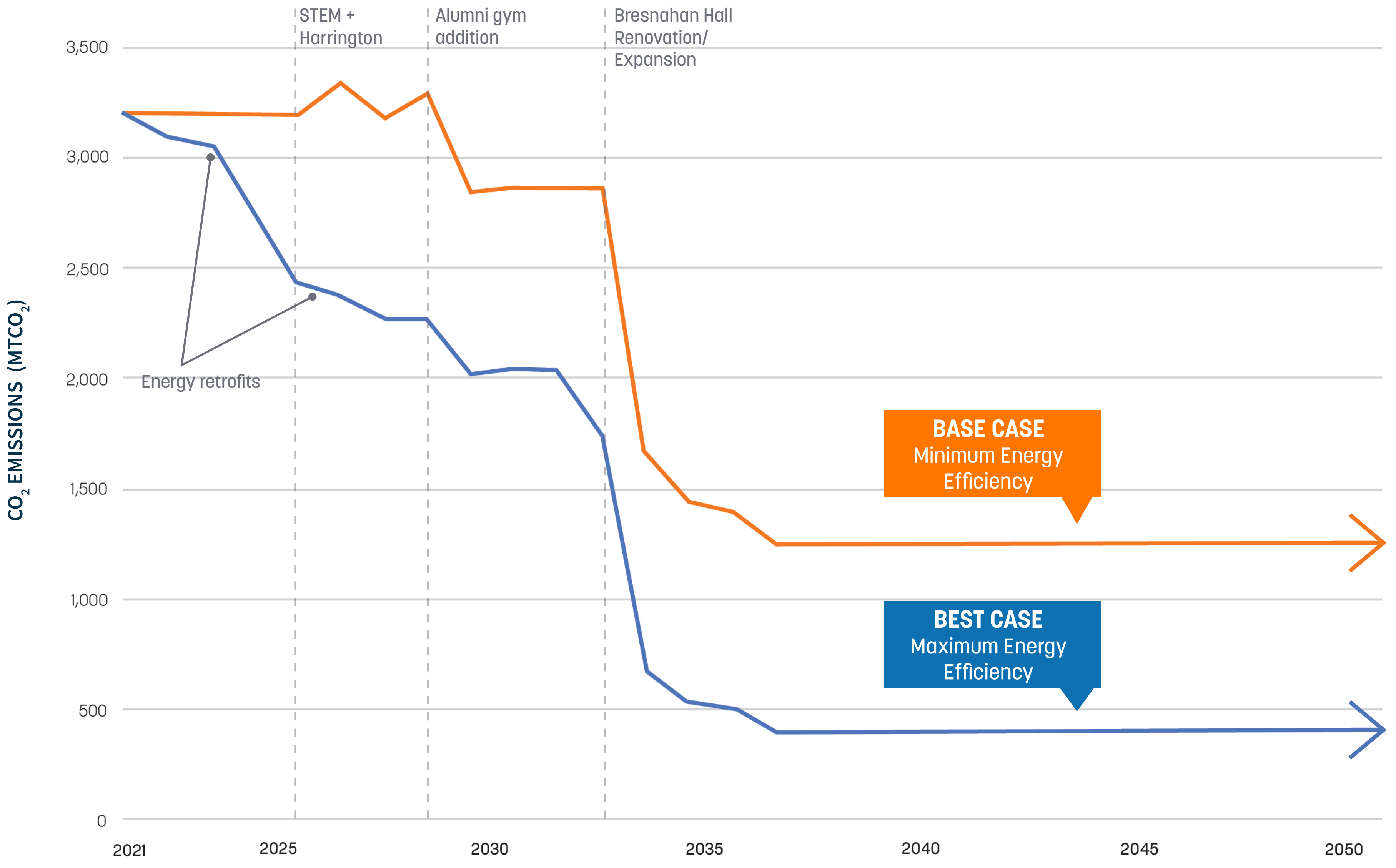
Building improvement costs for the two options can be summarized as follows:

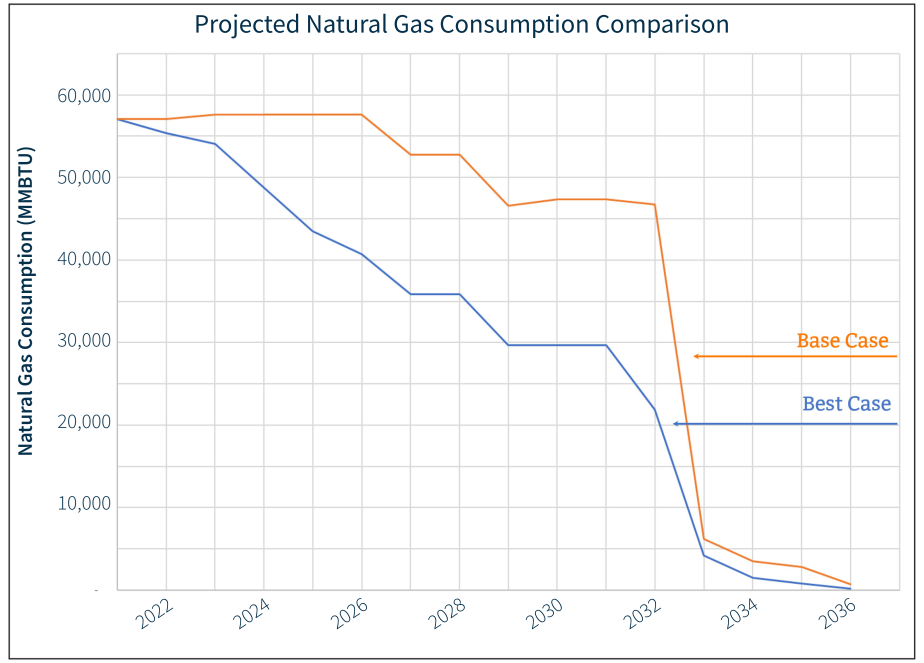
BASE CASE	BEST CASE
Minimum Energy Efficiency: Minimum changes required to comply with Exec Order 594. Reduced short term costs at the expense of higher Life Cycle costs	**Maximum Energy Efficiency:** Maximize energy efficiency throughout campus. Higher short term expenditures to achieve lower Life Cycle costs and capital renewal

• Maintain existing envelope
• Replace boilers with heat pumps
• Replace AHU coils:
  • Gas-fired components with hot water coils
  • DX coils with chilled water coils
• Replace terminal units with similar units designed for low temperature (120 °F) operation
• Add cooling to areas not presently cooled
• Install campus energy loop
• Install geothermal wells (~730 total)
• Upgrade campus electrical for increased capacity
	• Implement short-term energy measures (lighting upgrades, demand control ventilation, etc.)
	• Upgrade building envelopes to high performance standards
	• Replace existing mechanical systems with low energy mechanical systems (DOAS, radiant panels, chilled beams, etc.) for heating and cooling
	• Install building heat pumps sized for reduced loads.
	• Install campus energy loop
	• Install reduced number of geothermal wells (~311 total)

COMPARING CARBON EMISSIONS

"Best Case" maximum energy efficiency measures lead to 62% greater reductions in carbon emissions over 30 years compared to "Base Case" minimum energy efficiency measures.

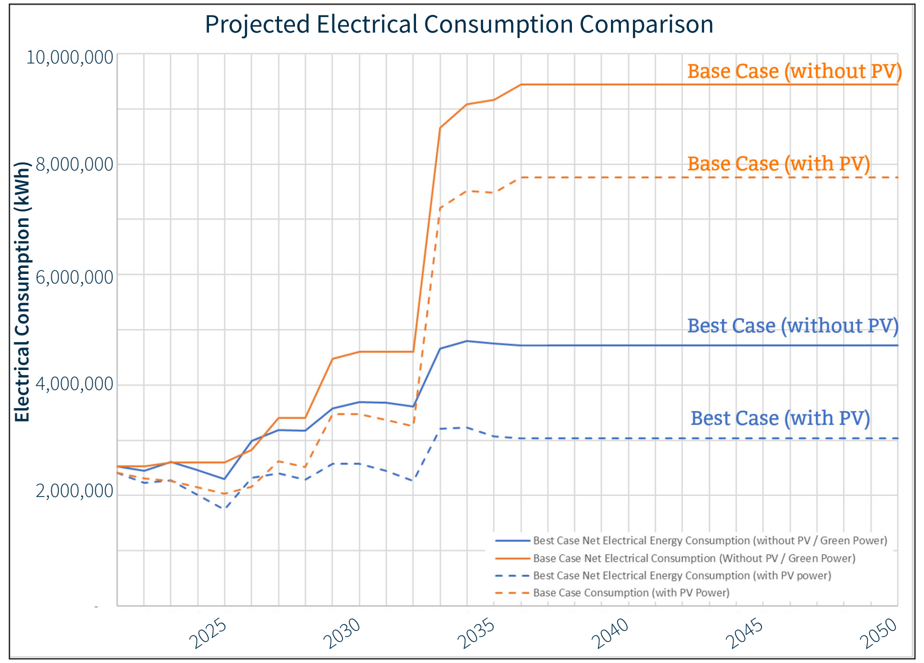




NATURAL GAS CONSUMPTION

Aggressive building energy retrofits result in a more significant natural gas consumption (and hence carbon emissions) reduction in the Best Case as compared to the Base Case. Once the buildings are connected to the energy transfer loop, the lower loads of the Best Case buildings result in a significantly lower electrical energy consumption and lower carbon footprint. The energy transfer loop utilizes only electrical power, most of which will be either generated on site using solar PV or purchased from green power suppliers in the future.

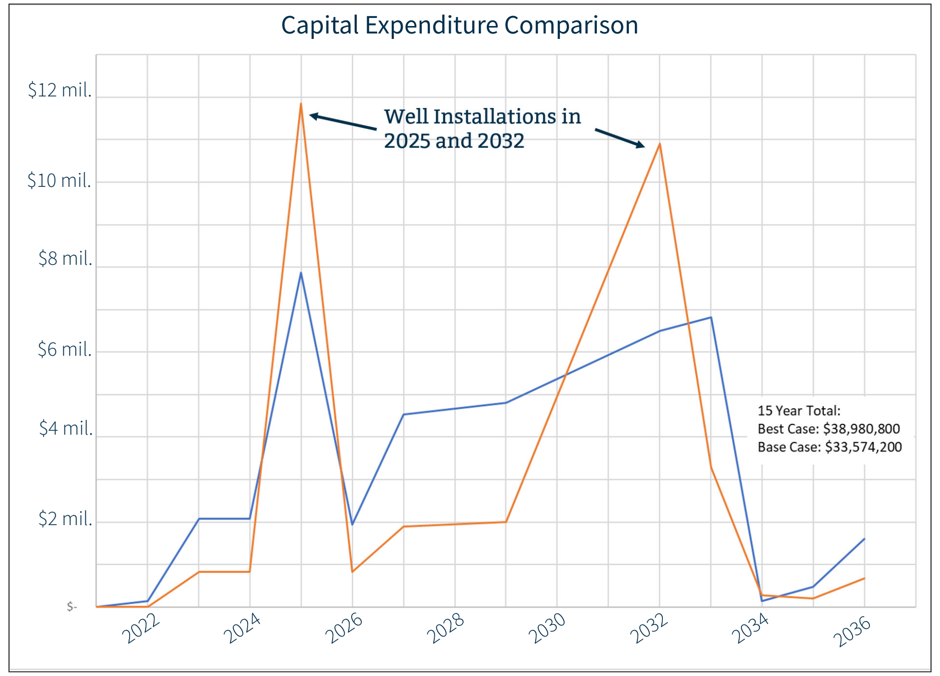
- Best Case Natural Gas Consumption
- Base Case Natural Gas Consumption



ELECTRICAL CONSUMPTION

The amount of electrical energy used by the heat pumps and the energy transfer loop is directly proportional to peak and average hourly building heating and cooling loads. The pumping energy is also proportional to the loads. Since the loads in the Best Case are significantly lower than those in the Base Case, the amount of electrical energy required to satisfy the loads is significantly lower in the Best Case. The solar PV generation potential is identical in both cases and is a key component in the achievement of campus carbon neutrality.

- Best Case Net Electrical Energy Consumption (without PV/Green Power)
- Base Case Net Electrical Energy Consumption (without PV/Green Power)
- Best Case Net Electrical Energy Consumption (with PV Power)
- Base Case Net Electrical Energy Consumption (with PV Power)

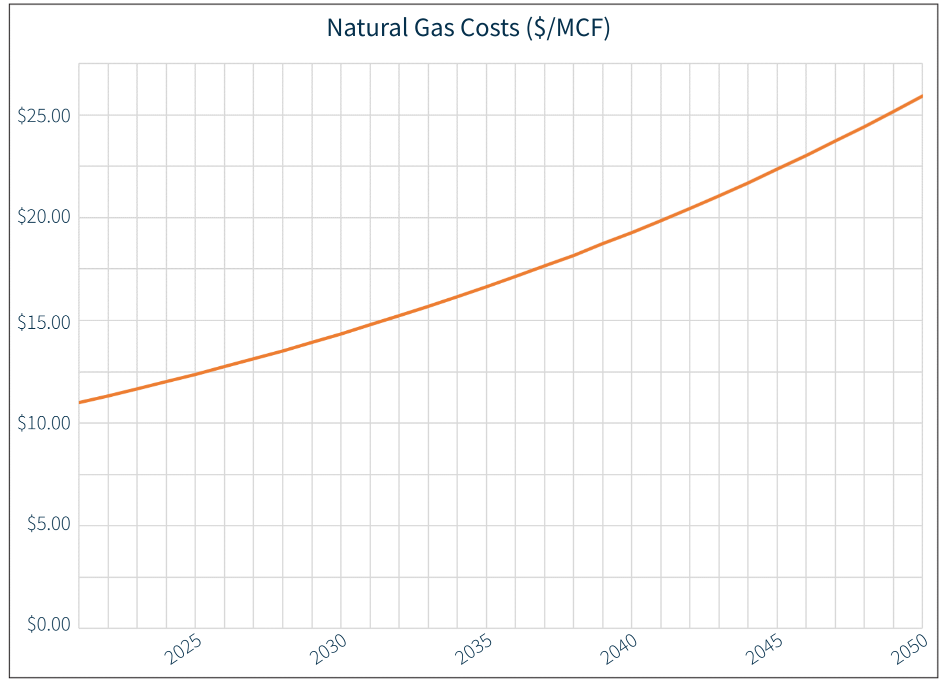


CAPITAL EXPENDITURE COMPARISON

The chart above summarizes the Capital Costs incurred by the two options over the next 30 years. The difference between the NPV of cash flows for the Best Case option was compared to those of the Base Case Option. The electrical and natural gas consumption rates were sourced from data provided by the Academy through utility bills, as well as a third party utility consumption monitoring and reporting software. The annual inflation rate is estimated to be 3%. Even though inflation in recent times has trended to be higher than 3%, this represents a reasonable estimate of the inflation rate going forward 30 years. In discounted cash flow analysis such as this, the discount rate expresses the time value of money and assists in the development and judgment of the most cost effective option, in today's dollars.

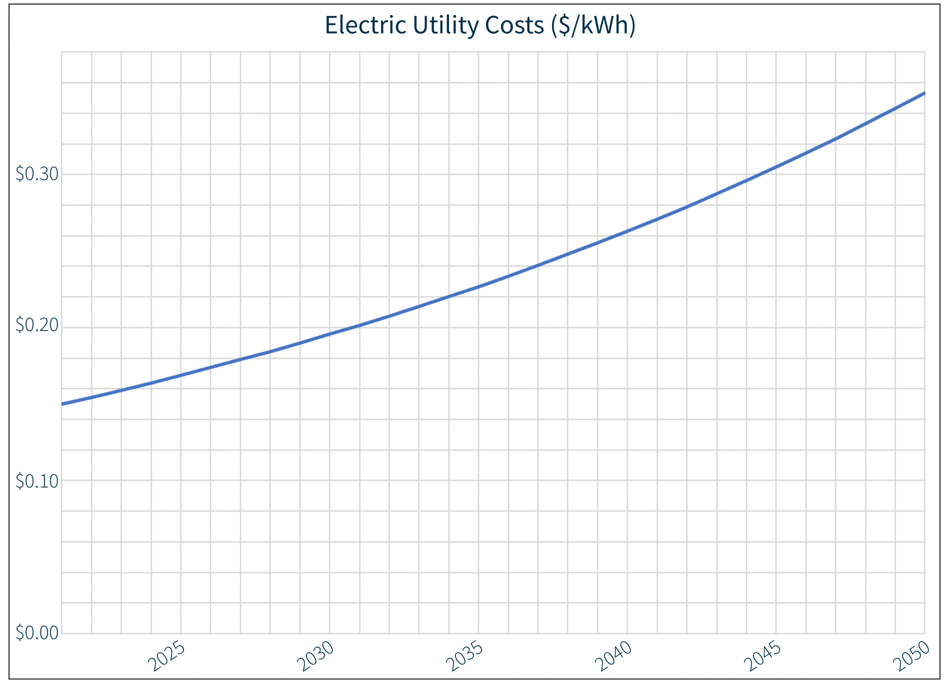
— Best Case Investment

— Base Case Investment



NATURAL GAS COSTS

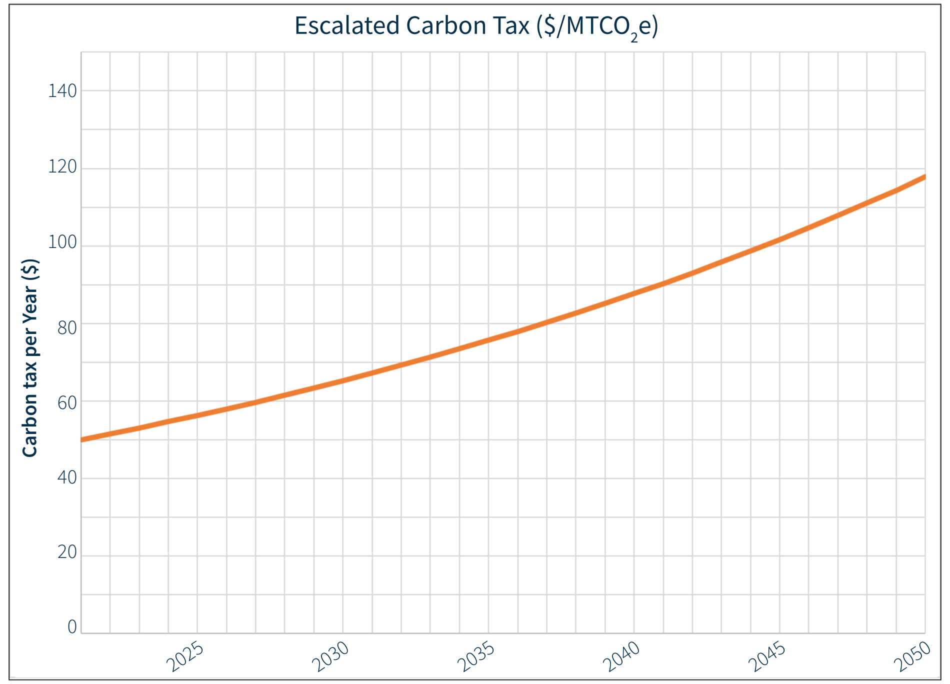
As shown in the chart above, the natural gas costs increase significantly over the next 30 years, even at a nominal inflation rate of 3%. Over the next 30 years, they will more than double to $26 per MCF.



ELECTRICITY COSTS

Electrical utility costs are projected to increase significantly over the next 30 years, even at a nominal inflation rate of 3%. Over the next 30 years, they will more than double to $0.35 per kWh.

Currently, no carbon taxes have been levied on emissions in the Commonwealth of Massachusetts. However, DCAMM suggested using a carbon tax rate of $50/MTCO2e per year. This option has been evaluated separately with the same carbon tax levied in both cases. According to the Congressional budget Office (CBO), the effects of a carbon tax on the U.S. economy would depend on how the revenues from the tax were used. Options include using the revenues to reduce budget deficits, to decrease existing marginal tax rates (the rates on an additional dollar of income), or to offset the costs that a carbon tax would impose on certain groups of people[9]. Lawmakers could increase federal revenues and encourage reductions in emissions of carbon dioxide (CO_2) by establishing a carbon tax, which would either tax those emissions directly or tax fuels that release CO_2 when they are burned (fossil fuels, such as coal, oil, and natural gas). Emissions of CO_2 and other greenhouse gases accumulate in the atmosphere and contribute to climate change—a long term and potentially very costly global problem in itself.



ESCALATED CARBON TAX

To analyze the effect of a Carbon tax on both options, a separate analysis was conducted by adding the costs of a carbon tax of $50/MTCO2e per year to both options. The actual tax would be dependent on the emissions incurred by each option in any given calendar year between 2021 and 2050. Since the Carbon tax is a variable that will likely change significantly over the next few years, it was inflated at the 3% rate used across the board in our analyses, the results of which are depicted in the above chart.

As shown, the carbon tax begins at $50/ MTCO2e per year, but escalates to $118 per MTCO2e by 2050 i.e. the end of the life cycle. This increase is significant and hurts the Base Case more than the Best case, since the Base case does not account for any significant reductions in energy consumption due to energy use efficiency improvements and hence carbon emissions reductions.

9 Effects of a Carbon Tax on the Economy and the Environment (cbo.gov)

CARBON OFFSETS

Another less feasible approach to "Carbon Neutrality" is the purchasing of Carbon Offsets. A carbon offset can be defined as the act of negating an identical amount of carbon emissions an entity releases into the atmosphere[10]. The offset is usually created either by supporting a renewable energy resource such as wind and solar or by planting trees.

Currently, the cost of carbon offsets in new England is approximately $5/ MTCO2e. However, with more social awareness regarding the negative impacts of carbon emissions, the demand for carbon offsets is increasing.

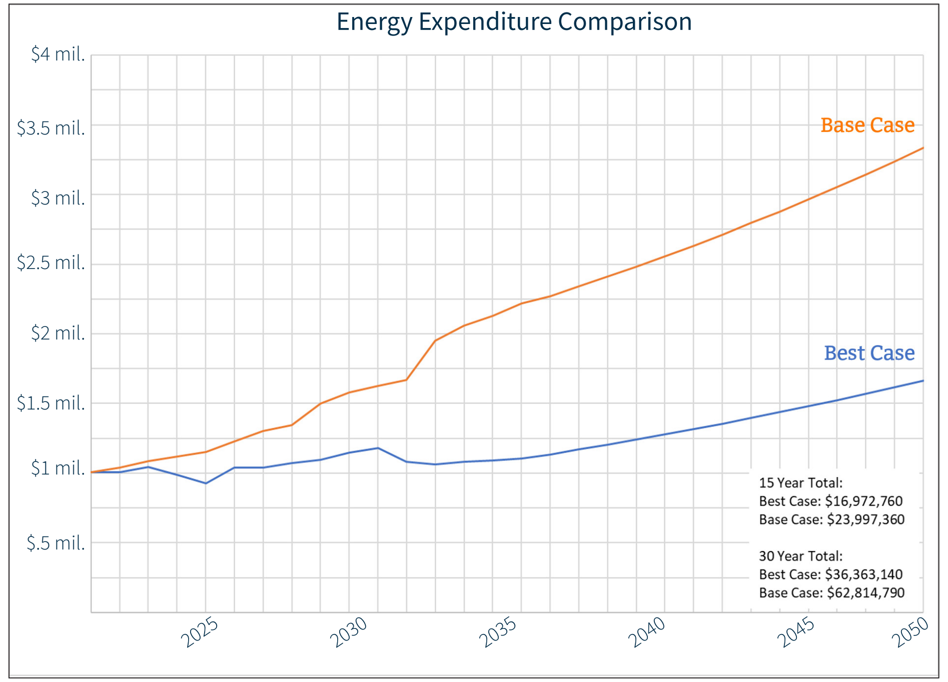
Experts predict that the price for carbon offsets could be as high as $50 per MTCO2e by 2030 . Additionally, the purchasing of carbon offsets does nothing towards decreasing energy consumption and improving the EUI of facilities on campus. As such, we recommend investing available funds into building improvements and development of the recommended energy loop in lieu of purchasing carbon offsets.

The following table summarizes findings based on the inputs listed previously. As shown in the table, the Base Case incurs higher 15 Year as well as higher 30 Year Utility Costs. This can be attributed to:

- The Best Case benefiting from the benefits of the recommended energy savings and building improvements program resulting in a progressively lower utility costs over the next 3 decades
- The energy savings resulting from the recommended energy efficiency upgrades, as well as the lower pumping power in the later years on the heat pump loop, results in a higher savings between the years 15 -30. This can be partially attributed to the inflation rate (3%) which results in a higher savings per unit of energy saved with each progressive year.

SUMMARY TABLE	BASE CASE	BEST CASE
15 Yr Utility Costs	$ 23,997,356	$ 16,972,756
30 Year Utility Costs	$ 62,814,788	$ 36,363,140
15 Yr Operational Costs	$ 38,293,644	$ 31,156,977
30 Yr Operational Costs	$ 92,638,765	$ 67,163,317
15 Yr (CapEx + OpEx)	$ 71,867,844	$ 70,136,822
30 Yr (CapEx + OpEx)	$ 126,212,965	$ 106,143,162
30 Year Carbon Tax (w/o inflation)	$ 3,031,235	$ 1,860,487
30 Yr Carbon Tax (w/inflation)	$ 4,346,010	$ 2,424,179
30 Year NPV of Costs	$ 72,612,931	$ 64,664,718
NPV of Costs Differential		$ 7,948,213

10 What is carbon offsetting? | World Economic Forum (weforum.org)



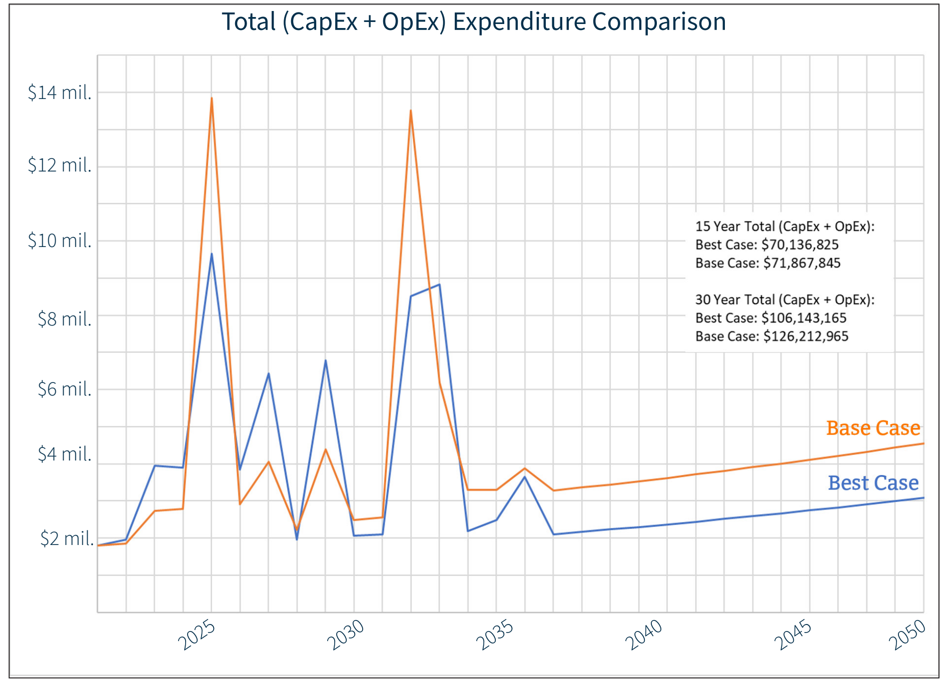
ENERGY EXPENDITURE COMPARISON

The above chart elaborates on annual utility costs and their variation over the life cycle. The operational costs include utility costs, as well as maintenance costs. The current maintenance costs are estimated to be $800,000. This figure includes cost of equipment repair replacement (and associated OEM and vendor labor costs), staff salaries and ancillary costs, costs of warranty renewals and extensions, and other maintenance costs.

In the Base Case as well as the Best Case scenarios, the maintenance costs have been escalated at 3%. In the Best-Case scenario, the maintenance costs of the cogeneration plant are eliminated in 2036. This value is estimated to be approximately $35,000 in today's dollars. The 15 year and 30 year operational costs are significantly lower for the Best case when compared to the Base Case on account of the lower energy costs. The following graph denotes the trends of the Operational Costs (Op Ex) over the next 30 years. This can be attributed to both accelerated energy savings as well as an overall reduction in maintenance costs over the years.

— Best Case Operational Costs

— Base Case Utility Costs



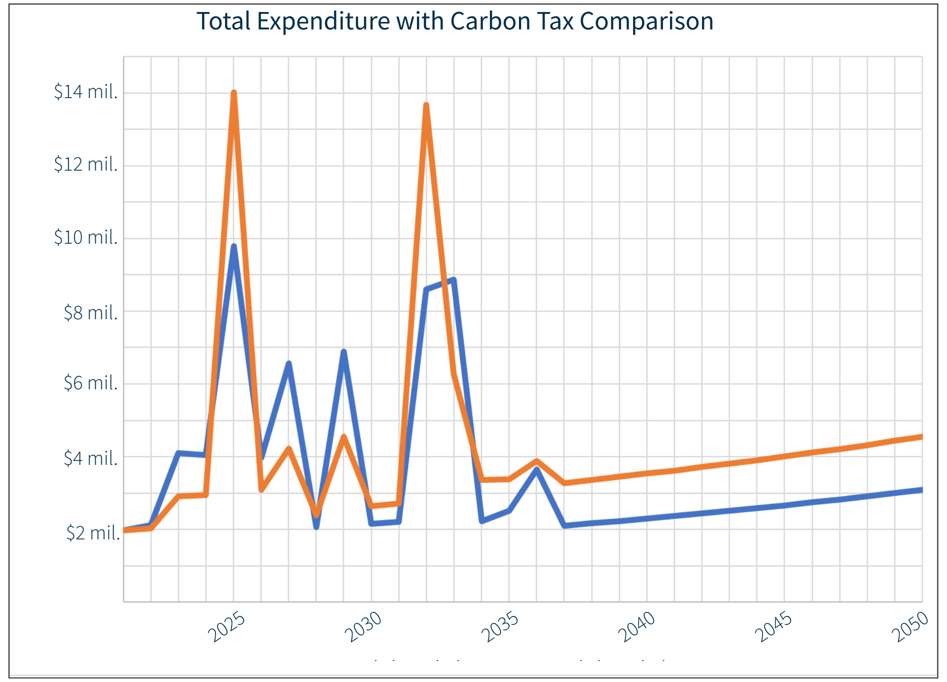
TOTAL EXPENDITURE COMPARISON

The sum of the Capital Expenditure and the Operational Expenditure in a given calendar year is total amount of negative cash flow incurred by the Academy. In other words, this amount represents the costs incurred by the Academy in any given calendar year. the following chart summarizes the estimated CapEx + OpEx trends between 2021 – 2050.

The Best Case incurs higher capital expenditure in the short term, except during the installation of the well fields. The quantity of well fields required to meet the existing loads without any energy efficiency improvements being undertaken significantly increases the total cost outlay, as shown in years 2025 and 2032 above. Over the life cycle, the lower energy costs and marginally lower maintenance costs of the recommended option more than make up for the initially high capital outlay.

— Best Case (CapEx + OpEx)

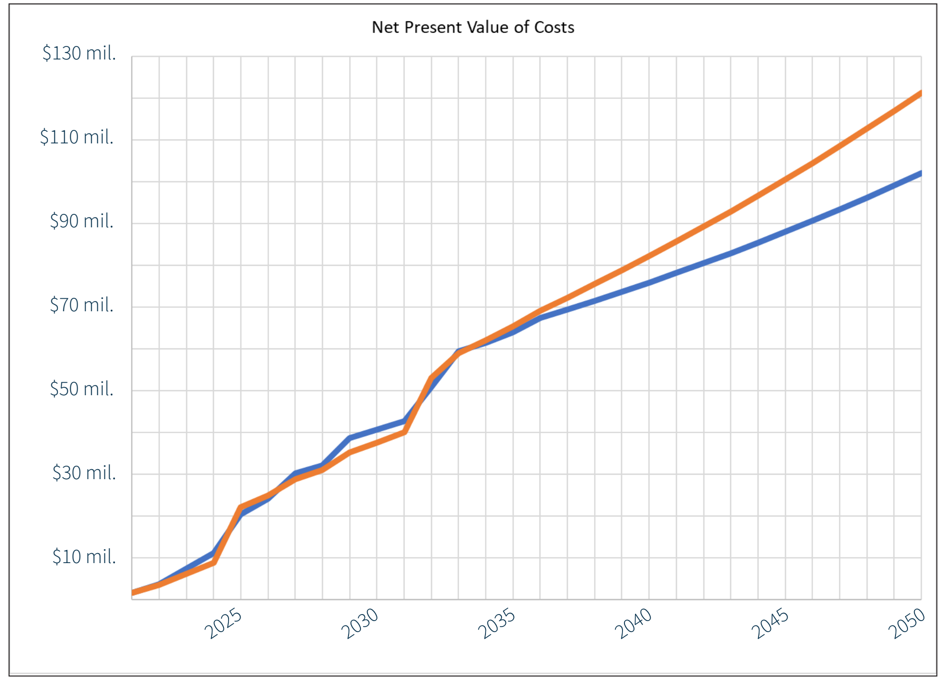
— Base Case (CapEx + OpEx)



TOTAL EXPENDITURE W/ CARBON TAX

If the proposed $50 per MTCO2e Carbon Tax is added to the above charts, the capital total expenditure trendlines is as shown below. The addition of the Carbon Tax makes the Best Case even more attractive.

- Best Case (CapEx + OpEx)
- Base Case (CapEx + OpEx)



NET PRESENT VALUE

The above chart denotes the Net Present Value of costs of both options. With a lower Net Present Value, the Best Case presents a more attractive option.

- Best Case NPV Cost
- Base Case NPV Cost

Sensitivity Analysis

Economic Sensitivity can be defined as the magnitude of reaction of results to a marginal change in the underlying factors. The analyses presented in this report attempt to predict the energy and financial performance of an entire campus over the next thirty years. Some of the key factors that contribute to the results are:

- Natural gas and electrical utility cost increases
  - Currently these have been estimated to rise at 3% annually
- Discount Rate of 4%
  - The discount rate is determined by the Weighted average cost of capital. It represents the cost, both fiscal and opportunity, incurred to invest financial resources into the project.
- Carbon Tax
  - The carbon tax evaluated has been estimated to be $50/MTCO2e. However, this tax is yet to be implemented and could vary significantly in both directions over the next few years
- Cost of heat pump wells: $20,000 per well.
  - This cost could decrease if the well installation projects were undertaken in bulk as well as with improving technologies due to higher capital investment from the market into research and development. This is analogous to the cost decreases seen in the installation of large scale commercial solar PV systems over the last 2 decades.

The scenarios in the table below were tested for the identification of the most critical factors for sensitivity.

A key consideration in any sensitivity analysis is the requisite consistency across fluctuations in variables. To be consistent with the predicted variation of high and low values across the evaluated factors, we estimated each factor to deviate by approximately 15% from its assumed value over the life cycle. This allows for an apples-to-apples sensitivity analysis.

FACTOR	EXISTING INPUT	HIGH INCREMENT %	HIGH INCREMENT VALUE	LOW INCREMENT %	LOW INCREMENT VALUE
Electrical ($/kWh)	0.15	15%	0.1725	15%	0.1275
Natural Gas ($/MCF)	11	15%	12.65	15%	9.35
Carbon Tax	50	15%	57.5	15%	42.5
Inflation Rate	3%	15%	3.5%	15%	2.55%
Discount Rate	4%	15%	4.6%	15%	3.40%

The table below summarizes the results of the sensitivity analysis. The two columns on the extreme right represent the percent change in the results based on the percent change in the underlying factor. The sensitivity analysis is more sensitive to factors with higher percent changes. As shown below, the highest percentage change results from the increase in electrical energy costs. This can be attributed to the following:

- Existing electrical costs are one of the most significant contributing factors to operational costs
- The future strategy for both cases involves the electrification of the campus and switching over from natural gas to electrical energy consumption.

This increases the amount of electrical energy consumed on campus and hence the effect of any changes in the electrical rates will have a higher impact on the feasibility of the recommended project.

FACTOR	HIGH INCREMENT VALUE NPV	LOW INCREMENT VALUE NPV	HIGH INCREMENT NPV DIFFERENTIAL ($)	LOW INCREMENT NPV DIFFERENTIAL ($)	% CHANGE IN NPV PER % CHANGE HIGH INCREMENT	% CHANGE IN NPV PER % CHANGE IN LOW INCREMENT
Electrical ($/kWh)	0.1725	0.1275	$ 9,490,610	$ 6,405,816	19%	-19%
Natural Gas ($/MCF)	12.65	9.35	$ 8,146,922	$ 7,749,504	3%	-3%
Carbon Tax (Non Escalated)	57.5	42.5	$ 8,674,747	$ 8,485,217	9%	7%
Inflation Rate	0.0345	0.0255	$ 8,916,159	$ 7,061,055	12%	-11%
Discount Rate	0.046	0.034	$ 6,929,055	$ 9,118,957	-13%	15%

Discussion

The proposed systems provide flexibility for additions and modifications. Additional buildings can be accommodated by expanding the geothermal loop and situating new heat pump chillers at varies sites with tie-ins. Additional solar photovoltaic systems can also be added as and where needed. Analyzing and estimating the associated costs of incorporating these buildings onto the loop is not within the scope of this project. We recommend further analysis in this regard.

The proposed new training ship is currently in design and will have a significant impact on the energy consumption as well as the carbon footprint. We recommend evaluating the impact of this ship as the design progresses.

This study relies heavily on the efficiencies of available commercial MEP equipment. It is recommended that the Academy and DCAMM evaluate available technologies on an ongoing basis since improvements in energy efficiency and conversion technologies could result in a significant reduction in future carbon emissions and energy consumption. For instance, the Coefficient of Performance (COP) of an air source heat pump (ASHP) is typically about 3.0 on an annual basis. However, the COP, or efficiency of heat transfer, for this technology is expected to increase significantly over the next decade along with a decrease in installed costs due to improvements in technology and sustainability research, as well as likelihood of increased incentives for heat pump technology.

Our overall recommendations and the associated benefits are summarized as follows:

SUMMARIZED RECOMMENDATIONS

- Implement energy conservation measures with short term payback in all buildings as soon as possible.
- Begin further deployment of PV systems throughout campus in coordination with building renovations.
- Develop energy transfer loop and well capacity for first 10 years of master plan recommendations.
- Utilize water source heat pumps connected to the campus loop for heating and cooling in all buildings.
- Include “deep energy retrofits” as part of all proposed building renovations and expansions.
- Maintain or relocate gas fired boiler plants for resiliency/back-up heating purposes.
- Investigate/obtain off-site renewably generated electricity.

BENEFITS OF IMPLEMENTING DEEP ENERGY RETROFITS WITH ENERGY LOOP/HEAT PUMPS

- Substantial reductions in energy use, energy costs and carbon emissions.
  - Increased percentage of required campus energy generated by on-site production.
  - Minimized exposure to energy cost increases.
- Reduced peak heating, cooling and electrical loads.
  - Major reduction in number of wells along with associated site disruption and cost.
  - Eliminates potential need to increase campus electrical distribution capacity.
  - Improves balance between heating and cooling loads.
- High level of flexibility
  - New energy sources can be integrated easily in future.
  - Energy sources can be located anywhere on campus.
- Supports phased implementation.
  - Can easily be implemented on a building-by-building basis.

- Improved occupant comfort.
    - New terminal heating equipment and envelope improvements.
- High level of resiliency.
    - Building plants elevated to address flooding concerns.
    - Local HW boilers maintained for emergency heating purposes.
    - Efficient buildings less subject to freezing problems.
- Capital renewal
    - Old, inefficient systems approaching end of life are replaced with new equipment having a long service life.

Appendices

APPENDIX 1: LIFE CYCLE COST ANALYSIS (LCCA) SPREADSHEET

APPENDIX 2: ENERGY DATA

APPENDIX 3: RESOURCES

APPENDIX 4: SITE VISIT NOTES

APPENDIX 5: RESILIENCE STRATEGIES

APPENDIX 1

LIFE CYCLE COST ANALYSIS
(LCCA) SPREADSHEET

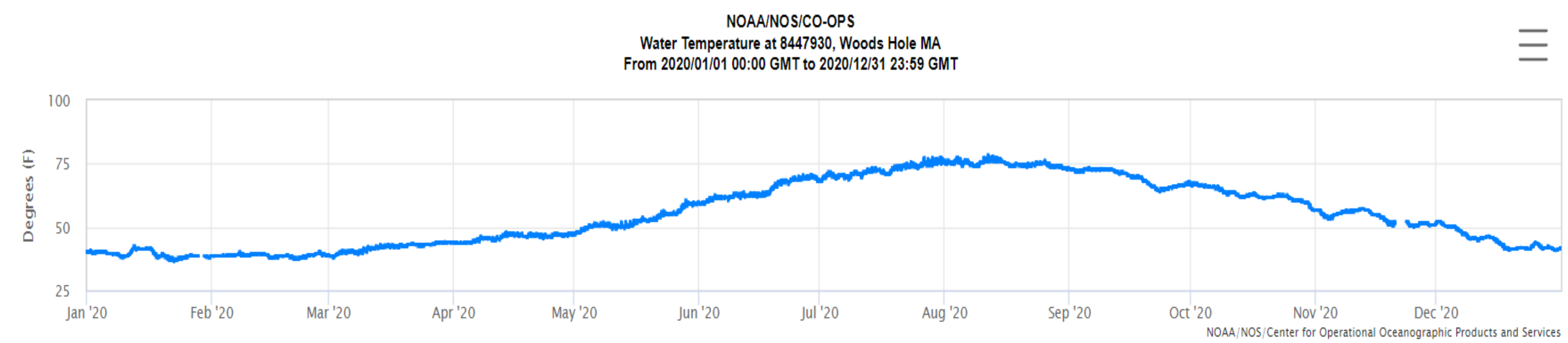
Year	Project	Year	Base Case Utility Costs	Best Case Utility Costs	Base Case Maintennce Costs	Best Case Maintennce Costs	Base Case Operational Costs	Best Case Operational Costs	Base Case (CapEx + Opex)	Best Case (CapEx + Opex)	Base Case OPEX with Carbon Tax	Best Case OPEX with Carbon Tax	Base Case with Carbon Tax (CapEx + Opex)	Best Case with Carbon Tax (CapEx + Opex)	Base Case Cumulative Cost	Best Case Cumulative Cost	Base Case NPV Cost	Best Case NPV Cost
2021	Company 1 Renovations	2021	$ 1,007,076	1,007,076	$ 800,000	$ 800,000	$ 1,807,076	$ 1,807,076	$ 1,807,076	$ 1,807,076	$ 175,931	$ 175,931	$ 1,983,006	$ 1,983,006	$ 1,807,076	$ 1,807,076	$ 1,737,573	$ 1,737,573
2022	Company 2 Renovations	2022	$ 1,037,288	1,006,169	$ 811,640	$ 811,640	$ 1,848,928	$ 1,817,809	$ 1,848,928	$ 1,968,870	$ 174,785	$ 169,473	$ 2,023,713	$ 2,138,344	$ 3,656,003	$ 3,775,946	$ 3,515,388	$ 3,630,717
	Year 1 Energy Retrofits	2023	$ 1,085,195	1,028,081	$ 823,449	$ 823,449	$ 1,908,644	$ 1,851,530	$ 2,739,644	$ 3,941,591	$ 175,768	$ 162,411	$ 2,915,412	$ 4,104,003	$ 6,395,647	$ 7,717,537	$ 6,149,661	$ 7,420,709
2023	Company 3 renovations	2024	$ 1,117,751	951,788	$ 835,431	$ 835,431	$ 1,953,181	$ 1,787,218	$ 2,784,181	$ 3,877,279	$ 174,622	$ 141,642	$ 2,958,804	$ 4,018,922	$ 9,179,829	$ 11,594,817	$ 8,826,758	$ 11,148,862
	Year 2 Energy retrofits	2025	$ 1,151,283	869,991	$ 847,586	$ 847,586	$ 1,998,869	$ 1,717,578	$ 13,851,769	$ 9,608,639	$ 173,477	$ 120,874	$ 14,025,246	$ 9,729,513	$ 23,031,598	$ 21,203,456	$ 22,145,767	$ 20,387,938
	Fantail Expansion	2026	$ 1,226,512	960,642	$ 859,918	$ 859,918	$ 2,086,431	$ 1,820,561	$ 2,917,431	$ 3,759,561	$ 174,725	$ 115,282	$ 3,092,155	$ 3,874,843	$ 25,949,029	$ 24,963,017	$ 24,950,989	$ 24,002,901
	Beachmoor completed	2027	$ 1,303,938	960,543	$ 872,430	$ 872,430	$ 2,176,369	$ 1,832,973	$ 4,063,869	$ 6,362,973	$ 166,741	$ 103,303	$ 4,230,610	$ 6,466,277	$ 30,012,897	$ 31,325,990	$ 28,858,555	$ 30,121,144
2024	Company 4 renovations	2028	$ 1,343,056	988,353	$ 885,124	$ 885,124	$ 2,228,181	$ 1,873,477	$ 2,228,181	$ 1,873,477	$ 165,596	$ 102,102	$ 2,393,776	$ 1,975,579	$ 32,241,078	$ 33,199,467	$ 31,001,036	$ 31,922,565
	Year 3 Energy retrofits	2029	$ 1,499,886	1,008,576	$ 898,003	$ 898,003	$ 2,397,888	$ 1,906,579	$ 4,397,888	$ 6,706,579	$ 158,967	$ 88,693	$ 4,556,855	$ 6,795,272	$ 36,638,966	$ 39,906,046	$ 35,229,775	$ 38,371,198
2025	Phase 1 Campus Loop and Wells	2030	$ 1,579,329	1,060,906	$ 911,069	$ 911,069	$ 2,490,398	$ 1,971,975	$ 2,490,398	$ 1,971,975	$ 160,988	$ 88,701	$ 2,651,386	$ 2,060,676	$ 39,129,364	$ 41,878,020	$ 37,624,388	$ 40,267,327
	Company 5 Renovations	2031	$ 1,626,709	1,090,624	$ 924,325	$ 924,325	$ 2,551,034	$ 2,014,949	$ 2,551,034	$ 2,014,949	$ 159,843	$ 87,449	$ 2,710,877	$ 2,102,397	$ 41,680,397	$ 43,892,969	$ 40,077,305	$ 42,204,778
	Year 4 of Energy Retrofits	2032	$ 1,667,105	988,846	$ 937,774	$ 937,774	$ 2,604,879	$ 1,926,619	$ 13,518,679	$ 8,423,619	$ 157,235	$ 64,919	$ 13,675,913	$ 8,488,538	$ 55,199,076	$ 52,316,588	$ 53,076,034	$ 50,904,412
2026	Company 6 Renovations	2033	$ 1,806,003	967,238	$ 951,418	$ 951,418	$ 2,757,421	$ 1,918,656	$ 6,044,421	$ 8,738,961	$ 65,859	$ 27,759	$ 6,110,280	$ 8,766,720	$ 61,243,497	$ 61,055,549	$ 58,887,978	$ 58,707,259
	STEM Building	2034	$ 1,908,272	981,033	$ 965,261	$ 965,261	$ 2,873,533	$ 1,946,294	$ 3,143,533	$ 2,090,294	$ 51,690	$ 15,650	$ 3,195,223	$ 2,105,944	$ 64,387,030	$ 63,145,844	$ 61,910,605	$ 60,717,157
	Harrington Program renovations	2035	$ 1,974,084	989,340	$ 979,306	$ 916,647	$ 2,953,390	$ 1,905,987	$ 3,153,390	$ 2,385,987	$ 47,226	$ 9,847	$ 3,200,616	$ 2,395,834	$ 67,540,420	$ 65,531,831	$ 64,942,711	$ 63,011,376
2027	Harrington Energy upgrades/HP	2036	$ 2,060,375	1,000,389	$ 993,555	$ 944,147	$ 3,053,930	$ 1,944,536	$ 3,723,930	$ 3,552,536	$ -		$ 3,723,930	$ 3,552,536	$ 71,264,349	$ 69,084,366	$ 68,523,413	$ 66,427,275
2028	Alumni Gym Addition	2037	$ 2,271,842	1,134,848	$ 1,008,011	$ 972,471	$ 3,279,853	$ 2,107,319	$ 3,279,853	$ 2,107,319	$ -		$ 3,279,853	$ 2,107,319	$ 74,544,209	$ 71,191,686	$ 71,677,118	$ 68,453,544
2029	Alumni Gym Energy Upgrades/HP plant	2038	$ 2,339,997	1,168,894	$ 1,022,678	$ 1,001,645	$ 3,362,675	$ 2,170,539	$ 3,362,675	$ 2,170,539	$ -		$ 3,362,675	$ 2,170,539	$ 77,906,878	$ 73,362,224	$ 74,910,459	$ 70,540,600
	Power Plant renovations/HP plant	2039	$ 2,410,197	1,203,960	$ 1,037,558	$ 1,031,695	$ 3,447,755	$ 2,235,655	$ 3,447,755	$ 2,235,655	$ -		$ 3,447,755	$ 2,235,655	$ 81,354,633	$ 75,597,879	$ 78,225,608	$ 72,690,269
2030	Company 8 complete (not tied into HP loop yet)	2040	$ 2,482,503	1,240,079	$ 1,052,654	$ 1,062,645	$ 3,535,157	$ 2,302,725	$ 3,535,157	$ 2,302,725	$ -		$ 3,535,157	$ 2,302,725	$ 84,889,790	$ 77,900,604	$ 81,624,798	$ 74,904,427
2032	Pande Dining Energy Upgrades	2041	$ 2,556,978	1,277,282	$ 1,067,970	$ 1,094,525	$ 3,624,949	$ 2,371,806	$ 3,624,949	$ 2,371,806	$ -		$ 3,624,949	$ 2,371,806	$ 88,514,738	$ 80,272,410	$ 85,120,325	$ 77,185,030
	Phase 2 of well construction or WWTP HX plant	2042	$ 2,633,688	1,315,600	$ 1,083,509	$ 1,127,360	$ 3,717,197	$ 2,442,961	$ 3,717,197	$ 2,442,961	$ -		$ 3,717,197	$ 2,442,961	$ 92,231,935	$ 82,715,371	$ 88,684,553	$ 79,534,011
	Campus Electrical service upgrade for BAU opti	2043	$ 2,712,698	1,355,068	$ 1,099,274	$ 1,161,181	$ 3,811,973	$ 2,516,249	$ 3,811,973	$ 2,516,249	$ -		$ 3,811,973	$ 2,516,249	$ 96,043,908	$ 85,231,620	$ 92,349,911	$ 81,953,481
2033	Energy upgrades to Companies and HP plant	2044	$ 2,794,079	1,395,720	$ 1,115,269	$ 1,196,017	$ 3,909,348	$ 2,591,737	$ 3,909,348	$ 2,591,737	$ -		$ 3,909,348	$ 2,591,737	$ 99,953,256	$ 87,823,357	$ 96,108,900	$ 84,445,536
	Bresnahan Hall Renovations/expansion	2045	$ 2,877,902	1,437,592	$ 1,131,496	$ 1,231,897	$ 4,009,397	$ 2,669,489	$ 4,009,397	$ 2,669,489	$ -		$ 4,009,397	$ 2,669,489	$103,962,653	$ 90,492,846	$ 99,964,089	$ 87,012,352
2034	Bresnahan Hall Energy upgrades/HP plant	2046	$ 2,964,239	1,480,720	$ 1,147,959	$ 1,268,854	$ 4,112,198	$ 2,749,574	$ 4,112,198	$ 2,749,574	$ -		$ 4,112,198	$ 2,749,574	$108,074,851	$ 93,242,420	$103,928,126	$ 89,656,173
2035	Flanagan hall energy upgrades/HP plant	2047	$ 3,053,166	1,525,141	$ 1,164,662	$ 1,306,920	$ 4,217,828	$ 2,832,061	$ 4,217,828	$ 2,832,061	$ -		$ 4,217,828	$ 2,832,061	$112,292,678	$ 96,074,481	$107,973,729	$ 92,379,308
2036	Kurz Hall Energy upgrades/HP plant	2048	$ 3,144,761	1,570,895	$ 1,181,608	$ 1,346,127	$ 4,326,369	$ 2,917,023	$ 4,326,369	$ 2,917,023	$ -		$ 4,326,369	$ 2,917,023	$116,619,047	$ 98,991,503	$112,133,699	$ 95,184,138
		2049	$ 3,239,104	1,618,022	$ 1,198,800	$ 1,386,511	$ 4,437,904	$ 3,004,533	$ 4,437,904	$ 3,004,533	$ -		$ 4,437,904	$ 3,004,533	$121,056,951	$101,996,037	$116,400,914	$ 98,073,112
		2050	$ 3,336,277	1,666,563	$ 1,216,243	$ 1,428,106	$ 4,552,519	$ 3,094,669	$ 4,552,519	$ 3,094,669	$ -		$ 4,552,519	$ 3,094,669	$125,609,470	$105,090,706	$120,778,337	$101,048,756

VAN ZELM HEYWOOD & SHADFORD, INC.

APPENDIX 2

ENERGY DATA

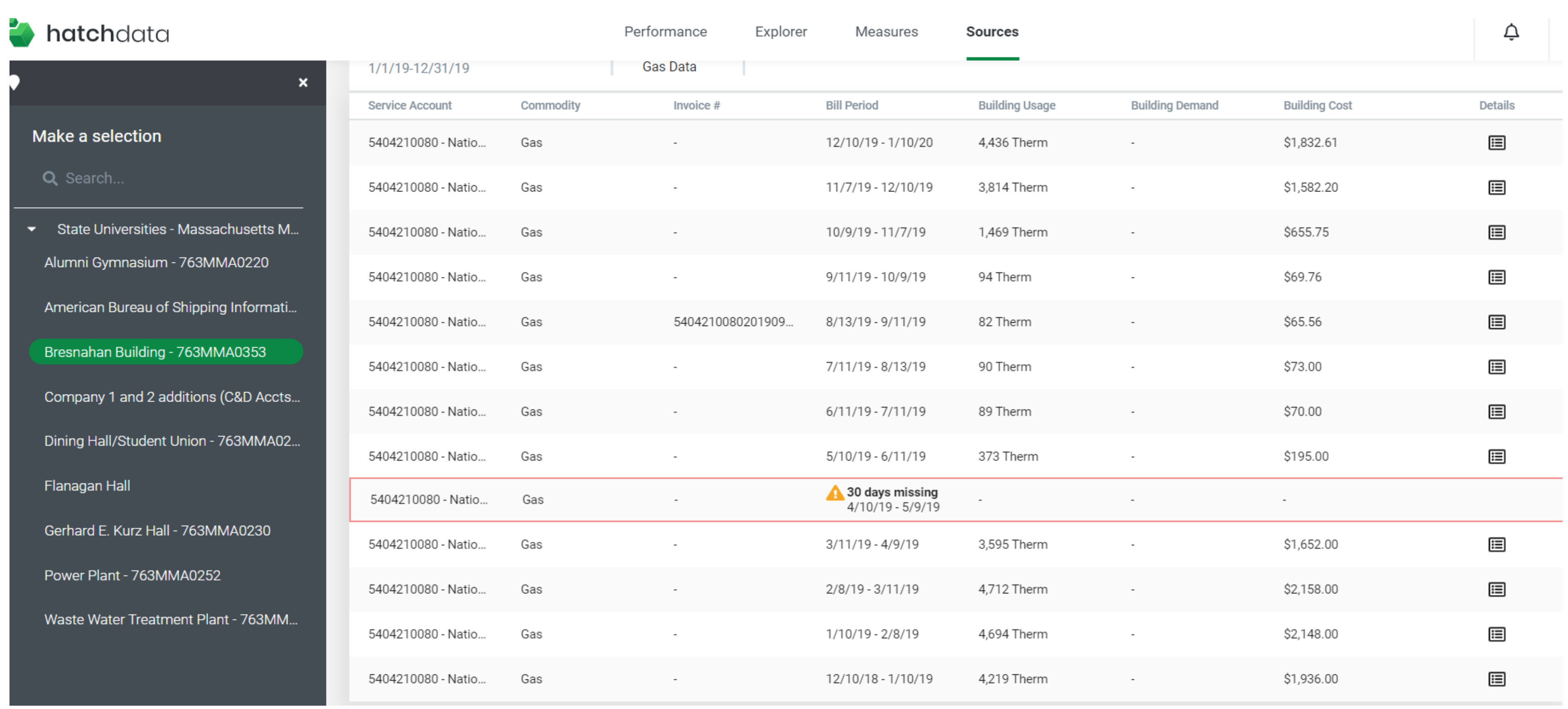
NOAA Water Temperature



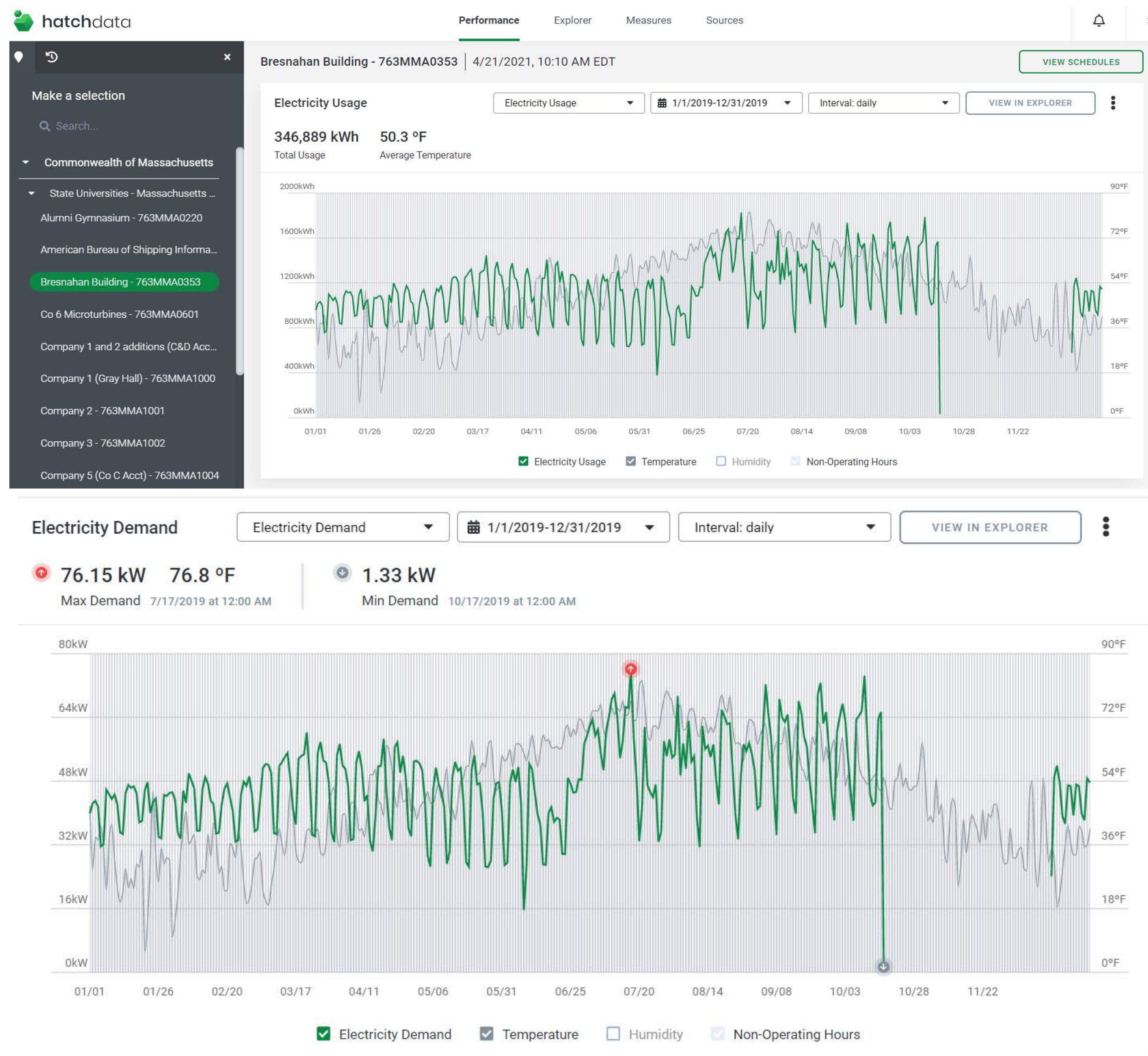
Raw Energy Data From Hatch

Hatch is a third party software front end and database utilized by MMA for energy tracking and trending.

Bresnahan Hall

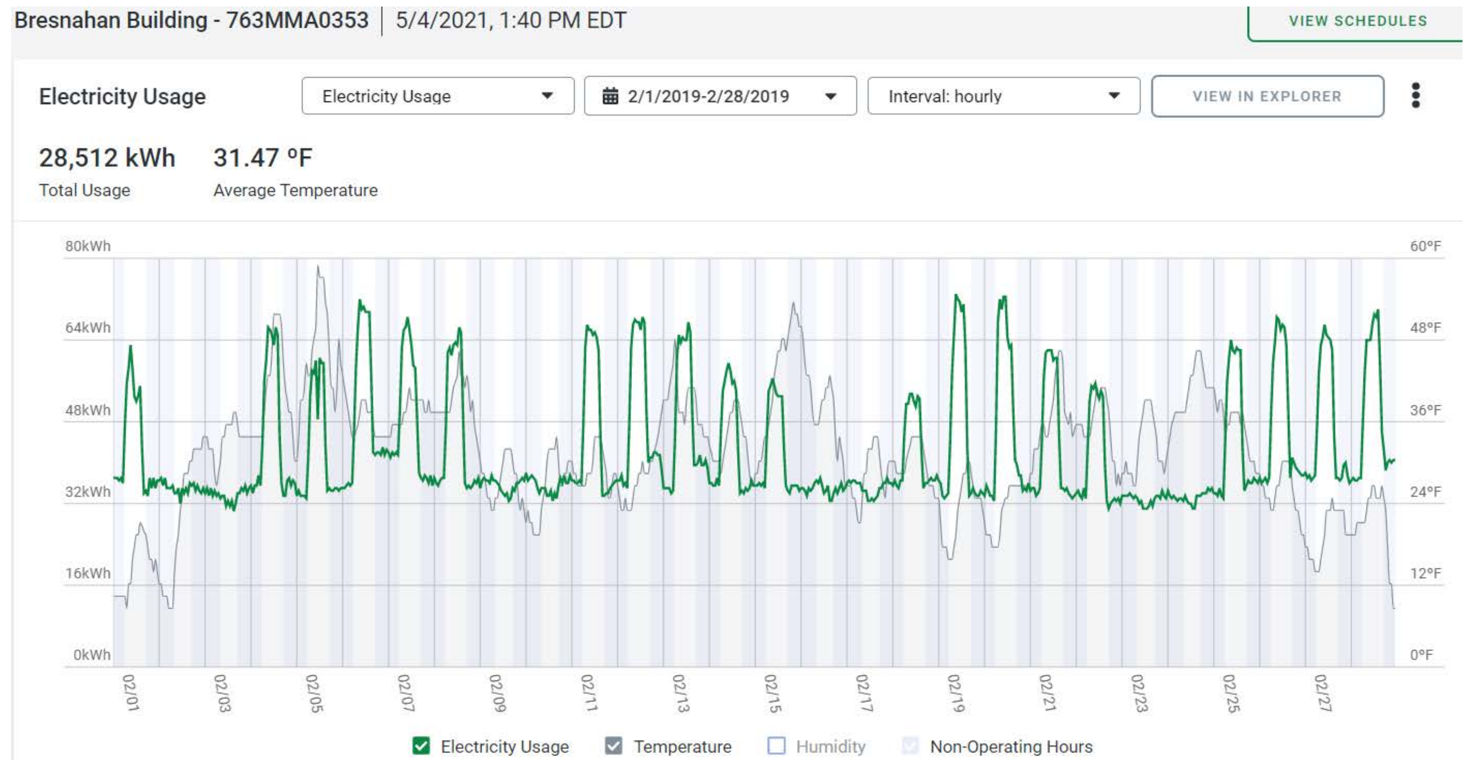


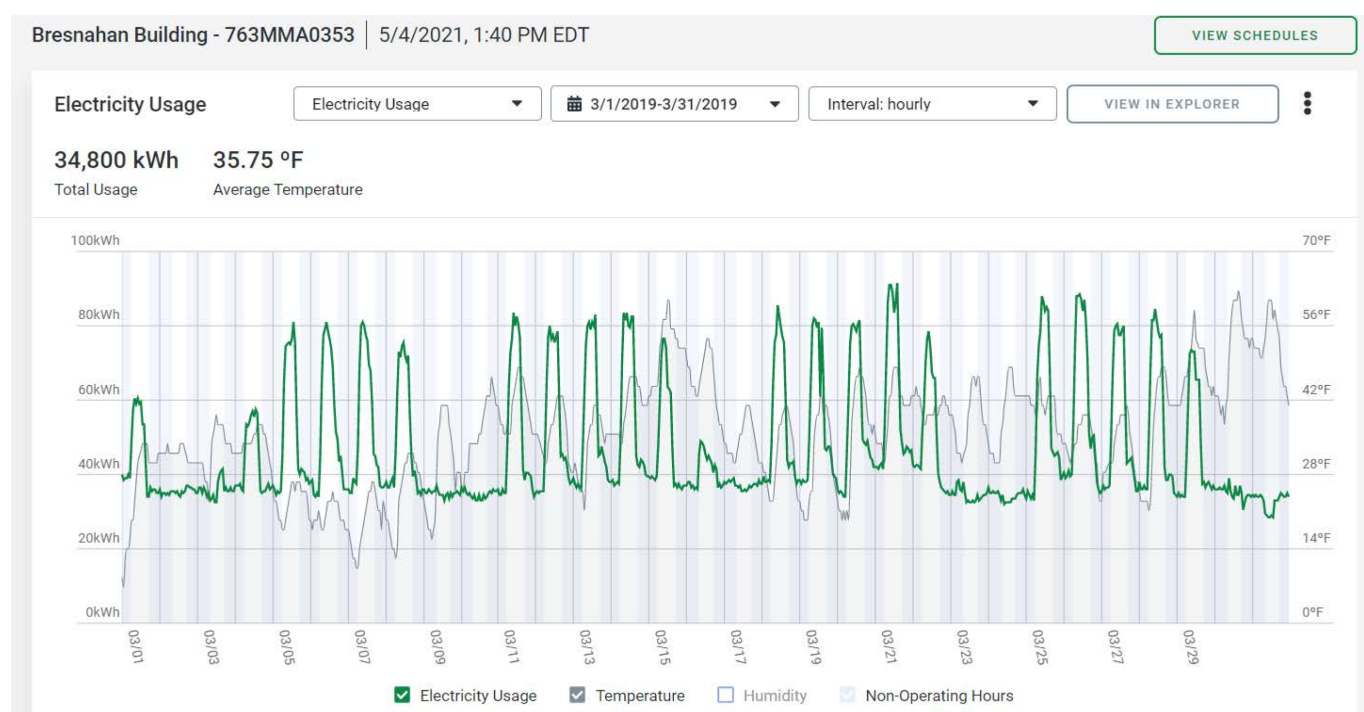
Service Account	Commodity	Invoice #	Bill Period	Building Usage	Building Demand	Building Cost	Details
5404210080 - Natio...	Gas	-	12/10/19 - 1/10/20	4,436 Therm	-	$1,832.61	
5404210080 - Natio...	Gas	-	11/7/19 - 12/10/19	3,814 Therm	-	$1,582.20	
5404210080 - Natio...	Gas	-	10/9/19 - 11/7/19	1,469 Therm	-	$655.75	
5404210080 - Natio...	Gas	-	9/11/19 - 10/9/19	94 Therm	-	$69.76	
5404210080 - Natio...	Gas	5404210080201909...	8/13/19 - 9/11/19	82 Therm	-	$65.56	
5404210080 - Natio...	Gas	-	7/11/19 - 8/13/19	90 Therm	-	$73.00	
5404210080 - Natio...	Gas	-	6/11/19 - 7/11/19	89 Therm	-	$70.00	
5404210080 - Natio...	Gas	-	5/10/19 - 6/11/19	373 Therm	-	$195.00	
5404210080 - Natio...	Gas	-	30 days missing 4/10/19 - 5/9/19	-	-	-	
5404210080 - Natio...	Gas	-	3/11/19 - 4/9/19	3,595 Therm	-	$1,652.00	
5404210080 - Natio...	Gas	-	2/8/19 - 3/11/19	4,712 Therm	-	$2,158.00	
5404210080 - Natio...	Gas	-	1/10/19 - 2/8/19	4,694 Therm	-	$2,148.00	
5404210080 - Natio...	Gas	-	12/10/18 - 1/10/19	4,219 Therm	-	$1,936.00	


hatchdata
Performance
Explorer
Measures
Sources
Make a selection
Search...
Commonwealth of Massachusetts
State Universities - Massachusetts ...
Alumni Gymnasium - 763MMA0220
American Bureau of Shipping Informa...
Bresnahan Building - 763MMA0353
Co 6 Microturbines - 763MMA0601
Company 1 and 2 additions (C&D Acc...
Company 1 (Gray Hall) - 763MMA1000
Company 2 - 763MMA1001
Company 3 - 763MMA1002
Company 5 (Co C Acct) - 763MMA1004
Bresnahan Building - 763MMA0353 | 4/21/2021, 10:10 AM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
1/1/2019-12/31/2019
Interval: daily
VIEW IN EXPLORER
346,889 kWh
Total Usage
50.3 °F
Average Temperature
2000kWh
1600kWh
1200kWh
800kWh
400kWh
0kWh
90°F
72°F
54°F
36°F
18°F
0°F
01/01
01/26
02/20
03/17
04/11
05/06
05/31
06/25
07/20
08/14
09/08
10/03
10/28
11/22
Electricity Usage
Temperature
Humidity
Non-Operating Hours
Electricity Demand
Electricity Demand
1/1/2019-12/31/2019
Interval: daily
VIEW IN EXPLORER
76.15 kW
76.8 °F
Max Demand 7/17/2019 at 12:00 AM
1.33 kW
Min Demand 10/17/2019 at 12:00 AM
80kW
64kW
48kW
32kW
16kW
0kW
90°F
72°F
54°F
36°F
18°F
0°F
01/01
01/26
02/20
03/17
04/11
05/06
05/31
06/25
07/20
08/14
09/08
10/03
10/28
11/22
Electricity Demand
Temperature
Humidity
Non-Operating Hours


Electricity Demand
Electricity Demand
1/1/2019-12/31/2019
Interval: daily
VIEW IN EXPLORER
76.15 kW 76.8 °F
Max Demand 7/17/2019 at 12:00 AM
1.33 kW
Min Demand 10/17/2019 at 12:00 AM
80kW
64kW
48kW
32kW
16kW
0kW
90°F
72°F
54°F
36°F
18°F
0°F
01/01 01/26 02/20 03/17 04/11 05/06 05/31 06/25 07/20 08/14 09/08 10/03 10/28 11/22
Electricity Demand
Temperature
Humidity
Non-Operating Hours


Bresnahan Building - 763MMA0353 | 5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
1/1/2019-1/31/2019
Interval: hourly
VIEW IN EXPLORER
31,049 kWh
Total Usage
29.98 °F
Average Temperature
70kWh
56kWh
42kWh
28kWh
14kWh
0kWh
60°F
48°F
36°F
24°F
12°F
0°F
01/01 01/03 01/05 01/07 01/09 01/11 01/13 01/15 01/17 01/19 01/21 01/23 01/25 01/27 01/29
Electricity Usage
Temperature
Humidity
Non-Operating Hours


Bresnahan Building - 763MMA0353
5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
2/1/2019-2/28/2019
Interval: hourly
VIEW IN EXPLORER
28,512 kWh
Total Usage
31.47 °F
Average Temperature
80kWh
64kWh
48kWh
32kWh
16kWh
0kWh
60°F
48°F
36°F
24°F
12°F
0°F
02/01
02/03
02/05
02/07
02/09
02/11
02/13
02/15
02/17
02/19
02/21
02/23
02/25
02/27
Electricity Usage
Temperature
Humidity
Non-Operating Hours


Bresnahan Building - 763MMA0353
5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
3/1/2019-3/31/2019
Interval: hourly
VIEW IN EXPLORER
34,800 kWh
Total Usage
35.75 °F
Average Temperature
100kWh
80kWh
60kWh
40kWh
20kWh
0kWh
70°F
56°F
42°F
28°F
14°F
0°F
03/01
03/03
03/05
03/07
03/09
03/11
03/13
03/15
03/17
03/19
03/21
03/23
03/25
03/27
03/29
Electricity Usage
Temperature
Humidity
Non-Operating Hours

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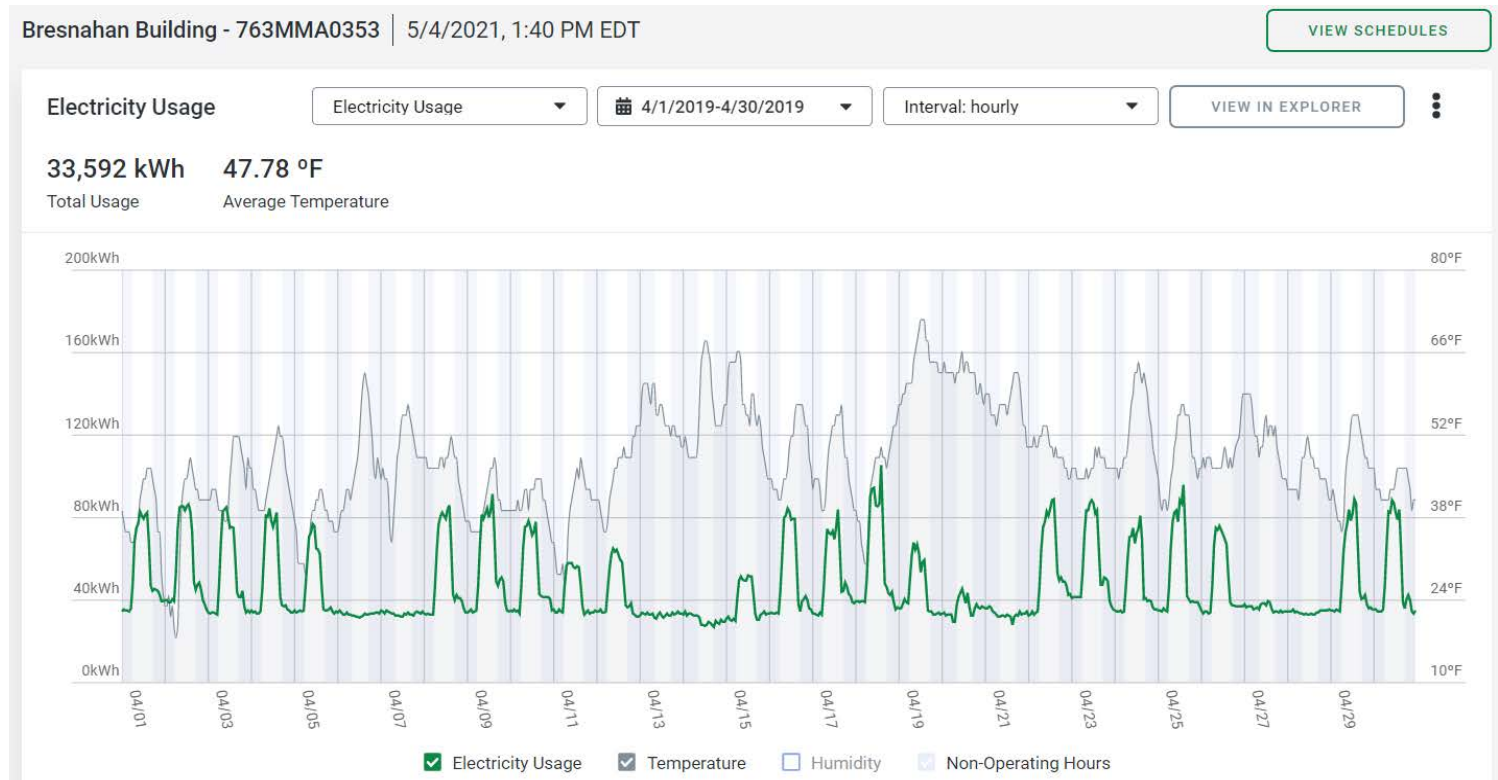
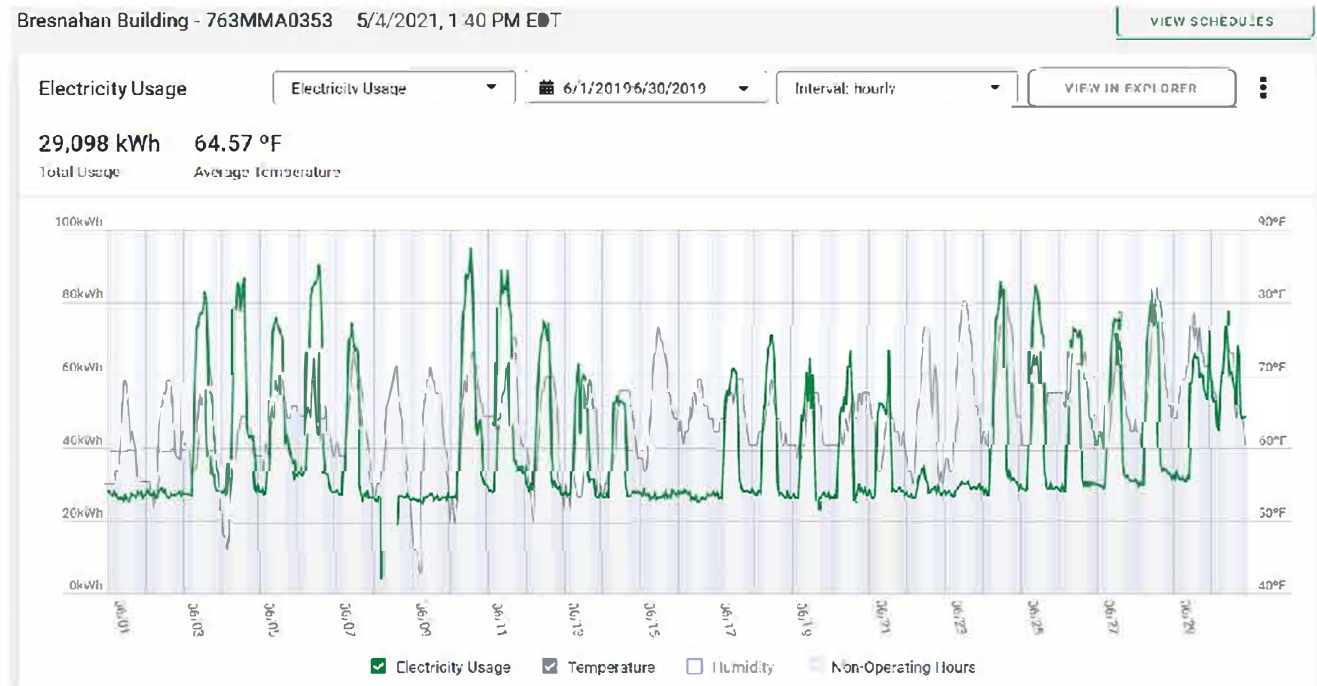
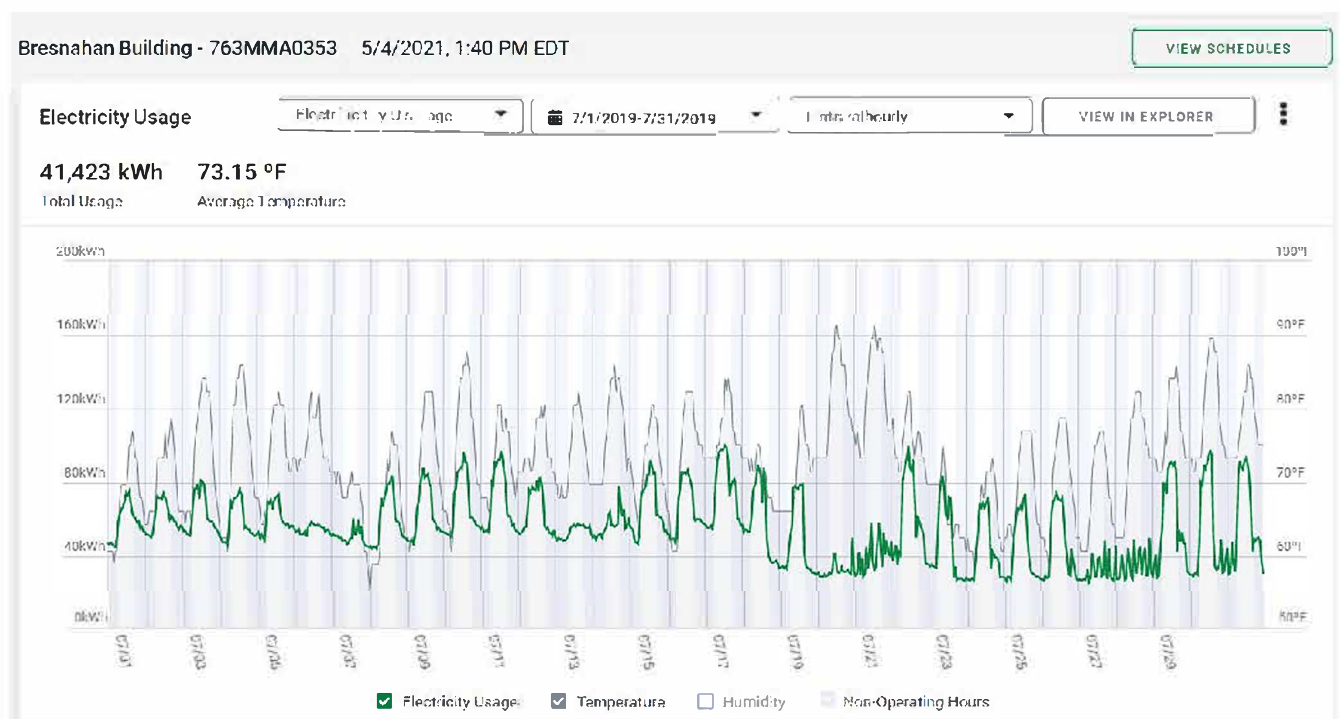
ENGINEERS
VAN ZELM HEYWOOD & SHADFORD, INC.

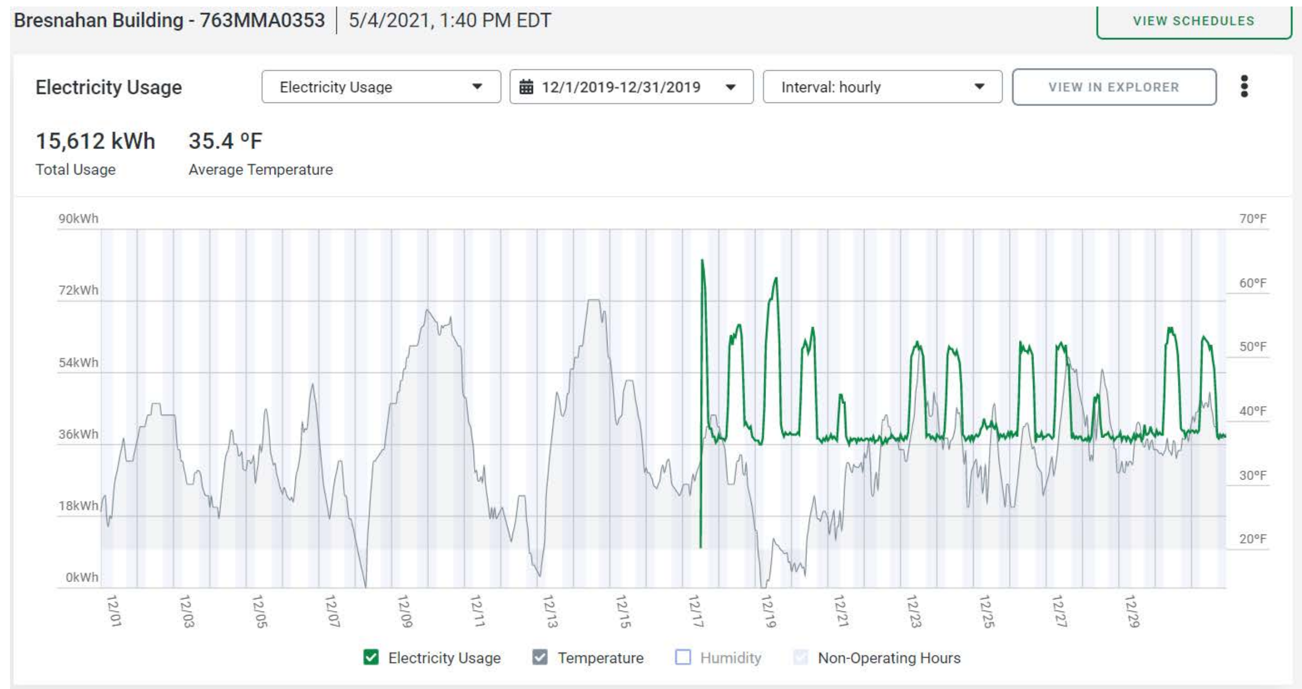



Bresnahan Building - 763MMA0353
VIEW SCHEDULES
Electricity Usage
Electricity Usage
6/1/2019-6/30/2019
Interval: hourly
VIEW IN EXPLORER
29,098 kWh
Total Usage
64.57 °F
Average Temperature
Electricity Usage
Temperature
Humidity
Non-Operating Hours

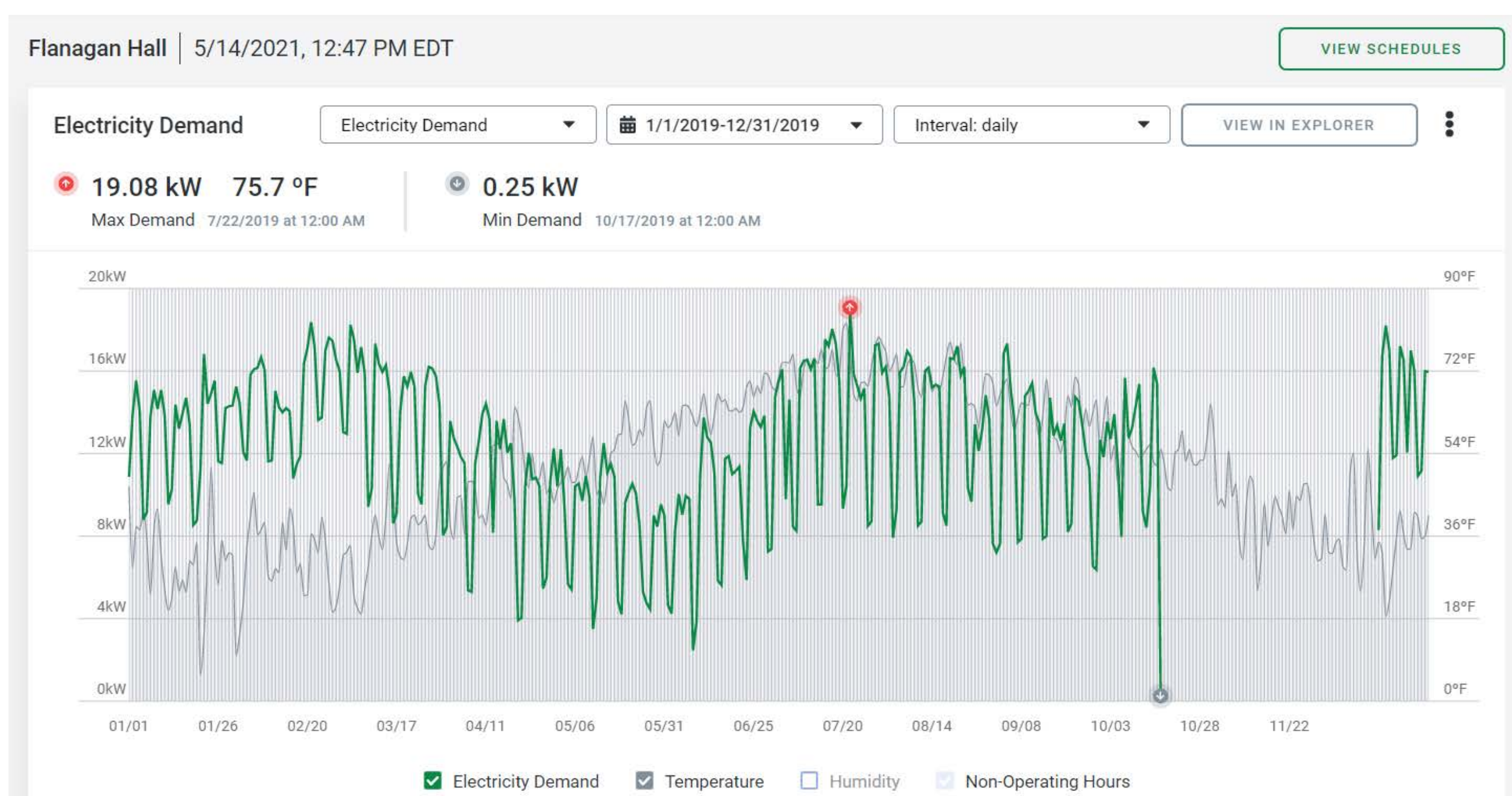

Bresnahan Building - 763MMA0353 5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
7/1/2019-7/31/2019
VIEW IN EXPLORER
41,423 kWh
Total Usage
73.15 °F
Average Temperature
Electricity Usage
Temperature
Humidity
Non-Operating Hours


Bresnahan Building - 763MMA0353
5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
8/1/2019-8/31/2019
Interval: hourly
VIEW IN EXPLORER
39,774 kWh
Total Usage
70.69 °F
Average Temperature
200kWh
160kWh
120kWh
80kWh
40kWh
0kWh
100°F
90°F
80°F
70°F
60°F
50°F
08/01
08/03
08/05
08/07
08/09
08/11
08/13
08/15
08/17
08/19
08/21
08/23
08/25
08/27
08/29
Electricity Usage
Temperature
Humidity
Non-Operating Hours


Bresnahan Building - 763MMA0353
5/4/2021, 1:40 PM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
10/1/2019-10/31/2019
Interval: hourly
VIEW IN EXPLORER
22,093 kWh
Total Usage
54.89 °F
Average Temperature
200kWh
160kWh
120kWh
80kWh
40kWh
0kWh
80°F
70°F
60°F
50°F
40°F
30°F
10/01
10/03
10/05
10/07
10/09
10/11
10/13
10/15
10/17
10/19
10/21
10/23
10/25
10/27
10/29
Electricity Usage
Temperature
Humidity
Non-Operating Hours

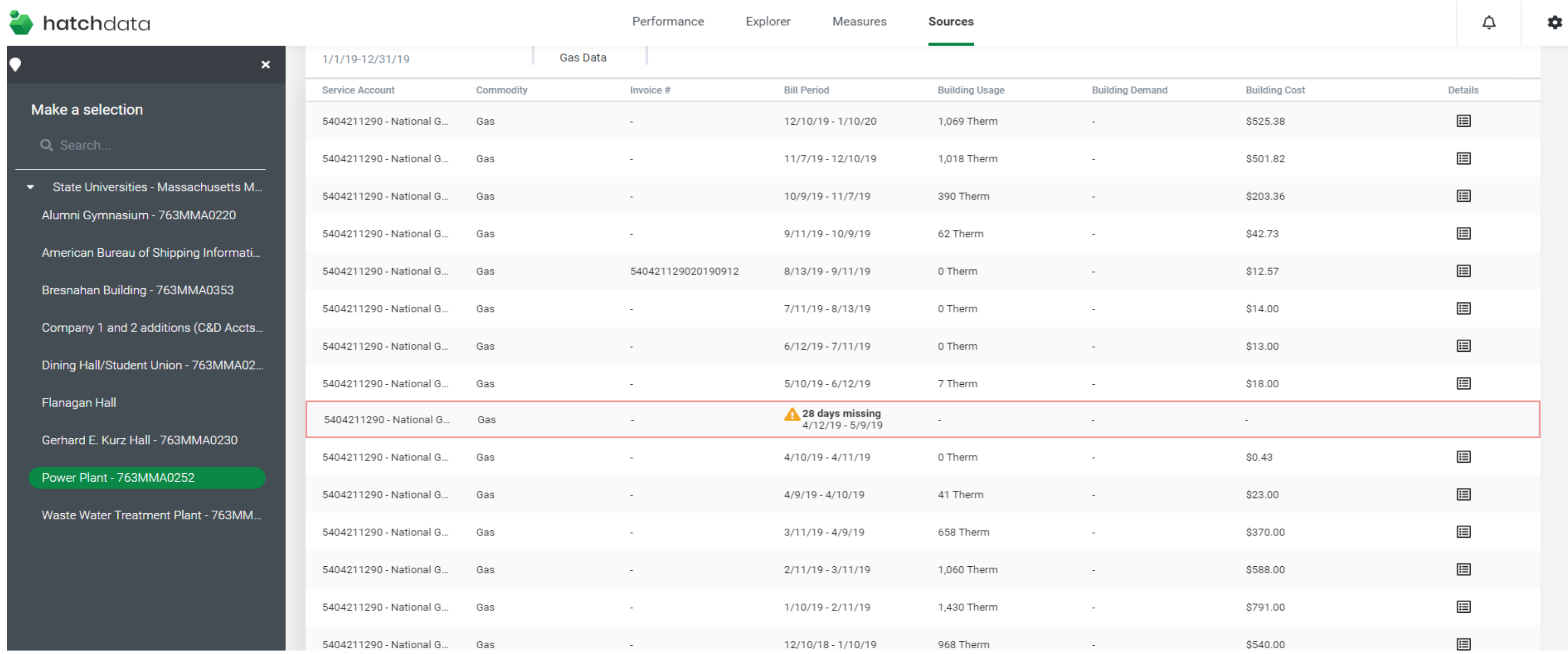


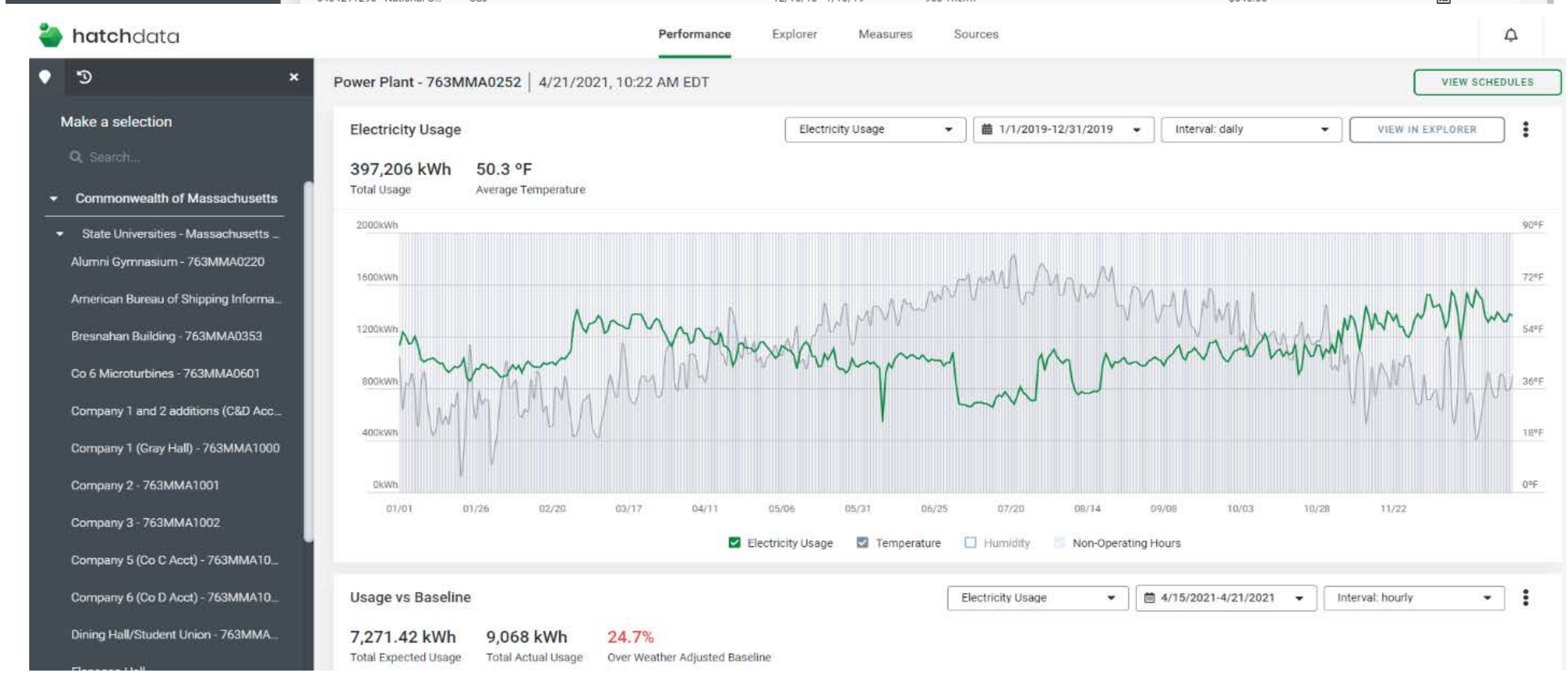
Flanagan Hall

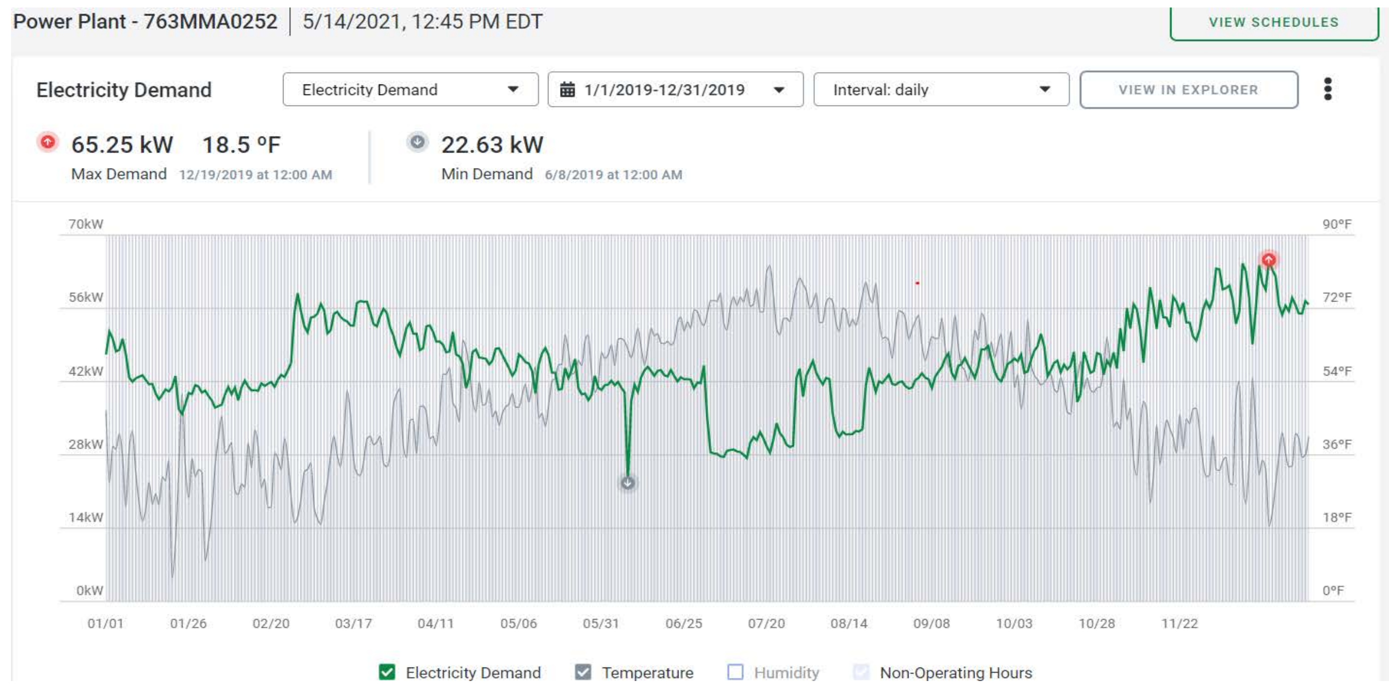


VANZELM
ENGINEERS
VAN ZELM HEYWOOD & SHADFORD, INC.

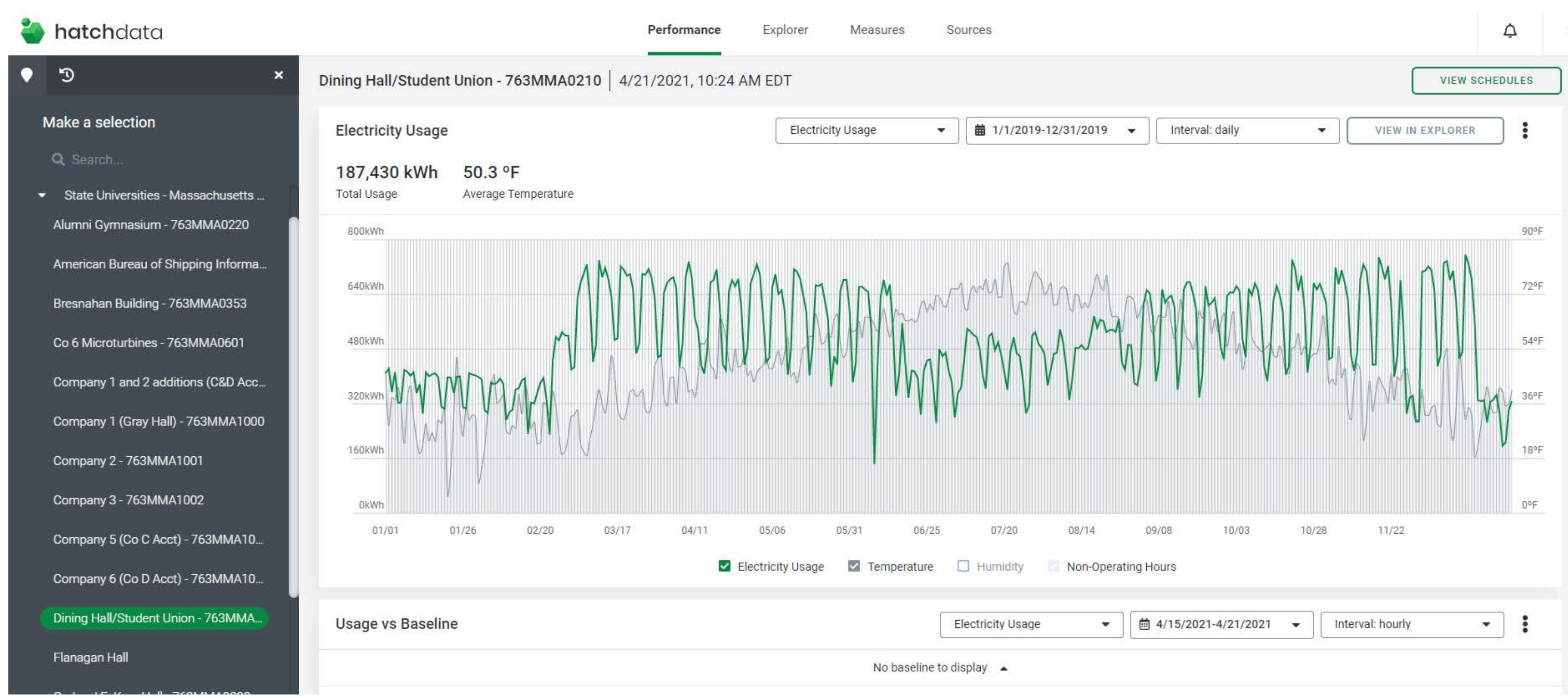
Power Plant

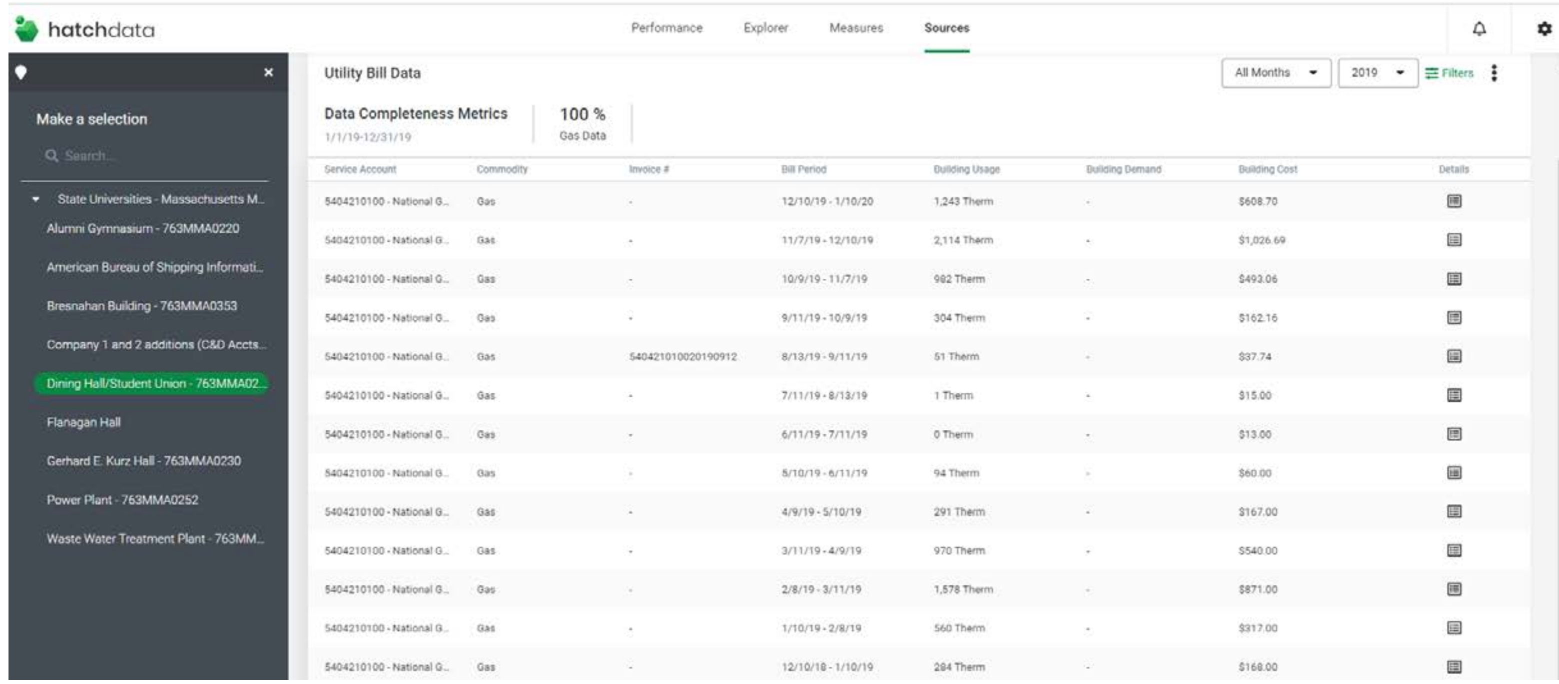




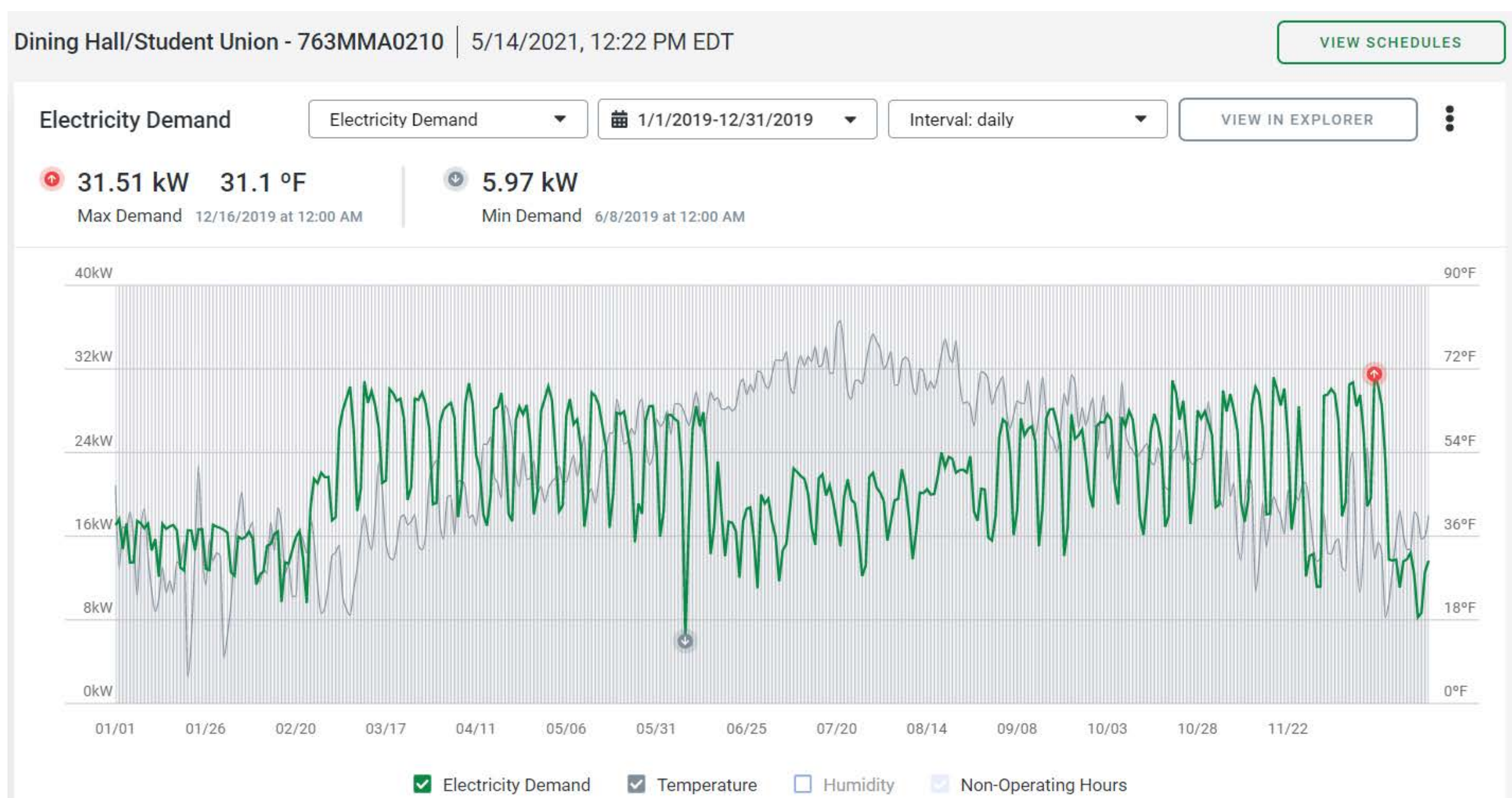


Pande Dining

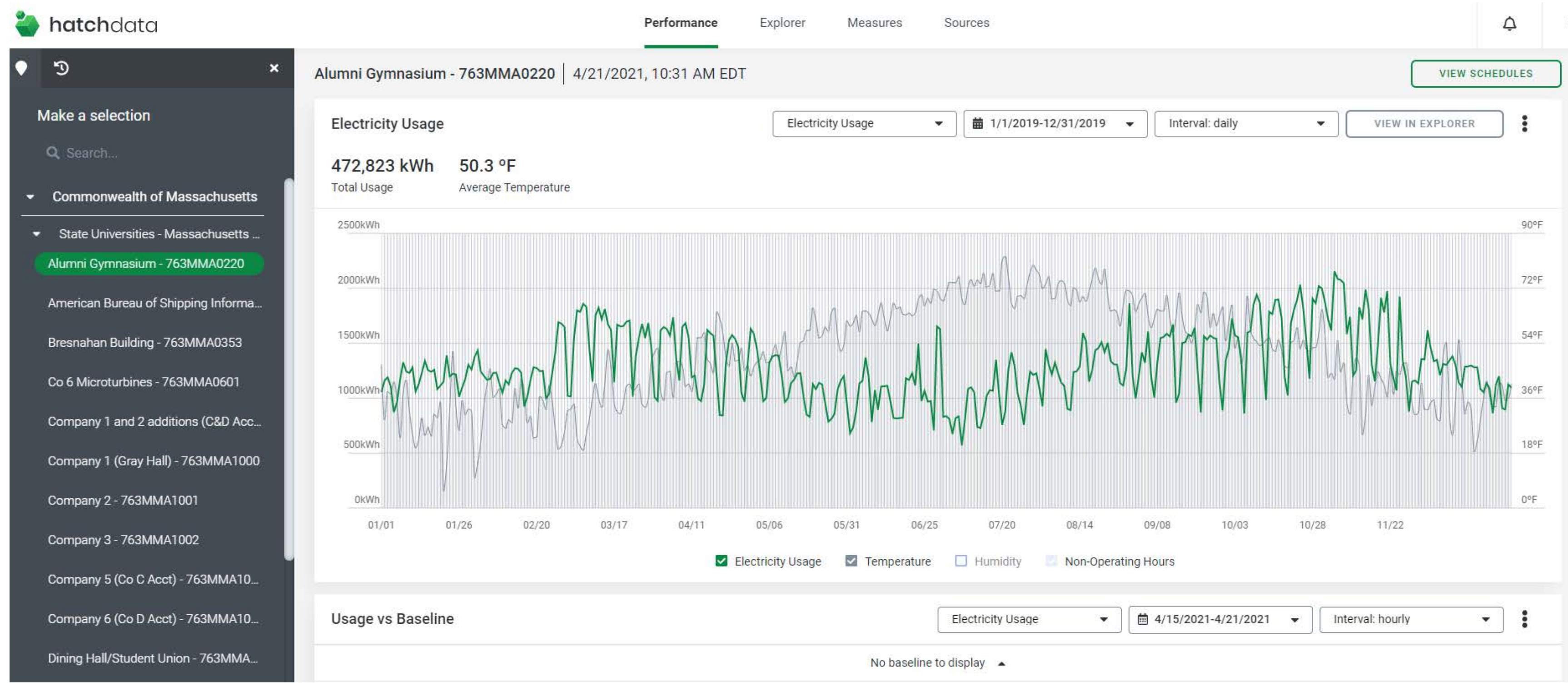


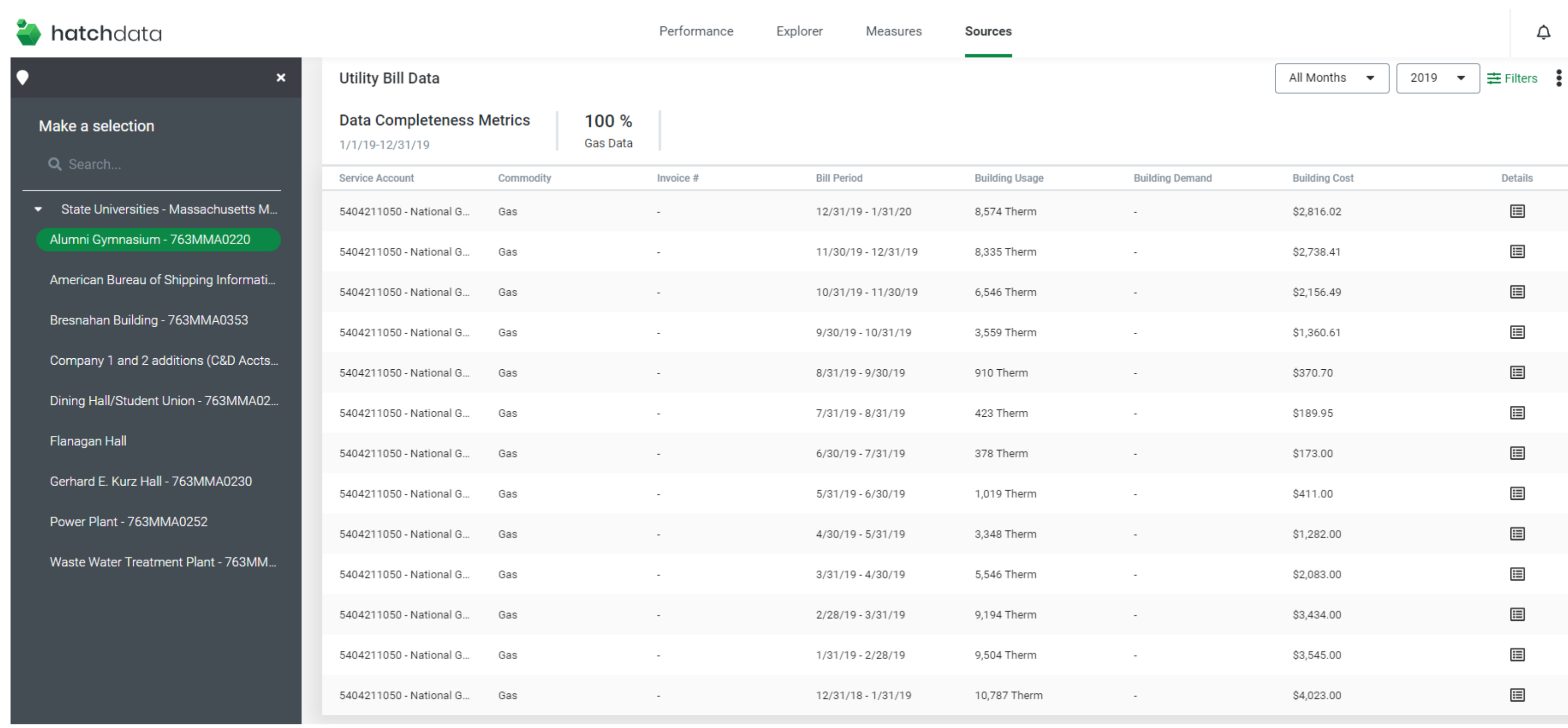


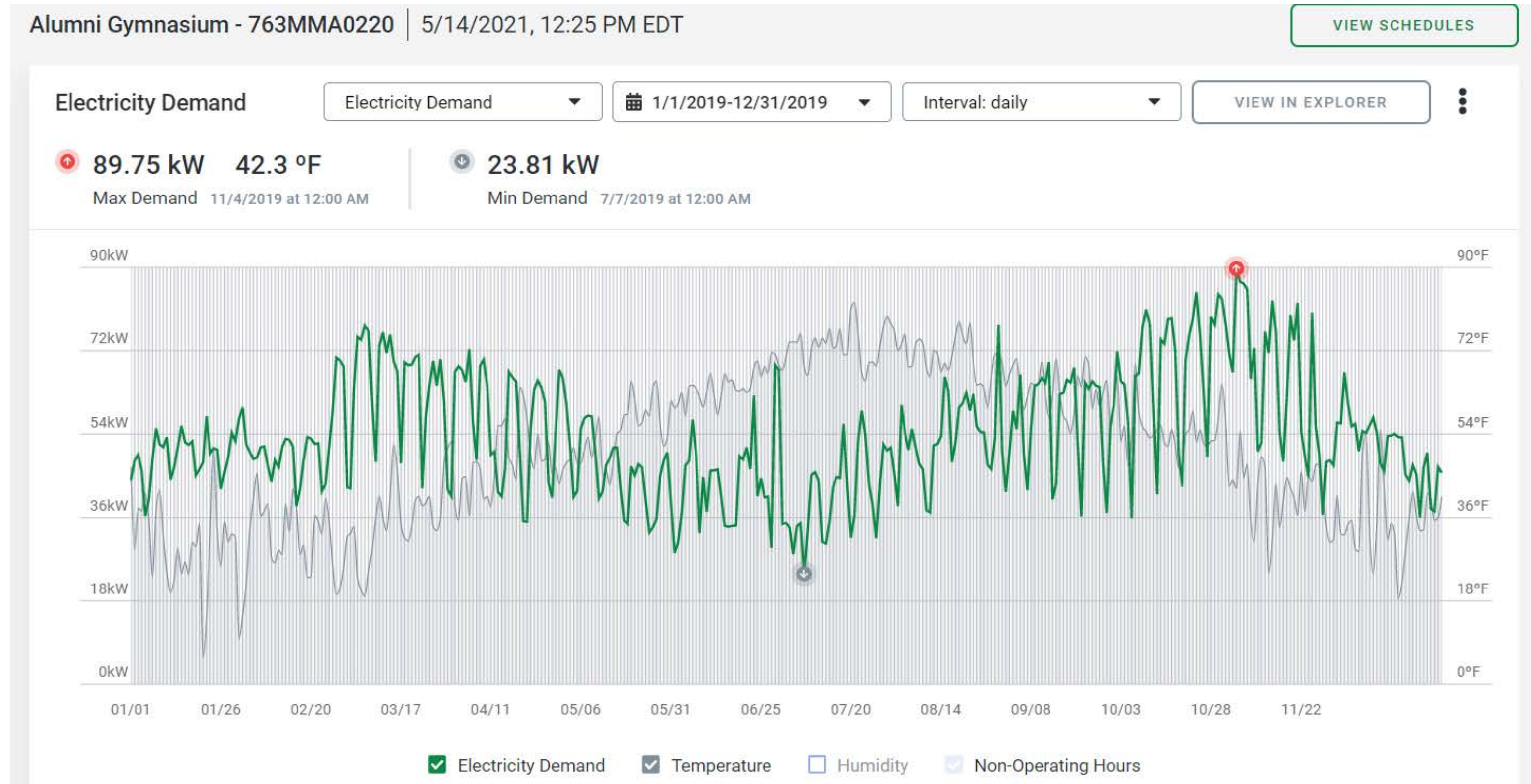
Service Account	Commodity	Invoice #	Bill Period	Building Usage	Building Demand	Building Cost	Details
5404210100 - National G...	Gas	-	12/10/19 - 1/10/20	1,243 Therm	-	$608.70	
5404210100 - National G...	Gas	-	11/7/19 - 12/10/19	2,114 Therm	-	$1,026.69	
5404210100 - National G...	Gas	-	10/9/19 - 11/7/19	982 Therm	-	$493.06	
5404210100 - National G...	Gas	-	9/11/19 - 10/9/19	304 Therm	-	$162.16	
5404210100 - National G...	Gas	540421010020190912	8/13/19 - 9/11/19	51 Therm	-	$37.74	
5404210100 - National G...	Gas	-	7/11/19 - 8/13/19	1 Therm	-	$15.00	
5404210100 - National G...	Gas	-	6/11/19 - 7/11/19	0 Therm	-	$13.00	
5404210100 - National G...	Gas	-	5/10/19 - 6/11/19	94 Therm	-	$60.00	
5404210100 - National G...	Gas	-	4/9/19 - 5/10/19	291 Therm	-	$167.00	
5404210100 - National G...	Gas	-	3/11/19 - 4/9/19	970 Therm	-	$540.00	
5404210100 - National G...	Gas	-	2/8/19 - 3/11/19	1,578 Therm	-	$871.00	
5404210100 - National G...	Gas	-	1/10/19 - 2/8/19	560 Therm	-	$317.00	
5404210100 - National G...	Gas	-	12/10/18 - 1/10/19	284 Therm	-	$168.00	



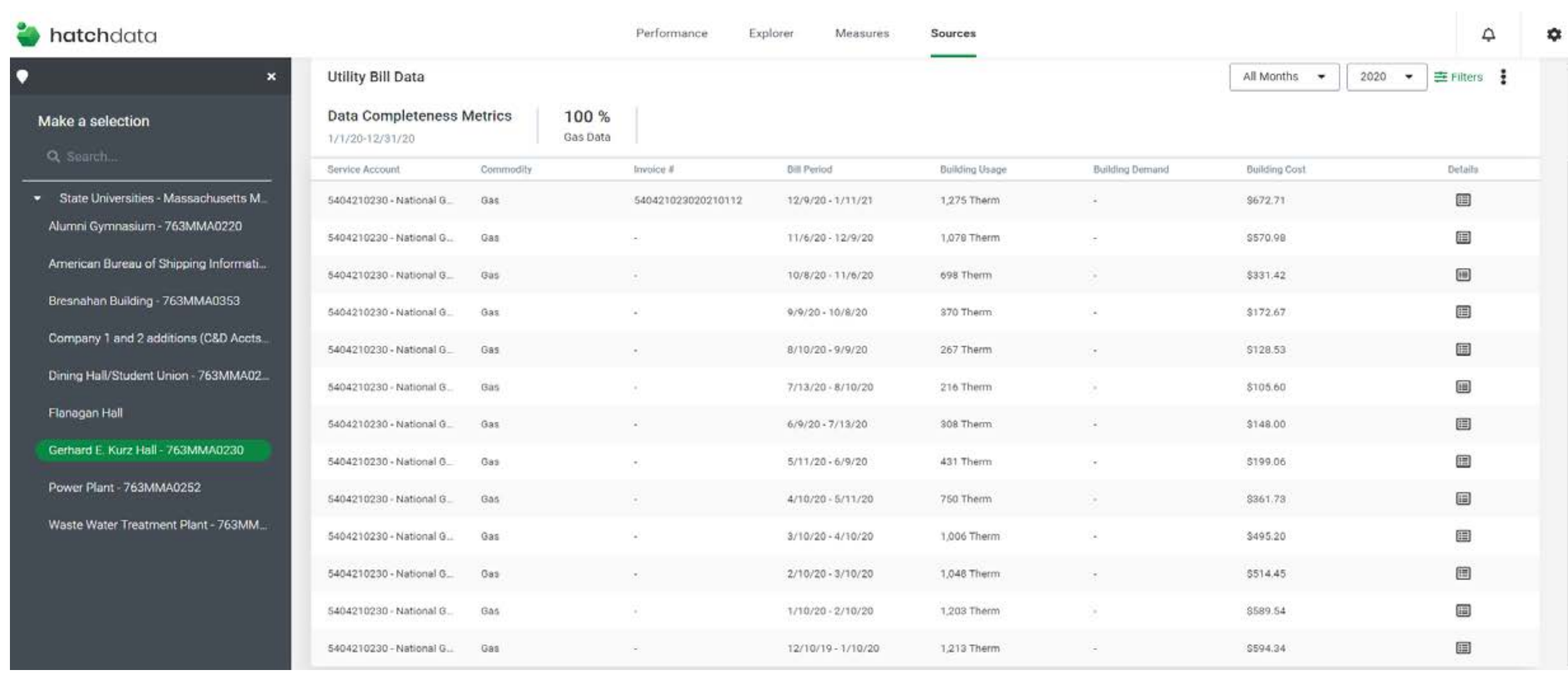
Alumni Gym


hatchdata
Performance
Explorer
Measures
Sources
Make a selection
Search...
Commonwealth of Massachusetts
State Universities - Massachusetts ...
Alumni Gymnasium - 763MMA0220
American Bureau of Shipping Informa...
Bresnahan Building - 763MMA0353
Co 6 Microturbines - 763MMA0601
Company 1 and 2 additions (C&D Acc...
Company 1 (Gray Hall) - 763MMA1000
Company 2 - 763MMA1001
Company 3 - 763MMA1002
Company 5 (Co C Acct) - 763MMA10...
Company 6 (Co D Acct) - 763MMA10...
Dining Hall/Student Union - 763MMA...
Alumni Gymnasium - 763MMA0220 | 4/21/2021, 10:31 AM EDT
VIEW SCHEDULES
Electricity Usage
Electricity Usage
1/1/2019-12/31/2019
Interval: daily
VIEW IN EXPLORER
472,823 kWh
Total Usage
50.3 °F
Average Temperature
2500kWh
2000kWh
1500kWh
1000kWh
500kWh
0kWh
90°F
72°F
54°F
36°F
18°F
0°F
01/01
01/26
02/20
03/17
04/11
05/06
05/31
06/25
07/20
08/14
09/08
10/03
10/28
11/22
Electricity Usage
Temperature
Humidity
Non-Operating Hours
Usage vs Baseline
Electricity Usage
4/15/2021-4/21/2021
Interval: hourly
No baseline to display


hatchdata
Performance
Explorer
Measures
Sources
Make a selection
Search...
State Universities - Massachusetts M...
Alumni Gymnasium - 763MMA0220
American Bureau of Shipping Informati...
Bresnahan Building - 763MMA0353
Company 1 and 2 additions (C&D Accts...
Dining Hall/Student Union - 763MMA02...
Flanagan Hall
Gerhard E. Kurz Hall - 763MMA0230
Power Plant - 763MMA0252
Waste Water Treatment Plant - 763MM...
Utility Bill Data
All Months
2019
Filters
Data Completeness Metrics
1/1/19-12/31/19
100 %
Gas Data
Service Account | Commodity | Invoice # | Bill Period | Building Usage | Building Demand | Building Cost | Details
5404211050 - National G... | Gas | - | 12/31/19 - 1/31/20 | 8,574 Therm | - | $2,816.02
5404211050 - National G... | Gas | - | 11/30/19 - 12/31/19 | 8,335 Therm | - | $2,738.41
5404211050 - National G... | Gas | - | 10/31/19 - 11/30/19 | 6,546 Therm | - | $2,156.49
5404211050 - National G... | Gas | - | 9/30/19 - 10/31/19 | 3,559 Therm | - | $1,360.61
5404211050 - National G... | Gas | - | 8/31/19 - 9/30/19 | 910 Therm | - | $370.70
5404211050 - National G... | Gas | - | 7/31/19 - 8/31/19 | 423 Therm | - | $189.95
5404211050 - National G... | Gas | - | 6/30/19 - 7/31/19 | 378 Therm | - | $173.00
5404211050 - National G... | Gas | - | 5/31/19 - 6/30/19 | 1,019 Therm | - | $411.00
5404211050 - National G... | Gas | - | 4/30/19 - 5/31/19 | 3,348 Therm | - | $1,282.00
5404211050 - National G... | Gas | - | 3/31/19 - 4/30/19 | 5,546 Therm | - | $2,083.00
5404211050 - National G... | Gas | - | 2/28/19 - 3/31/19 | 9,194 Therm | - | $3,434.00
5404211050 - National G... | Gas | - | 1/31/19 - 2/28/19 | 9,504 Therm | - | $3,545.00
5404211050 - National G... | Gas | - | 12/31/18 - 1/31/19 | 10,787 Therm | - | $4,023.00



Kurz Hall



Service Account	Commodity	Invoice #	Bill Period	Building Usage	Building Demand	Building Cost	Details
5404210230 - National G...	Gas	540421023020210112	12/9/20 - 1/11/21	1,275 Therm	-	$672.71	
5404210230 - National G...	Gas	-	11/6/20 - 12/9/20	1,078 Therm	-	$570.98	
5404210230 - National G...	Gas	-	10/8/20 - 11/6/20	698 Therm	-	$331.42	
5404210230 - National G...	Gas	-	9/9/20 - 10/8/20	370 Therm	-	$172.67	
5404210230 - National G...	Gas	-	8/10/20 - 9/9/20	267 Therm	-	$128.53	
5404210230 - National G...	Gas	-	7/13/20 - 8/10/20	216 Therm	-	$105.60	
5404210230 - National G...	Gas	-	6/9/20 - 7/13/20	308 Therm	-	$148.00	
5404210230 - National G...	Gas	-	5/11/20 - 6/9/20	431 Therm	-	$199.06	
5404210230 - National G...	Gas	-	4/10/20 - 5/11/20	750 Therm	-	$361.73	
5404210230 - National G...	Gas	-	3/10/20 - 4/10/20	1,006 Therm	-	$495.20	
5404210230 - National G...	Gas	-	2/10/20 - 3/10/20	1,048 Therm	-	$514.45	
5404210230 - National G...	Gas	-	1/10/20 - 2/10/20	1,203 Therm	-	$589.54	
5404210230 - National G...	Gas	-	12/10/19 - 1/10/20	1,213 Therm	-	$594.34	

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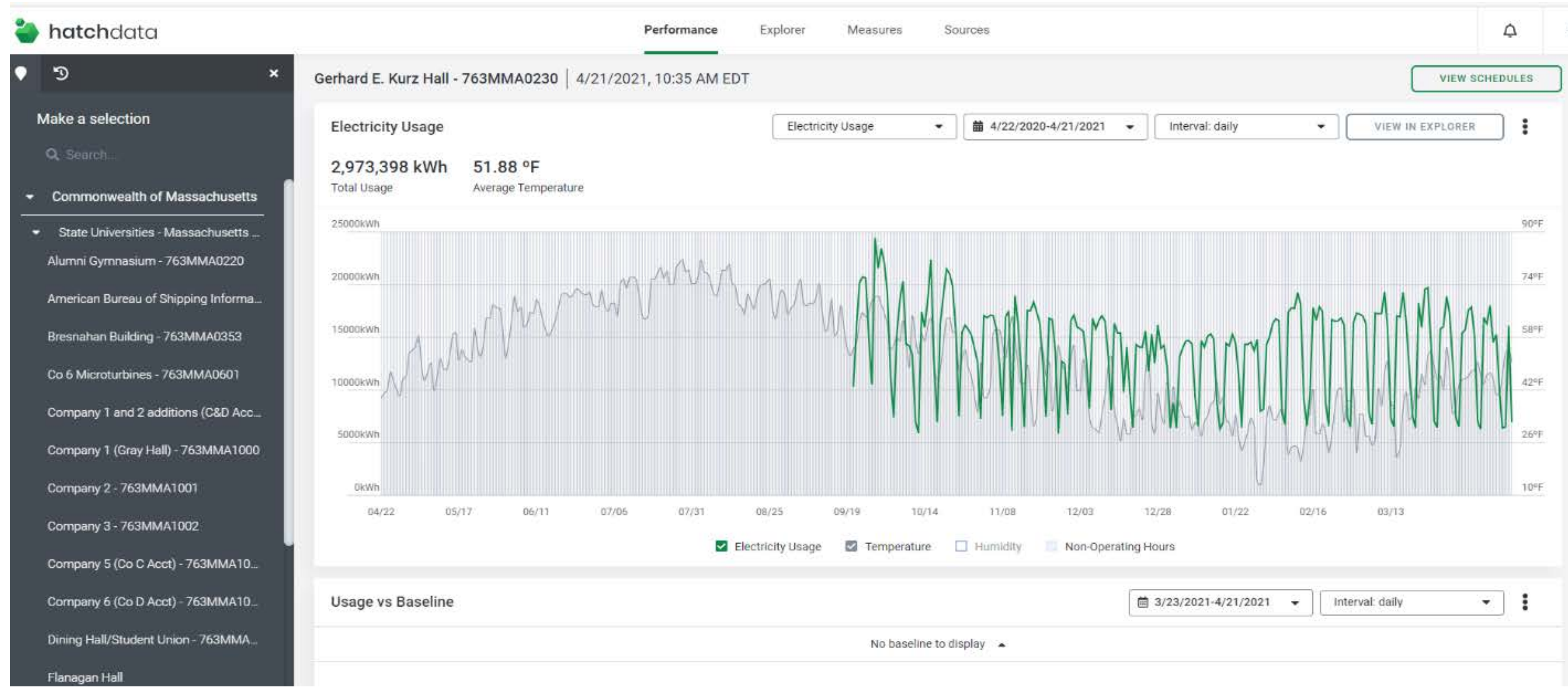
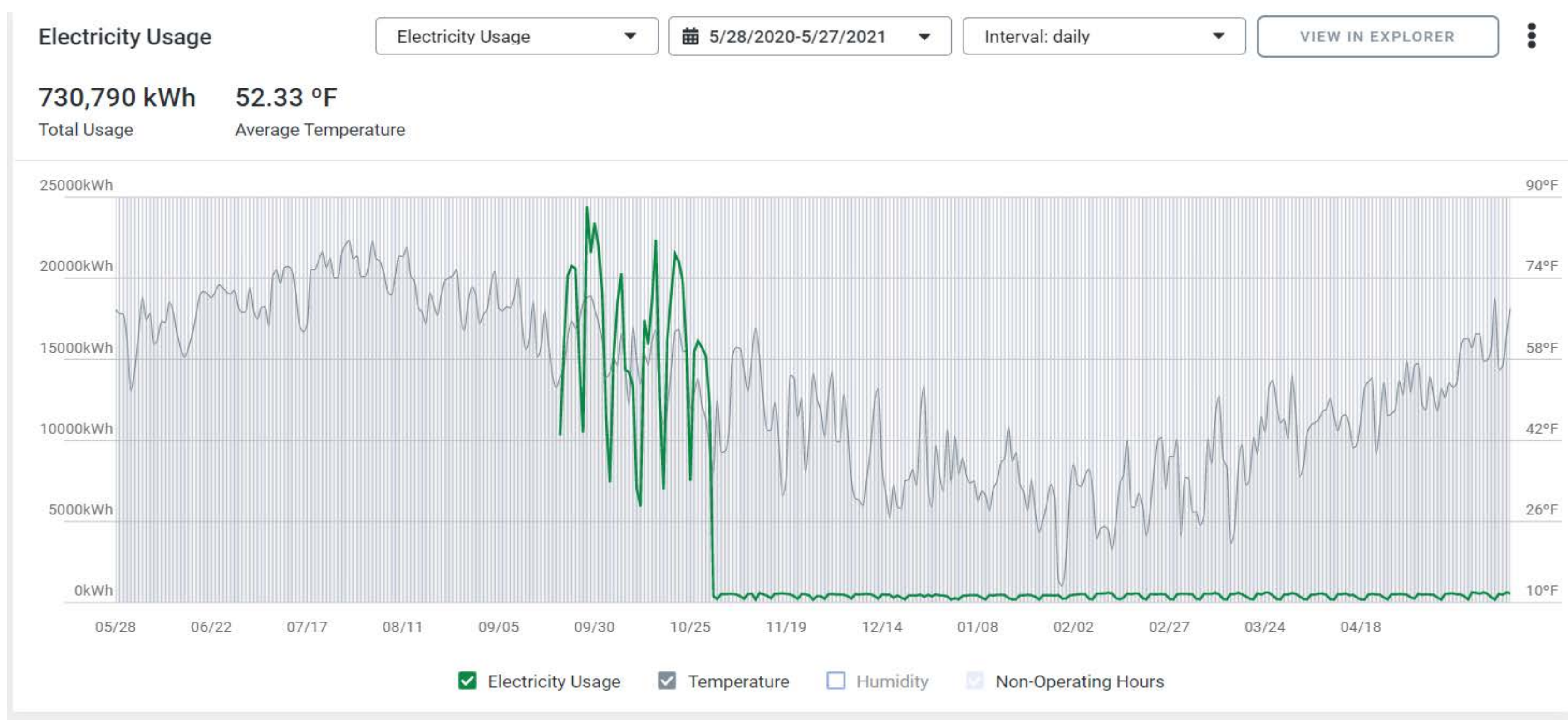
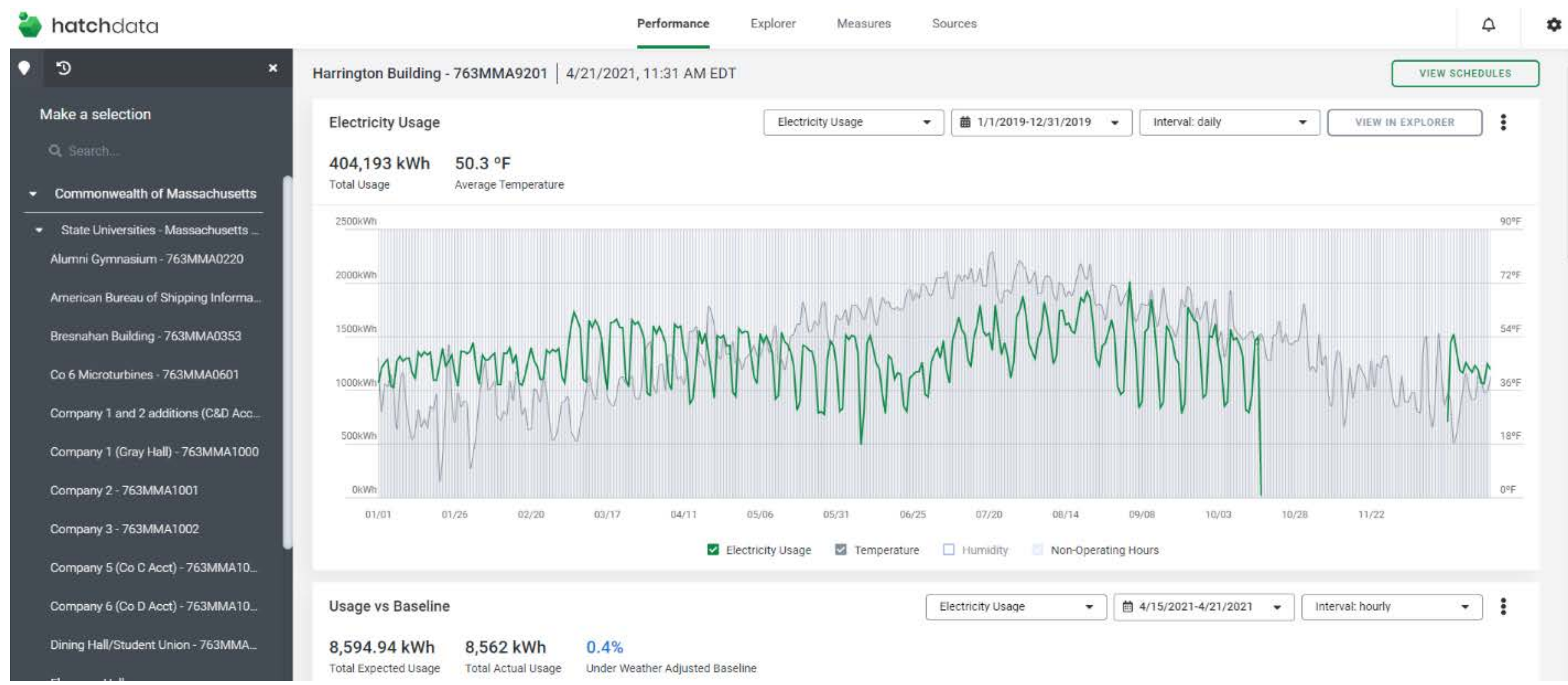
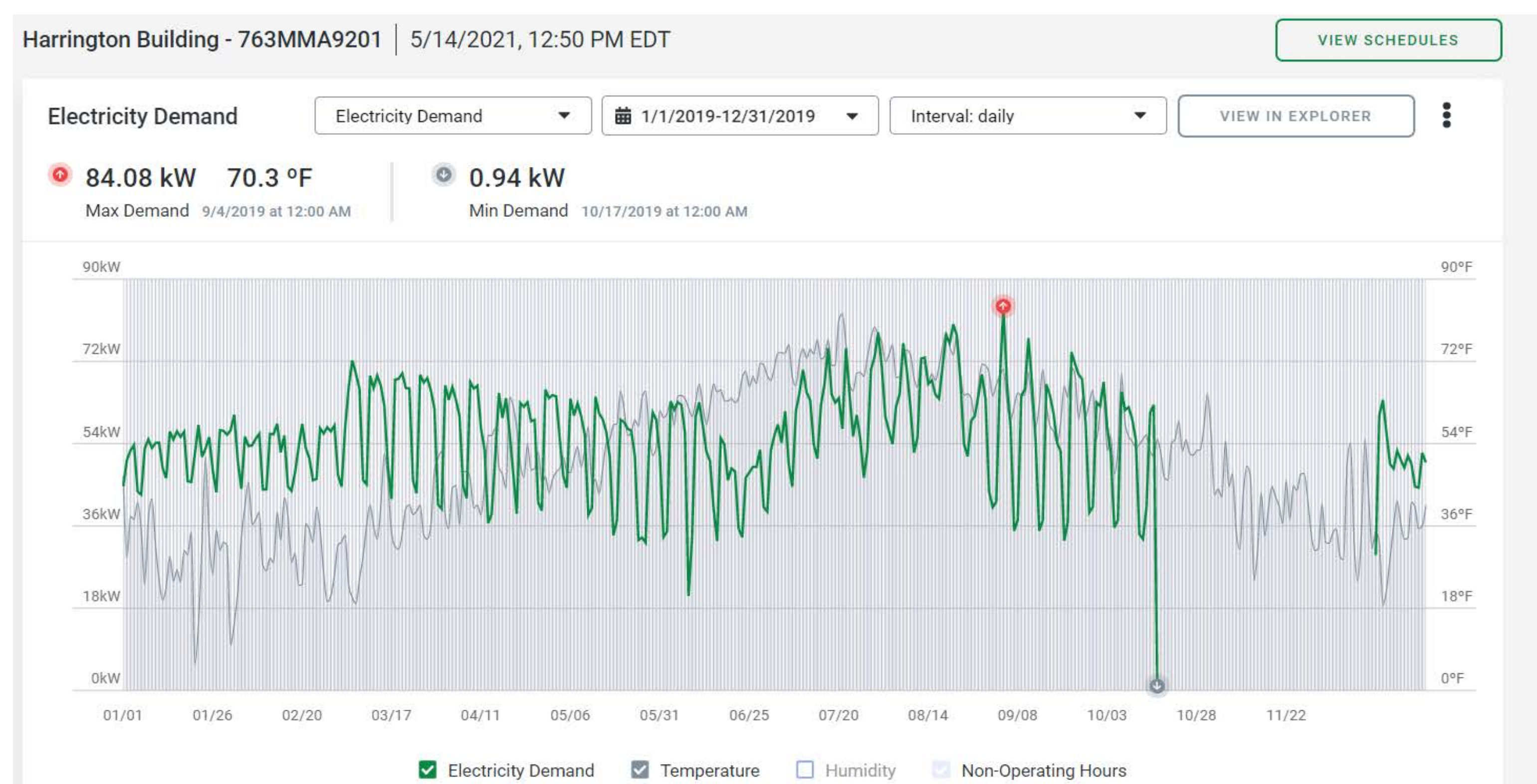


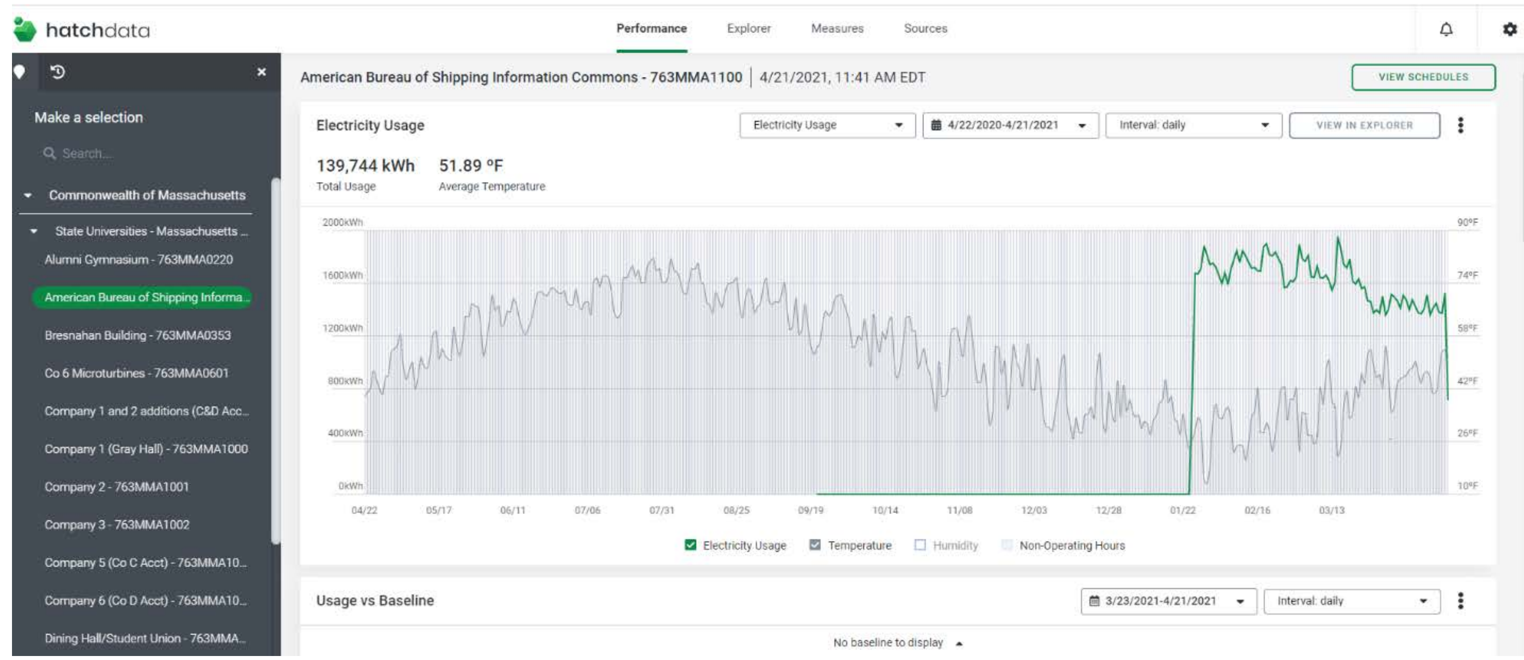


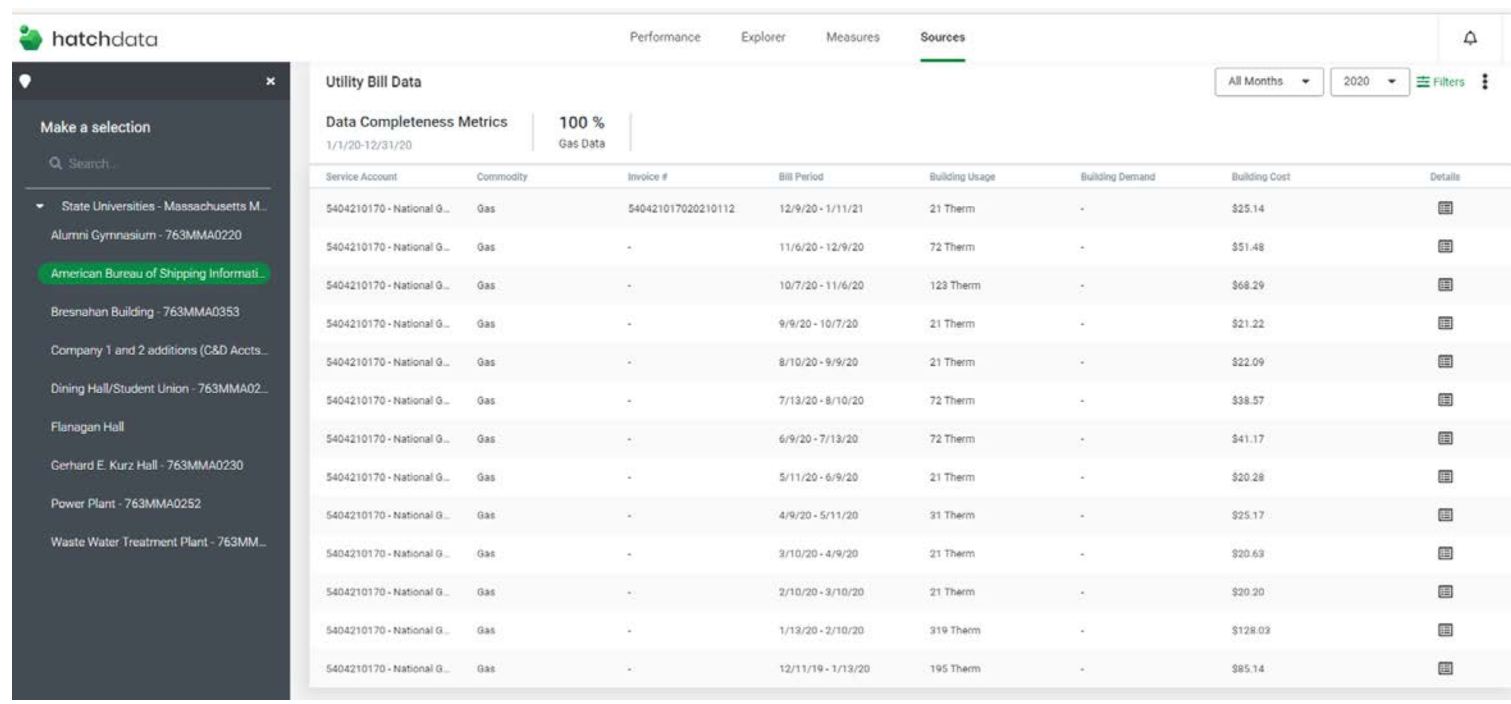
Harrington Hall





ABS Building





Service Account	Commodity	Invoice #	Bill Period	Building Usage	Building Demand	Building Cost	Details
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5404210170 - National G...	Gas	-	11/6/20 - 12/9/20	72 Therm	-	$51.48	
5404210170 - National G...	Gas	-	10/7/20 - 11/6/20	123 Therm	-	$68.29	
5404210170 - National G...	Gas	-	9/9/20 - 10/7/20	21 Therm	-	$21.22	
5404210170 - National G...	Gas	-	8/10/20 - 9/9/20	21 Therm	-	$22.09	
5404210170 - National G...	Gas	-	7/13/20 - 8/10/20	72 Therm	-	$38.57	
5404210170 - National G...	Gas	-	6/9/20 - 7/13/20	72 Therm	-	$41.17	
5404210170 - National G...	Gas	-	5/11/20 - 6/9/20	21 Therm	-	$20.28	
5404210170 - National G...	Gas	-	4/9/20 - 5/11/20	31 Therm	-	$25.17	
5404210170 - National G...	Gas	-	3/10/20 - 4/9/20	21 Therm	-	$20.63	
5404210170 - National G...	Gas	-	2/10/20 - 3/10/20	21 Therm	-	$20.20	
5404210170 - National G...	Gas	-	1/13/20 - 2/10/20	319 Therm	-	$128.03	
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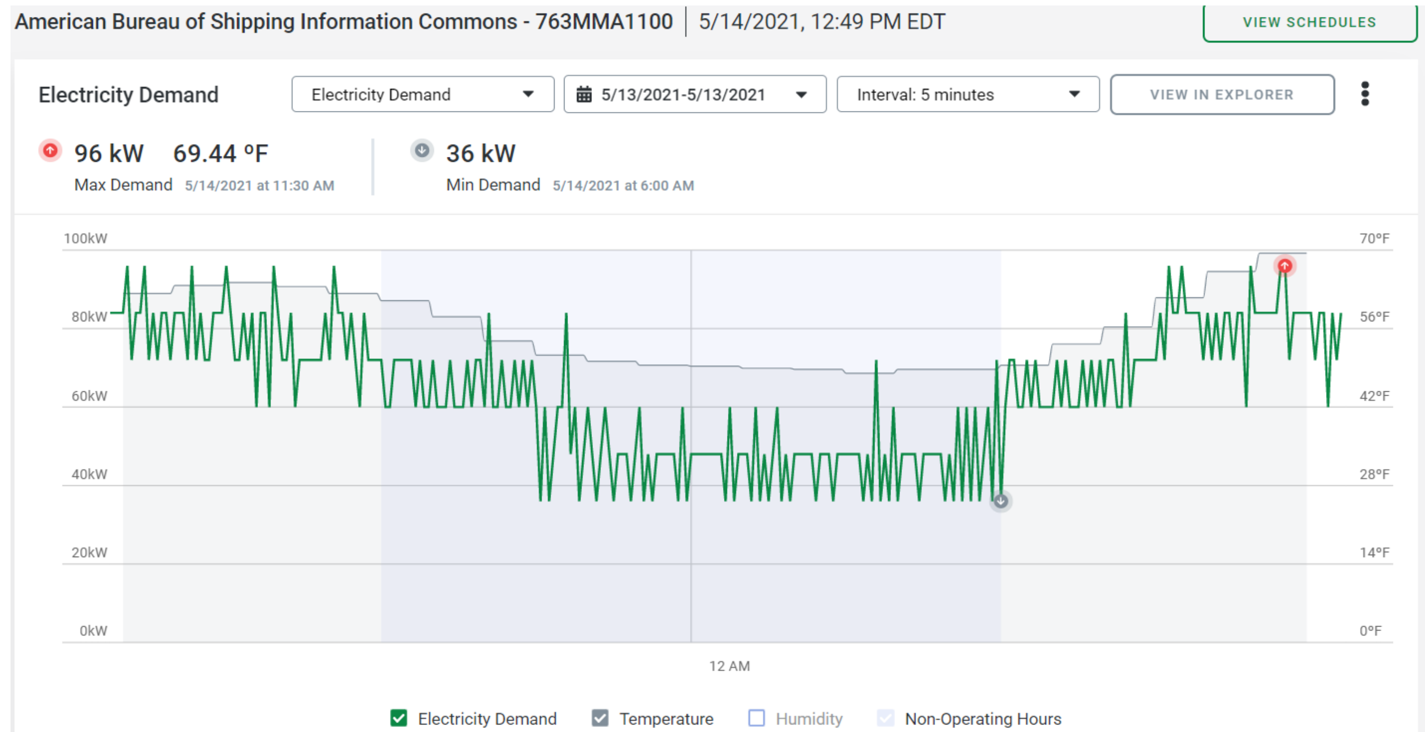
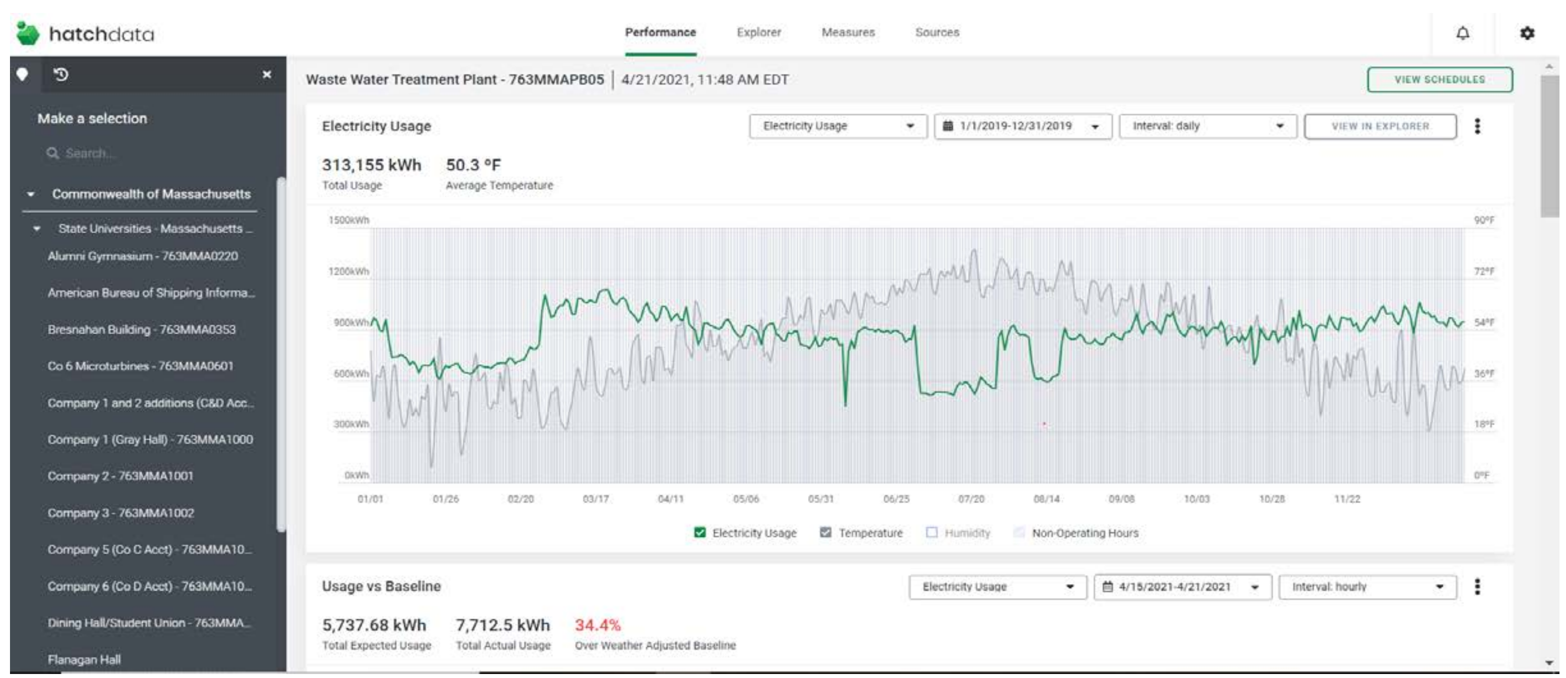
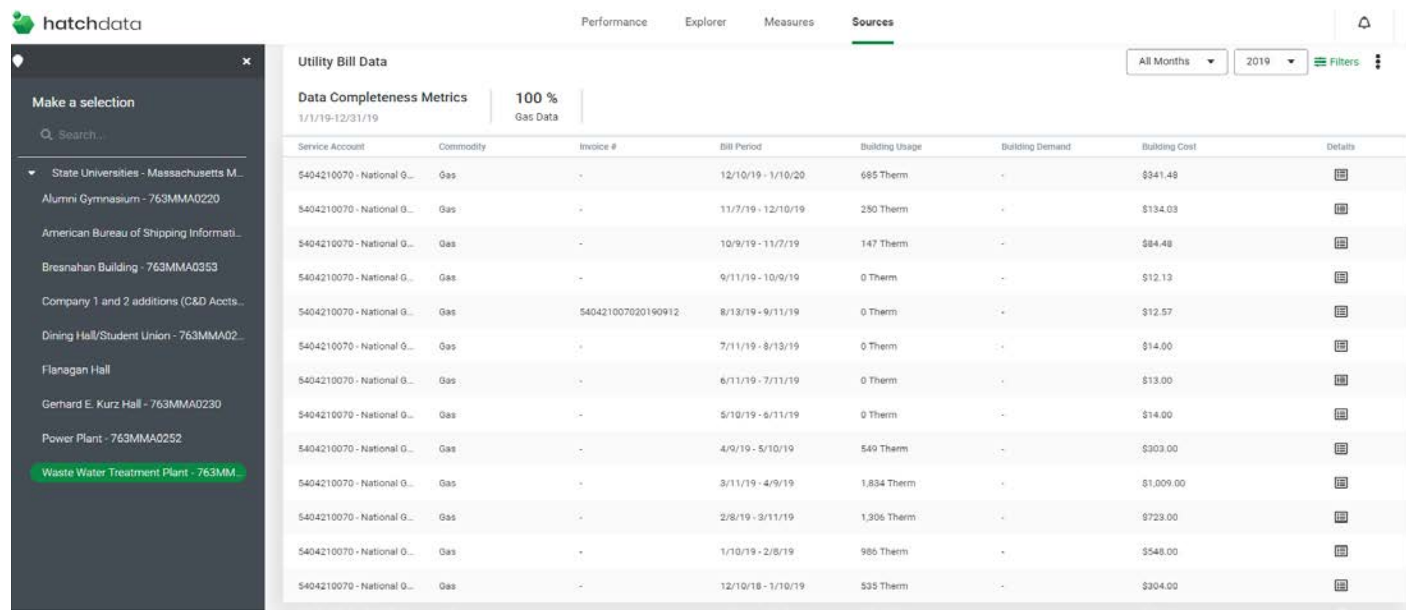


Wastewater Treatment Plant





hatchdata
Performance
Explorer
Measures
Sources
Make a selection
Search...
State Universities - Massachusetts M...
Alumni Gymnasium - 763MMA0220
American Bureau of Shipping Informati...
Bresnahan Building - 763MMA0353
Company 1 and 2 additions (C&D Accts...
Dining Hall/Student Union - 763MMA02...
Flanagan Hall
Gerhard E. Kurz Hall - 763MMA0230
Power Plant - 763MMA0252
Waste Water Treatment Plant - 763MM...
Utility Bill Data
All Months
2019
Filters
Data Completeness Metrics
1/1/19-12/31/19
100 %
Gas Data
Service Account | Commodity | Invoice # | Bill Period | Building Usage | Building Demand | Building Cost | Details
5404210070 - National G... | Gas | - | 12/10/19 - 1/10/20 | 685 Therm | - | $341.48
5404210070 - National G... | Gas | - | 11/7/19 - 12/10/19 | 250 Therm | - | $134.03
5404210070 - National G... | Gas | - | 10/9/19 - 11/7/19 | 147 Therm | - | $84.48
5404210070 - National G... | Gas | - | 9/11/19 - 10/9/19 | 0 Therm | - | $12.13
5404210070 - National G... | Gas | 540421007020190912 | 8/13/19 - 9/11/19 | 0 Therm | - | $12.57
5404210070 - National G... | Gas | - | 7/11/19 - 8/13/19 | 0 Therm | - | $14.00
5404210070 - National G... | Gas | - | 6/11/19 - 7/11/19 | 0 Therm | - | $13.00
5404210070 - National G... | Gas | - | 5/10/19 - 6/11/19 | 0 Therm | - | $14.00
5404210070 - National G... | Gas | - | 4/9/19 - 5/10/19 | 549 Therm | - | $303.00
5404210070 - National G... | Gas | - | 3/11/19 - 4/9/19 | 1,834 Therm | - | $1,009.00
5404210070 - National G... | Gas | - | 2/8/19 - 3/11/19 | 1,306 Therm | - | $723.00
5404210070 - National G... | Gas | - | 1/10/19 - 2/8/19 | 986 Therm | - | $548.00
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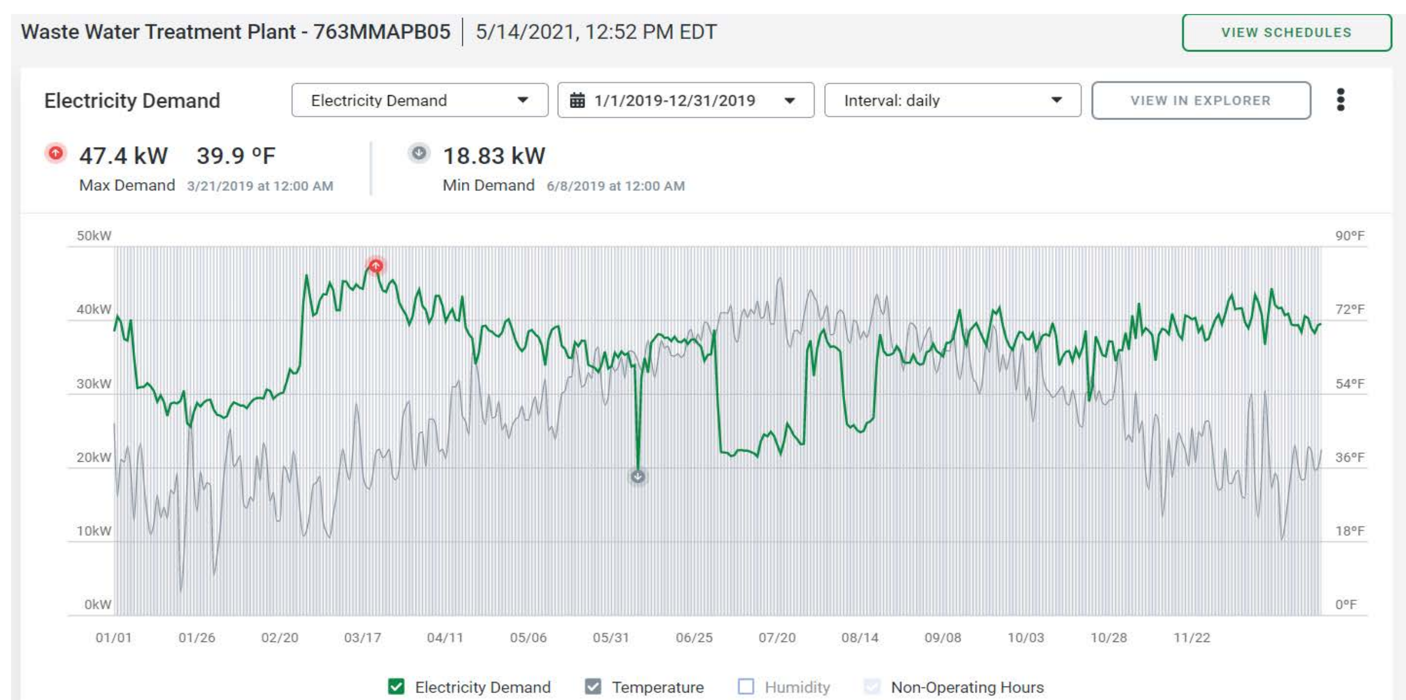

Waste Water Treatment Plant - 763MMAPB05 | 5/14/2021, 12:52 PM EDT
VIEW SCHEDULES
Electricity Demand
Electricity Demand
1/1/2019-12/31/2019
Interval: daily
VIEW IN EXPLORER
47.4 kW 39.9 °F
Max Demand 3/21/2019 at 12:00 AM
18.83 kW
Min Demand 6/8/2019 at 12:00 AM
50kW
40kW
30kW
20kW
10kW
0kW
90°F
72°F
54°F
36°F
18°F
0°F
01/01
01/26
02/20
03/17
04/11
05/06
05/31
06/25
07/20
08/14
09/08
10/03
10/28
11/22
Electricity Demand
Temperature
Humidity
Non-Operating Hours

Company 1

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APPENDIX 3

RESOURCES

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RESOURCES

- How to turn waste water into a source heat pump | ARANER
- A key review of wastewater source heat pump (WWSHP) systems - ScienceDirect
- Electricity Storage | US EPA
- https://www.energystorageexchange.org/
- https://www.pdhonline.com/
- https://www.goodmanmfg.com/resources/heating-cooling
- https://inspectapedia.com/aircond/Heat_Pump_COP.php
- https://www.engineeringtoolbox.com/heat-pump-efficiency-ratings-d_1117.html
- https://www.homeadvisor.com/r/heat-pump-vs-furnace/
- https://energyinformative.org/air-to-air-heat-pumps/
- http://rweng.com/blogpost/vrf-systems/
- https://industrialheatpumps.nl/en/how_it_works/refrigerants/
- https://www.greenmatch.co.uk/blog/
- http://www.sfu.ca/~mbahrami/ENSC%20461/Notes/Refrigeration%20Cycle.pdf
- https://www.nature.com/articles/s41893-020-0488-7/figures/1
- https://www.delcohvac.com/types-of-heat-pumps/
- https://highperformancehvac.com/heat-pump-types/
- http://siglercommercial.com/wp-content/uploads/2017/10/04-Water-Soure-Heat-Pumps.pdf
- https://www.sprsunheatpump.com/Ground-Water-Source-Heat-Pumps-pl6967826.html
- https://www.evergreenenergy.co.uk/heat-pumps/how-efficient-are-heat-pumps/

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APPENDIX 4

SITE VISIT AND
MEETING NOTES

RAW NOTES

April 30, 2021

Harrington:

1. Building about 50 years old
2. Mostly original systems – except as noted
3. Heat pump system – serves just offices in one section of the building
   a. Most of the HP's are newer (have been replaced)
   b. Individual room controls, no BMS connection
   c. Cooling Tower is reasonable shape
4. Boilers done about 7 years ago
5. Pumps rebuilt – good shape
6. HW system on OA reset schedule
   a. 0 - 60 OA
   b. 120-180 HW temp
7. Ventilation systems under control – time clock through BMS
8. Each room has its own thermostat
9. AHU systems ventilate building
10. Small amount of pneumatics left, mostly converted to local or BMS controls
11. DDC is Johnson
12. CR's have unit ventilators – mix of original and replaced units. Local control only (replaced Pneumatics with local t'stat)
    a. No set back no day/night schedule
13. Exhaust Fans are on energy management system (on at 6, off at 4:30 every day)
14. Generally people are comfortable in building – if anything too hot
15. Building needs more control over systems

NOTE – Avoid equipment on ground. Should be placed in building or on roof

Bresnahan:

1. Built in a couple of sections. Newer section in 2003.
2. Newer Classrooms – AHU with htg/cooling
3. About 70% of CR's have AC
4. Individual Mitsubishi systems – public safety, west side offices
5. Boilers fairly new – equipment in boiler room in good shape
6. Old Section (built in 60's) – radiation needs attention
7. Lab Section – just O.A. in/out
8. When addition was put on, building renovated – UV's and FCU's eliminated and 2 HRU's added on roof, kept radiation
9. All systems "work", but a mix of systems
10. Building under Metasys control
11. Some spaces have both splits and radiation

Athletic Center:

1. 12 yrs ago did new boilers and replaced some AHU's
2. More recently have done work on AHU's
3. Added AC to health services
4. Summer humidity issues – expect to be improved with work done on EF's and supply units
5. Supply and EF's under control
6. Original radiant heat
7. On Metasys
   a. Reset HW and scheduling
8. Plans to add AC? – would like, but $'s an issue
9. Interior offices need approach for adding AC

Dorms:

1. Company 1 renovation planned – adding controls and replacing FTR
   a. FTR original from 70's – maintenance issues
   b. Addition of controls to eliminate need to open windows.
2. Splits serving offices (CU's at grade)
3. EF's on roof need work
4. Fantail renovation coming
5. All companies have heat recovery ventilators serving toilets and providing make up air
6. No Ventilation in dorm rooms
   a. Desire for AC in dorm rooms? Limited summer camp humidity issues.

ABS:

1. Chilled Beams used in building – condensation issues
   a. Need to keep building sealed up and watch CHW temperature control
2. Never are able to "shut building down/set back" due to need to keep humidity under control
3. Generally building operates fairly well
4. HP's working well – units were supplied by Johnson Controls

June 10, 2021

Summary:

1. Dave: need a better handle on projected electrical usage for the ship.
   a. Allen: The new ship will be able to be used for disaster relief worker housing.
      1) Steam connection, but mostly electrical. Working through the electrical load right now. Trying to understand where we can max out the supply from shore, and working with others to determine load:
         - Opt 1: Only students, no scullery
         - Opt 2: Students out at sea
         - Opt 3: Disaster relief deployment

2. Sarah: Can you please update cost numbers and then send out the slides?
    a. Dave: Yes.
3. Sarah: In the areas with new boilers – do you know if they're running in low temp condensing mode often? How does that affect heat pump readiness?
    a. Dave: We're not sure if any other than ABS are condensing boilers. Operating temperatures would not achieve low temperatures often. Want to look at implementing more aggressive hot water recess schedules.
    b. Ed: None of the other boilers jumped out to me as condensing boilers – not designed to accept condensate. The boilers are good products, but not condensing.
4. Allen: Great. I want to make sure this is integrated into the master plan so that we can get a roadmap. I want to look down the road and see how implementation will unfold.
    a. Tamar: Definitely. Both the de-carbonization study and master plan will influence each other.
5. Dave: Is there a DCAMM or MMA stated goal of being de-carbonized by a certain date, or a target percentage by a certain date? That would influence phasing. We've asked before, but the answer wasn't clear.

June 24, 2021

This meeting was held to discuss CEI Hatch Platform Training.

1. Performance: Select MMA
    a. Baseline: 3 year average
2. Explorer
    a. Select Range
    b. Download CSV
    c. Some of the meters may have 0 readings when not working.
3. Measures
4. Sources
5. Bill Management
    a. Site and Account details
    b. Select building/meter
    c. Can download/print individual bills
6. Site and Utility data export
7. Renewables are additive at building level

August 13, 2021

1. Discussion regarding applicability of renewable technologies and fuel sources.
   a. David Madigan (van Zelm) elaborated on our analysis of sea water heat pumps and sea water temperatures.
   b. Preliminary conclusions were elaborated.
2. Considerations for campus heating and cooling systems were summarized.
   a. Central vs distributed systems were summarized.
   b. A semi distributed system is proposed.
3. Energy transfer loop operation was summarized.
   a. Energy Transfer Loop Benefits were summarized.
   b. Allen inquired about the potential layout of the loop.
   c. Dave elaborated with a slide that shows a proposed preliminary layout.
4. Discussion regarding wells:
   a. Elayne asked if the proposed STEM building can tap into Well Field 1. Dave said only a limited tap in, if at all, will be allowed.
   b. An alternate is to potentially develop a well field behind the STEM building near the water
   c. Wells for ABS Commons collapsed initially.
   d. Allen asked about estimated cost, Dave clarified that we have installed costs per well drilled. The actual total costs can be confirmed after confirming the number of wells to be installed.
   e. The effects of locating the wells on the parking lot were discussed. Dave elaborated that it is remote.
   f. Allen asked if we can we put additional wells near the field near STEM. This led to a discussion between team members on how many wells could potentially be accommodated, the condition of the soil and it's ability (or lack thereof) to incorporate wells.
5. Elayne asked about moving a portion of the loop to the practice field in lieu of the softball field since it has just been resurfaced within the last 3 years.
   a. Dave discussed 1 pipe vs 2 pipe or 4 pipe approaches.
6. The loop presents flexibility for future expansion.
   a. Which building other than STEM and ABS are able to connect? No other building. With Company 1 renovations being underway, doesn't lend itself to modification of systems. However, as Harrington is renovated, the loop could be expanded to include it. Additionally, as future Companies come online, they could be designed to accommodate

energy distribution systems that were compatible with the proposed loop infrastructure for ease of interconnection.

b. Irene asked if there were any opportunities to tie in the fan tail expansion to this. The team recommended that the peak and average loads of the expanded fan tail will have to be evaluated, however, based on the analysis done to date the additional loads would not be an issue.

7. Allen asked if the buildings would need minimal, major or medium modifications to accommodate the proposed loop

8. Potential impact of electrical loads due to the new system was discussed.

   a. Janet clarified that the Company 1 modifications are a facelift, and they might take another look at improving its energy efficiency.

9. We have to include new ship loads in this exercise since it will potentially affect the electrical loads.

   a. 200 amp, 2160 electrical feeder for ship currently.
   b. 300 kW is typical load on ship, 4160/480 v is currently installed.
   c. Currently they can deliver up to 800 kW with existing system.
   d. They currently have a small HW boiler that send 1500 lbs an hour.
   e. New training ship is 100% electric with small thermal provision as supplemental.
   f. 100 students and staff will be on the vessel 1,531 kW is needed on new ship design load.
   g. Average load will be much less.
   h. Existing system cannot provide 1500 kW to the ship.
   i. 6600V system on new ship. Switching the transfer out might be able to provide 1 MW to the ship.
   j. Another option is to put a new feeder at 6600V. This new feeder will cost $6 million.
   k. They are evaluating the feasibility of doing this.
   l. Ship will arrive in January 2024. 10 MMBTU/hr HX is being put on the ship.
   m. Existing boilers can provide approximately 50% of the requirement.
   n. Other option needs a completely new steam boiler but this is lot more complicated.

10. Dave tried to confirm that the ship doesn't have to be in the carbon neutral analysis. Paul asked when the anticipated future electrical load analysis will be completed. Dave replied that it was currently under progress and would be completed shortly.

   a. The most that they could do is a power purchase agreement.
   b. New feeder looks like the only feasible option; the $6 million fee also includes new electrical equipment.

c. Will this new feeder be tied into the existing new feeder?

d. van Zelm is progressing with its analysis of HVAC and electrical loads to meet the campus' future needs to incorporate into the carbon neutrality study. The quantity and preliminary sizing of geothermal wells is also being undertaken.

November 18, 2021 - WS#6 Presentation

1. Allen – Carbon emissions. 2032 decrease, does that include bringing on geothermal?
   a. Dave: Phasing diagram that we developed with Sasaki captures these elements and assigns a year to them. In 2032 is when we would develop second phase of wellfield. Hoping for an enabling project in association with STEM and first wellfield and loop, and first 10 years of building. After 10 years, we outrun capacity of enabling project, and need to develop a second wellfield.
2. Janet – Does this also account for domestic hot water conversion?
   a. Dave: Yes, all energy on campus, includes Beachmoor which we assume comes online in 2 years. Energy use of Beachmoor included.
3. Fran – if MA 2/3 of electric production is gas, aren't we hedging our bets that this number changes as well? If we convert to electric, won't it still be fossil fields?
   a. Dave: Most recent data from ISO New England (run grid in NE) – a couple of years ago 2/3 of production was gas. Right now, natural gas is about 50%, nuclear is between 20-30%, hydro is 10%, renewables are about 8%. But those numbers have been increasing over last 10 years. Renewables have gone up, fossil fuels have been eliminated, gas is now coming down. Many other states use a lot of gas and fossil fuels, but NE is a very clean grid, will continue to get cleaner. Benefit day 1 of going to electric. Not reflected in our documents, but likely to get cleaner. Our assumption in these graphs is that it will stay the same, but in reality, it will just get cleaner.
   b. Fran: Oncoming offshore wind, would be awesome if grid put out projection that lined up with some of these milestones. Would be awesome if renewables passed 50%.
   c. Betsy: We have commitments and contracts in place for offshore wind
   d. Dave: This is a conservative picture, we could include the projections
   e. Kathy Driscoll: ISO NE has a CELT forecast that provides what the energy mix is expected to be based on forward capacity market
4. Fran: PV – looked like 1.5 Megawatts of energy on campus – if array on ABS is rated at 100 kW, this would mean we need 15 of those arrays on campus. Does the rest of campus roof get us there? Does ABS actually get to 100kW?
   a. Dave: Maximum potential is 1.2 Megawatts. Would require all roofs to be maxed out with PV. Development assumes there would be upgrades to buildings that would remove less efficient air handling equipment, replace with heat pumps and indoor equipment. It's

aggressive, represents a maximum. We didn't include canopy because of neighbors, but that is something that could change over time. It's gaining acceptance.

   b. Jon: Assume 60-80% of roof area depending on building, what equipment we think would be needed.

   c. Dave: PV efficiency in terms of output per square foot has also been increasing. 18 – 21%.

5. Paul: Idea of system efficiency. We have a 90% efficient gas boiler on campus. We trade for a 30% efficient electron coming from power plant. Is heat pump 300% efficient?

   a. Dave: Yes, the way that is most apparent is cost. Electricity costs 5x natural gas, because electricity is coming from natural gas. Efficiency has gone up, combined cycle of gas power plants are going up. As hydro/nuclear/renewables increase, efficiency goes up.

   b. Dave: Heat pumps vary substantially. Heat pump serving combination heating and cooling application is somewhere in the coefficient of performance (COP) of 3 – 4, or 300-400% efficient. Efficiency has to do with lift. Ground source heat pump, if we keep loop temp at good level, we can bump efficiencies pretty dramatically. With offset loads (one building needs cooling, one needs heating), this becomes even more efficient. Heat pump technology is developing, not only in tech but also in how they are applied. Seen annual COP as high as 6.

   c. Jon: We assumed COP of 4 year round

   d. Tamar: Our Covetool modeling showed heating 4.2, cooling 6.3.

   e. Dave: Using minimum outside air for ventilation, can generate a cooling load. Combination of cooling and heating load can get COP in range of 7 or 8. Moving toward there in the industry, but requires investment in building systems to go along with heat pump systems.

6. Brian Cherry: It sounds like outside air is only being used for ventilation

   a. Dave: ABS represents a good example of what we are proposing. Represents consistency among campus system.

7. Brian Cherry: Domestic hot water, lower temps that you can operate at – often hot water isn't used in the same room it's made in. What does that system look like as far as loop/no loop? Are we on demand for domestic hot water? Low flow often leads to less usage of sinks, clogged discharge lines. How does domestic hot water system in 10 years look in this model?

   a. Dave: Good question. There is an evolution in the way we are dealing with domestic hot water. Domestic hot water historically done with natural gas or electric. Natural gas domestic hot water heaters are efficient. If we use a heat pump for dom hot water, COPs of 3, 4, or higher because often entering domestic hot water is pretty low (50,60 degrees). Domestic hot water load with heat pump, as well as building heating. Storage of hot water has to be at 135 degrees or greater.

   b. Dave: Alternative, which we would propose for companies – use dedicated heat pumps for domestic hot water (running off same campus loop). Which would include storage.

Coming on the market now. Buildings like Harrington or Kurz, electric point of use hot water for lavatories is a good solution, doesn't involve a lot of loss.

8. Allen – We talked about this being a model for the Commonwealth. Is that still on the table?
   a. Betsy: Yes, we are considering it to be a demonstration project.
9. Janet: What does $11 million mean on proposed enabling project?
   b. Dave: Base case requires more than twice as many wells, so twice as costly. To achieve loads associated with $5.8m project, you have to spend twice as much.
10. Allen: where is phase 2 well field?
    a. Dave: This is a big topic of conversation. Initially talked to practice field, but resilience tells us that is prime real estate for a building even 20-30 years from now. Downside of softball field: remote, diamond has just been redone. But cost of resurfacing the diamond is not that big when spending $5.8m on wellfield. Not quite as proximate to STEM, but if infrastructure project includes loop, it doesn't matter where the field is. Second phase would potentially be baseball field, parking lot, football field. With loop, well field can go anywhere.
    b. Allen – resurfacing cost to practice or football field would add another 0.
    c. Dave: We would only consider baseball field during phase 2, which would be around when resurfacing would have to happen anyway. Similar to logic with PV. PV installation should happen: When building is renovated, when roof needs to get replaced.
11. Fran: Need some time to digest this, look at assumptions. Up front capital, a big chunk of that is bonded. Does that include NPV, debt service? I find it wonderfully amazing that you project $20m over 30 years, but I'd want to get into the nuts and bolts. Support for up front costs makes it possible, otherwise it's a showstopper. Don't want to put this on backs of students.
    a. Betsy: No debt service on infrastructure portion. Borrowing would be on part of funding that has energy payback, paid back through savings over established timer period.
    b. Fran: That would be awesome. That's important to know.
    c. Dave: We think we're painting a relatively conservative picture. We're trying to portray that investments in building allows for these cost savings. But if you can't get the money up front, makes it difficult. Not including the maintenance savings, capital renewal costs. Can justify upgrades based on energy cost, but you get a win-win.
12. Fran: Looking at costs of wellfields, has there been any opportunity to look at heat sink of Cape Cod Canal?
    a. Dave: Yes, we discussed that in one of the earlier presentations. Loop temperature needs to be balanced in wellfields. If too much imbalance, wellfield performance can degrade – the key to avoiding this is balancing the campus heating and cooling loads as much as possible. Seawater heat exchanger represents a good, efficient way of heating or cooling loop. We did some analysis of water temps in Cape Cod Canal over 10 year period. Average temperatures are pretty good, would support beneficial interface with energy

loop. However, when looking at lowest temps, it's too cold to satisfy heating requirements. 20 years from now, it's possible we won't see those lows anymore. Would have to be part of phase 2. Wellfield imbalance becomes greater after 10 years because companies we are assuming are not air conditioned – imbalance on heating side. Seawater or wastewater would be good during phase 2.

b. Dave: Tidal energy has great potential in Cape Cod Canal as well – tidal energy research org up the canal. But not something that should be developed by MMA unless you get research dollars allocated. Better developed by separate developer.

13. Allen: Flanagan was not on our PV list since it's a historic building.
    a. Dave: PV list is probably a little aggressive, I agree that roof probably wouldn't be a good candidate.
    b. Tamar: Facing Canal would be possible
14. Fran: Any additional wind, vertical access?
    a. Dave: We looked at that, wind in your location is good. A second wind turbine on campus is supported, but main thing is permitting.
    b. Paul: Wind turbine would be politically difficult
    c. Tamar: If Academy pushes for one thing against neighbors, would be solar canopy over parking lot. Combine with geothermal, resurface after? Big ask because of neighborhood, but would be more realistic than additional turbine.
    d. Fran: Would be an interesting solution, lot needs to be resurfaced anyway.
    e. Allen: Along Buccaneer Way, putting a canopy up there, Worried about sports balls. Could be a way to address that fight.
15. Paul: Upcoming training ship not getting enough notice in this plan in terms of electric consumption. It's a totally electric ship, so we can provide heating and cooling electrically. Have to take a look at supplementing heat with upgrades to existing steam plant on shore, trying to convert to hot water system. Could heat pumps provide 180F hot water to ships?
    a. Dave: Heat pump technology development is progressing. Potential addition to air source heat pump to loop is a 2-stage heat pump. We don't want to run glycol in our loop.
        1) Note: Paul specified mentioned 180F hot water, which is above what currently available heat pumps can do in a single stage. The typical maximum hot water output is ~140F. This is do to the "lift" mentioned earlier, which is the difference between the source temperature (ambient air or ground) and the working fluid (hot water supply). It is possible to add a second stage to increase the maximum hot water temperature, but this requires a more detailed review of the specific ship support system. An alternative is running a lower water temperature in the ship.
    b. Paul: Perhaps a later stage project once we have experience heating the ship?
    c. Dave: Certainly possible, would have to look at loads

16. Dave: Last formal presentation, still putting together report, tweaking numbers. Presented numbers are good, fair model, but we are happy to take feedback on model, assumptions, and adjust model accordingly. Happy to address comments or information.
17. Paul: cogeneration in companies. Did you note the microturbine consumption? Footnote on slide?
    a. Dave: It took us quite a bit of time to determine how much gas is going to turbines, heating, domestic hot water. Company plant also serves some of the loads in Pande. A lot of complexity. We had to make some assumptions. I agree we can footnote it.
18. Fran: Timing of decarbonization with master plan, administration funding, all very interesting and we are grateful.
19. Tamar: We have been inspired to see the education model of MMA, seeing how the campus can be a teaching tool, a place for innovation. We think this could make such a good pilot for DCAMM as a demonstration.
20. Betsy: We are figuring out funding, project plan. Will be in touch to talk about details.
21. Elayne: Also thinking about timing so STEM project can dovetail into this.
22. Irene: Please submit comments after Thanksgiving holiday, will be folded into final report.

\- END -

Appendix 4b

COST ESTIMATES

Appendices

MMA - Enabling Phase 1 (Energy Loop & Wells)				
Based on:				
Supporting the first 10 years of development				
Building conversions with energy retrofits (reaching 25th percentile)				
Limited surface restoration allowance				
Pump Plants - Elevated within a building				
Branch piping brought to buildings, but not connected				
Phase 1 - Enabling				
Energy Loop (10" HDPE)	3,000	lf	$ 150	$ 450,000
Dewatering Allowance (Loop)	1	ls	$ 100,000	$ 100,000
Well Field (softball field)	170	ea	$ 20,000	$ 3,400,000
Well Field Pump Plant (in Bresnehan)	1	ls	$ 50,000	$ 50,000
Softball Field Restoration Allowance	1	ls	$ 120,000	$ 120,000
Energy Loop Pump Plant (in STEM Bld)	1	ls	$ 50,000	$ 50,000
Controls	1	ls	$ 25,000	$ 25,000
Branch piping to buildings (4" HDPE)				
Athletic	800	lf	$ 100	$ 80,000
Harrington	140	lf	$ 100	$ 14,000
Power Plant	240	lf	$ 100	$ 24,000
STEM	220	lf	$ 100	$ 22,000
Bresnehan	475	lf	$ 100	$ 47,500
Connect into ABS Commons Well Field	400	lf	$ 100	$ 40,000
Dewatering Allowance (Branch)	1	ls	$ 50,000	$ 50,000
Surface Restoration Allowance (Branch)	2275	lf	$ 50	$ 113,750
Sub Total:				**$ 4,586,250**
General Conditions/GC Markup			15%	$ 687,938
Contingency			10%	$ 527,419
TOTAL:				**$ 5,801,606**
		For Base Case		$ 11,023,052

Phase 2 - Well Field Buildout				
Based on Building conversions with energy retrofits (reaching 25th percentile)				
Well Field	172	ea	$ 20,000	$ 3,440,000
Well Field Pump Plant	1	ls	$ 50,000	$ 50,000
Well Field Restoration	1	ls	$ 150,000	$ 150,000
Branch piping to buildings (4" HDPE)				
Company 8	400	lf	$ 100	$ 40,000
Pande Dining	200	lf	$ 100	$ 20,000
Companies 1-7	400	lf	$ 100	$ 40,000
Kurtz	100	lf	$ 100	$ 10,000
Flannigan	600	lf	$ 100	$ 60,000
Dewatering Allowance (Branch)	1	ls	$ 50,000	$ 50,000
Surface Restoration Allowance (Branch)	2275	lf	$ 50	$ 113,750
Sub Total:				**$ 3,973,750**
General Conditions/GC Markup			15%	$ 596,063
Contingency			10%	$ 456,981
TOTAL:				**$ 5,026,794**
		For Base Case		$ 9,550,908

Year	Project	Base Case	Best Case
2021	Company 1 Renovations (as currently planned)	$ -	$ -
2022	Company 2 Renovations (as currently planned)	$ -	$ -
	Year 1 ECM Retrofits*		$ 135,885
2023	Company 3 renovations†	$ 831,000	$ 1,939,000
	Year 2 ECM Retrofits*	$ -	$ 135,885
	Fantail Expansion (as currently planned)		
	Beachmoor completed		
2024	Company 4 renovations†	$ 831,000	$ 1,939,000
	Year 3 ECM Retrofits*		$ 135,885
2025	Phase 1 Campus Loop and Wells	$ 11,021,900	$ 5,801,000
	Company 5 Renovations†	$ 831,000	$ 1,939,000
	Year 4 of ECM Retrofits*		$ 135,885
2026	Company 6 Renovations†	$ 831,000	$ 1,939,000
	STEM Building		
	Harrington Program renovations		
2027	Harrington Energy upgrades† / Heat Pump plant	$ 1,887,500	$ 4,530,000
2028	Alumni Gym Addition	$ -	$ -
2029	Alumni Gym Energy Upgrades† / Heat Pump plant	$ 2,000,000	$ 4,800,000
	Power Plant renovations† / Heat Pump plant		
2030	Company 8 complete (not tied into HP loop yet)		
2032	Pande Dining Energy Upgrades†	$ 612,500	$ 1,470,000
	Phase 2 of well construction or alternative source	$ 9,551,300	$ 5,027,000
	Campus Electrical service upgrade for BAU option	$ 750,000	
2033	Company 1 & 2 deep energy retrofits† and Heat Pump plant	$ 3,287,000	$ 5,740,305
	Bresnahan Hall Renovations/expansion		$ 1,080,000
2034	Bresnahan Hall Energy upgrades† /Heat Pump plant	$ 270,000	$ 144,000
2035	Flanagan hall energy upgrades† / Heat Pump plant	$ 200,000	$ 480,000
2036	Kurz Hall Energy upgrades† / Heat Pump plant	$ 670,000	$ 1,608,000
*	Energy Conservation Measures (Short term): RCx, Control Optimization, DCV, Lighting		
†	Building Renovations / Energy Efficiency Upgrades (Long Term): Full building renovations including upgrades to building envelope (insulation, windows, air sealing, etc) and major mechanical systems upgrades		

Appendix 5

RESILIENCE

STRATEGIES

Date	September 2021
Project Name	MMA De-carbonization Study
Project No.	SA#08198.01 // DCAMM#2101
Subject	Tasks 3.3 - 3.5: Resilience Strategies

Tasks 3.3 - 3.5: Resilience strategies

As a coastal campus, MMA is vulnerable to the long-term impacts of climate change. For the master plan and de-carbonization study, Sasaki researched building- and campus-scale strategies that ensure critical campus programs and infrastructure are protected from flooding.

TASK 3.5 BUILDING FLOOD RESILIENCE STRATEGIES

At the building scale, Sasaki researched floodproofing strategies that can be implemented on new and renovated building projects.

DRY FLOODPROOFING

Dry floodproofing strategies are the preferred method for keeping structures dry during flood events without the need for wet floodproofing measures. The most effective dry floodproofing strategy is elevating the first floor above the base flood elevation level. Temporary dry floodproofing measures include deployable flood barriers, or shields for doors, garages, and windows. Temporary barriers are effective for existing, vulnerable structures that cannot be` retrofitted or relocated. Dry floodproofing should be undertaken for all new construction to protect the asset from future floods.

WET FLOODPROOFING

Wet floodproofing strategies include measures that minimize damage to areas below the flood protection of a structure that is intentionally allowed to flood. These strategies help mitigate damage during the flood event, as well as the time it takes for flood water to recede. Wet floodproofing is a recommended strategy for MMA buildings that can accommodate floodable uses on the first floor, however it should be noted that wet floodproofing requires detailed planning to move furnishing and equipment out as well as to allow time for clean following a flooding event. Spaces that are wet flood proofed still require considerable cleanup following a flood event. Floodwaters often carry sediment, debris, and corrosive or hazardous materials; cleanup can still be extensive and include disinfecting and decontaminating surfaces. For these reasons, dry floodproofing where possible is the preferred strategy.

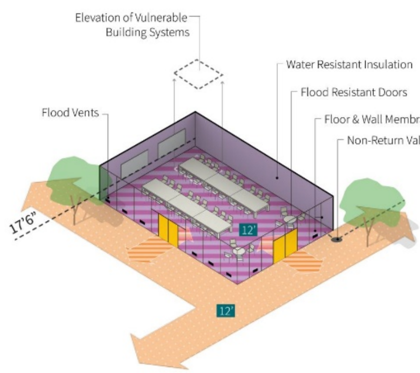
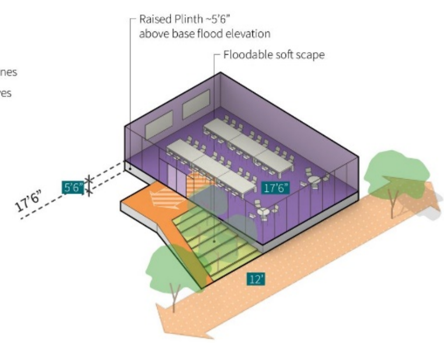
Wet floodproofing strategies include:

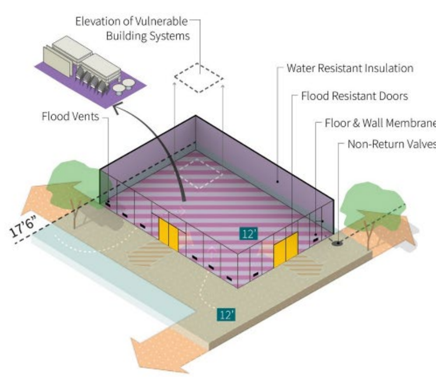
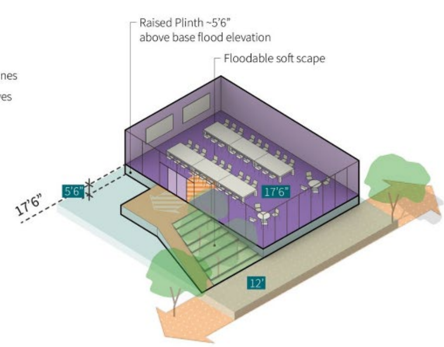
- Elevating vulnerable building systems above base flood elevation
- Water evacuation and management – methods like drain and sump pumps, non-return valves, and flood vents

- Using water-resistant material like floor and wall membranes, water resistant insulation, and flood resistant doors and windows. These materials will not rot or mold if exposted to flooding, and help preserve structures that remain water-logged.

Wet and dry floodproofing strategies can be compared graphically in the table below.

<table>
<tr><th></th><th>Wet Floodproofing</th><th>Dry Floodproofing</th></tr>
<tr><td>In dry weather, wet floodproofed buildings can accommodate programs that can be easily elevated given a flooding event. Vulnerable building systems should be elevated.

Dry floodproofed buildings have an elevated first floor above BFE, allowing for floodable uses on the first floor. Floodable softscape strategies are recommended.</td><td>
</td><td>
</td></tr>
<tr><td>In flooding conditions, programs in wet floodproofed building can be elevated; this requires careful planning prior to a flooding event. Water resistant insulation, doors, walls, and floors allow for a quicker recovery following a flooding event. Non-return valves and flood vents allow water to quickly dissipate.

In the same conditions, a dry floodproofed building is elevated above the flood level.</td><td>
</td><td>
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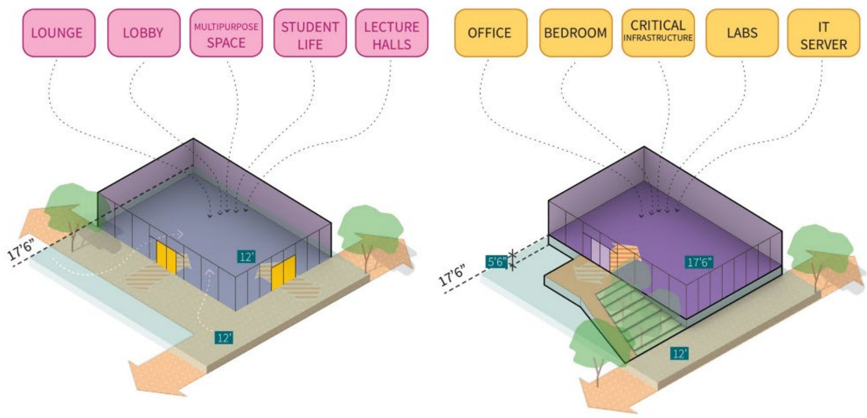
</table>

Dry floodproofed buildings can accommodate first floor uses that are more critical to the day-to-day function of the campus or would be a high cost to replace if damaged.

In wet floodproofed buildings, it is recommended that first floor uses include flexible spaces that will not cause major program disruption if temporarily taken offline after a flood event. As noted above, wet flood proofed spaces still require considerable clean up and investment following a flood.



TASK 3.3 CAMPUS-LEVEL FLOOD RESILIENCE STRATEGIES

At the campus scale, flood resilience strategies consider which programs might relocate from vulnerable areas, where equipment should be elevated, and whether to consider permanent barriers like berms and site walls. The de-carbonization study and master plan do not recommend the use of permanent barriers as these strategies were not found to be a cost-effective solution for protecting the campus from floods. The diagram below identifies vulnerable critical first-floor uses that should be elevated or otherwise relocated.

LANDSCAPE STRATEGIES AND MATERIALS

Reinforcement of the landscape edge is recommended to enhance the natural protection offered by flood-tolerant softscape. Restoration landscape buffers for flood resilience include native trees, shrubs, and herbaceous perennials that are adapted to localized storm surge, wind, and salt conditions. To protect from erosion, it is recommended to promote sand fencing dune nourishment in natural areas with more space, and to reinforce susceptible softscape edges with erosion-preventative natural coir blankets and rolls.

- Softscape materials:
  - Planting palette includes grasses like *Ammophilia breviligulata, Juncus gerardii,* and *Schizachyrium scoparium,* Herbaceus perennials like *Amsonia hubrichtii, Achillea x, Rudbeckia fulgida,* and *Echinacea purpurea* Trees and shrubs like *Juniperus virginiana, Pinus rigida Quercus alba, and Prunus serotine.*

    - Along with native salt-tolerant plants, choose turf species that may handle periodic salt water flooding

- Regrade zonal landscape areas to have adequate drainage as flood water recede

- Aerate turfs and reduce landscape soil compaction wherever possible to increase infiltration potential

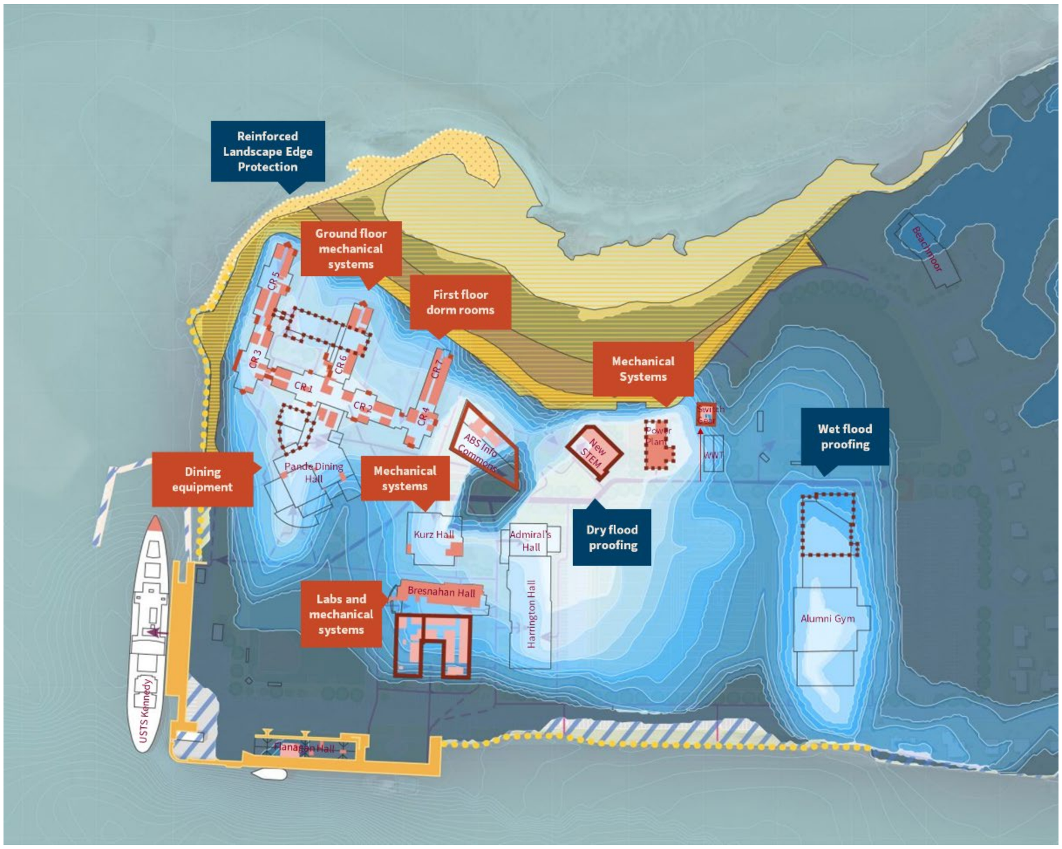
- Utilize a irrigation flushing technique after flooding to remove / dilute salts left from seawater in high priority landscape areas

- Hardscape materials:

    - Increase use of permeable paving surfaces and diversify techniques such as bonded aggregate or permeable cement pavers

    - Ensure metal landscape elements and furnishings are properly graded and powder coated for marine environments.

    - Affix landscape furnishings like benches, rain barrels, and waste receptacles



Vulnerable Critical Program (Mech, Labs, Storage, Circulation Cores)

Protected Critical Program (Mech, Labs, Storage, Circulation Cores)

Proposed Wet Flood Proofing

Proposed Dry Flood Proofing

Existing Dry Flood Proofing

Existing Deployable Flood Barriers

Salt Marsh

Coastal Dune

Wooded Area

Beach

Rip Rap

Seawall

TASK 3.4 GENERAL CAMPUS RESILIENCE STRATEGIES

General campus resilience strategies promote thermal comfort and ensure the campus can continue operations given power outages with emergency management strategies. These strategies aim to promote resilience without reliance on fossil fuels.

THERMAL COMFORT

Fall and Spring are considerably more comfortable for campus users at MMA, however trees can be strategically located to provide shade for cooling in extreme heat during the summer and protection from cold winds in the winter. Trees, especially with evergreen foliage help to buffer winter winds, while deciduous trees provide shade in hot autumn and spring days.

EMERGENCY MANAGEMENT

- The MMA campus currently depends on diesel generators to provide services for emergency management.
- In the future, as battery storage prices decrease, the campus can consider identifying buildings that provide critical services in the event of an emergency, and adding battery power with solar PV to allow these facilities island off-grid in the event of a power outage.
- As always, critical infrastructure, including the heating and cooling plant, transformers, switchgear and pumps, should be raised above flood levels.