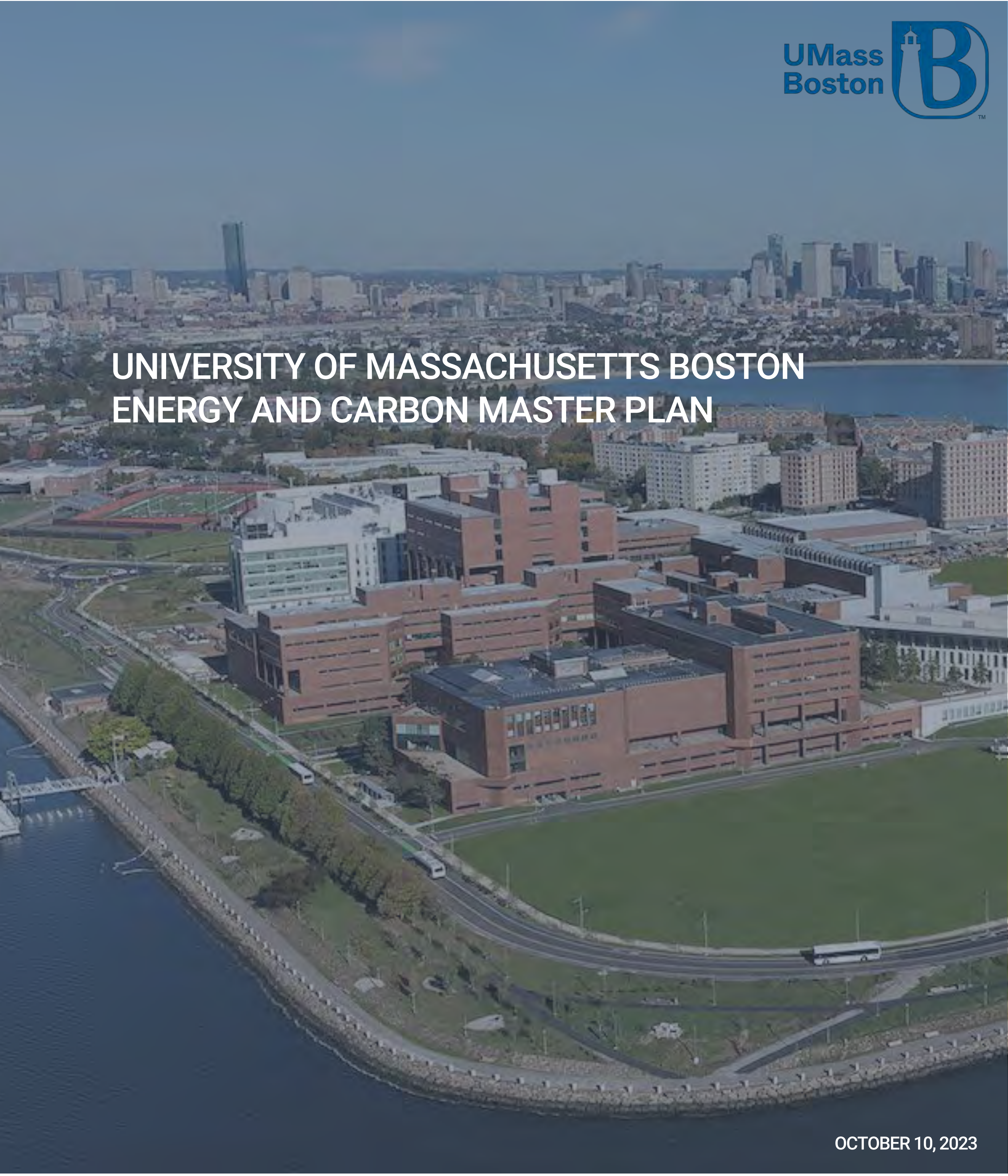

UMass Boston

UNIVERSITY OF MASSACHUSETTS BOSTON ENERGY AND CARBON MASTER PLAN

OCTOBER 10, 2023

BR+A   atelier ten   Weston & Sampson   VERMEULENS

Office of the Chancellor
100 Morrissey Boulevard
Boston, MA 02125-3393

9/29/2023

To the Campus Community:

Following our recent introduction of the new **Campus Master Plan**, I am pleased to introduce a related initiative, UMass Boston's new **Energy & Carbon Master Plan**.

The best available science tells us that the world needs to cut emissions dramatically by mid-century or sooner to avert the most catastrophic effects of climate change. In large part, this calls on all sectors to accelerate the global transition to low-carbon energy. In Massachusetts, Executive Order 594 – issued in 2021 – establishes milestones for state agencies and operations to reduce greenhouse gas emissions in alignment with the statewide goal of achieving net-zero carbon by 2050.

Transitioning UMass Boston to net-zero carbon emissions is indeed a complex undertaking. It will require re-engineering infrastructure and investment in new technologies. And it will entail operational planning around a core commitment to sustainability. It will also provide benefits of improved building comfort while decreasing energy costs.

The goal of the new Energy & Carbon Master Plan then is to provide a pathway that gets UMass Boston to net-zero and to a more resilient campus by 2050 by:

- Reducing energy consumption and enhancing resiliency in existing buildings.
- Building energy efficient and resilient new buildings.
- Switching fuel sources by electrifying the Central Utilities Plant and expanding sea-water heat pumps.
- And utilizing renewable energy, on and offsite.

These measures will not only enable UMass Boston to be in compliance with the state Executive Order 594. They are, as well, consistent with our mission of teaching, research, and service for the greater good – in this case, a more sustainable future.

And so, UMass Boston will continue taking steps to transform our energy systems and reduce our emissions to ensure that we're doing our share in the fight against climate change.

I look forward to the implementation of the Energy & Carbon Master Plan.

Marcelo Suárez-Orozco
Chancellor, University of Massachusetts Boston

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Report Disclaimer

BR+A has produced this document under an agreement between BR+A and University of Massachusetts Boston, Boston, MA. BR+A disclaims any obligation to any other person with respect to any material presented in this document and no person may rely upon this document without advance and express written consent from BR+A and such person's written agreement to be bound by the limitations, qualifications, terms, conditions, and indemnities to BR+A set forth in that agreement. BR+A specifically states that its review in question is subject to monetary restraints and scope limitations. Given those limitations and conditions, BR+A has made what, in its opinion, is a reasonable investigation, limited to visual observations. BR+A has also relied upon interviews and documents with the understanding that independent verification of their factual content is beyond the scope of BR+A's work.

The materials presented in this document are "to BR+A's knowledge" where such phrase means to BR+A's actual knowledge of the subject matter after such inquiry as BR+A considered reasonable considering the qualifications and limitations upon the scope of work.

All results are only developed to a conceptual level. All results are subject to change. Energy results are predictions of future energy consumption are to be used for comparison purposes only. BR+A cannot guarantee that these results will reflect actual energy consumption due to the uncertainty of actual schedules of use, weather and other unforeseen factors. Cost estimates are based on current market conditions.

Investigation for the presence of asbestos containing materials (ACM), PCB's, CFC's, radon, and other environmentally hazardous materials was not part of this project's scope of work. In addition, a review and certification that the buildings have been designed to meet current lateral loading (wind and seismic) or accessibility requirements, is not part of this review.

1 – EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The University of Massachusetts Boston (UMB) is an urban public research university with a commitment to environmental stewardship on campus and sustainability research and education. The goal of the Energy and Carbon Master Plan ("the Plan") is to provide practical, cost-effective energy efficiency, electrification, on-site renewable, and resiliency solutions. The plan also addresses the goals and milestones of Executive Order 594, "Leading By Example: Decarbonizing and Minimizing Environmental Impacts of State Government". This order supports the statewide goal of achieving net zero greenhouse gas (GHG) emissions in 2050 and limits the burning of fossil fuels in buildings and in vehicles. The Leading by Example (LBE) program encourages maximizing the installation of onsite renewable energy. It also supports long-range planning efforts so that the capacity of critical infrastructure and energy systems can withstand growing weather-related impacts associated with climate change. By implementing a range of initiatives and investments, UMB aims to meet environmental mandates, significantly reduce emissions, and create a sustainable campus for the future.

The campus is expected to undergo a variety of changes between now and 2050 to meet the evolving academic community needs and address building asset end of life. The campus is currently comprised of 13 buildings totaling 1,751,900 square feet. Buildings are currently served heating hot water and chilled water from a central plant powered by burning natural gas. Major equipment at the central plant is anticipated to need replacement within the next 5-10 years. Furthermore, the current Campus Master Plan anticipates a 33% growth by 2050. Therefore, upgrades at the central plant will be needed. This is a key opportunity to electrify the central plant and avoid burning more fossil fuels on campus. In addition, a collection of older buildings referred to as the Heritage Buildings are expected to undergo major renovations. This is a key opportunity for projects to reduce loads imposed on the central plant, improve building energy efficiency, and transition to low temperature hot water systems. In addition, current climate models indicate the CUP location could be at risk for flooding by 2050. Lastly, there are operational issues, low-cost energy conservation measures, and deep energy retrofit opportunities that were identified during the plan development. These are key opportunities to reduce loads imposed on the central plant and improve building energy efficiency.

The team evaluated a wide range of energy efficient, electrified alternatives for these anticipated projects. For the central energy plant, a sensitivity analysis was conducted to determine the viability of electrification technologies. The analysis considered UMB specific criteria including emissions, feasibility, cost, operations, and resiliency. This informed a recommendation to carry technologies through to more detailed scoping, energy analysis, and cost estimation. The outputs of this analysis were organized using tools such as life cycle cost and choosing by advantage. This provided a holistic picture such that the key stakeholder team had all required information to make an informed decision about which options to include in the Plan.

The Plan details a path towards a carbon neutral and more resilient campus. The framework of the Plan incorporates energy efficiency, electrification, on-site renewable, and resiliency solutions. The campus will focus on significantly reducing energy consumption. This allows the "right-sizing" of the new central plant for the new electrification strategies. UMB will also advance recommended onsite renewable energy options. In addition, to meet commitments to net-zero greenhouse gas emissions, UMB will pursue offsite renewable electricity purchases. The campus will continue to look at ways to mitigate emissions associated with fleet vehicles, commuting, and other sources, but that was not the focus of this plan. The Climate Hazards assessment indicated likely future vulnerabilities to flooding and heat; therefore, the campus will move forward with the proposed climate resiliency actions for current and future buildings.

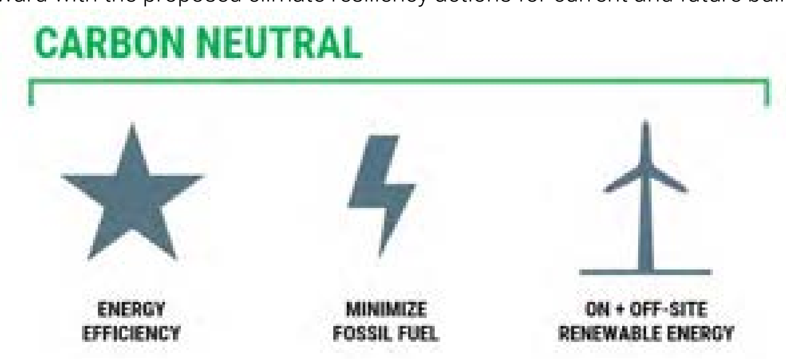


Figure 1: Overall carbon neutral strategy

Plan Framework

Energy Efficiency: Reducing energy reduces emissions. Energy reduction is planned through major renovation and comprehensive energy projects. Highest emitters are prioritized to have a cost-effective, significant impact. Major renovations are the best opportunities to reduce energy consumption. This is a holistic approach to building system renewal. Comprehensive energy projects focus on proper building operation, low-cost energy conservation measures, and deep energy retrofits. A key focus is on regular third-party testing of energy systems (“retrocommissioning”) to ensure ongoing proper operation.

Electrification: The shift from traditional fossil fuel burning heating equipment to electric alternatives contributes to reducing emissions and promoting sustainability. The new central plant incorporates electrified technologies such as high-temperature heat pumps, seawater heat pumps, air-to-water heat pumps, and geothermal heat pumps. Air source heat pumps are identified as the primary means of electrification. New construction and major renovations will connect to the central plant so that they’re fully electrified, eliminating the need for additional gas capacity. The MA Clean Energy Standard requires in 2023 that 26% of electricity be provided from renewable sources, increasing to 80% by 2050.

Asset End of Life: Energy efficiency and electrification projects are aligned with the estimated end of life of equipment. This improves the cost effectiveness of projects. It also prevents the need to retire equipment early.

Phased Approach: A phased approach enables the gradual implementation of upgrades and improvements. The plan suggests phasing in central plant capacity and equipment to proactively electrify ahead of new construction and major renovations. This allows for UMB to make significant progress towards carbon neutrality while also being able to take advantage of future technologies.

Low Temperature Hot Water: A low temperature hot water system is the most cost-effective alternative. Campus systems are currently designed for high temperature hot water. In the short term following the boiler upgrades, buildings should be stressed tested to understand the maximum temperature required. Buildings systems such as air handling units, fan coil units, and variable air volume terminal units incorporate low temperature coils so that the plant can transition to low temperature hot water in the future.

Coordination and Budgeting: Close coordination during capital planning is recommended to ensure that project budgets encompass both the building costs of individual projects and the central plant upgrades. This integrated approach avoids budgetary limitations and optimizes the allocation of resources.

Maintenance and Staffing: Given that the recommended equipment is not currently present on campus, maintenance and staffing requirements require special consideration. It is important to assess the skill sets and expertise needed to operate and maintain the new systems effectively.

Resilient Buildings: Enhancing the resiliency of campus operations is a crucial consideration. Relocating the central plant to a more resilient location/elevation is proposed to ensure the critical operation remains functional during potential disruptions and natural disasters. Future improvements on the UMB campus should incorporate resiliency and adhere to the City of Boston's Climate Resilient Design Guidelines and the Resilient Massachusetts Action Team's Climate Resilience Design Standards and Tool. This ensures that all projects align with industry best practices and withstand the potential impacts of climate change.

The key stakeholder team agreed on a new central plant in a new location to address the potential flood risk associated with the current central plant location. The basis of design for the new central plant is 100% electrification by 2050 with natural gas reserved for back-up heating. The new central plant incorporates electrified technologies such as high-temperature heat pumps, seawater heat pumps, air-to-water heat pumps, geothermal heat pumps, and natural gas boilers for backup purposes as detailed in the conceptual diagram below.

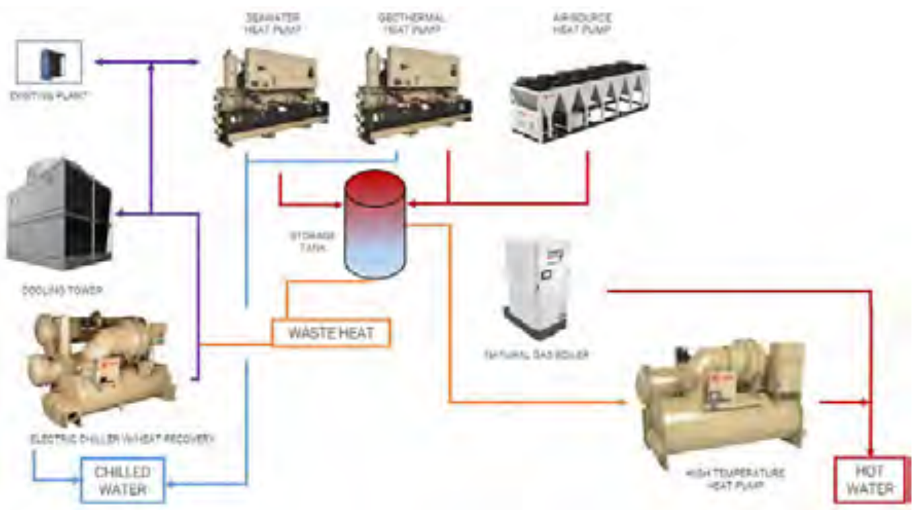


Figure 2: Central Energy Plant Conceptual Diagram

The existing buildings on the campus require high-temperature heating hot water at 180°F. However, current heat pump technology is unable to meet the entire heating demand of the campus with a single machine type particularly given the lack of consistent heat source. To address this issue, the Plan specifies the use of high-temperature heat pumps. These heat pumps are designed to provide high-temperature heating hot water meeting the specific requirements of the existing buildings. Additionally, the Plan outlines a strategy for renovating the buildings with low-temperature hot water systems. As these renovations occur the high-temperature heat pumps can be retired. A low-temperature hot water system is the most cost-effective option over the entire life cycle, indicating that it offers significant benefits in terms of system efficiency and operational costs.

The current UMB seawater pump house is only used for heat rejection. The Plan expands this function to also extract heat from Savin Hill Cove for a waste heat loop to serve the high-temperature heat pumps. The stakeholder team agreed on this strategy to align with the current seawater pump house overhaul project. In addition, the seawater heat pump option was the second most life cycle cost-effective option. A key challenge with this strategy is the permitting process, with attention to the discharge temp allowed and its interaction with tidal cycles. Therefore, it is a limited heat source, and other technologies are required to achieve the full campus heat capacity. If the existing permit cannot be expanded to incorporate these performance requirements, then additional air-source heat pumps will be required.

A finite area for geothermal wells is anticipated given the urban environment and campus growth. A geothermal field consisting of 525 boreholes is scoped between University Dr E and the HarborWalk. This area was closely coordinated with the Campus Master Plan team to avoid conflicts with campus growth. A geothermal test well is recommended prior to work to confirm performance criteria assumptions. If the test well results prove favorable, then the geothermal scope may be moved up in the implementation timeline.

Air-to-water heat pumps are scoped to meet most of the campus heating needs. This technology is ideal in an urban environment with spatial limitations given the technology's heat capacity density. Air-to-water heat pumps will be located on the roof of the new central plant.

Natural gas boilers are scoped as a back-up heating source for low temperature conditions and power outages. Fuel diversity is a key resiliency strategy of the Plan. This is the best solution at this time given the alternative of backing up heat pumps would require an extensive investment of generators, fuel storage, and switchgear. A phased approach will allow UMB to incorporate the most efficient technology at the time of implementation inclusive of new technologies that may eliminate the need for natural gas for back-up.

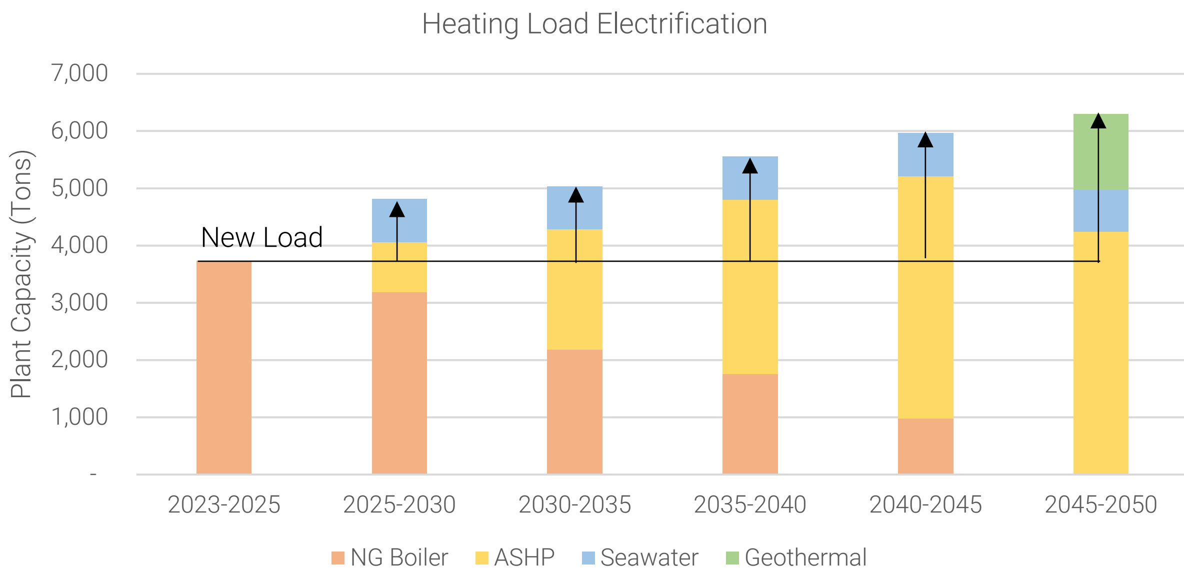


Figure 3: Heating Load Breakdown by Electrification Strategy

Figure 4: Projected 2050 Campus Map

Conformance with the Plan is estimated to result in the following outcomes:

- 34% energy usage reduction.
- 86% fossil fuel emissions reduction (100% excluding P3 and process natural gas)
- 20% reduction in operating costs (70% increase including growth and escalation)
- 7% increase in total capital spending between 2023 and 2050 ($345M increase above the $4.1B baseline costs)

Through the implementation of the Plan, the campus is predicted to comply with EO 594's fossil fuel emissions reduction goal by demonstrating more than 60% reduction in onsite emissions by 2040 and 95% by 2050. Electrifying the central plant utilizing electricity and renewable resources will achieve an 85% reduction in onsite emissions. It is estimated that natural gas use in commercial kitchens in the resident halls could contribute 12% to emissions. However, it is predicted that by 2050, electric equipment will be the gold standard and possibly a requirement for commercial kitchens. The remaining amount 2% of greenhouse gases are used by labs for research. While there are initiatives to reduce these pollutants with research alternatives, their continued use would comfortably be under the 5% allowed in 2050.

2 – EXISTING CONDITIONS REPORT

INTENT

This report provides a high-level summary of facility condition information, building age data, system type and energy sources, operating parameters, and estimated lifespan for major equipment. The analysis will inform our understanding of the overall functionality and suitability of physical facilities and anticipated base-case replacement timeline.

This report is also intended to define the baseline existing energy and GHG emissions. It also catalogues the most significant factors that drive energy and fossil fuel consumption for UMB's facilities.

PROCESS

We began the process by performing walk-throughs of all buildings on UMB's campus. We also interviewed facilities staff and reviewed documentation provided to us by UMB. Documentation provided by UMB included past energy audit reports, infrastructure assessment reports, and construction documents. Some of the information provided had gaps, but we worked with UMB to attempt to collect this remaining information to the best of our shared ability.

UMB also provided remote access to the Building Management Systems (BMS). This allowed us to review BMS operating conditions and trend data. Based on all of this information, we assessed the condition of major infrastructure and prepared this energy and infrastructure assessment report.

RATING SYSTEM FOR EQUIPMENT CONDITION

Major systems include a condition rating, with 4 tiers, defined as follows:

- New condition. Indicates that the equipment is new or in like-new condition and only requires standard maintenance.
- Good condition. Indicates that the equipment is typically in the first two-thirds of its anticipated useful lifespan and may require standard maintenance or limited replacement of components.
- Fair condition. Indicates that the equipment is typically in the final third of its anticipated useful lifespan and may require more involved maintenance and/or replacement of components.
- Poor condition. Indicates that the equipment is nearing or beyond its anticipated useful lifespan, has significant deficiencies and is likely in need of immediate or imminent replacement or major refurbishment.

CAMPUS OVERVIEW

BUILDING OVERVIEW

The University of Massachusetts Boston Campus, located on Columbia Point, is comprised of 13 buildings totaling 1,751,900 Square Feet (detailed by Table 1). The Campus Center, Integrated Science Center, and University Hall were constructed in 2004, 2014, and 2015, respectively. All other buildings included within this analysis were constructed during the original campus development project in 1970. All buildings primarily rely on plant heating hot water (HHW) and chilled water (CHW) except Service.

Table 1: Boston Campus – Building Information

Building Designation	Square Footage	Building Use	Building Heating Type	Building Cooling Type
Campus Center	370,324	Classroom/Office	Plant HHW	Plant CHW
Central Utility Plant	27,941	Central Plant	Electric**	Plant CHW
Clark Athletic Center	119,144	Athletic Center includ. ice rink	Plant HHW	Plant CHW
Healey Library	327,301	Classroom/Office*	Plant HHW	Plant CHW
Integrated Science Center	231,110	Lab	Plant HHW	Plant CHW
McCormack Hall	275,059	Classroom/Office*	Plant HHW	Plant CHW
Pump House	4,314	Support	Electric	Local Air-cooled Heat Pumps
Quinn Administration Building	103,335	Office	Electric	Plant CHW
Residence Hall (East and West)	260,000	Residence	Plant HHW	Plant CHW
Service and Supply	80,581	Office/Support	Electric	Plant CHW
University Hall	150,000	Classroom/Office*	Plant HHW	Plant CHW
Wheatley Hall	293,397	Classroom/Office*	Electric (preheat) & Plant HHW	Plant CHW

*Includes 15-25% lab space

**Space heating within Central Utility Plant building

In addition to the UMass Boston Campus, there are an additional 6 campus satellite buildings located on Nantucket Island (Detailed by Table 2). These buildings primarily serve as research and housing facilities, and add a total of ~8,500 square feet to the scope of analysis.

Table 2: Nantucket Campus – Building Information

Building Designation	Square Footage	Building Use
Main House	1,862	Research Facility
Well House	90	Research Facility
Laboratory	1,088	Research Facility
Gouin Village	2,988	Residential Building
Workshop	1,960	Research Facility/Operations
Small Beach House	461	Residential Building

The 2022 Master Plan suggests significant growth on campus over the next 25 years. Based on information in the report and coordination with UMB, an increase of 33% in square footage is anticipated. Below is a list of buildings and space types. This information is subject to change based on updates from the 2022 Master Plan Team.

Table 3: Future Growth – Building Information

Building Designation	Square Footage	Building Use
Academic Building A	80,000	Office/Classroom/Lab
Academic/Recreation B	110,000	Office/Classroom/Recreation
Academic Building C	120,000	Office/Classroom/Lab
Academic Building D	283,000	Office/Classroom/Lab
Academic Building E	72,000	Office/Classroom/Lab
ISC Addition	38,000	Office/Classroom/Lab
Clark Athletic Center Addition	16,000	Recreation
Campus Support Building	10,000	Facilities

MECHANICAL EQUIPMENT EXISTING CONDITIONS

HEAT GENERATION EQUIPMENT

Boilers

The CUP Boiler Plant consists of four (4) natural gas fired Cleaver Brooks fire tube hot water boilers, four (4) primary hot water pumps and three (3) secondary hot water circulation pumps.

Table 4: Table of CUP Boilers and specifications serving UMASS Boston Campus Heating Loads.

Equipment Designation	Condition	Make/Model	Output Capacity (MBH)	Install Year	Estimated End of Life
Boiler-1	Good	800 HP Cleaver Brooks CB 700-800	26,778	2001	2026
Boiler-2	Surface Corrosion	800 HP Cleaver Brooks CB 700-800-125	26,778	2001	2026
Boiler-3	Good	400 HP Cleaver Brooks CBLE 400	13,390	2001	2026
Boiler-4	Good	800 HP Cleaver Brooks CBLE 700-800	26,778	2012	2037

The boiler plant provides 170-190°F hot water for distribution to supply the Campus buildings' space heating loads. Boilers 1, 2, and 4 operate as the primary heating units during the peak heating demand season. Boiler B-3 is the "swing" boiler, which is primarily used during shoulder seasons when heating is required in low loading conditions. The boiler burners modulate to maintain the 190°F set point, using the Hawk 4000 as a controller, in addition to Oxygen trimming capabilities. Estimated end of life is based off of site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

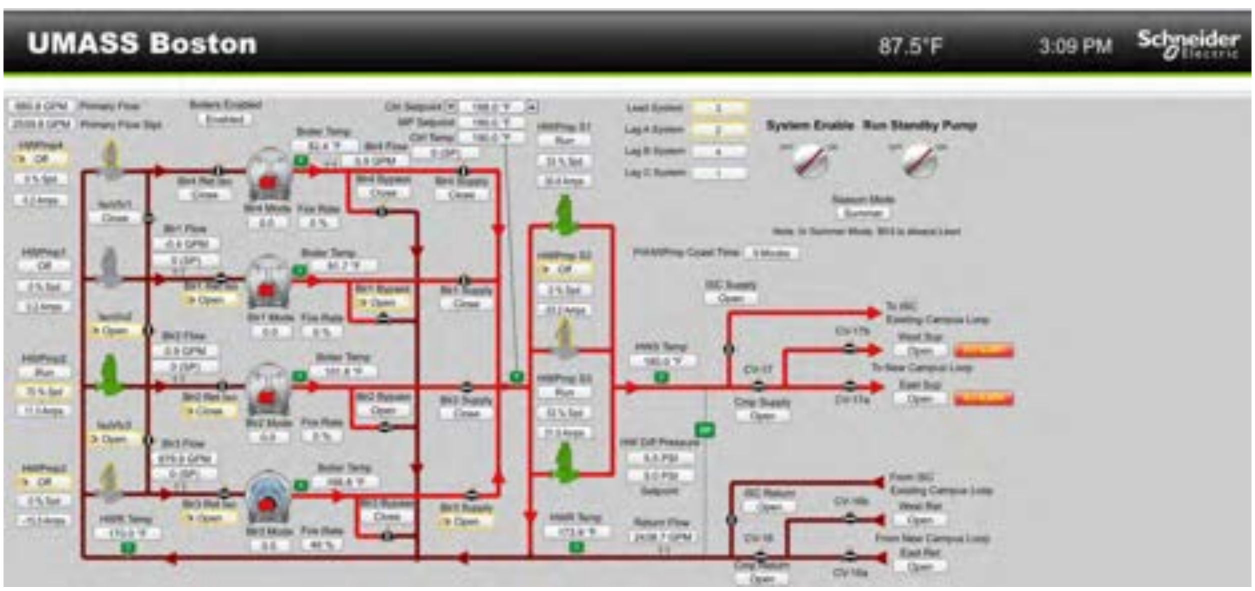


Figure 5: Building management system screenshot of heating hot water system

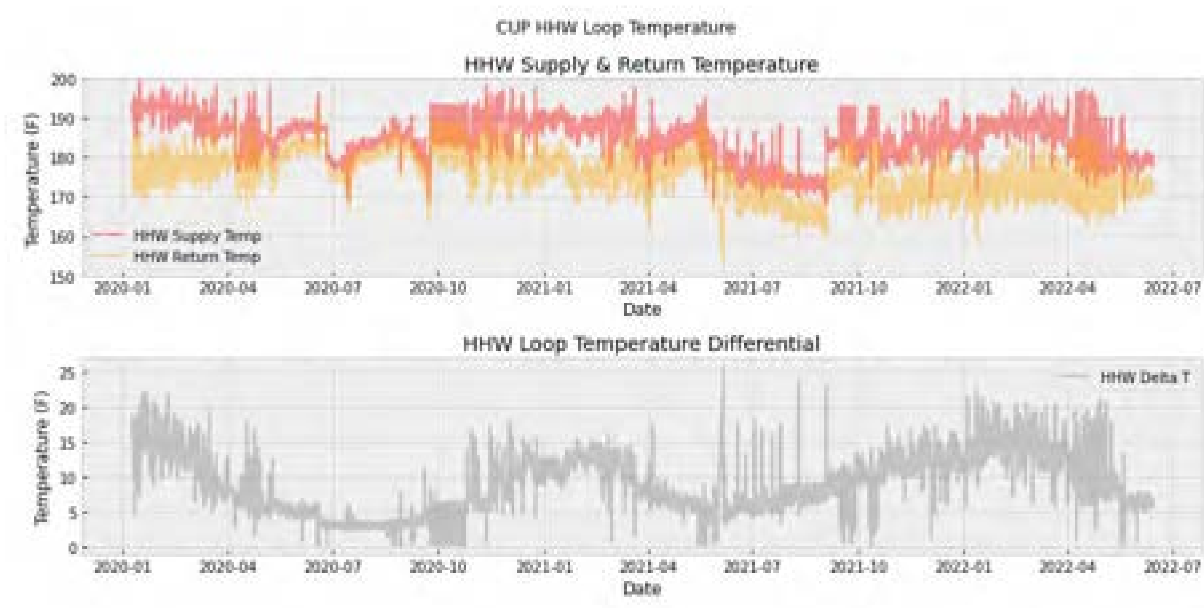


Figure 6: Hot Water Supply & Return Temperature Chart demonstrates consistent 170-190F setpoint is achieved by boiler plant. No setback observed within the trend.

The primary hot water pumps are staged on and off as each of their respective boiler are staged on. The VFDs for the primary pumps are modulated to maintain the boiler flow setpoint. The secondary hot water pumps modulate to maintain differential pressure (setpoint: 5 psi). There is a flow measuring station that measure secondary system hot water flow. During the primary cooling months (July 1st – September 31st), the CUP hot water system typical flow output ranges from ~1,900 to 2,200 GPM. During the primary heating months (December 1st – April 30th), the primary hot water loop flow increases to a typical range of ~3,000 to ~4,500 GPM.

Table 5: Table of Building Heating Hot Water Secondary Loop Setpoint and Setback Temperatures.

Building Designation	Summer HHW Setpoint @ OAT	Winter HHW Setpoint @ OAT
Campus Center	170°F @ >50°F	185°F @ <30°F
Clark Athletic Center	170°F @ >50°F	185°F @ <30°F
Healey Library*	170°F @ >50°F	185°F @ <30°F
Integrated Science Center	120°F @ >50°	185°F @ <30°F
McCormack Hall	165°F @ >50°F	185°F @ <30°F
Quinn Administration Building	120°F @ >50°	185°F @ <30°F
Residence Hall (East and West)	120°F @ >50°	185°F @ <30°F
Service and Supply	150°F @ >50°F	185°F @ <30°F
University Hall*	170°F @ >50°F	185°F @ <30°F
Wheatley	160°F @ >50°F	185°F @ <30°F

* Information not available based on graphics. Recommend review with UMB.

Table 5 indicates values observed from the BAS used as control points for the secondary heating hot water loops serving each individual building.

CHILLERS AND HEAT REJECTION EQUIPMENT

Chillers

The CUP houses all chillers that supply load to the UMass Boston Campus chilled water loop. The Chiller Plant consists of (3) York and one (1) Trane centrifugal water-cooled chillers, five (5) chilled water pumps, seven (7) condenser water pumps, four (4) sea water-to-condenser water plate and frame heat exchangers (PFHX), a condenser water PFHX and two (2) open cell cooling towers located on the roof of the new Integrated Science Center. With the exception of chiller 1 (CH-1), the chiller plant heat rejection utilizes a common condenser water loop which rejects heat to a sea water-to-condenser water PFHXs. CH-1, located in the Integrated Science Complex, rejects heat to the cooling towers. There exists a condenser water heat exchanger that allows the common condenser water system and the cooling towers to exchange heat without system cross contamination. The ability to reject condenser water through the cooling towers allows for supplemental heat rejection during condenser water to sea water heat rejection limitation due to low tides. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

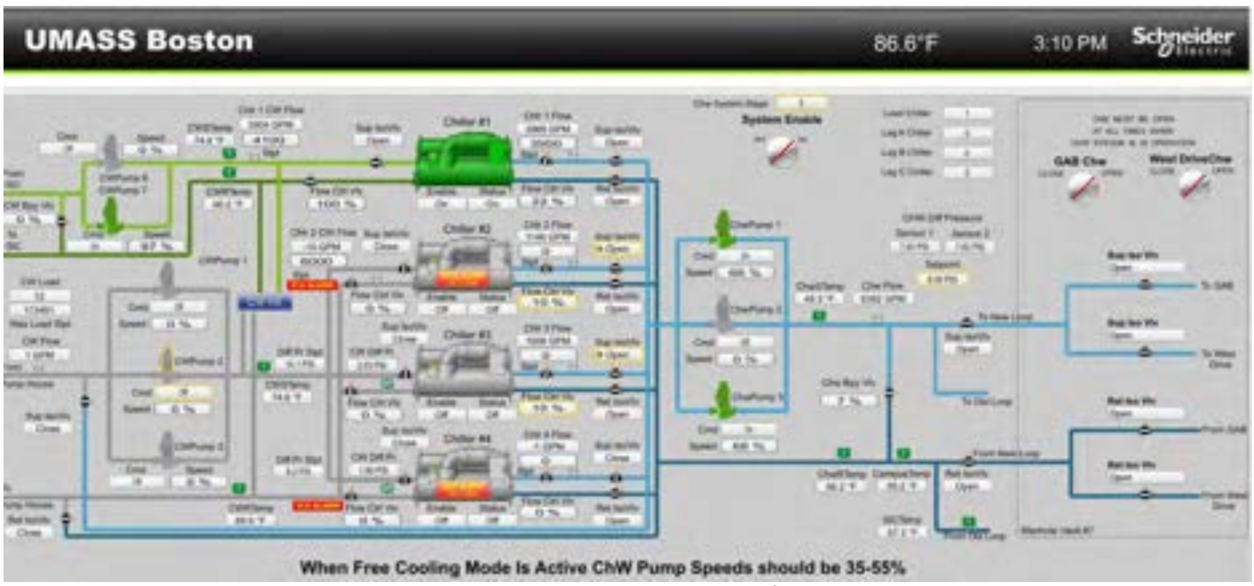


Figure 7: Building management system screenshot of chilled water system

Table 6: Table of CUP Chillers and specifications serving UMASS Boston Campus Cooling Loads.

Equipment Designation	Heat Rejection Equipment	Make/Model	Type	Capacity (Tons)	Condition	Install Year	Anticipated Replacement
Chiller-1	Cooling Towers	Trane Centravac CDHF2000	Dual compressor R-123 low pressure centrifugal chiller	2,000	Good	2004	2027
Chiller-2	Common Condenser Water System	York YKWFVBJ4-DHES	Single compressor R-134a high pressure centrifugal chiller	1,880	Good	2004	2027
Chiller 3	Common Condenser Water System	York YKVHTDJ4-DEHS	single compressor R-134a high pressure centrifugal chiller	1,910	Good	2004	2027
Chiller-4	Common Condenser Water System	York YKVHTVJ4-DHEH	single compressor R-134a high pressure centrifugal chiller	2,060	Good	2004	2027

The chillers stage on and off based on Campus load. Chillers modulate to maintain a constant 42°F CHW leaving temperature. The chilled water pumps are staged to match Campus cooling load. The secondary chilled water pumps modulate to maintain a differential pressure (setpoint: 9 psi).

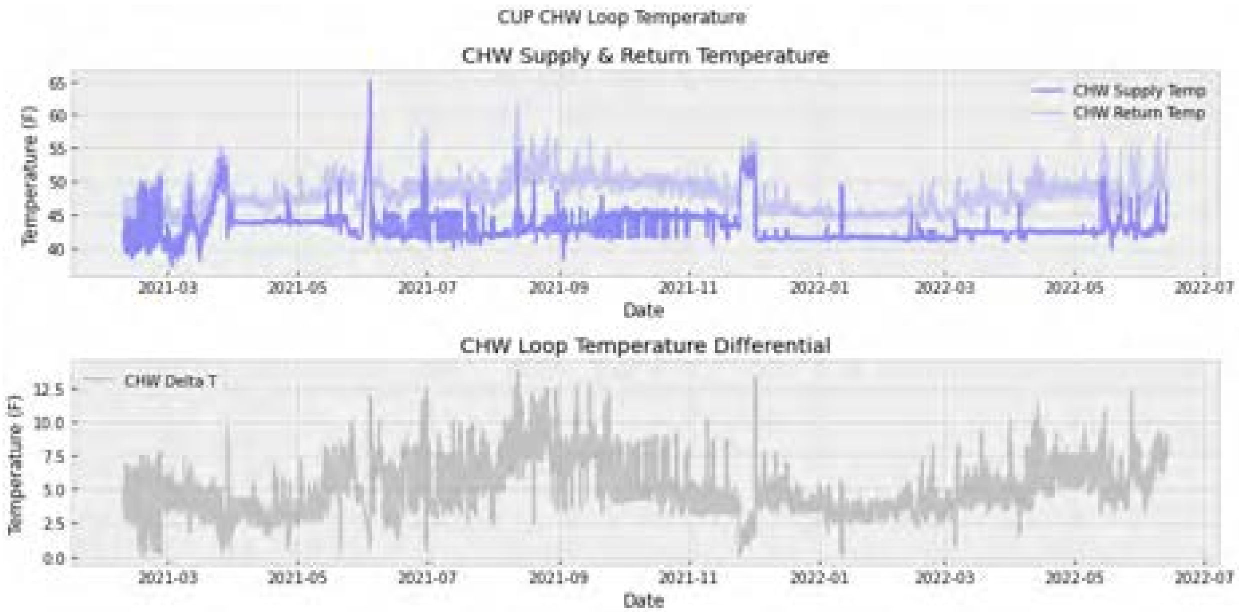


Figure 8: Chilled Water Supply & Return Temperature Chart demonstrates a typical supply temperature between ~40F and ~50F, with a mean of 42.8F is achieved by chiller plant over the most recent year of data (2021-02 through 2022-07).

Table 7: Table of Building Chilled Water Secondary Loop Setpoint and Setback Temperatures.

Building Designation	Summer Setpoint	Winter Setpoint
Campus Center	50°F	57°F
Clark Athletic Center	50°F	58°F
Healey Library	*	*
McCormack Hall	50°F	57°F
Quinn Administration Building	50°F	57°F
Integrated Science Center	44°F	44°F
Residence Hall (East and West)	50°F	57°F
Service & Supply	50°F	57°F
University Hall	50°F	57°F
Wheatley	50°F	57°F

* Information not available based on graphics. Recommend review with UMB.

<u>Cooling Towers</u>

There are two (2) open cell cooling towers that were added with the construction of the Integrated Science Center. The cooling towers can reject heat for CH-01 or the common condenser water loop. The cooling towers operate to maintain a condenser entering temperature of 75°F and 65°F when the free cooling heat exchanger is enabled.

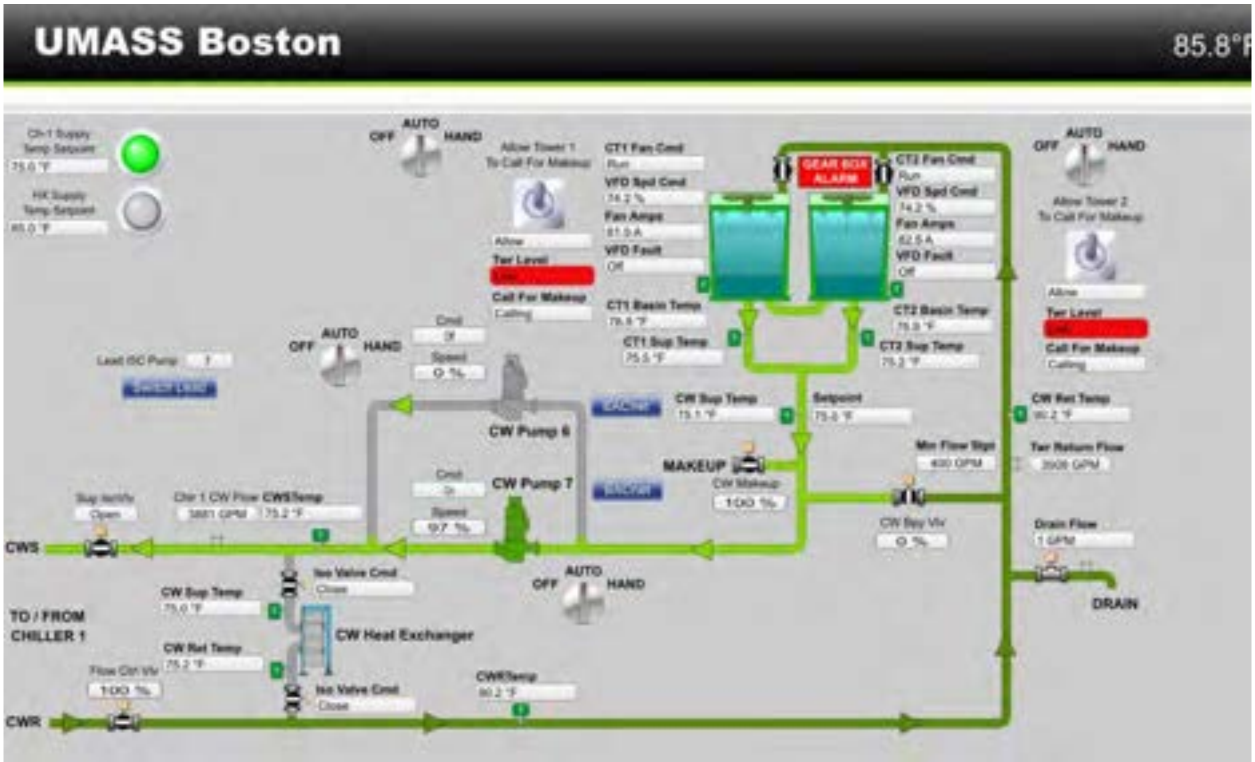


Figure 9: Building management system screenshot of cooling tower system (at Integrated Science Center

Table 8: Table of the Condenser Water Loop/Heat Rejection Equipment

Equipment Designation	Location	Capacity	Condition	Install Year	Anticipated Replacement
Cooling tower – CT-1, CT-2	Integrated Science Center	3000 GPM/Cell, 100 HP fan/Cell	Good	2014	2034
Condenser water Cooling Tower/ Heat Exchanger pump- CWP-4, CWP-5	Central Plant	6000 GPM, 90 FT, 200 HP	Good	2014	2034
Condenser water Cooling Tower Heat Exchanger Cond. HX	Central Plant	30,000 MBH, 6000 GPM, CT 83/93F, Plant Condenser Loop 85/ 95F	Good	2000	2024
Condenser water Cooling Tower Pumps- CWP-6, CWP-7	Integrated Science Center	4100 GPM/ 80 Ft/ 125 HP	Good	2014	2034

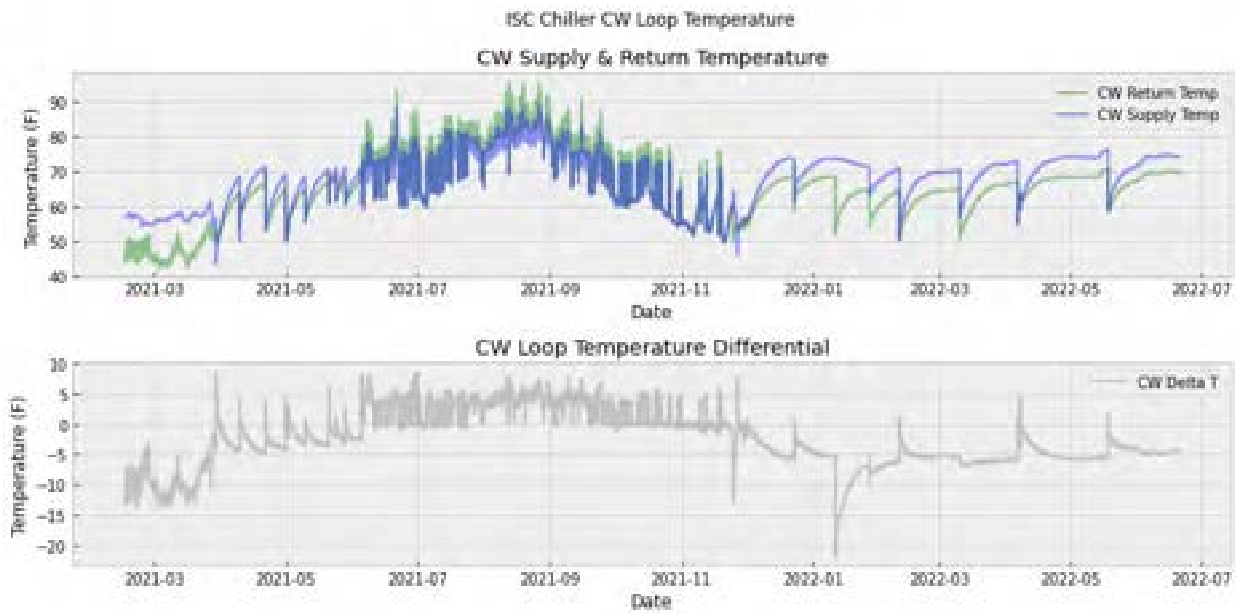


Figure 10: Integrated Science Center *Cooling Tower Condenser Water Loop Supply/Return Temperatures and Condenser Water Loop Temperature Differential.*

The condenser water pumps are staged to match chiller heat rejection loads. The cooling towers modulate to maintain a setpoint of 75°F in when CH-1 is enabled and 65°F when the free cooling heat exchanger is enabled. The CWPs are modulate to maintain a flow setpoint (max setpoint: 4100 gpm). There is no trended historical data for tracking the heat rejection by the common condenser water loop to the sea water PFHXs.

<u>Sea Water Heat Exchangers – Condenser Water Loop</u>

There are four (4) vertical turbine, variable speed, sea water pumps (P-21, -22, -23, and -24) that provide sea water circulation to the SW-to-CW plate and frame heat exchangers (PFHXs). On an annual basis, the PFHXs typically achieve ~2°F-8°F sea water temperature differential. During the low cooling-demand months (December-May), a reduction in flow through sea water PFHXs is evident.

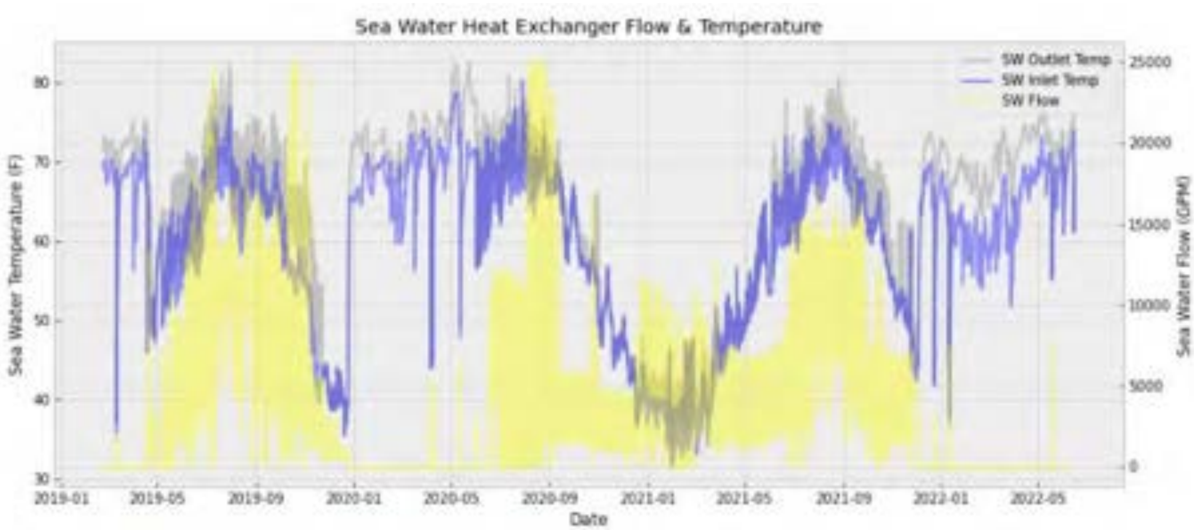


Figure 11: Sea Water Heat Exchanger Inlet/Outlet Temperatures and SW PFHX Flow.

There are three (3) 37,500 MBH and one (1) 18,750 MBH SW-to-CW PFHXs located in the Pump House. Each heat exchanger receives heat from the chiller plant heat rejection condenser water loop and transfers it to the incoming sea water. The flow of the sea-water through the PFHX's during the peak cooling months of the year (July-October) typically ranges from ~8,000GPM to ~20,000GPM. The sea water pumps operate ~ 1,000-10,000 gpm during the months September through June of CY 2021.

Table 9: Table of pumps & heat exchangers serving the Seawater Heat Exchanger

Equipment Designation	Capacity	Condition	Install Year	Anticipated Replacement
Sea Water Pump: P-21, P-22, P-23	7500 GPM, 110FT, 300 HP	Good	2013	2026
Sea Water Pump: P-24	3750 GPM, 110 FT, 150 HP	Good	2013	2026
Sea Water to Condenser Water Heat Exchanger HX-1, HX-2, HX-3	37,500 MBH, 7500 GPM, Sea Loop 70/80F, Condenser Loop 85/ 95F	Good	2017	2030
Sea Water to Condenser Water Heat Exchanger HX-4	18750 MBH, 3750 GPM, Sea Loop 70/80F, Condenser Loop 85/ 95F	Good	2017	2030
Condenser Water Pumps – CWP-1, CWP-2, CWP-3	8875 GPM, 85 FT, 250 HP	Good	2011	2024

Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D). Due to the corrosive nature of salt water, the life expectancy of the sea water pumps and PFHXs are de-rated by 30%, relative to typical base-mounted pump life expectancy.

Observed Heat Rejection Loads

The heat rejection of the mechanical cooling equipment is served by the common condenser water loop, which subsequently rejects heat to the Sea-to-Water Heat Exchangers, and the two (2) Integrated Science Center cooling towers.

Table 10: Heat Rejection Equipment and Capacities, with observed Heat Rejection Loads from BAS.

	Condenser Water Capacity	Chiller Capacity	CY2021 June November Heat Rejection loads (MMBtu/h)
Sea Water	31,200-82,320 MMBtu/h (at low and high tide respectively)	70,200 MMBtu/h (5,850 Tons)	Average: 30,270 Peak: 63,600 25th Percentile: 22,565 75th Percentile: 36,245
Integrated Science Center Cooling Towers	24,000 MMBtu/h	24,000 MMBtu/h (2,000 Tons)	
Totals	55,200 – 106,320 MMBtu/h	94,200 MMBtu/h (7,850 Tons)	2,285 – 63,600

From the BAS data, the relative loading of each type of heat reject equipment is analyzed at the 15-minute peak heat rejection loads of each month. Note that the sea water heat rejection is estimated using the cooling load, heat of compression factor and calculated cooling tower heat rejection. The cooling tower heat rejection is estimated using the cooling tower condenser water temperature and flow BAS data. Reasonable data for this analysis is limited given the suspect data of the historical condenser water and sea water flow, and the BAS datapoint log value limitations. The minimum heat rejection capacity is referenced from the UMass Boston Condensing Water Study report produced by ARUP on July 19th, 2021.

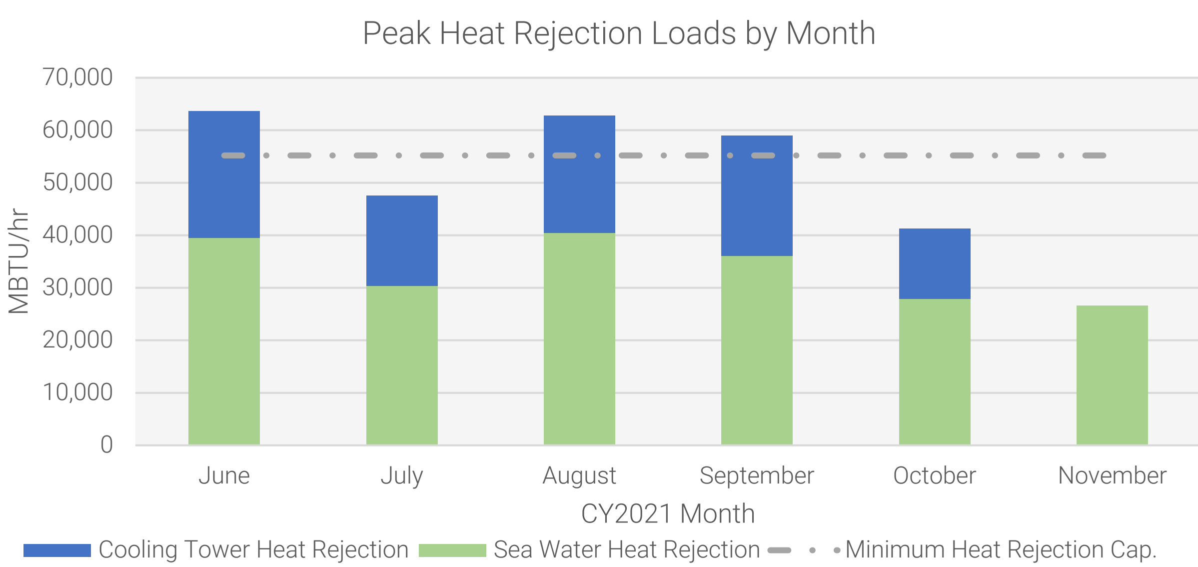


Figure 12: Monthly 15-minute Peak Heat Rejection Load Estimates, with Minimum Heat Rejection Capacities shown.

From the figure above, the heating rejection capacity (and therefore the cooling capacity) is limited during coincidence of peak loading with low-tide conditions. At the peak heat rejection load over the CY2021 cooling season (at 2021-06-30 19:00:00 EST), there is a +15% increase in required heat rejection relative to the minimum heat rejection capacity at low tide to meet the campus cooling loads. During the high cooling demand months, the summation of the heat rejection capacity of the cooling towers and sea water heat exchange systems are observed to have a limiting potential for affecting the cooling load able to be supplied. The occurrences of increased CHW supply temperature likely result from the limitation of heat rejection. Figure 9 demonstrates the CHW supply temperature deviation from the 44°F setpoint over a similar time period, which may be resulting from limited heat rejection capacity of the condenser water loop and cooling towers. As seen during the shoulder season months, the sea water heat rejection has enough capacity to reject the total load necessary to meet the peak loading conditions during those months.

HVAC BUILDING SYSTEMS/AIRSIDE DISTRIBUTION

Campus Center

The Campus Center is a 4-story building that houses offices, classrooms, and a commercial kitchen. The AHUs serving this building are in Fair condition as they were installed in 2004. Most of the units are on the penthouse, except for AHU-1 and AHU-2 which are located in lower level mechanical room. All units are recirculation units. The units all have HHW preheat coils and chilled water coils. Units have VFDs and vary airflow based on demand except AHU-7 which is 2-speed. None of these units have heat recovery or humidification. In general, individual zones are served by VAVs with HHW reheats. See table below for more air handling unit details. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

Table 11: Campus Center Air Handling Unit Details

Equipment Designation	Condition	Anticipated Replacement (Year)	Location	Supply Flow (CFM)	Minimum OA Flow (%)	Areas Served
AHU-1	Fair	2024	Mech Rm. U217	40,000	33%	West Bldg.
AHU-2	Fair	2024	Mech Rm. U217	40,000	33%	West Bldg.
AHU-3	Fair	2024	Mech Rm. 4500	40,000	33%	East Bldg.
AHU-4	Fair	2024	Mech Rm. 4500	40,000	33%	East Bldg.
AHU-5	Fair	2024	Mech Rm. 4500	40,000	33%	East Bldg.
AHU-6	Fair	2024	Mech Rm. 4500	40,000	33%	East Bldg.
AHU-7	Fair	2024	Mech Rm. 4500	14,000	50%	East Bldg.

Clark Athletic Center

The Clark Athletic Center is a 2-story building that houses gyms, offices, and the ice rink. The AHUs serving this building are in Fair condition but are expected to be past their useful life. Most of the units are located in the spaces they serve. All units are recirculation units. The units all have HHW preheat coils and chilled water coils. None of these units have heat recovery or humidification. Units have VFDs but run constant. In general, individual zones are served directly by these units.

Insufficient information was available to provide additional details on the existing air handling units: AC-8 and AC-9. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. See table below for more air handling unit details. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

Table 12: Clark Athletic Center Air Handling Unit Details

Equipment Designation	Condition	Anticipated Replacement (Year)	Location	Supply Flow (CFM)	Minimum OA Flow (%)	Areas Served
AC-1	Fair	2030	Rink	25,300	15%	Rink
AC-2	Fair	2030	Rink	25,300	15%	Rink
AC-3	Fair	2030	Gym	14,440	50%	Gym
AC-4	Fair	2030	Locker Room	17,600	50%	Locker Room
AC-5	Fair	2030	Gym	18,000	15%	Gym
AC-6	Fair	2030	Gym	18,000	15%	Gym
AC-7	Fair	2030	Lobby	25,000	15%	Lobby
AC-10	Fair	2030	Weight Room	2,120	50%	Weight Room
AC-11	Fair	2030	Locker Room	2,450	50%	Locker Room
AC-12	Fair	2030	Administration	1,800	15%	Administration

Healey Library

The Healey Library is an 11-story building that houses office, classroom, library, and lab space types. The AHUs serving this building are in Poor condition are past their useful life and have known operational issues. All units are recirculation units. The units all have HHW preheat coils and chilled water coils. None of these units have VFDs or heat recovery. The Archive AHU is the only unit with humidification. In general, individual zones are served by VAVs with electric reheats.

Insufficient information was available to provide additional details on the existing air handling units: AHU-S1, AHU-S2, AHU-S2A, AHU-S3, AHU-S4, AHU-S5, AHU-S6, AHU-S7, AHU-S8, Archive AHU. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. Note that this building is expected to undergo a major renovation. Therefore, this information may not be as useful as other buildings which may undergo targeted renovation projects.

Integrated Science Center

The Integrated Science Center is a 6-story building that houses wet labs. The AHUs serving this building are in Good condition as they were installed in 2014. Most of the units are located in the penthouse. All units 100% outside air. The units also all have Konvekta energy recovery coils and chilled water coils. Units have VFDs and vary airflow based on demand. AHU-2-1 has humidification via an electrode humidifier. In general, individual zones are served by VAVs with HHW reheats; chilled beams with HHW and CHW coils; and HHW radiant panels. See table below for more air handling unit details. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

Table 13: Integrated Science Center Air Handling Unit Details

Equipment Designation	Condition	Anticipated Replacement (Year)	Location	Supply Flow (CFM)	Minimum OA Flow (%)	Areas Served
AHU-1-1	Good	2034	Penthouse	80,000	100%	West Wing
AHU-1-2	Good	2034	Penthouse	80,000	100%	West Wing
AHU-2-1	Good	2034	Penthouse	30,000	100%	Vivarium
AHU-3-1	Good	2034	Penthouse	50,000	64%	Office
AHU-4-1	Good	2034	Penthouse	50,000	100%	East Wing
AHU-4-2	Good	2034	Penthouse	50,000	100%	East Wing

McCormack Hall

McCormack Hall is a 5-story building that houses office, classroom, and lab space types. The AHUs serving this building are in Poor condition and are past their useful life with known operational issues. All units are recirculation units. The units all have HHW preheat coils and chilled water coils. None of these units have heat recovery or humidification. Units have VFDs but run constant. In general, individual zones are served by variable volume and constant volume terminal boxes with HHW reheats.

Insufficient information is available to provide additional details on the existing air handling units: AHU-1, AHU-1_N2, AHU-2, AHU-3, AHU-4, AHU-5, AHU-6, AHU-7, AHU-8, AHU-9, and AHU-10. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. Note that this building is expected to undergo a major renovation. Therefore, this information may not be as useful as other buildings which may undergo targeted renovation projects.

Quinn Administration Building

Quinn Administration Building is a 3-story building that houses offices, a service garage for campus vehicles, and an iHub data center. The AHUs serving this building are in Poor condition are past their useful life and have known operational issues. Units are located in the penthouse. All units are recirculation units. The units all have electric preheat coils and chilled water coils. None of these units have VFDs, heat recovery or humidification. In general, individual zones are served by variable volume terminal boxes with electric and HHW reheats.

Insufficient information is available to provide additional details on the existing air handling units: AC-1, AC-2, and AF-3. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. Note that this building is expected to undergo a major renovation. Therefore, this information may not be as useful as other buildings which may undergo targeted renovation projects.

Residence Hall (East and West)

Residence Hall East is an 11 story building that houses student housing and a commercial kitchen. Residence Hall West is a 9 story student housing building. The AHUs serving this building are in Good condition as they were installed in 2018. Units are located on the roof. All units are 100% outside air units except the units serving the Office and Dining. The units all have HHW preheat coils and chilled water coils except the laundry make-up unit which only has a cooling coil. Units have VFDs and vary airflow based on demand. ERU-1, ERU-2, and ERU-3 have a single energy wheel. None of these units have humidification. In general, individual zones are served by variable volume terminal boxes with HHW reheats and dual temperature fan coil units. See Table 21 for more air handling unit details. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D). See table below for more air handling unit details.

Table 14: Residence Hall Air Handling Unit Details

Equipment Designation	Condition	Anticipated Replacement (Year)	Location	Supply Flow (CFM)	Minimum OA Flow (%)	Areas Served
ERU-1	Good	2048	Roof (East)	11,000	100%	East
ERU-2	Good	2048	Roof (East)	12,800	100%	East
ERU-3	Good	2048	Roof (West)	11,300	100%	West
AHU-1	Good	2048	1st floor (East)	10,000	100%	Servery
AHU-2	Good	2048	1st floor (East)	7,000	29%	Offices
AHU-3	Good	2048	1st floor (East)	10,000	27%	Dining
MUA-1	Good	2048	1st floor (East)	6,000	100%	Laundry

Service and Supply

Service and Supply is a 2-story building that houses offices, a service garage for campus vehicles, a machine shop, and an iHub data center. The AHUs serving this building are in Poor condition, are past their useful life and have known operational issues. Units are located in the penthouse. All units are recirculation units. The units all have electric preheat coils and chilled water coils. HV-3 is the only unit with VFDs and heat recovery. None of the units have humidification. In general, individual zones are served by variable volume terminal boxes with electric reheats.

Insufficient information was available to provide additional details on the existing air handling units: AC-1, AC-2, HV-1, HV-2, HV-3, and the Machine Shop unit. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. Note that this building is expected to undergo a major renovation. Therefore, this information may not be as useful as other buildings which may undergo targeted renovation projects.

University Hall

University Hall is a 4-story building that houses office, classroom, and lab space types. The AHUs serving this building are in Good condition as they were installed in 2015. Most of the units are on the penthouse. All units are recirculation units. The units all have HHW preheat coils and chilled water coils. Units have VFDs and vary airflow based on demand. AHU serving the 3rd floor is the only unit with heat recovery or humidification. AHU-R-1 also has humidification. In general, individual zones are served by VAVs with HHW reheats. See table below for more air handling unit details. Estimated end of life is based on site observations, installation documentation, and ASHRAE Life Expectancy estimates (see Appendix D).

Table 15: University Hall Air Handling Unit Details

Equipment Designation	Condition	Anticipated Replacement (Year)	Location	Supply Flow (CFM)	Minimum OA Flow (%)	Areas Served
AHU-G-1	Good	2045	5th floor mech room	62,500	35%	VAV (FLRS 1-4)
AHU-G-2	Good	2045	5th floor mech room	62,500	35%	VAV (FLRS 1-4)
AHU-L-1	Good	2045	5th floor mech room	40,000	100%	Level 3 Lab
AHU-L-2	Good	2045	5th floor mech room	40,000	100%	Level 3 Lab
AHU-A-1	Good	2045	5th floor mech room	11,500	36%	Recital Hall
AHU-R-1	Good	2045	5th floor mech room	8,500	20%	500-person lecture

Wheatley Hall

Wheatley Hall is a 6-story building that houses office, classroom, and lab space types. The AHUs serving this building are in Poor condition are past their useful life and have known operational issues. All units are recirculation units. The units all have electric preheat coils and chilled water coils. None of these units have VFDs, heat recovery or humidification. In general, individual zones are served by variable volume terminal boxes with HHW electric.

Insufficient information was available to provide additional details on the existing air handling units: HC-1, HC-2, HC-3, HC-4, HC-5, HC-6, HC-7, HC-8, HC-9, HC-9A, HC-10, HC-11, HC-12, HC-12A, HC-13, HC-14, HC-15, HC-16, and AHU-10. If additional information is available related to capacity, outside air requirements, and areas served, then this information can be added at a later date. Note that this building is expected to undergo a major renovation. Therefore, this information may not be as useful as other buildings which may undergo targeted renovation projects.

CAMPUS LOAD CONDITIONS

The hourly heating and cooling loads are analyzed from metered data representing 2021-01 through 2022-07. The average peak heating season and peak cooling season loads are considered along with the maximum peak values.

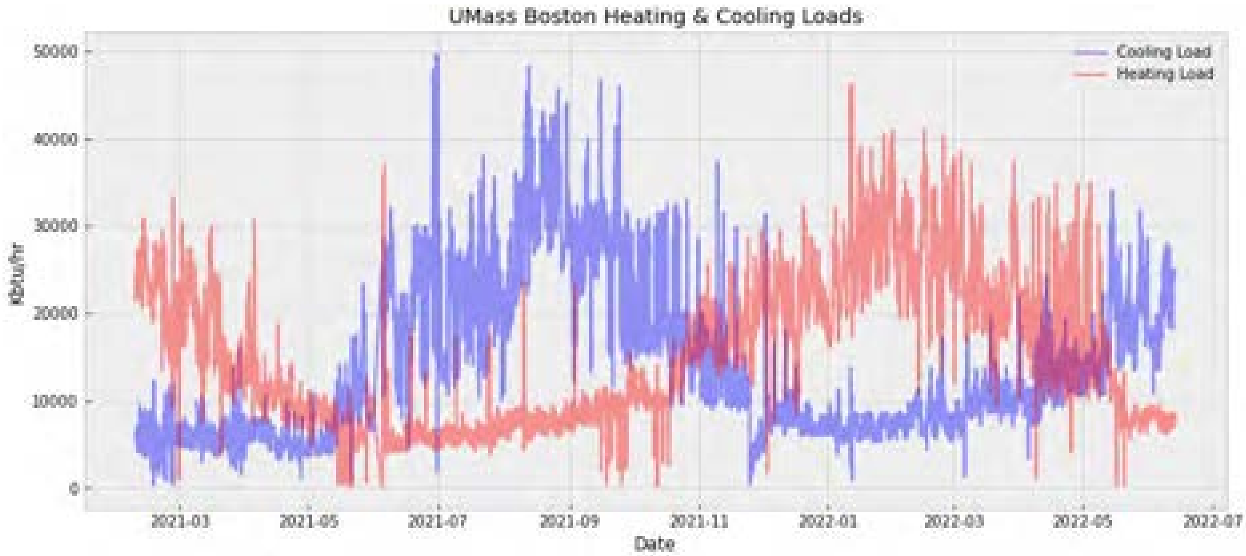


Figure 13: CY2021-CY2022 Heating and Cooling MBH campus loading conditions as calculated from BAS data. Maximum Cooling and Heating Loads are 49,650 MBH and 46,275 MBH, respectively.

On June 29th, 2021 at 7:30 PM, the peak cooling chilled water load of 49,650 MBH (4,140 tons) on the CUP is calculated using BAS data (53% of the total chiller plant capacity – 7,850 tons). The mean cooling demand over the entire dataset is 14,160 MBH (1,180 tons). During the primary cooling season (July 1st – September 31st), the mean campus cooling load is 27,485 MBH (2,290 tons, and a 46% reduction compared to peak cooling demand). Note these peak loads vary from the energy model. This is likely due to reduced occupancy during the trend period and deficient heat rejection capacity at low tide. During the primary heating season (December 1st – April 30th), the mean cooling load of the campus is 9,485 MBH (790 tons). The cooling load baseline demand of 7,200 MBH (600 tons) during peak heating season.

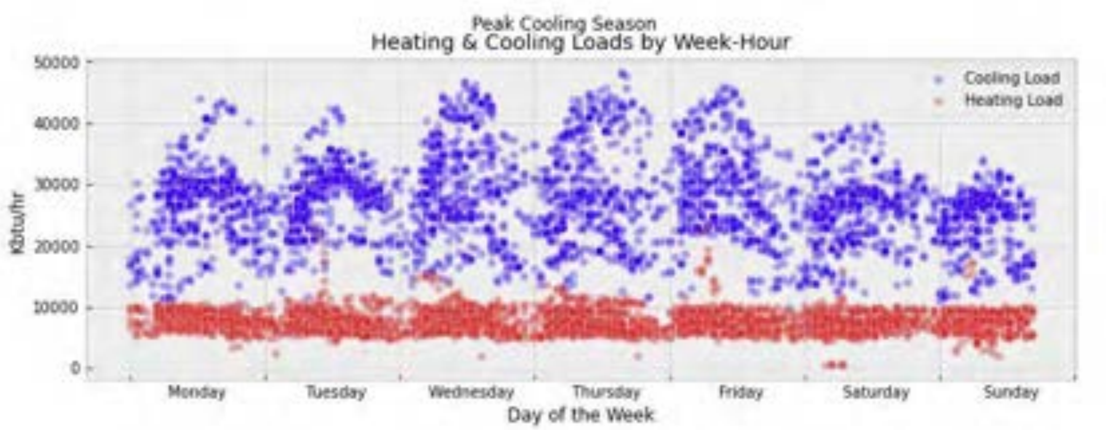


Figure 14: Cooling & Heating Loads from July 1st – September 31st by Week-Hour.

On January 12th, 2022 at 8:45am, a peak heating hot water demand of 46,275 MBH on the central plant is calculated using the BAS data, resulting in light load on the boiler plant during peak conditions, relative to the total output capacity (49% loaded at total plant capacity of 93,724 MBH). Ranging the entire dataset, a mean campus heating hot water load of 15,600 MBH is calculated. During the primary heating season (December 1st – April 30th), the mean campus heating load of the campus is 23,050 MBH (43% reduction compared to peak heating demand). During the primary cooling season (July 1st – September 30th), the mean campus heating load is 7,770 MBH. Daily morning ramp up of heating equipment is evident. Heating loads are lower overnight but remain consistent over the weekends relative to weekdays. Static heat loading throughout the peak cooling season, with a baseline heating demand of 6,350 MBH.

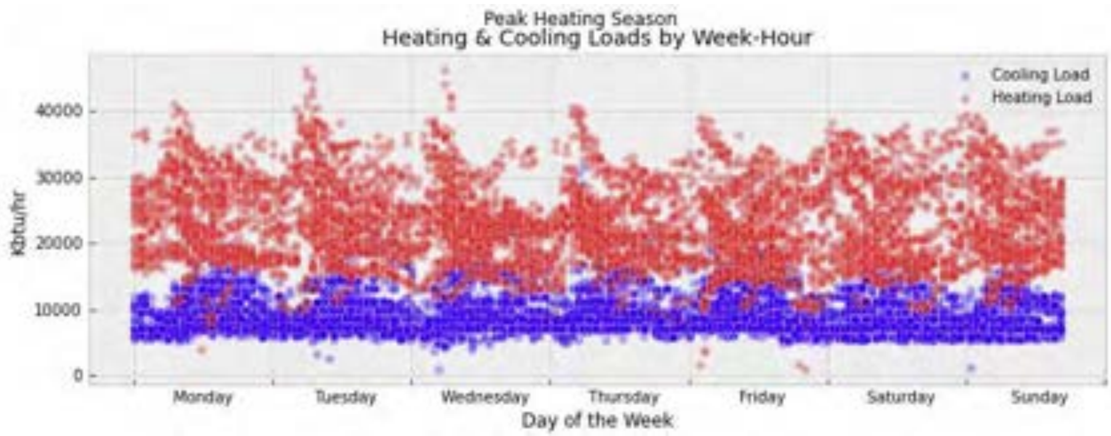


Figure 15: Cooling & Heating Loads from December 1st – April 30th *by Day of the Week.*

CAMPUS ELECTRIC EXISTING CONDITIONS

CAMPUS ELECTRIC UTILITY CONNECTION

Utility to the campus is served via (4) 15kV utility feeders from Dewar Street to a main campus switchgear line up in the switchgear service building updated in 2014 and distributed in a campus loop consisting of (10) circuit breakers labeled F1-F10.

Table 16: Campus Main Switchgear Details

Building Served	Designation	Circuit	Dedicated/Loop
Integrated Science Complex	F4 (ISC #1) F6 (ISC #2)	1200A	Dedicated
Healey Library	F2 (Healey #1) F7 (Healey #2)	1200A	Dedicated
Central Utility Plant	F5 (UP#1) F10 (UP#2)	1200A	Dedicated
Quinn Administration Building	F1 (Loop A/West) F8 (Loop B/West)	1200A	Campus Loop West
Service and Supply	F1 (Loop A/West) F8 (Loop B/West)	1200A	Campus Loop West
Clark	F1 (Loop A/West) F8 (Loop B/West)	1200A	Campus Loop West
University Hall (GAB 1)	F1 (Loop A/West) F8 (Loop B/West) F3 (Loop B/East) F9 (Loop A/East)	1200A	Campus Loop West/East
Campus Center	F3 (Loop B/East) F9 (Loop A/East) F1 (Loop A/West) F8 (Loop B/West)	1200A	Campus Loop West/East
Wheatley Hall	F3 (Loop B/East) F9 (Loop A/East)	1200A	Campus Loop East
McCormack	F3 (Loop B/East) F9 (Loop A/East)	1200A	Campus Loop East

BUILDING ELECTRIC UTILITY CONNECTION

This section outlines the electric utility connection for each campus building. The typical transformer service life is approximately 25-30 years but is dependent upon loading of the transformer.

Each building has its own respective transformer(s) that provide power to local equipment via a building switchboard. Many transformers were updated and replaced in kind as part of a 2014 campus improvement project.

Table 16: Campus Switchboards

Building Served	Equipment Designation	XFMR Quantity	KVA Rating (FF/AA)	Type	Install Year	End of Life
Campus Center	STA.511-10	2	2500	Unit Substation	2004	2034
Central Utility Plant	STA.511- 9 STA.511-13 STA.511-13	2 1 1	50000 1500 1000	Pad mount silicone-filled type	1973 2013 2013	2003 2043 2043
Clark Athletic Building	STA.511-14	2	1500	Pad mount oil-filled type	1978	2008
Healey Library	STA.511-3	2 1	1500 1000	Pad mount oil-filled type	1978	2008
Integrated Science Complex	STA.511-3	2	2500	Unit substation	2014	2044
McCormack Building	STA.511-6	4	2500	Pad mount dry type	2014	2044
Pump House	STA.511-7	1	1000	Pad mount dry type	2006	2036
Quinn Administration Building	STA.511-2	1	2000	Pad mount oil-filled type	1978	2008
Residence Hall (East and West)	-	-	-	Pad mount oil-filled type	2018	2048
Service and Supply	STA.511-1	1	1500	Pad mount oil-filled type	1973	2003
University Hall (GAB 1)	-	2	2000	Unit Substation	2016	2036
Wheatley Hall (North)	STA.511-12	2 1	2500 1500	Pad mount oil-filled type	2014	2044
Wheatley Hall (South)	STA.511-12	4	2500	Pad mount oil-filled type	2014	2044

DOMESTIC HOT WATER

Most buildings utilize heating hot water from the plant for domestic hot water heating. Some buildings still rely on local gas fired domestic hot water with storage. The Integrated Science Center is the only renewable domestic hot water system. There are expected to be some opportunities to reduce operating temperatures as a low cost energy efficiency measure. Further discussion with UMB is recommended. See table below for

Table 17: Building Domestic Hot Water Systems

Building Designation	Building Heating Type	Setpoint
Campus Center	Plant HHW, Semi-instantaneous Gas	140F
Clark Athletic Center	Plant HHW Semi-instantaneous Electric	140F
Healey Library	Plant HHW Semi-instantaneous Electric	120F
Integrated Science Center	Local Solar DHW / Semi-instantaneous Gas	120F / 140F
McCormack Hall	Plant HHW Semi-instantaneous Electric	165F**
Quinn Administration Building	Plant HHW Semi-instantaneous Electric	120F
Residence Hall (East and West)	Plant HHW / Semi-instantaneous Electric	120F / 140F
Residence Hall (Kitchen)	Plant HHW Semi-instantaneous Electric	120F
Service and Supply	Plant HHW Semi-instantaneous Electric	130F**
University Hall	Plant HHW Semi-instantaneous Electric	130F**
Wheatley Hall	Plant HHW	130F**

**Potential opportunity to reduce setpoint

BASELINE ENERGY CALIBRATION FOR THE EXISTING CAMPUS AND FUTURE GROWTH PREDICTION

The energy calibration performed during this phase is to develop a baseline representation of the existing campus heating, cooling and electricity profiles. The baseline is comprised by aggregating the energy consumption of campus buildings, the CUP, and takes into account the current operating profiles observed from the BAS, metered data and site walk-through. In addition, the baseline energy model uses the current climate data. This baseline dataset is the foundation of future phases and will be used as point of comparison for studies looking at the impact of future growth, energy retrofits, electrification, and future climate scenarios.

This energy model is needed to develop the baseline given limited metering and trend data sets. It therefore is used to supplement missing information and provides an hourly and annual dataset for the campus heating, cooling and electricity use.

In this phase, the energy model is also used to incorporate future change variables: weather and growth. In future phases, it can be used to analyze opportunities for building energy retrofits, alternatives CUP systems, and electrification; both the current and future climate data can be used for these analyses as well.

In summary, the process included in the Phase 1 energy calibration and future growth includes:

1. Develop calibrated campus scale energy models to represent the existing buildings.
2. Identify individual building energy use intensities distributed by energy source to understand the fossil-fuel dependencies of each building.
3. Simulate predicted growth in electricity, chilled water and hot water loads for the new high-performance buildings that are expected to occur between 2025-2040.
4. Estimate the total increase in energy use, space conditioning demand with the future weather projection.

ENERGY MODEL CALIBRATION

Energy models representing the building type, square footage, system description, condition, and operation of the existing buildings as presented in Table 1 are analyzed using eQUEST DOE 2.2 simulation software. The energy models are calibrated using the 2019 data from the campus metered data provided by UMB.

As seen in Fig 11 and 12, the monthly electricity and natural gas consumption for the modeled existing campus buildings align with the metered data. The model calibration includes standard assumptions related to internal loads, occupancy, functioning of older HVAC systems, building schedules in lieu of the availability of detailed building-level sub-metered data and building operation. The annual consumption of electricity and gas in the calibrated models deviates by 3 and 5% respectively when compared to the metered energy data. It must be noted that sometimes utility companies bill posthumously which could be one of the reasons for the monthly deviations between December-March.

Table 18: Summary metrics from the modeled existing representational campus buildings

	Consumption (annual)	Demand (peak, month)
Electricity	61,540 MWH	12,000 kW, August
Natural Gas	179,650 MMBTU	108,800 kBtu/hr, January

LIMITATIONS

The analysis below is a high-level approach for a campus-wide calibration that can help understand the energy distribution and building operation of the campus as a whole. While the energy models are representational buildings, the calibration to align coincidental peaks across several buildings is limited given the available metering for the campus-level study. Additionally, the models have not been normalized for weather conditions in 2019 and use a typical meteorological year weather file for simulation.

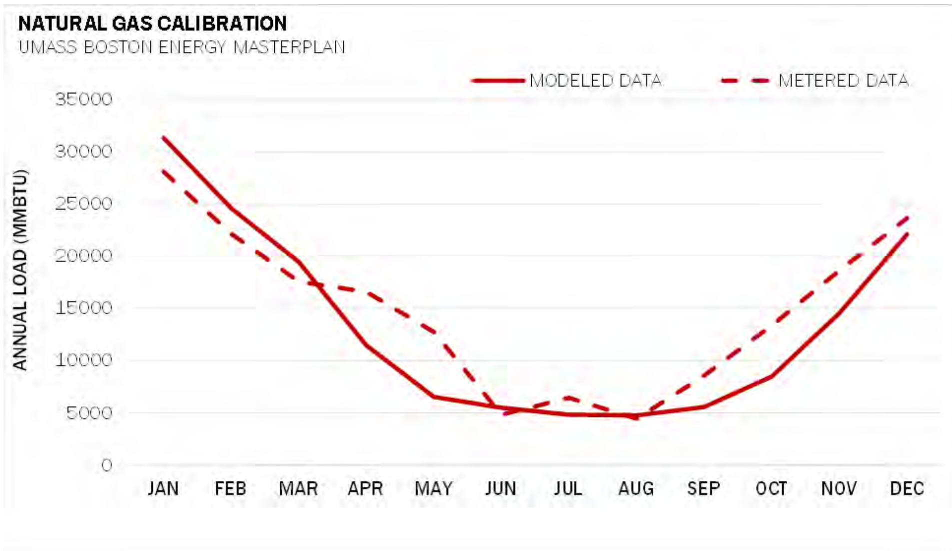


Figure 16: Monthly Natural Gas Comparison- Modeled vs Metered

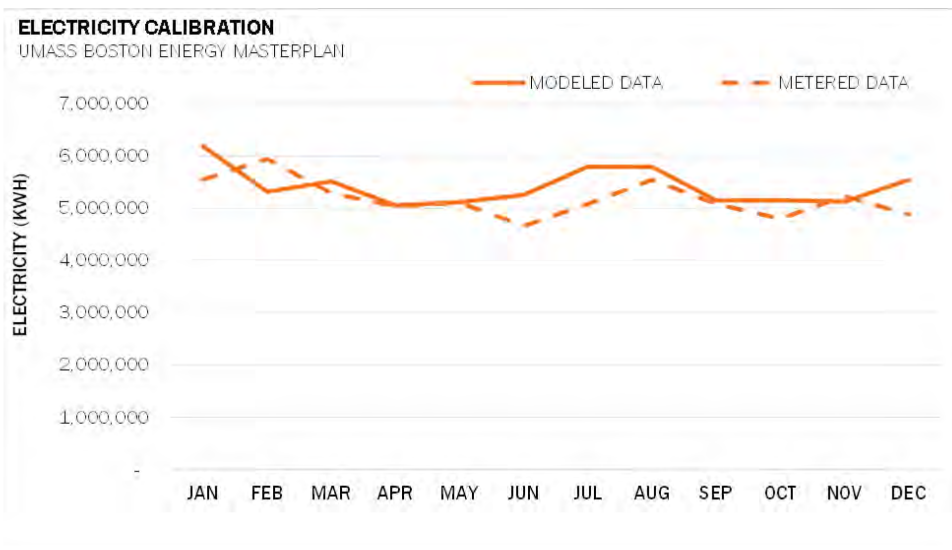


Figure 17: Monthly Electricity Comparison- Modeled vs Metered

Table 19: Summary of annual energy consumption and emissions for the existing representational buildings

	Annual Consumption	Annual Emissions
Electricity*	61,540 MWH	17,931 Tons CO2e
Natural Gas**	179,650 MMBTU	9,540 Tons CO2e

*2019 Electricity emissions factor: 85.4 kg/MMBTU

**Natural Gas: 53.06 KG/MMBTU

The calculated building energy use intensities (EUI) for the existing buildings and the predicted distribution by energy source is provided in Table 19. The campus center and the residence hall have significant kitchen and dining component resulting in high on-site combustion. Note that the EUIs below includes the central plant efficiencies.

Table 20: Modeled Energy Use Intensities for Existing Buildings

Existing Buildings	Area (Sf.)	Energy Use Intensity (kBtu/Sf/Yr)	Electricity EUI (kBtu/Sf/Yr)	Gas EUI (kBtu/Sf/Yr)
McCormack Hall	275,059	224	103	121
Wheatley Hall	293,397	169	117	52
Healey Library	327,301	140	126	14
Quinn Administration Building	103,335	90	89	2
Service and Supply	80,581	181	140	41
Clark Athletic Center	119,144	92	87	5
Campus Center	370,324	134	41	93
Integrated Science Center	231,110	314	141	173
University Hall	150,000	202	103	100
Residence Hall (East and West)	260,000	129	36	93

The hourly distribution of the simulated chilled water and hot water load for the existing building on campus is provided in Fig 13. The estimated chilled water peak loads in the months of July and August are between 70,000-80,000 MBH while the hot water peak loads during January is between 55,000-65,000 MBH in the campus energy models. To assist in calibrating the energy model with metered data, an exercise is performed to compare the two data sets. However, the results of this study found the data is not readily comparable due to the following issues: the sea water heat rejection was not in operation during the period which the heating data below is collected and the metered data is collected from a pandemic year whereas the simulated baseline is for a typical (pre-pandemic) scenario.

Table 21: Summary metrics from the modeled existing representational campus buildings

Utility	Annual Consumption	Max Demand	Min Demand
Chilled Water	148,400 MMBTU	89,950 KBTU/hr	1,125 KBTU/hr
Hot Water	91,675 MMBTU	63,450 KBTU/hr	203 KBTU/hr
Electricity	61,540 MWH	12,000 KW	3,465 KW
Natural Gas	179,650 MMBTU	108,800 KBTU/hr	770 KBTU/hr

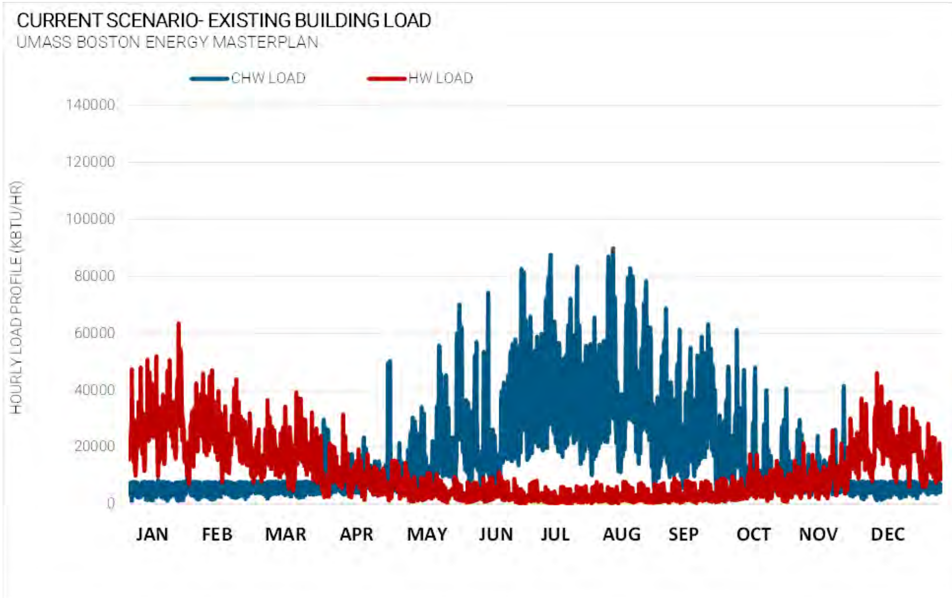


Figure 18: Existing Building Load Profiles

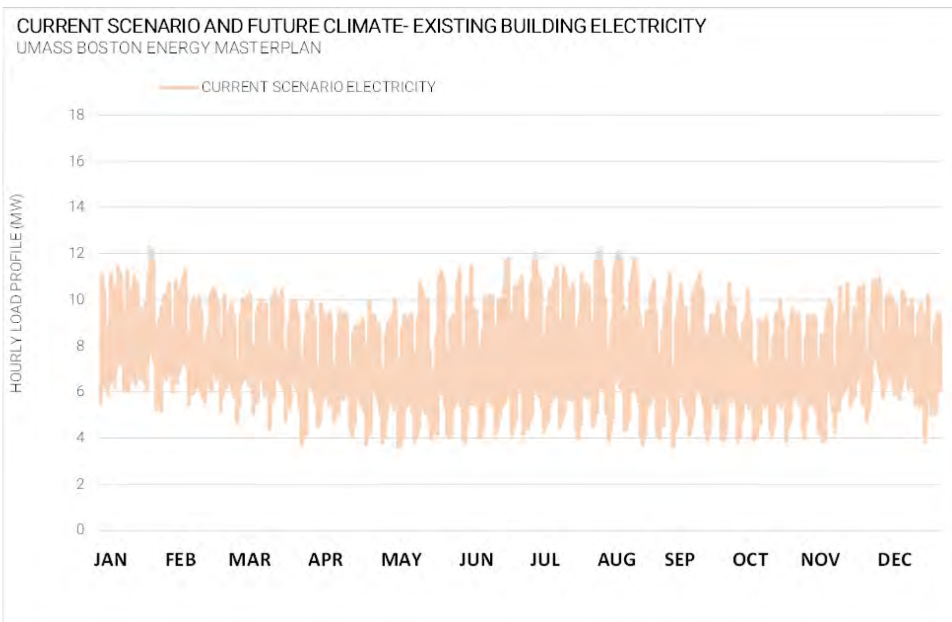


Figure 19: Existing Building Electricity Profiles

FUTURE WEATHER IMPLICATIONS ON ENERGY USE

The future weather in Boston, Massachusetts is anticipated to show greater heat stress during summer. The future weather predictions indicate that the mean annual temperature in MA are expected to be as much as 2.8-6.2°F warmer and there could be 19-40 fewer days when the temperatures fall below 32°F. The increase in warmer days will result in a 20% increase in cooling energy consumption and ~20-30% increase in the operational peak cooling load by 2050. Fig 15 and Fig 16 illustrate results of a simulation using future climate data layered on the campus energy model. The results suggest by how much the campus chilled water demand could increase. The future climate file used in this study is the RCP 4.5 future weather scenario and it is applied to the existing buildings, as they operate today. Although the winters are predicted to be warmer in Boston, the analysis does not account for the reduction in hot water demand as a conservative approach while planning for future infrastructure.

Table 22: Predicted impact of future climate on operational peak demands

Utility	Incremental Increase in Demand Due to Future Climate
Chilled Water	10-20%
Hot Water	No increase
Electricity	10-15%
Natural Gas	No increase

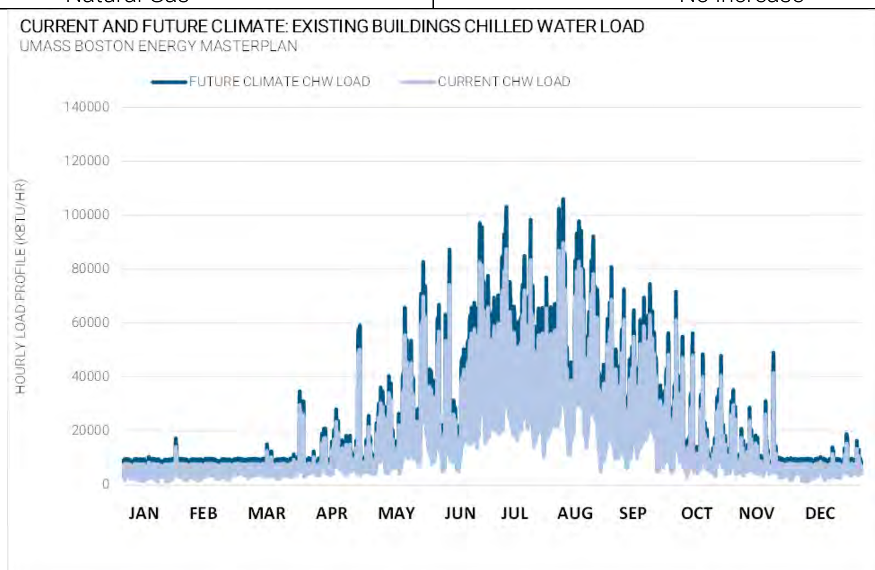


Figure 20: Future Climate: Existing Building Loads- Chilled Water Loads

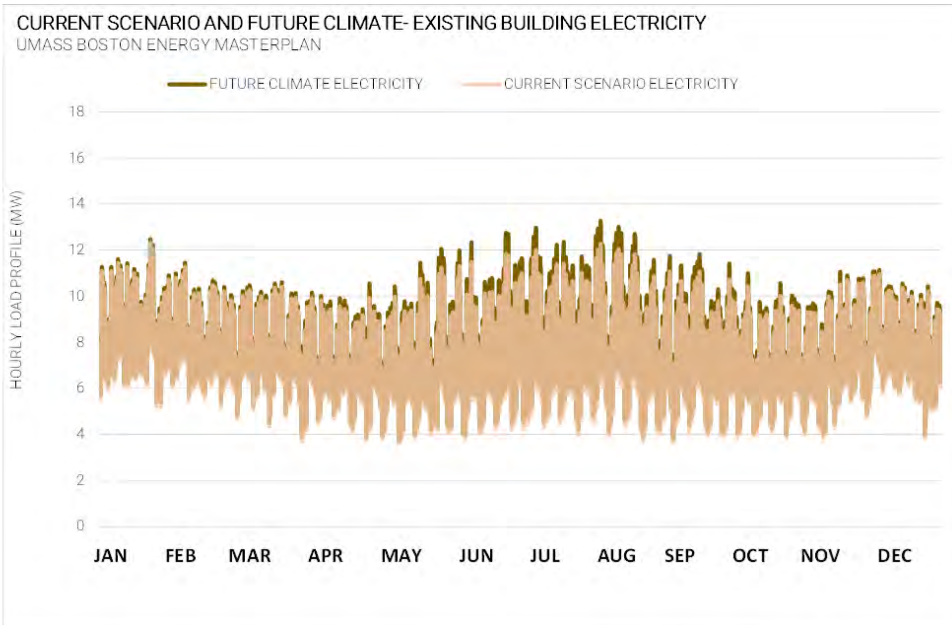


Figure 21: Future Climate: Existing Building Utilities

FUTURE GROWTH IMPLICATIONS ON ENERGY USE

Between the years 2025-2040 several new projects are being planned that will add nearly 729,000 square feet to the campus. Table 22 shows the predicted increase in annual cooling, hot water, electricity and natural gas consumption as well the potential impact on the campus infrastructure. Fig 17, 18,19, and 20 show the hourly profiles for chilled water, hot water, electricity and natural gas for both the existing (if left as is in the current conditions) and the future high-performance new addition buildings.

Table 23: Predicted Increase in Annual Consumption and Infrastructure based on predictive modeling for future buildings

Utility	Incremental Annual Consumption	Incremental Peak
Chilled Water	10-20%	10-20%
Hot Water	7-17%	10-20%
Electricity	15-25%	17-27%
Natural Gas	6-16%	10-20%

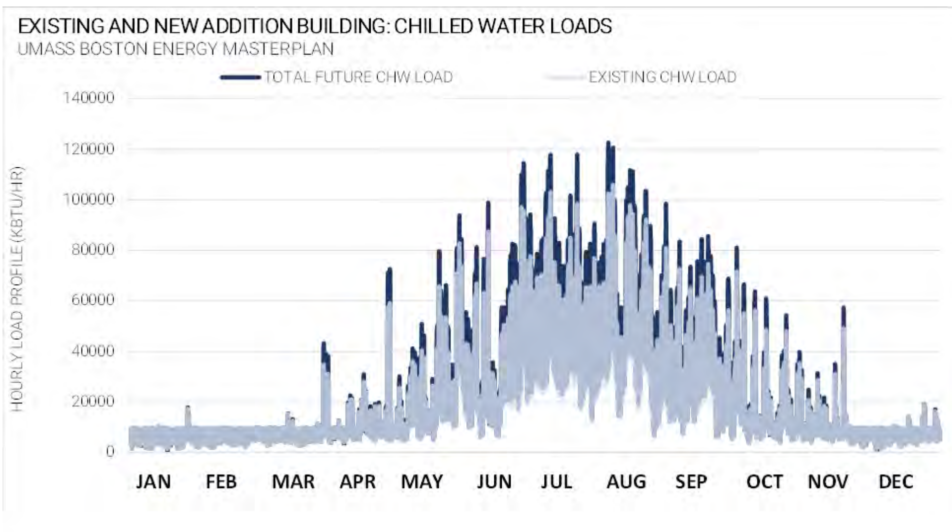


Figure 22: Current and New Addition Building: Chilled Water Loads

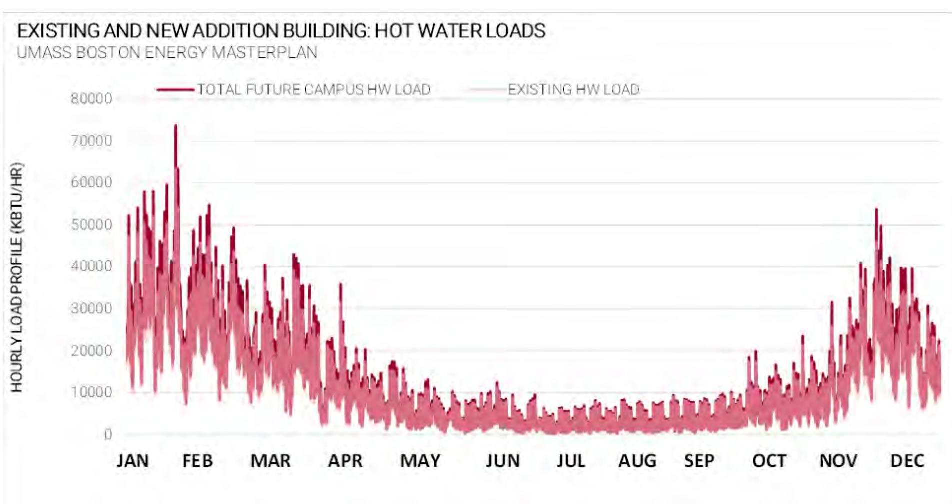


Figure 23: Current and New Addition Building Comparison: Hot Water Loads

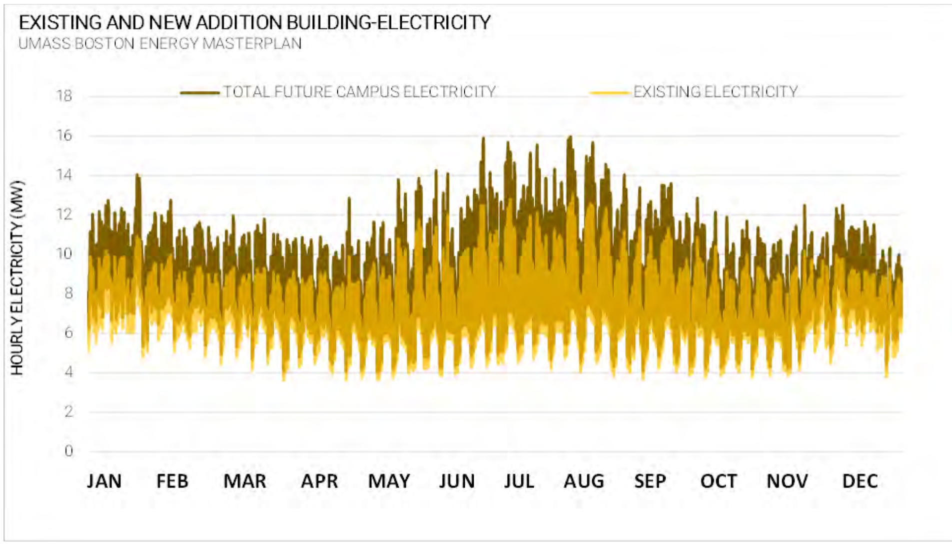


Figure 24: Current and New Addition Building Comparison: Electricity

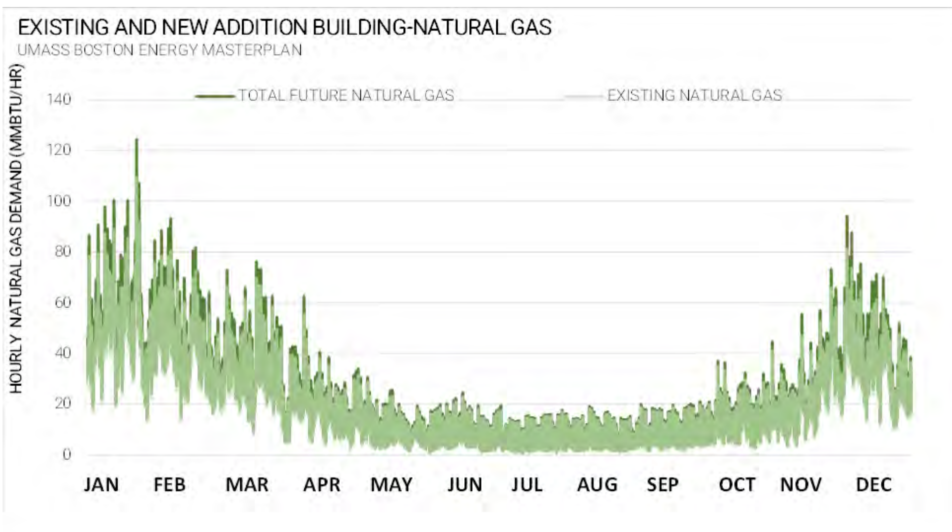


Figure 25: Current and New Addition Building Comparison: Natural Gas

Table 24: Summary of annual energy consumption and emissions for the existing and new addition building

Utility	Consumption	Emissions
Electricity*	76,701 MWH	22,350 Tons CO2e
Natural Gas**	198,958 MMBTU	10,570 Tons CO2e

*2019 Electricity emissions factor: 85.4 kg/MMBTU
**Natural Gas: 53.06 KG/MMBTU

BUILDING RANKINGS

Prioritizing the highest energy consumers for projects is the most cost effective strategy to achieving load reductions on campus. These buildings are ideal for priority projects. The priority project approach helps align multi-stakeholder decision-making and build momentum such that similar strategies can be applied across all core end uses. In order to help prioritize buildings that would be ideal candidates for priority projects, buildings have been ranked across a set of key criteria: energy use intensity, energy change over time, energy use intensity target, combustion emissions, and facility conditions. The analysis below breaks down how buildings rank in each key criteria.

Energy Use Intensity (EUI) – Energy use intensity is a measurement of energy density – unit of energy per square foot. This helps conduct an apples-to-apples comparison of buildings of different sizes. Building level metering is not available. Therefore, campus electricity and natural gas meter data as well as building management system trend data was used to calibrate a campus energy model inclusive of individual building energy profiles and associated EUI. Buildings with a higher EUI are ranked higher. Below is a summary of the highest ranked buildings in this key criteria.

Building	EUI Score	EUI Target Score	Combustion Score	Facility Condition Score	Overall Score
Integrated Science Center	100	0	78	88	66
McCormack Hall	80	78	22	75	66
Clark Building	78	22	44	25	42

High priority — Medium priority — Low priority

Figure 26: Top EUI scores

Energy Use Intensity Target – Load reduction strategies are the first step toward a carbon neutral future. Load reduction strategies significantly reduce EUI. Based on building end use, BR+A has established a target EUI for load reduction strategies from our experience, SUNY Directive 1B-2, and other benchmarks. The higher a building's modeled EUI is from the target, the higher it is ranked. Below is a summary of the highest ranked buildings in this key criteria and their associated targets.

Table 25: Building EUI Targets

Building	Target EUI
Wheatley Hall	73
McCormack Hall	80
Healey Library	63
Quinn Administration Building	71
Clark Building	143
Service and Supply	37
Campus Center	59
Integrated Science Complex	208
University Hall	80
Residence Hall (East and West)	63
Site S	30
Site G	30
Site T	30
Site R2	51
Site PE	160

Building	EUI Score	EUI Target Score	Combustion Score	Facility Condition Score	Overall Score
Service	11 (High priority)	100 (High priority)	0 (Low priority)	38 (Low priority)	37 (Low priority)
Campus Center	44 (Medium priority)	89 (High priority)	100 (High priority)	100 (High priority)	80 (High priority)
McCormack Hall	89 (High priority)	78 (High priority)	22 (Low priority)	75 (High priority)	66 (High priority)

High priority — Medium priority — Low priority

Figure 27: Top EUI Target scores

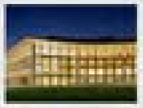
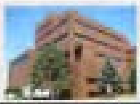
Combustion Emissions – The goal of this project is to reduce emissions on campus as the campus works towards its goal of carbon neutral by 2050. Electricity can be generated by renewable sources. It's expected that 80% of grid electricity in Massachusetts will be generated by renewable sources by 2050. Note that the remaining 20% will need to be procured through renewable sources. Therefore, it's more important to prioritize electrification strategies. Buildings with the highest carbon emissions from natural gas as estimated by the campus energy model rank higher. Below is a summary of the highest ranked buildings in this key criteria.

Building	EUI Score	EUI Target Score	Combustion Score	Facility Condition Score	Overall Score
Campus Center	44 (Medium priority)	89 (High priority)	100 (High priority)	100 (High priority)	83 (High priority)
Wheatley Hall	56 (Medium priority)	56 (Medium priority)	89 (High priority)	63 (High priority)	66 (High priority)
Integrated Science Center	100 (High priority)	0 (Low priority)	78 (High priority)	88 (High priority)	66 (High priority)

High priority — Medium priority — Low priority

Figure 28: Top Combustion scores

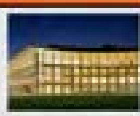
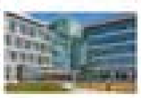
Facility Condition – Deferred maintenance may make decision-making easier when it comes to implement load reduction strategies. The available Sightlines equipment replacement costs were reviewed. Using this information, a "facility condition" score was established based on the replacement costs associated with key energy use assets. A higher score indicates a higher total value of equipment replacement costs relative to other buildings. Below is a summary of the highest ranked buildings in this key criteria.

Building		EUI Score	EUI Target Score	Combustion Score	Facility Condition Score	Overall Score
Campus Center		44 —	89 ∧	100 ∧	100 ∧	83 ∧
Integrated Science Center		100 ∧	0 ∨	78 ∧	88 ∧	66 ∧
McCormack Hall		89 ∧	78 ∧	22 ∨	75 ∧	66 ∧

∧ High priority — Medium priority ∨ Low priority

Figure 29: Top Facility Condition scores

Overall Score – In summary, buildings with the highest average score are anticipated to be the best candidates for energy efficiency projects. Weight factors were equally applied to each key criteria in order to establish an overall score for each building. Weight factors should be reviewed by UMB at this stage to align with goal priority. Below is a summary of the highest average score. Appendix C for a list of all building scores.

Building		EUI Score	EUI Target Score	Combustion Score	Facility Condition Score	Overall Score
Campus Center		44 —	89 ∧	100 ∧	100 ∧	83 ∧
Integrated Science Center		100 ∧	0 ∨	78 ∧	88 ∧	66 ∧
Wheatley Hall		56 —	56 —	89 ∧	63 ∧	66 ∧

∧ High priority — Medium priority ∨ Low priority

Figure 30: Top Overall scores

CAMPUS FUTURE CLIMATE HAZARDS ASSESSMENT

The University of Massachusetts Boston has taken steps to plan for the impacts of climate change with the development of a Hazard Mitigation Plan (2014), Emergency Operations Plan (2020), and Campus Wide Evacuation Plan (2018). To better understand the University's exposure to flood, wind, heat, and drought hazards, a resilience assessment of existing conditions was performed utilizing future climate projections.

OVERVIEW OF COASTAL FLOOD RISK IN THE CITY OF BOSTON

Areas of Boston are currently at risk of flooding, as evident by the recent nor'easters in January and March 2018. Coined the "Bomb Cyclone," the January 4, 2018 storm flooded downtown Boston and trapped cars in ice with two feet of flood waters in some areas, and tide gauges broke records set in 1978.[2] Wind gusts topped 90 mph and more than 24 inches of snow fell in some areas in the Northeast.[3]

Sea levels are projected to rise approximately 4.2 ft by 2070 in the Boston area.[4] The City of Boston instituted "Climate Ready Boston," as the entity responsible for updating climate projections, preparing vulnerability assessments, and creating neighborhood-scale resilience plans to protect and prepare communities for climate change impacts. The City of Boston identified the planning horizon of 2070 (in approximately 50 years) with an estimated up to 40 inches of sea level rise[5] (based on recommendation from the Boston Harbor Flood Risk Model BH-FRM) as a target for neighborhood flood protection. Climate Ready Boston prepared conceptual flood barriers and alignments for neighborhoods, including South Boston and Dorchester. In addition to the neighborhood studies, the City of Boston has advanced several other initiatives to support planning, designing, and constructing climate resilient buildings and infrastructure.

MASSACHUSETTS COAST FLOOD RISK MODEL (MC-FRM)

The Massachusetts Coast Flood Risk Model (MC-FRM) is a statewide model developed by Woods Hole Group for coastal communities to assess coastal flood risk and inform planning and design. The MC-FRM is a probabilistic, hydrodynamic model that "simulates the physics-based flow of water" over water bodies and over land. The MC-FRM provides annual probability of flooding and associated projected water surface elevations for present day, 2030, 2050, and 2070 conditions. The MC-FRM supersedes the Boston Harbor Flood Risk Model (BH-FRM) that was used in the development of Climate Ready South Boston and Dorchester for district scale climate adaptation solutions.

Table 26: Projected water surface elevations in feet, Boston City Base from the Massachusetts Coast Flood Risk Model (MC-FRM) for the University of Massachusetts Boston

Annual Exceedance Probability	2030	2050	2070
	Projected Water Surface Elevation (ft BCB) from MC FRM		
0.1%	18.5	20.4	22.1
0.2%	18.2	20	21.7
0.5%	17.7	19.4	21.1
1%	17.5	18.9	20.7
2%	-	18.4	20.2
5%	-	17.8	19.6

Table 26 identifies the associated projected water surface elevations in feet, Boston City Base (ft-BCB) associated with annual probabilities across different planning horizons. Figure 26 shows the annual probability and extents of flooding for 2030, 2050, and 2070, respectively. These maps are representative of flooding but may not reflect actual conditions and water surface elevations should always be referenced in comparison to ground elevation to understand potential flooding. The buildings exposed in each of these planning horizons are summarized in Table 27. Critical infrastructure including some for power, heating, and cooling are located in the Central Utility Plant (CUP) and switchgear house with elevations of 20 ft-BCB and 34.5 ft-BCB, respectively. The CUP may be at risk, as the projected water surface elevations may exceed 20 ft-BCB during the 0.2% event as soon as 2050. In addition to the vulnerability of buildings, entrance and exit roads are also expected to be inundated. The

2 https://www.businessinsider.com/noreaster-bomb-cyclone-boston-floods-2018-1

3 https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/03/02/updates-winds-are-howling-and-the-water-is-rising-as-noreaster-bears-down/

4 https://resilientma.org/changes/sea-level-rise

5 https://www.boston.gov/sites/default/files/embed/file/2018-09/climatereadysouthboston_execsum_v9.1s_web.pdf

Hazard Mitigation Plan and Evacuation Plan noted that Morrissey Boulevard, Mount Vernon Street, and Day Boulevard are known to flood and may impede travel.

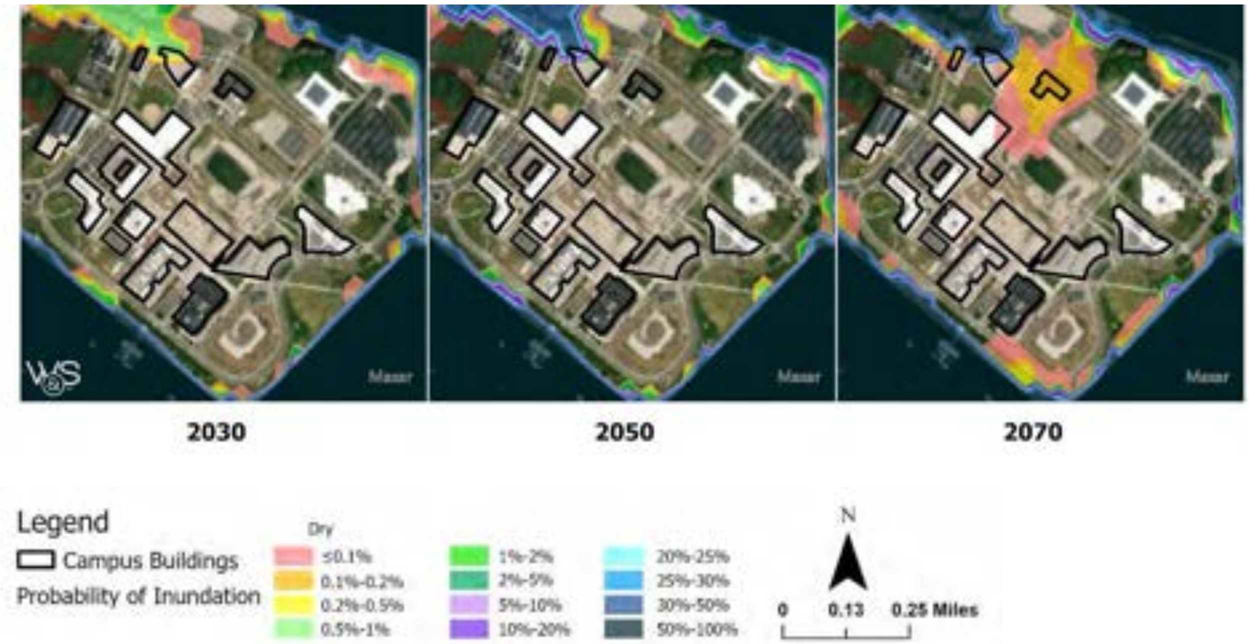


Figure 31: Annual percent probability on Inundation in 2070 based on the Massachusetts Coast Flood Risk Model

Table 27: Probability of Inundation for 2030, 2050, and 2070 from the Massachusetts Coast Flood Risk Model (MC-FRM) for the University of Massachusetts Boston

Planning Horizon	Residence Hall East	Residence Hall West	Historic Calf Pasture Pumping Station	Clark Athletic Center	Wheatley Hall
2030	0.9%	0.1%	-	-	-
2050	36%	5%	-	-	-
2070	73%	12%	0.1%	<0.1%	<0.1%

FEMA

The FEMA National Flood Hazard map accounts for coastal, riverine, and stormwater flooding based on statistical estimates on historical data. Although most of the campus is outside of FEMA flood zone, Historic Calf Pasture Pumping Station and Residence Hall East are located within the FEMA 100-yr (1% annual exceedance probability) flood zone. The MC-FRM projections better account for coastal flooding and show further extents than FEMA.

Figure 32: FEMA National Flood Hazard Layer for University of Massachusetts Boston

PRECIPITATION

Precipitation events such as rain and snow are expected to occur more frequently and with greater intensity because of climate change. Maximum annual daily precipitation for the City of Boston and the University is projected to be 2.9 inches by 2030, and about 4.3 inches by 2070, compared to the historical average of 2.1 inches.[6] New England has already experienced an increase in frequency of extreme rain and snow events. These events now occur 85% more frequently than they did 60 years ago, and a storm that used to occur every 12 months now occurs every 6.5 months on an average.[7]

[6] Climate Projections. Resilient MA: Climate Change Clearinghouse for the Commonwealth of Massachusetts. 2022.

[7] *Madsen, Travis, and Nathan Willcox. 2012. When It Rains It Pours – Global Warming and the Increase in Extreme Precipitation. Environment America Research and Policy Center.* *https://environmentamerica.org/sites/environment/files/reports/When%20It%20Rains,%20It%20Pours%20vUS.pdf*.

Figure 33: Boston Water and Sewer Commission inundation model indicating the locations of stormwater or wastewater pipes (yellow), manholes, catch basins, or pipe size changes (blue), and outfalls (red).

Stormwater flooding occurs during a precipitation event where the rate of rainfall is greater than the stormwater system capacity of the piped infrastructure. The piped infrastructure included in the Boston Water and Sewer Commission's city-wide inundation model. Stormwater infrastructure has been identified next to the University Hall and the residence halls. There is likely other infrastructure on campus that has not been included in this model, therefore providing an incomplete representation of stormwater flow and possible flooding. If stormwater systems become overwhelmed it can cause water to inundate roadways and properties. Stormwater flooding can occur anywhere in Boston and is not limited to areas surrounding water bodies. Flood mitigation measures could be considered to mitigate flooding for the affected buildings, roads, and the university community members that live and work here.

EXPOSURE TO WIND RELATED HAZARDS

High winds can occur during hurricanes, tropical storms, tornadoes, nor'easters, and thunderstorms. The University is located in Suffolk County, which has experienced multiple tornadoes and is frequently affected by thunderstorm wind. The University's location along the coast makes the campus more susceptible to high winds. The City of Boston has an ultimate design gust wind speed (highest average speed measured over a three-second interval) of 139 mph for a Risk Category IV building.[8] This means that buildings and other structures represent a substantial hazard to human life in the event of failure, or buildings and other structures designated as essential facilities pose a moderate threat under a high-risk storm event. On March 31st, 2016, the University issued alerts urging community members to avoid the area around

[8] MA State Building Code, 9th ed, Base Volume, Section 1604.11. https://up.codes/viewer_export/juris_key/massachusetts/pub/int_building_code_2015/ref/new_1604.11

Healey Library as strong winds from the Northeast dislodged building material from the library roof.[9] Falling trees and branches during a high wind event can block traffic and emergency routes causing further threats. Downed trees may cause property damage and service disruptions by damaging overhead power lines. The campus does not have any overhead power lines, thus reducing this risk.

EXPOSURE TO HEAT RELATED HAZARDS

High heat and associated dry weather conditions can cause heat related health hazards, HVAC failure, wildfire, and/or drought. From 1979-2018, there were over 11,000 deaths in the United States attributed to heat related causes.[10] The National Weather Service (NWS) issues a Heat Advisory when the Heat Index is forecast to reach 100-104˚F for two or more hours. The NWS issues an Excessive Heat Warning if the Heat Index is forecast to reach 105˚F for two or more hours and a Heat Wave is considered three or more consecutive days with temperatures above 90°F.[11]

By 2030, Boston is projected to experience an average of 12 days per year with maximum temperatures above 90°F. That number is projected to increase to about 39 days by 2070, compared to a historical average of between 7 and 8 days per year.[12] With rising temperatures, there are possibilities of more power cuts in the future due to overloading the electric grid on high heat days. There is no backup power supply for indoor cooling on campus. Also, there is limited heat rejection at low tide and chilled water loop temperature cannot be maintained.

High heat days may also increase the risk of fire hazards. Strong winds can exacerbate extreme fire conditions, especially wind events that persist for long periods, or ones with significant sustained wind speeds that quickly promote fire spread through the movement of embers or exposure within tree-crowns. The chances of wildfires are the highest at the Wildland Urban Interface (WUI) areas. The University is not located in or near a WUI area and therefore has a low wildfire risk.

[9] "Plaza by Healey Library Temporarily Barricaded", The Mass Media. http://www.umassmedia.com/news/plaza-by-healey-library-temporarily-barricaded/article_80ec70b4-f842-11e5-a3d7-674dc20be673.html

[10] Climate Change Indicators: Heat-Related Deaths. EPA, https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths

[11] Heat. NOAA, https://www.weather.gov/bgm/heat

12 Climate Projections. Resilient MA: Climate Change Clearinghouse for the Commonwealth of Massachusetts. 2022.

EXPOSURE TO DROUGHT

Drought is an extended period of deficient precipitation. Drought conditions occur in virtually all climatic zones, yet its characteristics vary significantly from one region to another since it is relative to the normal precipitation in that region. Agriculture, water supply, aquatic ecosystems, wildlife, and the economy are vulnerable to the impacts of drought.[13] While drought is unlikely to have a direct impact on the UMass Boston campus, activities such as water usage contribute to regional stress during drought.

Figure 34 Historical weekly average drought data from 2000 – 2020

The Commonwealth uses a multi-index system to determine the severity of a drought or extended period of dry conditions. A determination of drought level is based on seven indices: Precipitation (percent of normal), Crop Moisture Index, Keetch-Byram Drought Index (KBDI), Groundwater levels, Stream flow levels, and Index Reservoir levels. Drought levels are declared on a regional basis for each of the six regions in Massachusetts. The end of a drought is determined by precipitation and groundwater levels since these have the greatest long-term impact on streamflow, water supply, reservoir levels, soil moisture and potential for forest fires.[14]

Historical drought data was obtained from the US Drought Monitor (USDM) in total number of weeks that each county in MA has been in severe drought condition between 2000 and 2020. The University has historically experienced 42 weeks of severe drought over the past 20 years. This is moderate compared to the rest of the Commonwealth.

Figure 35 Number of historic consecutive dry days experienced in the summer

Since one of the indicators of drought is dry conditions or water deficits, data for the maximum number of consecutive days with daily precipitation less than 0.1 mm was also evaluated. However, the number of consecutive dry days is not directly correlated to the number of weeks of severe drought. The University has historically experienced an average of 8.1 consecutive dry days in the summer months. This is high compared to the rest of Commonwealth. The University relies on the Massachusetts Water Resources Authority (MWRA) for its water supply. The MWRA has redundancy in its water supplies in the Quabbin and Wachusett Watersheds and Reservoirs, improving the resilience compared to sourcing only from local wells and smaller water supplies.

[13] Massachusetts Executive Office of Energy and Environmental Affairs (EEA) and the Massachusetts Emergency Management Agency (MEMA). 2013. Massachusetts Drought Management Plan. https://www.mass.gov/doc/massachusetts-drought-management-plan/download

LIMITATIONS

The climate projections referenced in this report are based on up-to-date climate science and published data available for the region at this time. However, the data do not come without assumptions and uncertainties. The MC-FRM outputs provided by Woods Hole Group are based on underlying climate projections and data provided by others that have not been independently reviewed by the project team. Actual climate conditions will vary and may be more or less extreme than the projections and conditions listed in this report, which may affect the recommendations for flood protection elevation for different planning activities. The Commonwealth of Massachusetts plans to update their climate projections at least every five years through the State Hazard Mitigation and Climate Adaptation Plan process.

3 – ALTERNATIVES ANALYSIS

EXECUTIVE SUMMARY

The goal of this phase is to define and evaluate a variety of options so key UMB stakeholder have all the information they need to determine which is best option to reduce energy and emissions on campus. The team identified typical project types, developed carbon neutral options for each, and presented the optimal solutions for UMB approval. After review with UMB, it was determined that prototypes for the central plant, a major renovation project, and a comprehensive energy project would help create a framework for UMB future planning. Wheatley Hall was identified as the best candidate for a Major Renovation and the Integrated Science Center is the best candidate for a Comprehensive Energy Project.

Project profiles and detailed scope descriptions for the central plant and each prototype project were developed to evaluate and quantify energy, emissions, construction cost, maintenance cost, and life cycle cost. Several scenarios were detailed in order to outline a range of opportunities. These opportunities were compared to a baseline case. The baseline case assumes UMass Boston maintains their existing fossil fuel equipment. The baseline scenario was compared to more efficient scenarios including heat recovery chillers, heat pumps, and geothermal.

Note that the central plant options presented predate the new energy code. These options are no longer compliant with the latest energy code. Therefore, this section serves as a reference point of the cost effectiveness of individual strategies/technologies rather than options that could be adopted for the Implementation Plan. The following Implementation Plan section details a compliant central plant strategy. The major renovation and comprehensive energy project scopes are still acceptable under the new energy code.

This section also includes an evaluation of possible on-site PV and off-site renewable strategies to meet the goals of the “Renovations and Comprehensive” as well as “Energy Projects Renewable and Clean Energy Resource” objectives in Executive Order 594. These strategies can provide a financial benefit to the University while contributing to increasing the amount of renewable electricity in the region.

CENTRAL PLANT OPTIONS

Five (5) options were developed looking at a variety of technologies to help right-size an electrified central plant alternative. Option 1b (Coil Replacement) is expected to be the most cost-effective option. This option consists of heat recovery chillers, air-to-water heat pumps, and geothermal. It is estimated to have a $115M reduction over a 30-year period compared to the Baseline Alternate. In addition, it is estimated to have <1% life cycle cost premium compared to the Natural Gas Baseline. This is primarily due to optimized design and low temperature hot water strategy. This option is only achievable if **all** hot water coils on campus are replaced with low temperature hot water alternatives. Note that these options no longer meet the requirements of the new Stretch Energy Code. However, the analysis provides a relative comparison of the cost effectiveness of varies strategies and informs the prioritization of strategies as part of the Implementation Plan.

	Baseline	Baseline Alt	Option 1	Option 1b	Option 1c	Option 2
	Natural Gas Boilers	Electric Boiler	Geo/ASHP	+ Coil Replacement	+ Seawater Heating	+ Geo Heavy
Construction Cost	6	5	2	4	3	1
Energy Cost	2	1	3	6	5	4
Future Emissions	1	2	3	6	5	4
Campus Area	6	5	2	4	3	1
Maintenance Cost	2	1	5	4	3	6
Water Cost	2	2	4	3	6	5
Life Cycle Cost	6	1	3	5	4	2
Resiliency	5	6	6	6	6	6
Flexibility	5	6	6	6	6	6
Familiarity	6	5	5	5	5	5

1-6 Better relative to others (rank of 6 is best)

Figure 36: Plant options advantages and disadvantages

MAJOR RENOVATION (WHEATLEY HALL)

Based on the current analysis Wheatley Hall, "Good" is expected to be the most cost-effective option given that the project is expected to undergo a major renovation. This option includes air-side energy recovery and decoupled heating/cooling and ventilation. This results in an annual emissions reduced of 36% compared to the Business-as-usual. The recent update to the Stretch Energy Code and Boston's adoption of the Specialized Opt-in Code are likely to require strategies beyond the Business As Usual Case. This will depend on the final project scope.

	BAU	Good	Best
Construction Cost	3	2	1
Energy Cost	1	2	3
Maintenance Cost	3	3	3
Life Cycle Cost	3	3	1
Resiliency	2	2	3
Flexibility	2	2	3
Familiarity	3	3	3

Figure 37: Wheatley Hall options advantages and disadvantages

COMPREHENSIVE ENERGY PROJECT (INTEGRATED SCIENCE CENTER)

Multiple energy projects were evaluated for the Integrated Science Center to reduce energy consumption. These efforts will result in reduced energy consumption, emissions, and right sizing of central plant equipment. There are several systems that are currently not functioning properly: airflow setbacks, heat recovery chiller, Konvekta, and solar thermal systems. Correction of these systems is estimated to result in significant energy reductions particularly heating energy. Also, there are several low hanging energy conservation measure opportunities: LED conversations and lower air-change-rates (ACH).

ALTERNATIVE ENERGY MEASURE DESCRIPTIONS

There are many technologies and fuels that can be considered when developing a carbon neutral master plan. It is important to focus the primary effort on proven solutions, namely energy efficiency, electrification via heat pumps, solar photovoltaic (PV) for on-site renewable energy, and procurement of off-site renewable electricity. But, other technologies and fuels may be considered; some may be valuable as a supplement to the primary strategies, others are not recommended.

This section provides a synopsis of a wider range of technologies and fuels, including a high-level assessment of the emissions, feasibility, cost, and potential resiliency advantages. A recommendation is made for each, listing them as a primary, supplemental or rejected option. The table below provides a quick visual reference, followed by more detailed narratives of the supplemental and rejected options. The primary recommended options are addressed in other sections of the report.

AEM #	Alternative Energy Measure	Low Construction Cost	Low Maintenance	Reduced Energy Cost	Low Life Cycle Cost	Familiar to Facilities Staff	Carbon Emissions Reduction	Resiliency Benefits	Space Requirements	Primary Solution Pass / Fail	Peaking + Back up System Pass / Fail
1	Biodiesel generator	-	-	X	X	X	X X X	✓✓	✓	Fail	Fail
2	Biodiesel boiler	✓	✓	X	X	X	X X X	✓	✓	Fail	Fail
3	Biomass boiler (wood chips)	-	-	✓	X	X	X X X	✓	X	Fail	Fail
4	Electric boiler	✓	✓✓	X X X	X X X	X	X X X	X	✓	Fail	Fail
5	Heat-recovery electric chiller	✓	✓	✓	✓	-	✓✓✓	✓	✓✓	Pass	n/a
6	HP (air-to-water) - large scale	✓	-	X	✓	X	✓✓	X	✓✓✓	Pass	n/a
7	HP (air-to-water) - small scale	✓	-	X	✓	X	✓✓	X	✓✓✓	Pass	n/a
8	GSHP closed loop, horizontal	X	✓✓	✓	-	X	✓✓	X	X X X	Fail	n/a
9	GSHP closed loop, vertical	X	✓✓	✓✓	✓	X	✓✓✓	X	✓	Pass	n/a
10	GSHP open loop	-	X X	✓✓	-	X	✓✓✓	X	✓	Fail	n/a
11	TTES (Tank Thermal Energy Storage)	-	✓✓✓	-	-	-	X	✓	X	Pass	n/a
12	Solar Thermal	X	X	✓	X X	✓	✓	-	X	Fail	n/a
13	Photovoltaics	✓	✓✓✓	✓✓✓	✓✓	✓	-	✓	✓	Pass	n/a
14	Battery storage	X	✓✓	✓	✓	X	✓✓	✓✓	✓	Pass	n/a
15	Wind turbine	X X	✓	✓	X X	X	✓	✓	X X X	Fail	n/a

✓✓✓, ✓✓, ✓ Better relative to others (multiple instances represent better)
X, XX, XXX Worse performance to others (multiple instances represent better)

Figure 38: Alternative energy measure pro/cons

AEM 1, 2 - BIODIESEL GENERATORS + BOILERS

Biodiesel generators combust biodiesel to generate electricity. Biodiesel boilers combust biodiesel to generate heat.

Emissions

Biodiesel may result in lower carbon emissions than conventional fossil fuel diesel and natural gas. But, biodiesel is not life-cycle carbon neutral. There are emissions associated with growing the feedstock and processing and transporting the biodiesel. Per Eversource's 2022 DPU 20-80 individual filing local feedstock supply is a limiting factor in New England.[15] In addition, increased farming for biodiesel feedstock can result in land use changes that further increase the life cycle emissions of biodiesel. Biodiesel also results in lower particulate emissions that conventional fossil fuel diesel. But, biodiesel results in higher particulate emissions than natural gas. Particulates negatively impact air quality and human health.

Feasibility, Cost and Operations

Biodiesel generators, boilers, fuel storage and associated systems is more expensive to procure and higher cost to operate (due to higher maintenance and energy costs) than conventional fossil fuel diesel and natural gas. Therefore, there is no life cycle cost advantage to biodiesel generators. Biodiesel is also less stable than conventional fossil fuel diesel and needs to be consumed and replenished periodically; therefore, biodiesel should not be used solely as a back-up fuel source.

Resiliency

Biodiesel generators offer similar resiliency benefits as conventional fossil fuel diesel generators. They offer greater resilience than natural gas generators for short-term electric power failures, because the fuel is stored on-site. But, they offer lesser resilience than natural gas generators for long-term electric power failures, because they do not have a limitless source of fuel (which natural gas can offer). Fuel delivery may not be achievable in an event.

Recommendation

Biodiesel generators and boilers are not recommended for UMB. This is due to the lack of emissions savings and the large area required for a plant of this type.

AEM 3 - BIOMASS BOILERS

Biomass boilers combust wood chips or wood pellets to generate heat.

Emissions

Biomass may result in lower carbon emissions than conventional fossil fuel diesel and natural gas. But, biomass is not life-cycle carbon neutral. There are emissions associated with growing some types of feedstock and processing and transporting the biomass. In addition, increased farming for some types of biomass feedstock can result in land use changes that further increase the life cycle emissions of biomass. Combustion of biomass results in higher particulate emissions than natural gas. Particulates negatively impact air quality and human health.

Feasibility, Cost and Operations

Biomass boiler plants, including boilers, fuel storage areas, tuck access, and conveying systems requires a large area and is not compatible with urban campuses, such as UMB.

Resiliency

Biomass boilers offer similar resiliency benefits as conventional fossil fuel oil boilers. They offer greater resilience than natural gas generators for short-term electric power failures, because the fuel is stored on-site. But, they offer lesser resilience than natural gas generators for long-term electric power failures, because they do not have a limitless source of fuel (which natural gas can offer). Fuel delivery may not be achievable in an event.

[15] https://www.eversource.com/content/docs/default-source/rates-tariffs/eversource-plan-future-of-gas.pdf?sfvrsn=38fe8d62_2

Recommendation

Biomass boilers are not recommended for UMB. This is due to the lack of emissions savings and the large area required for a plant of this type.

AEM 4 - ELECTRIC BOILERS

Electric boilers use electric resistance to generate heat.

Emissions

Electric resistance results in higher emissions than on-site combustion of natural gas for heating. In the future, as grid emissions become lower, electric resistance will be lower emissions than on-site combustion of natural gas for heating. But, electric resistance heating results in high peak electrical demands, which currently results in operation of the high emissions "peaker" plants on the grid. High peak demands also makes it more difficult (and more expensive) for the grid to shift toward reliance entirely on renewable energy systems, because the energy storage capacity must be increased.

Feasibility, Cost and Operations

Electric resistance boilers require large electric infrastructure and result in high energy costs. Therefore, they are not life cycle cost effective. Operation of electric resistance boilers is relatively simple and low maintenance.

Resiliency

Electric resistance boilers are not a resilient system, because they rely on electricity to operate, and would require large generators, in case of electric grid failure. It is far more efficient and cost effective to rely on combustion boilers as a resilient heating source, than it would be to rely on electric boilers and generators.

Recommendation

Electric resistance boilers could be considered as a small part of a central heating plant, but they provide limited advantages. Therefore, they are not recommended as part of this study. They are provided as an alternative baseline to showcase the advantages of heat pump technology.

AEM 5, 6, 7 - HEAT-RECOVERY ELECTRIC CHILLER AND AIR-SOURCE HEAT PUMPS

Heat recovery electric chillers simultaneously create heating and cooling. This allow for efficient means of thermal generation in the summer time to serve both cooling and reheat needs as well as in the winter time to serve heating needs and base cooling needs. For the purposes of this study, air source heat pumps are only scoped to generating heating. This study also evaluates a custom engineering solution of cascading heat recovery in two stages to achieve high temperature hot water. This is a newer concept at the time of this report and carries inherent Owner as an early adopter of these or any other unconventional technology. Heat-recovery electric chillers and air source heat pumps are recommended as primary systems for UMB. Note that federal and MassSave incentives are currently available for this air source heat pumps. Incentives are time-sensitive and may not be available in the future.

AEM 8, 9, 10 - GROUND-SOURCE HEAT PUMPS

Ground-source heat pump systems rely on electric heat pumps, coupled with a ground heat-exchanger to provide heating and cooling. The ground heat-exchanger can be one of three types: vertical closed loop, horizontal closed loop, and open loop.

Emissions

All types of ground-source heat pump systems result in high-efficiency electric sources of heating and cooling. This results in significantly lower emissions than any combustion or electric resistance-based system.

Feasibility, Cost and Operations

Vertical closed-loop is the most common type of ground-source heat exchanger in this region. This is due to the fact that it requires less area than horizontal ground-source systems and avoids the problems associated with open-loop systems.

Horizontal closed-loop requires approximately 10x the area required for vertical ground-source systems.

Open-loop systems can result in fouling and/or corrosion of pumps and heat exchangers. Contrary to popular belief, open loop systems (assuming no bleed water) do not provide significantly greater capacity than vertical closed-loop systems of similar depth and therefore offer little advantage.

Resiliency

Ground-source heat pumps are not typically considered to be a resilient system, because they rely on electricity to operate, and would require larger generators, in case of electric grid failure. It is less expensive to rely on combustion boilers as a resilient heating source, rather than rely on ground-source heat pump systems and have to increase the capacity of the generators.

Recommendation

Vertical closed loop ground-source heat pump systems are likely a valuable component of the carbon neutral solutions for UMB. This is a highly efficient and all electric heating and cooling source. Note that federal and MassSave incentives are currently available for this technology. Incentives are time-sensitive and may not be available in the future. Horizontal closed loop is not recommended, due to unreasonable space requirements. Open loop is not recommended, due to maintenance risks.

AEM 11 - TANK THERMAL ENERGY STORAGE

Tank thermal energy storage is typically large tanks that store chilled water or hot water, allowing heat pumps to operate more consistently, charging up the tanks during periods of low thermal load, and then simultaneously discharging from the tanks and running the heat pumps during periods of high thermal load. This reduces the required heat pump capacity and reduces peak electric demand on the grid. Given UMB"s expected high temperature hot water needs, a thermal storage tank can be considered as part of a two-stage heating/heat recovery system to meet campus needs.

Emissions

Thermal energy storage can result in reduced operating emissions, when thermal energy is generated and stored during periods of low grid emissions and discharged during periods of high grid emissions.

Feasibility, Cost and Operations

Thermal energy storage is most advantageous when loads are highly variable. The thermal loads for the UMB campus are anticipated to be less variable in the future, as energy retrofit projects are implemented. In addition, to be effective, the volume of thermal storage is very large, requiring a significant amount of space.

Resiliency

Thermal energy storage systems can offer some resiliency advantages by reducing the peak thermal load on back-up heating systems. However, this strategy would not replace the recommended natural gas back-up strategy. This alternative would require additional infrastructure and costs (generators, fuel tanks, switchgear, pumps, piping, etc.). This is not recommended particularly given fuel delivery may not be achievable in an event.

Recommendation

Thermal storage is a critical component and right sized for high temperature hot water two stage heat pump solutions.

AEM 12 - SOLAR THERMAL

Solar thermal is a renewable energy system that relies on solar radiation to provide heating.

Emissions

Solar thermal systems result in zero operating emissions.

Feasibility, Cost and Operations

Solar thermal systems are highly efficient at converting solar energy into a useful energy source. But, the thermal varies from very high values on clear days to zero output at night. It is difficult to align the thermal energy production with the heating demand of a building or campus. Therefore, solar thermal systems are typically paired with large thermal storage tanks. Solar thermal produces more energy between April and August than between September and March, because of the shorter days and lower sun-angle in the Fall and Winter. This does not align well with the heating demand profile of buildings or campuses, particularly when heat recovery systems are in place. Solar thermal systems are also relatively complex and high cost. Therefore, solar thermal systems offer little value, when compared with solar photovoltaic systems and heat pumps.

Resiliency

Solar thermal systems offer little resiliency benefit, due to their reliance on clear skies for optimal output.

Recommendation

Solar thermal systems are not recommended as a primary component of the alternative energy systems for UMB. This is largely due to the fact that solar photovoltaic systems and heat pumps systems can perform a similar role and are lower cost to install, are more life cycle cost effective and offer greater flexibility and emissions reduction.

AEM 13, 14 - SOLAR PHOTOVOLTAIC + BATTERY STORAGE

Solar photovoltaic (PV) is a renewable energy system that relies on solar radiation to produce electricity. Batteries allow storage of electricity and offer peak-shaving opportunities.

Emissions

Solar PV systems result in zero operating emissions. Batteries can result in reduced operating emissions, when electricity is stored during periods of low grid emissions and discharged during periods of high grid emissions.

Feasibility, Cost and Operations

Solar PV systems are feasible, cost effective and low maintenance. The SMART incentive program is a key factor in cost effectiveness of these projects. As part of the SMART incentive, UMB does not own the REC. Therefore, this asset would not be able to be used towards their carbon neutral goal. Other RECs could be procured ("REC arbitrage"). Alternatively, a third-party developer could offer a power purchase agreement (PPA) in which case UMB does not own the system but pays a lower rate for electricity.

Battery systems vary in terms of cost-effectiveness, based on the building demand profile and the SMART incentive program. Projects can also participate in utility demand response program. This program provides a $200/kW demand response incentive. If the ESS can utilize 50% of its capacity to support demand response, it can also receive a higher incentive. This amount is not guaranteed annually for the life of the project but, we believe, load management will demand more and more value as such, we have a high confidence in there being some demand response incentive in place for at least 10-years if not more.

Resiliency

Solar PV systems and batteries can offer some resiliency advantages by reducing the electric load on generators.

Recommendation

Solar PV is recommended and, in some instances, batteries are recommended for UMB. The evaluation of solar PV and batteries is addressed in detail in a separate section of this report. Note that federal and state incentives are currently available for this technology. Incentives are time-sensitive and may not be available in the future.

AEM 15 - WIND TURBINES

Wind turbines are a renewable energy system that relies on wind to generate electricity.

Emissions

Wind turbines result in zero operating emissions.

Feasibility, Cost and Operations

Small-scale wind turbines are not cost effective and are typically used only as a visual indication that renewable energy is being generated on a site. This is not a local reason to install a renewable energy system. Large-scale wind turbines are marginally cost-effective in sub-optimal sites, such as the UMB campus. In addition, they result in a "strobe" effect, due to the moving shadows of the blades. Urban sites are not an appropriate application and are typically met with stiff opposition from nearby residents.

Resiliency

When paired with batteries and solar PV systems, wind turbines can offer some resiliency advantages by reducing the electric load on generators.

Recommendation

Wind turbines are not recommended for UMB. This is largely due to the fact that solar PV systems can perform a similar role and are lower cost to install, are more life cycle cost effective and are less likely to raise opposition from neighbors.

Other Considerations

In addition to the technologies outlined above, there are also two fuel sources that are not recommended, but may be considered in the future for UMB. These are renewable gas and hydrogen and are outlined below. Additional consideration will have to be given considering relative location to Logan International Airport.

RENEWABLE GAS

Renewable gas is a term that is used to describe methane from renewable or waste sources. This includes methane collected from landfill sites and anaerobic digesters. In rural settings or sites adjacent to landfills, the methane can be piped directly to combustion equipment such as generators and boilers. In some cases, the methane is injected into the natural gas utility distribution network. When methane from renewable or waste sources is injected into the natural gas utility distribution network, a renewable gas certificate may be generated, which can then be purchased by natural gas consumers to offset the carbon footprint of the gas that they consume (assuming that the renewable gas credits meet additionality standards). Per Eversource's 2022 DPU 20-80 individual filing that RNG supply is not approaching technical market potential due primarily to economics, cost, and local feedstock supply.[16]

For buildings and campuses in urban settings, the only reasonable means of relying on renewable gas is to purchase renewable gas credits. The process of procuring renewable gas credits is similar to the process commonly used to procure renewable electricity credits for electricity.

Emissions

Renewable gas may be considered carbon neutral. But, renewable gas represents a very small percentage of natural gas production and is not typically considered a significant opportunity to decarbonize the majority of building thermal energy needs.

Feasibility, Cost and Operations

When renewable gas credits are purchased, it has no direct impact on the fuel source for buildings and campuses; natural gas would still be combusted on-site. Therefore, conventional natural gas generators and boilers would continue to be used and natural gas would still be consumed. Procuring the renewable gas credits would simply be an additional operating cost. Therefore, there is no life cycle cost advantage to renewable gas.

[16] https://www.eversource.com/content/docs/default-source/rates-tariffs/eversource-plan-future-of-gas.pdf?sfvrsn=38fe8d62_2

Resiliency

Renewable gas offers no resiliency advantages beyond conventional natural gas-based systems.

Recommendation

If UMB continues to consume natural gas and renewable gas becomes economically feasible, then it is recommended UMB review if credits meet additionality standards. This should be considered only after the natural gas consumption has been reduced to a very small value.

HYDROGEN

Hydrogen is a combustion fuel that can be generated from renewable electricity, through the process of electrolysis. In this case, it is essentially a means of storing renewable energy. Hydrogen can be stored and distributed as a liquid fuel, most often used as a fuel for transportation. Hydrogen can also be injected into the natural gas utility distribution network, but typically only at low concentrations.

Emissions

Hydrogen, when generated from renewable energy, may be considered a carbon neutral fuel. But, it is far more energy efficient to use the renewable energy directly, particularly when heat pumps are used for heating.

Feasibility, Cost and Operations

Hydrogen is primarily a means of energy storage, similar to batteries. But, other battery technologies are currently more cost effective and common in campus settings. Therefore, there is no life cycle cost advantage to hydrogen. While an abundance of seawater is available, limited technological advancements with seawater electrolyzers and an urban environment with limited space for associated infrastructure and renewable energy production suggest on-site hydrogen production is not feasible at this time.

Resiliency

Hydrogen offers no resiliency advantages, compared to other energy storage technologies.

Recommendation

The hydrogen industry has not been extensively developed for building energy needs and is more commonly used to fuel transportation. Direct utilization of renewable energy to operate heat pumps for emission-free heating and other battery technologies for energy storage have largely overtaken hydrogen technology. Therefore, hydrogen technology is not recommended for UMB.

CENTRAL PLANT OPTIONS

This section of the report provides a summary of the central plant option analysis. It includes a scope matrix that defines the system options, the load profiles used as a basis for the energy calculations, a summary of the geothermal bore field study, a summary of the results for energy and energy cost, emissions, construction costs, life cycle costs, and an overall summary. This analysis accounts for the future weather and growth of the campus planned until the year 2050. It assumes that all buildings on the campus will be connected to the campus district energy system including the buildings that are currently using electric resistance heating. Note that this analysis is considered a “business as usual” scenario and therefore does not include any other energy efficiency improvements to the existing buildings.

The underlying concept behind the central plant electrification options are heat recovery, repurposing waste heat from cooling as useful thermal energy for heating buildings and processes. Existing energy data and future energy modeling confirm the campus has year-round heating and cooling loads.

Although the fundamental principle of using waste heat from cooling to provide useful heat for HVAC loads is relatively straightforward, some unique types of equipment are required to integrate this solution into the existing campus utilities. Currently, heating hot water is distributed throughout campus at temperatures as high as 190°F for heating. Conventional heat recovery chillers can only generate hot water up to around 140°F. To overcome this limitation, the options utilize a two-stage approach, where waste heat is collected from auxiliary heat recovery condensers fitted to the cooling chillers at an intermediate temperature (approximately 100°F) and heat pumps are used to boost the temperature to hot water and/or steam, depending on the option. The heat recovery loop also includes a large thermal buffer tank to allow the heat pumps to operate without having to exactly match instantaneous cooling demand. The heat recovery loop can also be used to add external heat into the system through air-source or ground-source heat pumps.

The options described in the following section would provide electrification for part of the future campus peak heating demand, which is estimated at approximately 60,000 MBH. All options include gas boilers to support peak heating conditions when outside air temperatures are below 10°F. Note that this is a risk given possible rising natural gas operational costs due to electrification. Note that the central plant options presented predate the new energy code. These options are no longer compliant with the latest energy code. Therefore, this section serves as a reference point of the cost effectiveness of individual strategies/technologies rather than options that could be adopted for the Implementation Plan. The following Implementation Plan section details a compliant central plant strategy. The major renovation and comprehensive energy project scopes are still acceptable under the new energy code.

While the central focus of the study is electrification, the options include replacing most of the central heating and cooling infrastructure (boilers, chillers, pumps), as much of the equivalent equipment in the existing plant is aging and will need to be replaced before 2040. The necessity for deferred maintenance provides a good opportunity to upgrade equipment for heat recovery and electrification. This also affords UMB an opportunity to move the existing central plant equipment out of its current location into a new location given that the current equipment may be below the future flood risks. Regardless, a new central plant will be required as future growth is expected to exceed the current plant capacity.

Note that increased electrical demand in all options is not expected to necessitate a utility service upgrade.

Maintenance and staffing requirements required further review given that recommended equipment is not currently on campus.

BASELINE – NATURAL GAS BOILERS

The baseline approach assumes the UMB maintains the natural gas boilers for heating. Conventional chillers and cooling tower are used in existing and new central plant. A new central plant space is expected to be required for additional boilers, chillers, and cooling towers to meet future campus growth heating needs.

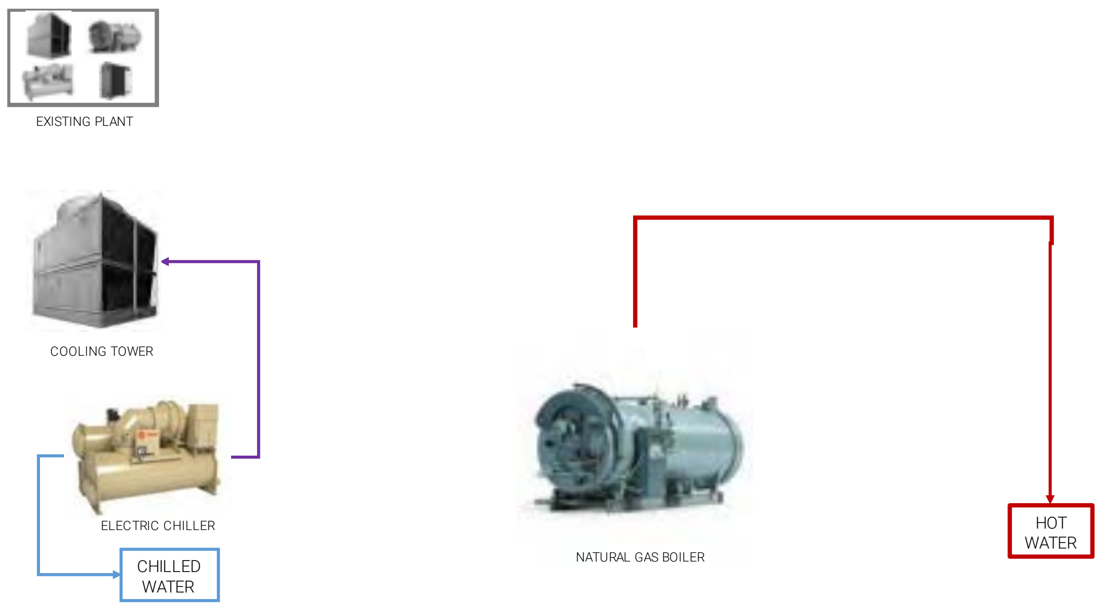


Figure 39: Central Plant Baseline Option Equipment Configuration

BASELINE ALTERNATIVE – ELECTRIC BOILERS

The baseline alternative is an approach for electrifying the central plant with electric hot water boilers. The electric boilers would functionally replace the existing gas-fired boilers, although gas boilers would still be used as peaking. A new central plant space is expected to be required for this equipment as well as additional boilers, chillers, and cooling tower to meet future campus growth heating and cooling needs.

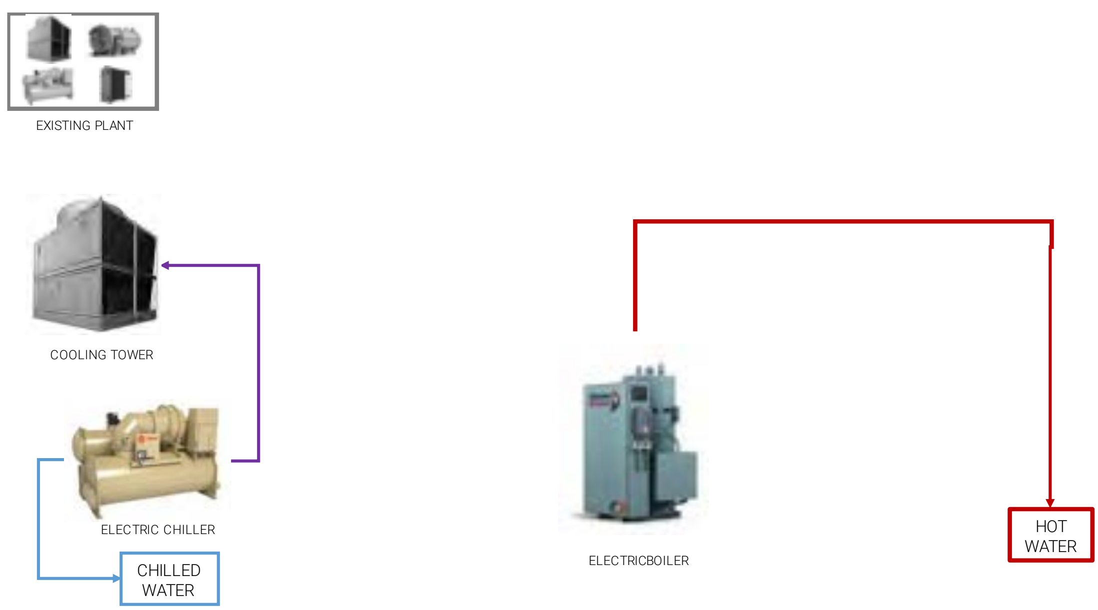


Figure 40: Central Plant Alternative Baseline Option Equipment Configuration

OPTION 1– GEOTHERMAL/AIR-TO-WATER HEAT PUMPS

In Option 1, waste heat is used to generate high temperature hot water (150 °F) using a high temperature centrifugal heat pump. From a mechanical standpoint, the heat pump is a conventional centrifugal chiller with the evaporator connected to the heat recovery loop. This arrangement is called a "Cascade" and is conceptually similar to a series counterflow chiller configuration. This concept was developed around Trane CVHF chillers similar to what is currently installed in the plant. This option includes a large waste heat storage tank. The extent to which this supplemental heat is required depends on the actual heating and cooling profile for the campus and may change over time based on weather, campus growth, and plant operations. This equipment is expected to meet the needs of summer heating and winter cooling. Therefore, review of the future effectiveness of the seawater cooling system should be reviewed for cost effectiveness as the heat traditional rejected into the seawater is now being repurposed to meet the heating needs of the campus. Natural gas boilers would be used to produce peak hot water system when there is insufficient waste heat for the heat pumps.

Waste heat is also generated from air-to-water heat pumps and geothermal heat pumps. Air-to-water heat pumps would be located on the roof of the new central utility plant. Geothermal bore fields are specified for the future campus quad and ISC green space.

An advantage of the high temperature heat pump is that it can be configured to operate as a back-up chiller, saving upfront costs for redundant primary chilled water equipment. Using waste heat for heating instead of rejecting to a cooling tower also saves water. This configuration also allows for simple conversion to low temperature hot water in the future by removing the high temperature heat pump once all campus heating coils have been converted to low temperature.

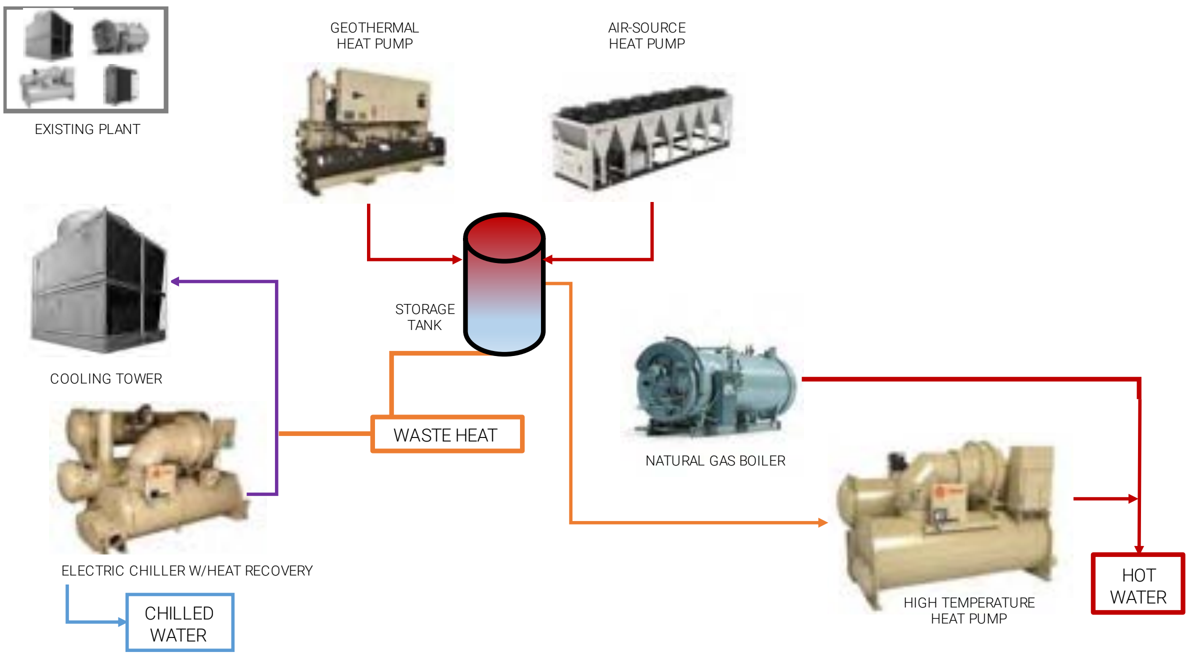


Figure 41: Central Plant Option 1 Equipment Configuration

OPTION 1B – GEOTHERMAL/AIR-TO-WATER HEAT PUMPS + LOW TEMPERATURE HOT WATER

The heating hot water system could gradually transition to lower temperature (120-130°F) with incremental retrofits to building heating coils. Lower temperatures would improve the efficiency of the heat pumps. This option is explored in Option 1B.

Air handling unit heating and reheat coils, variable air volume reheats, fan coil unit, and fin tube radiation coils at University Hall, Campus Center, Residence Hall, Integrated Science Center, and Clark would have to be replaced. The majority of this equipment is expected to be in need of replacement prior to 2050. All other buildings are expected to undergo major renovation. New equipment installed as part of major renovations is recommended to utilize low temperature hot water coils (110-120°F).

In the previous option, the only thermal source for the heat pumps is cooling waste heat. In Option 1B, the geothermal and air-source heat pump injecting low temperature hot water directly into the distribution loop. Geothermal borefields are only specified for the new campus quad. **This option is only achievable if all hot water coils on campus are replaced with low temperature hot water alternatives.**

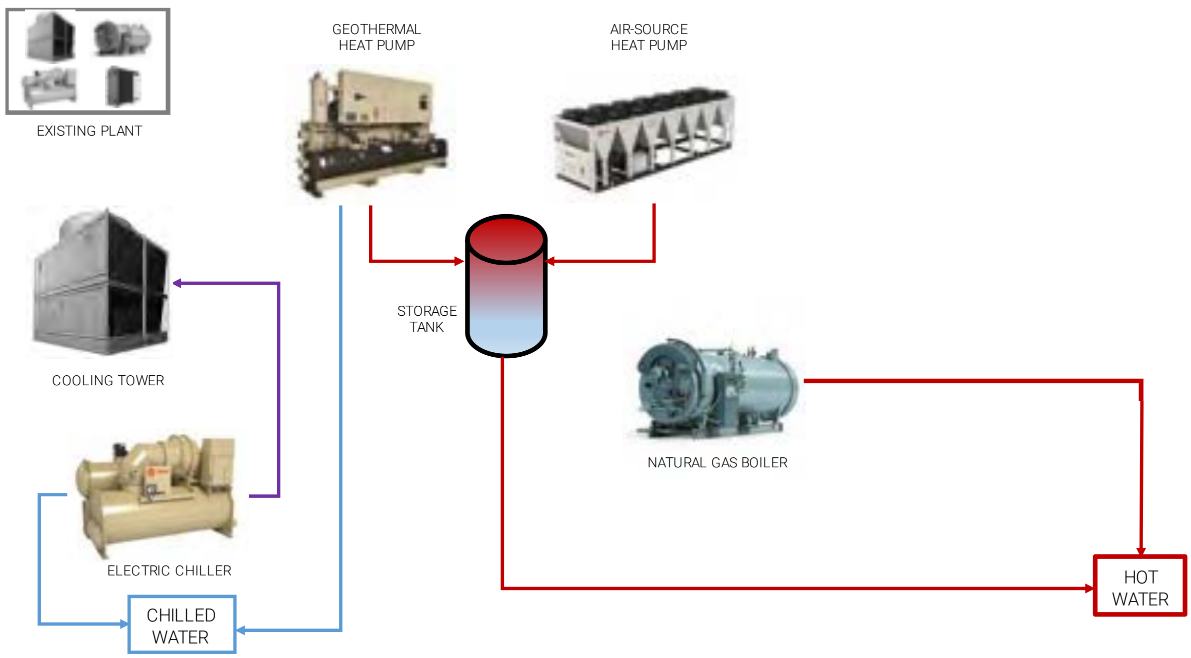


Figure 42: Central Plant Option 1b Equipment Configuration

OPTION 1C– SEAWATER/AIR-TO-WATER HEAT PUMPS

This option is similar to Option 1 except the existing seawater condenser loop is reconfigured such that heat pumps can provide both cooling and waste heat energy. This would require the CH-2,-3,-4 condenser piping to connect to the existing and new cooling towers. New heat pumps would be installed in the new central plant to provide both cooling (similar to the existing chillers) and waste heat. The seawater waste heat system can replace the need for a geothermal system. **This option is only achievable if the current seawater permit can be amended to allow for heating.**

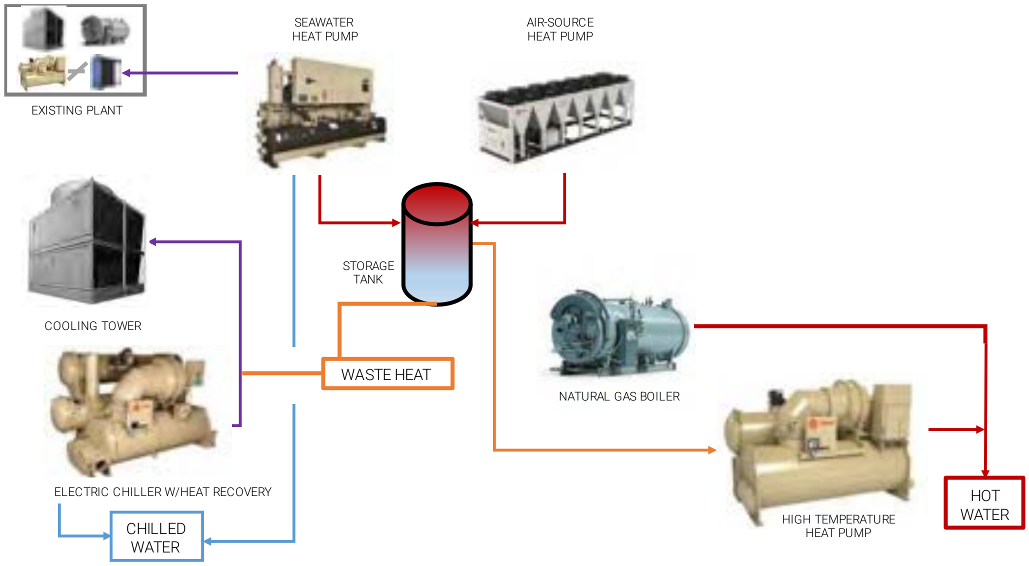


Figure 43: Central Plant Option 1c Equipment Configuration

OPTION 2 – GEOTHERMAL HEAVY/ AIR-TO-WATER HEAT PUMPS

This option is similar to Option 1 except the geothermal capacity is increased. Geothermal bore fields are specified for the future campus quad, ISC green space, and Campus Center green space. Natural gas boilers would be used to produce peak hot water system when there is insufficient waste heat for the heat pumps.

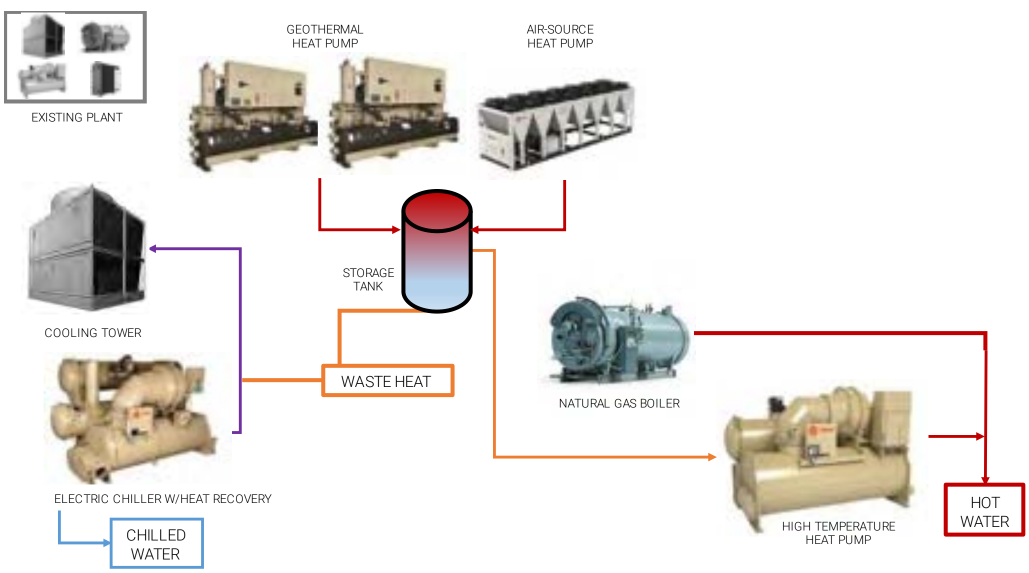


Figure 44: Central Plant Option 2 Equipment Configuration

OPTIONS DESCRIPTIONS/MATRIX

	Baseline Natural Gas	Baseline Alt. Electric Boilers	Option 1 + Geo/ASHP	Option 1b + Coil Replacement	Option 1c + Seawater Heating	Option 2 + Geo Heavy
CHW Chillers	Replace (4) existing 2,000 ton centrifugal chillers Install (2) new 2,000 ton chillers (in new plant) similar to York YK Change from variable primary to primary/secondary Provide (6+1) 3200 gpm (100 HP) primary pumps and (3+1) 6400 gpm (270 HP) secondary pumps	Same as Baseline	Replace (4) existing 2,000 ton centrifugal chillers similar to Trane CentraVac Install (1) new 1,600 ton centrifugal chillers similar to Trane CentraVac with full heat recovery Install (1) new 800 ton centrifugal chillers similar to Trane CentraVac with full heat recovery Provide (5+1) 3400 gpm (110 HP) primary pumps and (3+1) 5600 gpm (240 HP) secondary pumps	Same as Option 1	Same as Option 1	Same as Option 1
Cooling Towers	Replace (2) existing 2,500 ton cooling towers Install (3) new 2,500 ton cooling towers (in new plant) Provide (5+1) 6000 gpm (180 HP) condenser water pumps	Same as Baseline	Replace (2) existing 2,500 ton cooling towers Install (2) new 2,500 ton cooling towers (in new plant) Provide (4+1) 4000 gpm (120 HP) condenser water pumps	Same as Option 1	Same as Option 1	Same as Option 1
Seawater Exchange	Preventative maintenance (3) 37,500 MBH HXs, replace (1) 18,750 MBH HX	Same as Baseline	Same as Baseline	Same as Baseline	Preventative maintenance (3) 37,500 MBH HXs, replace (1) 18,750 MBH HX Install (3) new 1,000 ton centrifugal chillers (glycol) similar to Trane CentraVac with full heat recovery (3) 300 Ton modular screw heat pump (glycol) similar to Trane RTWD Provide (6+1) 1600 gpm (50 hp) primary pumps, (6+1) 1600 gpm (50 hp) primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank Provide contingency for piping reconfiguration such that CH--2,-3,-4 are repiped to connect to only the cooling towers and specified heat pumps are utilize current seawater heat exchangers, piping, etc.Assume seawater condenser loop is glycol and requires glycol fill and associated accessories.	Same as Baseline
Heat Recovery Chillers	n/a	n/a	Install (2) 22,000 MBH centrifugal and (2) 5,000 MBH screw high temperature cascading heat pump (@150F HWS) similar to Trane CentraVac (1) 22000 MBH plate frame heat exchanger Provide (2+1) 3000 gpm (90 HP) pumps, (2+1) 1500 gpm (90 HP) pumps, (2+1) 1500 gpm (90 HP) pumps Provide (2) 700 gpm (20 HP) pumps, (2) 700 gpm (20 HP) pumps, (2) 700 gpm (20 HP) pumps	Install (5) 170 Ton screw heat pump (@130F HWS) similar to Trane RTWD Provide (5+1) 300 gpm (10 HP) pumps, (5+1) 300 gpm (10 HP) pumps	Same as Option 1	Same as Option 1
Heat Recovery Loop	n/a	n/a	Install 16" Heat Recovery Supply and Return loop in New CUP	n/a	Same as Option 1	Same as Option 1
Thermal Storage	n/a	n/a	Provide 400,000 gallon heat recovery thermal storage tank Approx (25' diameter x 30' height)	Same as Option 1	Same as Option 1	Same as Option 1
GSHP / Geo	n/a	n/a	(4) 300 Ton modular screw heat pump similar to Trane RTHD Closed Loop Vertical Borefield 289 Boreholes at 500 ft depth Provide (4+1) 750 gpm (35 HP) geothermal pumps and (4+1) 750 gpm (15 HP) primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank	(2) 300 Ton modular screw heat pump similar to Trane RTHD Closed Loop Vertical Borefield 145 Boreholes at 500 ft depth Provide (2+1) 750 gpm (35 HP) geothermal pumps and (2+1) 750 gpm (15 HP) primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank	n/a	(6) 300 Ton modular screw heat pump similar to Trane RTHD Closed Loop Vertical Borefield 434 Boreholes at 500 ft depth Provide (6+1) 750 gpm (35 HP) geothermal pumps and (6+1) 750 gpm (15 HP) primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank
Air-to-water Heat Pumps	n/a	n/a	(17) 230 Ton Air-to-Water heat pumps similar to Trane ACX Provide (3) 1000 gpm (20 hp) and (3) 2000 gpm (35 hp) primary HW pumps Heat pumps configured to charge heat recovery loop and thermal storage tank	(19) 230 Ton Air-to-Water heat pumps similar to Trane ACX Provide (4) 1000 gpm (20 hp) and (3) 2000 gpm (35 hp) primary HW pumps Heat pumps configured to charge heat recovery loop and thermal storage tank	Same as Option 1	(15) 230 Ton Air-to-Water heat pumps similar to Trane ACX Provide (4) 1000 gpm (20 hp) and (2) 2000 gpm (35 hp) primary HW pumps Heat pumps configured to charge heat recovery loop and thermal storage tank
Electric Boilers	n/a	Install (2) 2.5 MW Hot Water Electric Boilers similar to Cleaver Brook WB 480V Operating Voltage	n/a	n/a	n/a	n/a
Natural Gas Boilers	Replace in kind (3) 800 BHP and (1) 400 BHP natural gas hot water boilers Add (4) 800 BHP natural gas hot water boilers (in new plant) similar to Cleaver Brooks CBLE	(Backup only) Replace in kind (3) 800 BHP and (1) 400 BHP natural gas hot water boilers Add (4) 800 BHP natural gas hot water boilers (in new plant) similar to Cleaver Brooks CBLE	Same as Baseline Alt.	Same as Baseline Alt.	Same as Baseline Alt.	Same as Baseline Alt.
Building DHW Considerations	n/a	n/a	Replace indirect gas DHW heaters with electric at the following buidlings: Campus Center: (2) 100kW 600 gal electric water heater (similar to PVI Durawatt)	Same as Option 1	Same as Option 1	Same as Option 1
Buiding Coil Replacements	n/a	n/a	n/a	Replace AHU coils and fin tube with low-temperature HW coils (see existing conditions report) University Hall Campus Center Residence Hall ISC Clark Replace VAV with reheats (with low-temperature HW coils) University Hall (1/1200 sf) Campus Center (1/1200 sf) Residence Hall (~17 total) ISC (1/450 sf) Replace FCUs with low-temperature HW coils Residence Hall (1/450 sf) Note that fin tube radiation, radiant panel, and similar heating only terminal equipment will also have to be replaced. Assume contingency allocation.	n/a	n/a
Electrical Service	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (2) 15kV padmounted switches Provide (4) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (4) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV: 480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads. Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)
Space Requirements	Approx 6,000 sf of new CUP, including 1,000 sf of double-height space	Approx 9,000 sf new CUP, including 1,000 sf of double-height space	Approx 15,000 sf of new CUP, including 4,000 sf of double-height space Alt: Provide +20,000 sf of future space for new equipment to replace current CUP equipment at end of life	Approx 12,000 sf of new CUP, including 3,000 sf of double-height space	Approx 17,000 sf of new CUP, including 4,500 sf of double-height space	Approx 15,000 sf of new CUP, including 4,000 sf of double-height space

Figure 45: Central Plant Option Matrix

GEOTHERMAL MAP

The map below details the areas of campus that have been scoped for geothermal. The map shows a wide range of potential options. The areas assume 500' deep boreholes at 20'x20' foot spacing yielding ~2.5 tons of heating per borehole. A test bore is strongly recommended to validate these assumptions. Note that care was taken to locate boreholes near the current Central Utility Plant particularly in anticipation that the future central plant expansion is recommended adjacent. Other areas of the campus are available. However, additional bore fields sites are not expected to be cost effective as detailed in the life cycle cost analysis of this section. Additional considerations include:

- Soil management: UMass Boston is situated on a former municipal landfill and must follow rules set forth by regulations developed and monitored by the Massachusetts Department of Environmental Protection (DEP). UMass Boston's Excavated Materials Management plan is a comprehensive plan for handling soil safely. Whenever soil below the landfill cap is disturbed, a series of protocols are followed.
- Bioswales/drainage: The current design of the campus quad includes bioswales and other stormwater management strategies. Care should as it relates to this design to accommodate boreholes and associated piping distribution between the boreholes and central plant. (Noted by Dennis Swinford on 9/30/22)

Update: rea "1, 1b, 2" is no longer a viable location due to planned engineered stormwater systems.

Figure 46: Possible geothermal field well locations

CENTRAL PLANT EXPANSION LOCATIONS

The map below details the relative sizes of each options' estimated central plant expansion. Expansion is expected regardless of option due to campus building and program growth. In general, the options with high temperature heat pumps have require a greater area given this additional equipment including redundancy/resiliency of gas-fired equipment. The expansions were thoughtfully collocated near the existing Central Utility Plant, main electrical infrastructure, and associated distribution. Relocation of the greenhouse will be a consideration. In addition, expansion to support resiliency requiring reconfiguration of the HHW/CHW distribution is recommended for further discussion with the stakeholder team. See "Campus Resiliency" section for more details. Note that these areas are not reserved as part of the current Master Planning effort at this time.

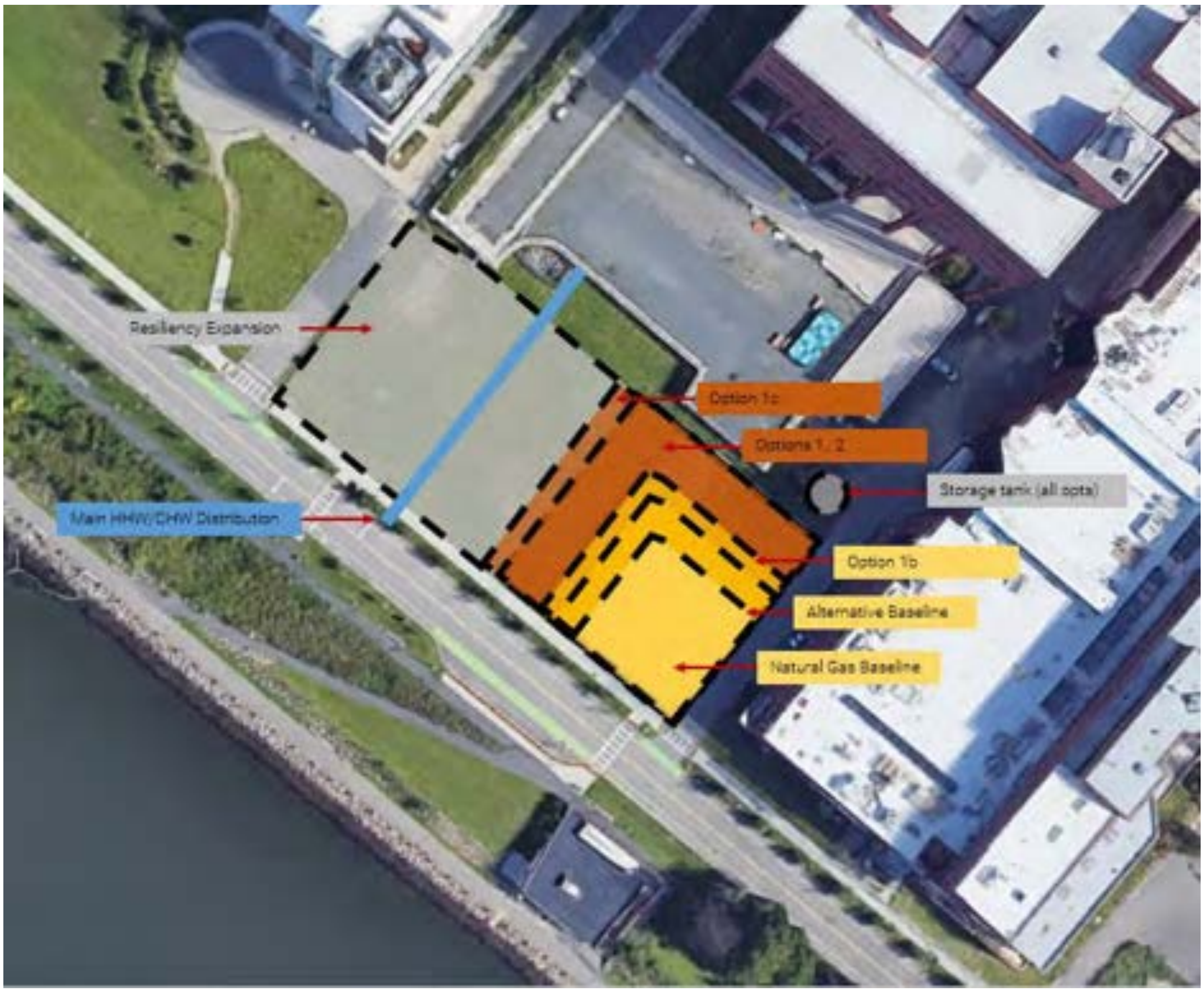
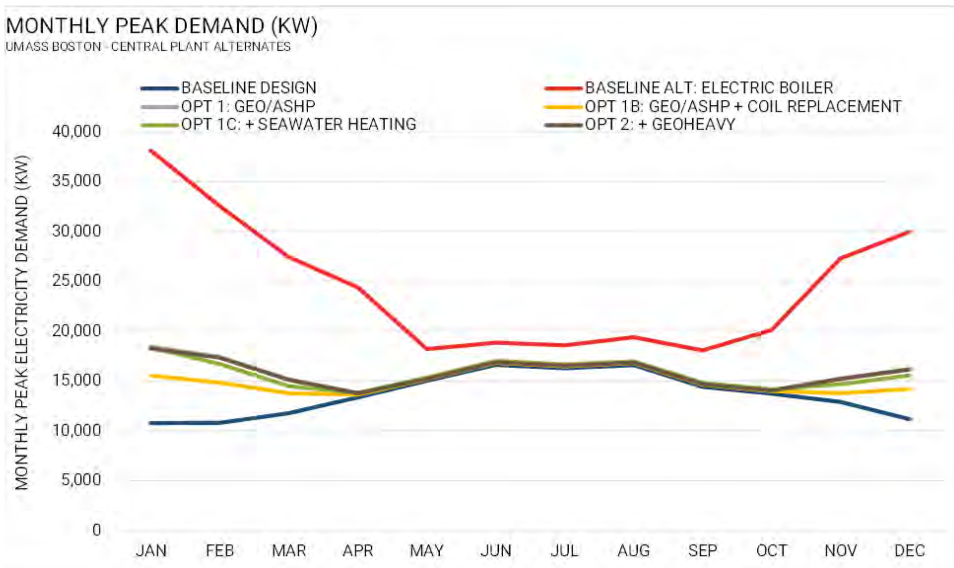


Figure 47: Possible central plant expansion locations

LOAD COMPARISON

The figure below shows the annual electricity profiles for each of the central plant alternates. As expected, the baseline alternate with electric boilers shows the highest electrical peak demand of 38 MW in the month of January. It is worth noting that the high-efficiency all-electric central plant alternates (Options1, 1C and 2) show a marginal 2-3% increase in the peak electricity demand. Additionally, option 1B demonstrates a potential reduction of nearly 7% compared to the Baseline Design primarily due to the high-efficiency water cooled chillers with heat recovery embedded in the design and the coil replacement that allows the heat pumps to operate efficiently in the winter months. The electricity demand for the high-efficiency alternates increases by 50-80% in January in comparison to the existing central plant with natural gas boilers. Although the operational demand for electricity would be higher than the current campus experiences, the existing electric infrastructure is understood to be large enough to accommodate an efficient all-electric central plant.



	Existing central plant with future load	Baseline Alt: Electric Boiler	Opt 1: GEO/ASHP	Opt 1B: GEO/ASHP + Coil Replacement	Opt 1C: + Seawater Heating	Opt 2: + Geoheavy
Monthly Peak Demand in KW	18,030	38,090	18,440	16,830	18,340	18,240
Demand month	June	January	January	June	January	January

Figure 48: Monthly peak electricity demand for central plant alternates

The figure below shows the predicted annual load distribution between the different heating systems for Option 1: Geo/ASHP scenario. The load distribution shows that the campus has tremendous opportunity to recover heat from within the buildings. With the limited capacity well-field evaluated in this option, it is able to offset nearly 11% of the heating load. Air source heat pumps and the cascading heat pumps assist in providing the rest of the heating demands on campus. It must be noted that with the cascading heat pumps in place, the gas boilers are expected to be operational at temperatures below 10°F and will manage less than 1% of the overall heating load.

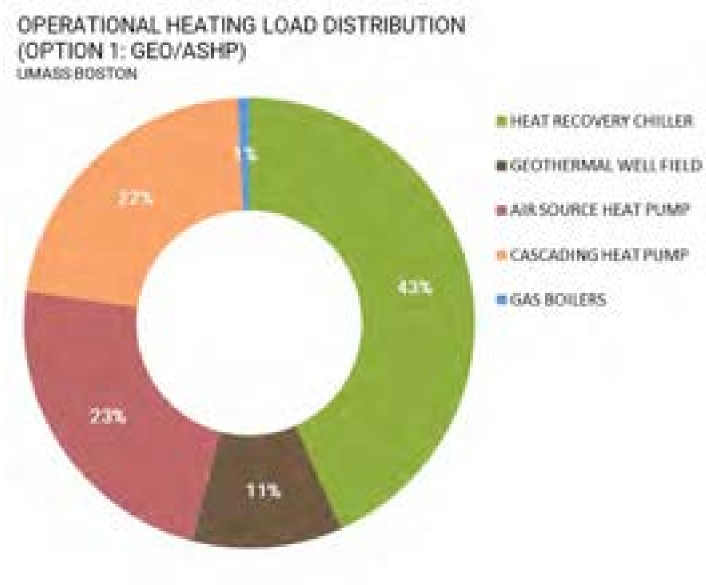


Figure 49: Annual load distribution- heating plant (Option 1)

ENERGY RESULTS

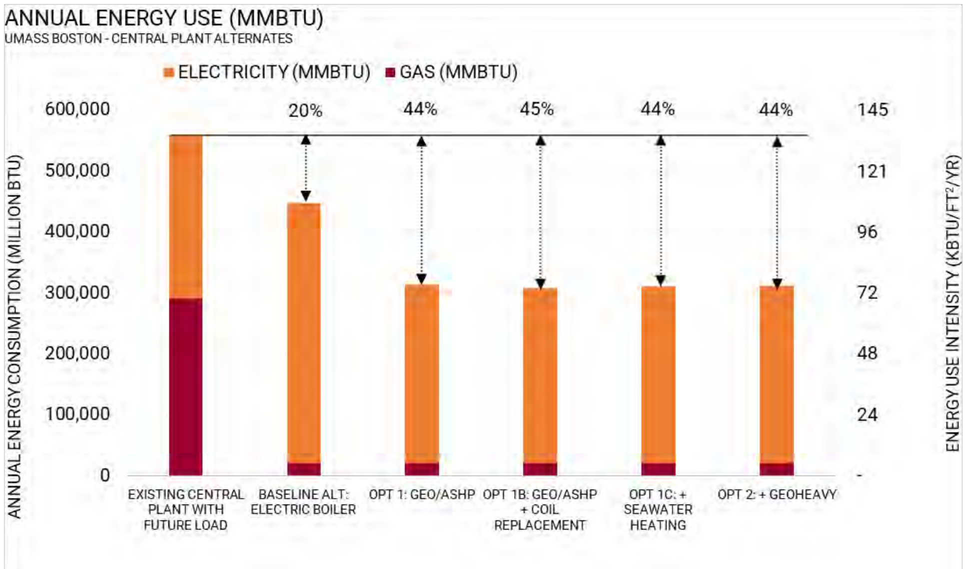


Figure 50: Annual energy comparison for central plant alternates

As seen in the figure above, upgrading the hot water plant with new electric boilers, and replacing the existing chillers with new conventional water-cooled chillers could potentially demonstrate 20% savings in energy use compared to the existing central plant. Options 1, 1B, 1C, and 2 include heat recovery chillers, and heat pumps, showing on the order of 45% savings in the overall site energy use. These high-efficiency electric heating systems nearly eliminate the consumption of natural gas for space heating. It must be noted that the gas consumption for the all-electric alternates as indicated on the graph is associated with commercial kitchens and lab process loads.

ENERGY COST RESULTS

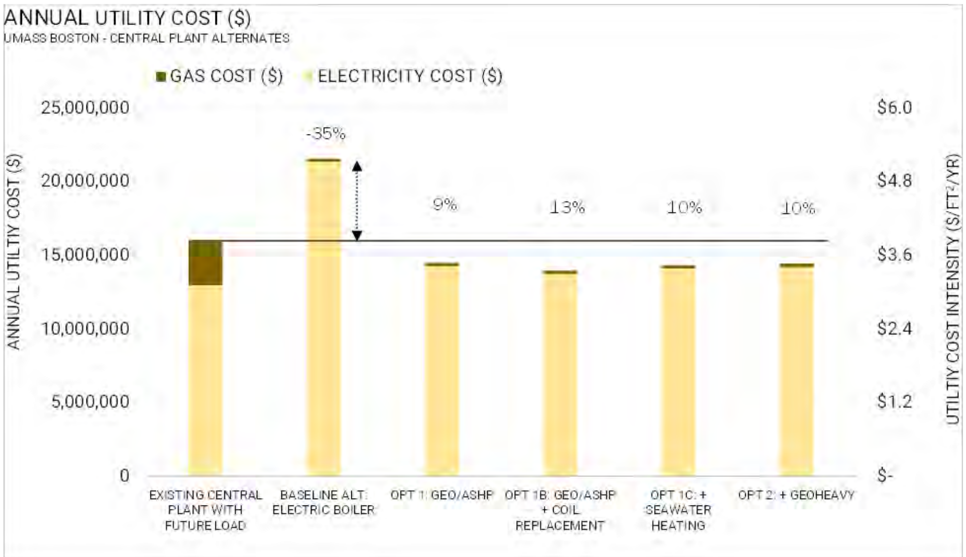


Figure 51: Annual utility cost comparison for central plant alternates – 2022 utility rates

The figure above shows the annual utility costs for all central plant alternatives compared to the existing central plant with new natural gas boilers and conventional electric chillers. This analysis assumes the 2022 utility rate structure and accounts for the electricity demand charges. See Appendix F for assumed rate structures. The annual electricity cost comprises 40-50% of the electric utility cost from the electricity demand and supply charges for the all-electric central plant alternates. As anticipated, the Baseline Alternative with electric boilers shows a significant increase in utility cost. The high-efficiency all-electric options 1, 1B, 1C and 2 show a 9 - 13% decrease in utility cost compared to the Baseline case.

EMISSIONS RESULTS

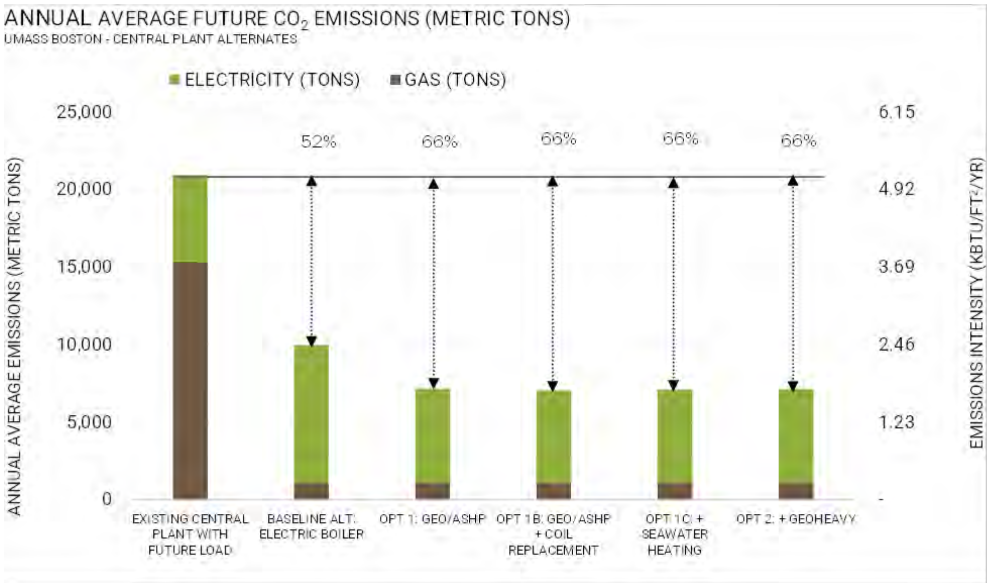


Figure 52: Annual greenhouse gas emissions comparison for central plant alternates in 2050

The figure above shows the estimated greenhouse gas emissions (GHG) for the campus existing buildings and the future growth. See Appendix F for assumed emission rates. The analysis assumes the predicted electricity emissions factors for the year 2050, which is projected to be a third of the current electricity emissions factors. With the emissions intensity threshold requirements put forth by the Building Energy Reporting and Disclosure (BERDO) and the net zero emissions goal by 2050 as described under Executive Order 594, high-efficiency all-electric heating plant is a priority for UMB. As the electric grid is expected to get cleaner, Options 1, 1B, 1C, and 2 show more than 65% reduction in GHG emissions compared to the existing central plant. Note that the gas emissions indicated in the all-electric central plant alternates are associated to the commercial kitchens and lab process loads.

CONSTRUCTION COST COMPARISON

The equipment costs detailed by Vermeulens reflect a conceptual cost estimate. Each equipment type cost is isolated to show the relative cost impact for each equipment option considered. The figure below represents the relative cost for each equipment option when compared to the Natural Gas Boiler Baseline.

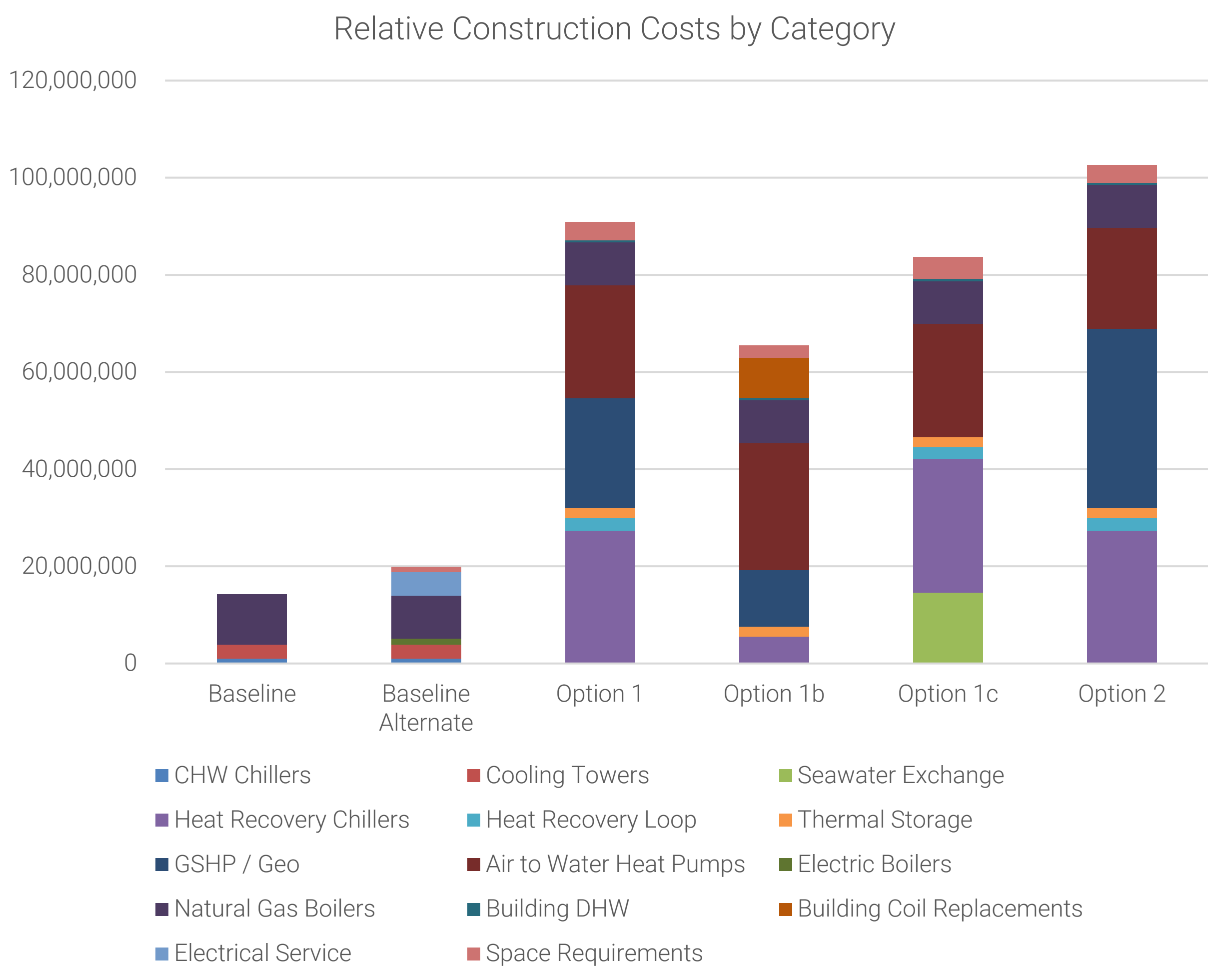


Figure 53: Relative construction costs associated with each equipment category of each equipment configuration option

All options have a first cost premium compared to the Baseline and Alternative Baseline. The largest equipment premiums are air-to-water heat pumps, geothermal, and heat recovery chillers. As more boreholes are required, the areas are more remote from the proposed central plant location. Therefore, there is a premium associated with horizontal pipe runs. Option 2 has the highest premium these considerations. Option 1b yields the lowest relative construction cost premium compared to the baseline totaling $51M. See Appendix H for more details. Note that this does not include additional first cost savings as a result of energy efficiency.

LIFE CYCLE COST RESULTS

A relative 30-year net present value life cycle cost analysis (LCCA) provides a long-term capital cost comparison between four (4) primary equipment options considered compared to Natural Gas Boiler and Electric Boiler baselines. The LCCA utilizes the modeled annualized energy usage and monthly peak demand to estimate the operating costs of each equipment configuration option. Additionally, it incorporates the construction cost, maintenance cost, and potable water cost. The analysis shows the premium (not total) associated with each parameter for each option.

The relative analysis takes into consideration the premiums associated with each option within each category. The electric utility costs factor the energy [kWh] usage and the monthly peak demand [kW] of the energy models into the rates provided by CES to calculate anticipated operating costs. The included construction are estimated by Vermeulens and reflect the conceptualized purchase and installment price. The associated equipment maintenance costs are reflective of the manufacturer's recommended equipment maintenance, historical maintenance costs, and are inclusive of labor and replacement parts. The maintenance cost breakout by equipment type is listed in Appendix F. The potable water costs are calculated using the campus modeled Cooling Tower Make-up Water gallons, multiplied by a cost factor sourced from the current water rates in the City of Boston.

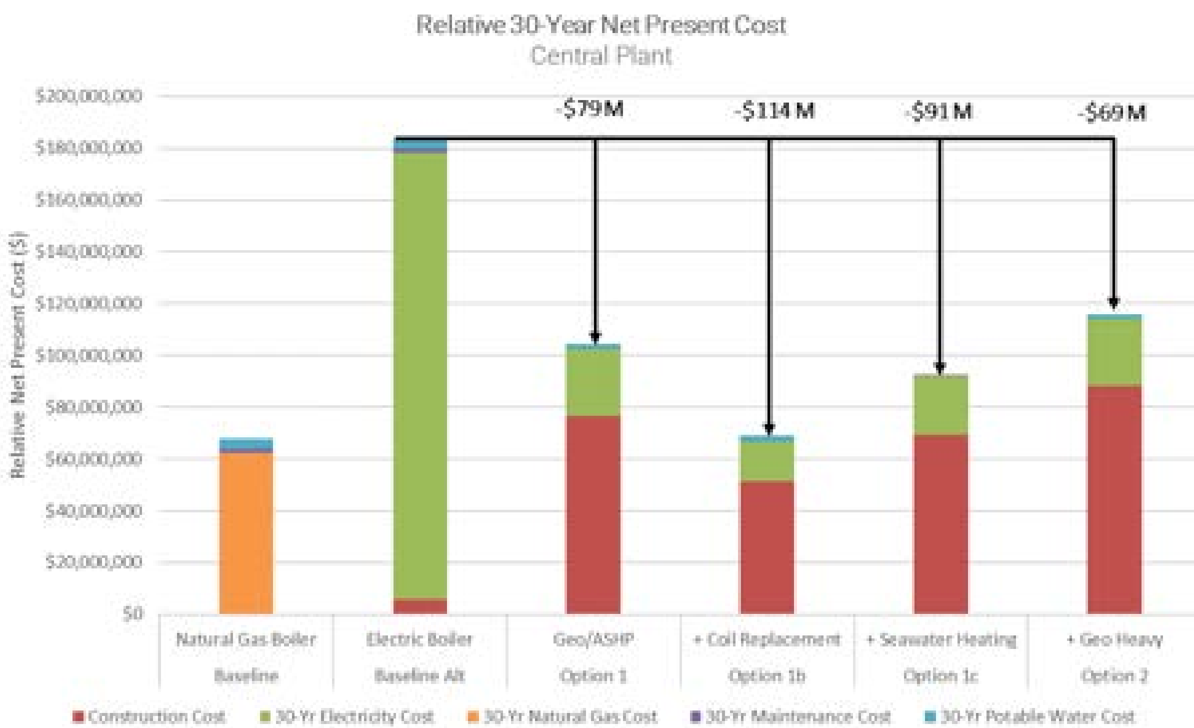


Figure 54: 30-Year Net Present Value Costs of each main equipment configuration

Overall, construction cost is the most influential parameter in the analysis. Geothermal is the major cost factor. Options with greater number of boreholes are generally less cost effective. Another key factor is energy costs. The heat pump efficiency results in ~10% annual energy cost reductions. The electric boilers have a significant operating energy cost given high peak demands. Potable water and maintenance costs have a minimal impact of the result. The options are able to take advantage of rejecting heat to the hot water loop or seawater instead of a cooling tower. This reduces cooling tower use and therefore water consumption compared to the baselines.

RECOMMENDATIONS SUMMARY

	Existing central plant with future load	Baseline Alt: Electric Boiler	Opt 1: GEO/ASHP	Opt 1B: GEO/ASHP + Coil Replacement	Opt 1C: + Seawater Heating	Opt 2: + Geoheavy
Electricity (MMBTU)	268,100	426,300	291,900	286,300	289,100	291,100
Gas (MMBTU)	289,500	20,700	20,700	20,700	20,700	20,700
Site Energy Use (MMBTU)	557,600	446,900	312,500	306,900	309,800	311,800
Energy Use Intensity	135	108	76	74	75	75
Energy Savings		20%	44%	45%	44%	44%
Electricity (TONS)	5,580	8,870	6,070	5,960	6,020	6,060
Gas (TONS)	15,360	1,100	1,100	1,100	1,100	1,100
GHG Emissions (tons)	20,940	9,960	7,170	7,050	7,110	7,160
GHG Intensity (tons/sf/yr)	5.1	2.4	1.7	1.7	1.7	1.7
Savings		52%	66%	66%	66%	66%
Electricity Cost ($)	$7.22 M	$11.6 M	$7.89 M	$7.74 M	$7.81 M	$7.87 M
Electricity Demand ($)	$5.76 M	$9.75 M	$6.36 M	$6 M	$6.29 M	$6.35 M
Total Electricity Cost ($) (Demand + Supply + Delivery)	$12.98 M	$21.35 M	$ 14.25 M	$ 13.74 M	$ 14.1 M	$ 14.22 M
Gas Cost ($)	$ 3.05 M	$0.25 M	$0.25 M	$0.25 M	$0.25 M	$0.25 M
Energy Cost	$ 16.05 M	$ 21.6 M	$ 14.5 M	$ 13.95 M	$ 14.35 M	$ 14.45 M
Energy Cost Intensity ($/sf/yr)	$3.9	$5.2	$3.5	$3.4	$3.5	$3.5
Energy Cost Savings		-35%	9%	13%	10%	10%

Figure 55: Summary metrics for site energy, utility cost and GHG emissions- Central plant alternates

	Baseline	Baseline Alt	Option 1	Option 1b	Option 1c	Option 2
	Natural Gas Boilers	Electric Boiler	Geo/ASHP	Coil Replacement	Seawater Heating	+ Geo Heavy
Construction Cost	✓✓✓	✓✓✓	✓✓	✓✓	✓	✓
Energy Cost	X	X	✓✓	✓✓✓	✓✓	✓✓
Future Emissions	X	✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
Campus Area	✓	✓	X	X	✓	X
Maintenance Cost	✓✓✓	✓✓	✓	✓	✓	✓
Water Cost	X	X	✓✓	✓✓	✓✓	✓✓
Life Cycle Cost	✓	✓	✓✓✓	✓✓	✓✓	✓✓
Resiliency	✓	✓✓	✓✓	✓✓	✓✓	✓✓
Flexibility	✓	✓	✓✓	✓	✓✓	✓✓
Familiarity	✓✓	X	X	X	X	X

✓✓✓, ✓✓, ✓ Better relative to others (multiple instances represent better)
X Worse performance or does not meet goals

Figure 56: Plant options advantages and disadvantages

	Summary
Construction Cost	The baselines are the least first cost/capital cost options given less quantity of equipment. Therefore, they rank higher in this category.
Energy Cost	The options have lower energy costs compared to the baselines. Therefore, they are ranked higher in this category.
Future Emissions	The options have lower energy costs compared to the baselines. Therefore, they are ranked higher in this category. The Natural Gas Baseline does not achieve the goals of Executive Order 594.
Campus Area	Each options requires some extent of future central plant expansion. Options 1, 1b, and 2 are ranked lower in these categories given the extent of the geothermal borefields. Note that the areas scoped for geothermal are not anticipated to be scoped as part of the Campus Master Plan.
Maintenance Cost	The baselines have less maintenance cost given less quantity of equipment. Therefore, they rank higher in this category.
Water Cost	The options have lower water costs compared to the baselines given the use of heat pumps which reject heat to the heat hot water loop as opposed to the cooling towers.
Life Cycle Cost	The natural gas baseline has the least life cycle cost compared to the options. However, Option 1b has <1% total life cycle cost premium.
Resiliency	The options and alternative baseline have better resiliency given fuel diversification (electric and natural gas) compared to the Natural Gas Boiler baseline (natural gas only). Resiliency could be further improved by relocating existing equipment out of the current Central Utility Plant location. This topic is recommended for further discussion in Phase 3.
Flexibility	Options 1, 1b, 2, and the alternative baseline have the flexibility to transition to lower temperature hot water in the future.
Familiarity	The are no instances of the electric hot water boilers and heat pump technology on campus.

Figure 57: Plant options advantages and disadvantages explained

Based on our analysis, Option 1b (Coil Replacement) is expected to be the most cost-effective option. It is estimated to have a $115M reduction over a 30-year period compared to the Baseline Alternate. In addition, it is estimated to have <1% life cycle cost premium compared to the natural gas Baseline. This is primarily due to optimized design and low temperature hot water strategy. This option is only achievable if **all** hot water coils on campus are replaced with low temperature hot water alternatives.

MAJOR RENOVATION – WHEATLEY HALL

Wheatley Hall is primarily an office/classroom building with lab space. This building was selected by the key stakeholder group to serve as a framework for similar building type major renovation projects given its Building score in Phase I. Major renovation of facilities afford the university a great opportunity to reduce energy consumption on campus such that central plant solutions can be right sized in the future.

BASELINE – REPLACE IN KIND

The baseline option reflects a business as usual approach, where equipment would be replaced in kind. Much of this equipment is beyond its useful life. The equipment remains in the same configuration and size as the existing systems.

OPTION 1 – DECOUPLED HEAT/COOL/VENT + ENERGY RECOVERY

In Option 1, the building undergoes a major renovation. Air side systems are reconfigured to enable a decoupled heating/cooling and ventilation system. In this configuration, the air handling units are only responsible for providing ventilation. Air handling units are upgraded with energy recovery. Heating and cooling needs are provided by fan coils units. Lighting systems are upgraded with LED light fixtures and automatic occupancy and daylight controls.

The envelope is not upgraded. However, recent Stretch Code adoption suggests that envelope upgrades may be required in this option. Further discussion is required to understand if envelope upgrades are anticipated as part of the Master Plan. The UMB Sightlines database suggests a roof replacement and window replacement within the same timeframe discussion for the major renovation. Therefore, envelope upgrades may be required under the new Stretch Code. Envelope upgrades are recommended in the interest of energy efficiency.

OPTION 2 – DECOUPLED HEAT/COOL/VENT + ENERGY RECOVERY + ENVELOPE UPGRADES

In Option 2, the building undergoes a major renovation. Heating/cooling and ventilation are decoupled similar to Option1. Enhanced dual-wheel energy recovery is added to the air handling units. In addition, envelope upgrades are included. The roof is replaced enabling increased insulation. The envelope would be overclad enabling continuous thermal insulation. Single-pane glazing is replaced with triple glazing.

OPTIONS DESCRIPTION/MATRIX

Description	Business-as-usual	Good	Best
Wall Performance	Existing conditions only: 4" brick, 2" rigid insul, 8-12" CB R-15 20% WWR	Same as BAU	R-30 continuous insulation, white
Roof Performance	Existing conditions only: 7" LW Conc., 3" insul, 4.75" conc. Estimated R-10	Same as BAU	R-50 continuous insulation, white
Glazing Performance	Existing conditions only: Estimated U-0.5	Same as BAU	Triple glazing punched assembly u-value: 0.20, SHGC: 0.26
Ventilation System	One-for-one AHU Replacement: AHU (no VFD, no energy recovery) Heating: Electric preheat (one HHW preheat) Cooling: CHW	DOAS Single Wheel (50% EF) - Qty. 2 - 60,000 CFM	DOAS Dual Wheel (80% EF) - Qty. 2 - 60,000 CFM
Zone Heating and Cooling	Existing conditions only: Terminal units (VAV/CV) (electric reheat) Split ACs (elevator rooms)	Fan coil units (1 unit/500 sf) VAVs (ventilation only (1/1200 sf)	Same as Good
Plant Heating	Existing conditions only: Plant HHW Building distribution pumps (VFD but constant) VDC boiler (perimeter heat)	Same as BAU	Same as BAU
Plant Cooling	Existing conditions only: Plant CHW Building DIstribution pumps (VFD but constant)	Same as BAU	Same as BAU
Lighting	Replace fluorescent fixtures in kind	LED	Same as Good
Lighting Controls	Manual switches	Occupancy sensors Daylight sensors	Same as Good
Plumbing Water Heating	Existing conditions only: Separate Plant HHW with storage tanks Building distribution pumps and set back on aquastat	Same as BAU	Same as BAU
Electrical Service	Existing conditions only: Primary: (3) 2500kVA XFRM, (1) 1500kVA XFRM Secondary: (3) 4000A MAIN, (1) 3000A MAIN,	Same as BAU	Same as BAU
Solar	74 kW	74 + 300 kW	74 + 300 kW

Figure 58: Major Renovation options matrix

ENERGY RESULTS

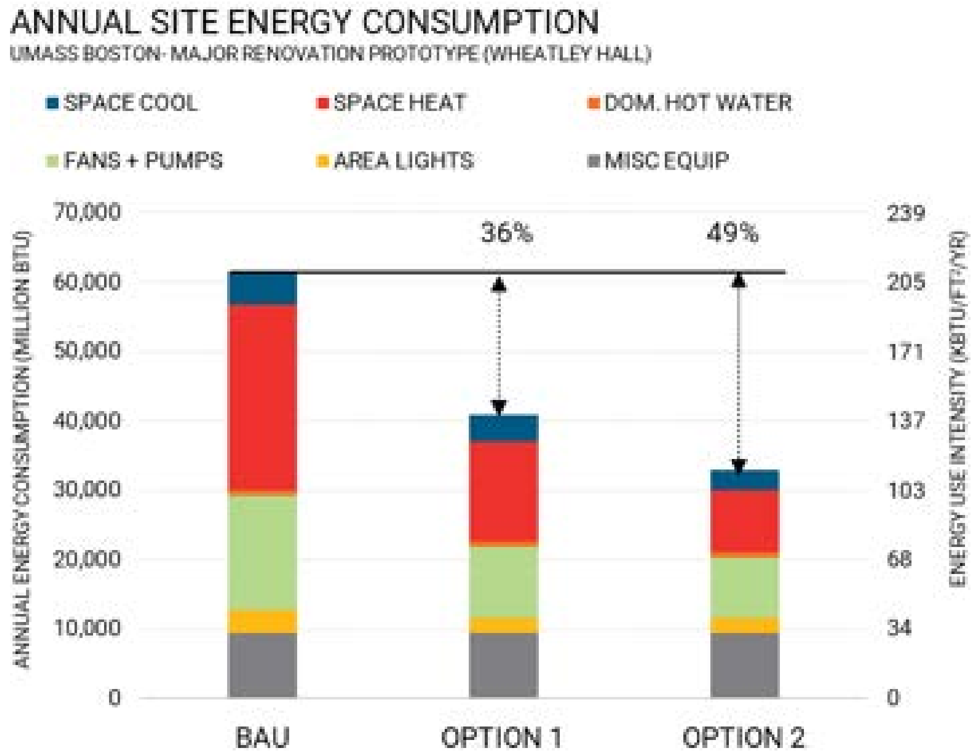


Figure 59: Annual site energy use comparison for Wheatley Hall

The figure above shows the site energy use comparison between the business-as-usual (BAU) scenario and the two design options for Wheatley Hall. Note that this analysis assumes Wheatley Hall is connected to the existing central plant and translates the efficiency of the central plant to the building. Option 1 shows nearly 36% reduction in annual site energy consumption compared to the BAU case. The savings can be primarily attributed to space heating energy reduction from air-side heat recovery included as a part of the major renovation. Additionally, a decoupled ventilation system results in lower fan energy consumption. Transitioning from fluorescent lighting fixtures to all LED fixtures contributes to lighting energy and space cooling energy use reduction. Based on preliminary estimates, the Wheatley Hall roof has the potential to include an additional PV array (~225 KW) that can help offset nearly 4-5% of the site energy use for both options (energy savings are included in the graph). Along with the renewable energy offset, Option 2 shows a 49% reduction in annual site energy consumption compared to the BAU case. Envelope upgrades such as triple pane glazing, high performance walls and roofs along with a high-efficiency dual wheel reduce the building's heating demand by nearly 30% compared to Option 1. This analysis shows that existing buildings, such as Wheatley Hall have the potential to undergo deep energy retrofits and yield significant savings in heating demand, a necessity to the success of transitioning to an all-electric system.

ENERGY COST RESULTS

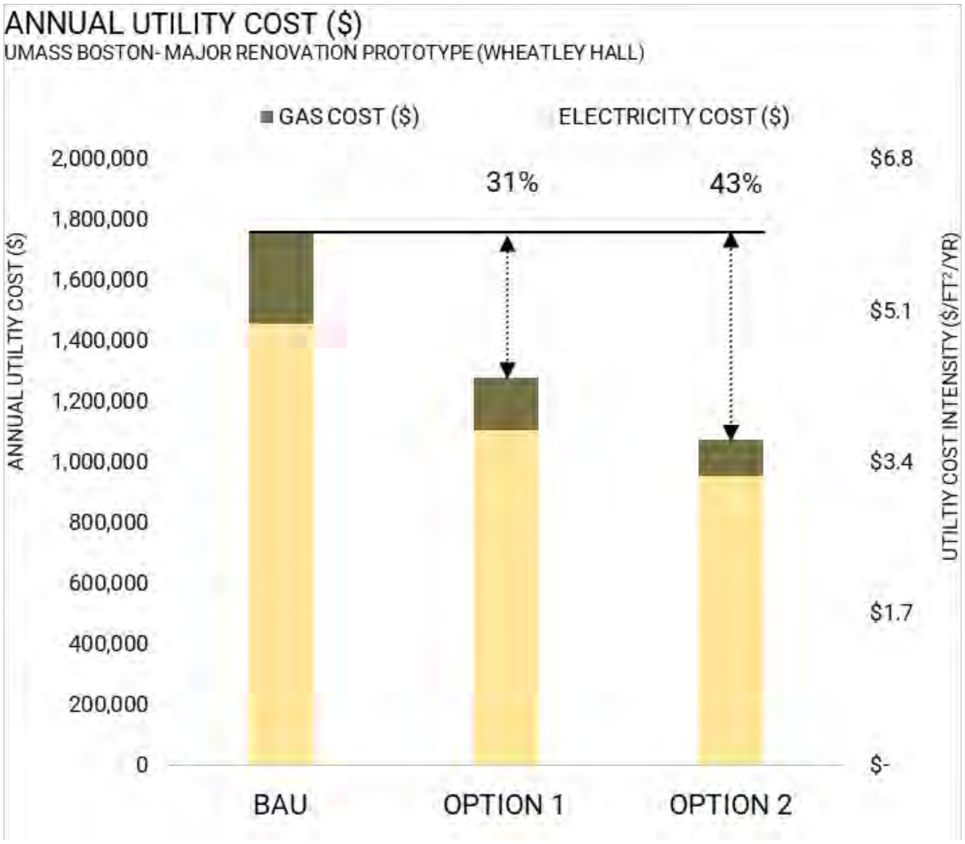


Figure 60: Annual utility cost comparison for Wheatley Hall – with 2022 utility rates

The figure above shows the utility cost comparison between the business-as-usual (BAU) scenario and the two design options for Wheatley Hall. Option 1 shows 31% while Option 2 shows 43% savings in annual utility cost. Savings in gas are primarily a result of the space heating energy reduction. The electricity cost reduction is the result of savings in space cooling, fan, and lighting energy use. On-site renewables included in both options help offset nearly 6-7% of annual utility cost (cost savings are included in the graph).

Note that this analysis assumes the 2022 utility rate structure and accounts for the utility's electricity demand charges. See Appendix F for assumed rate structures.

EMISSIONS RESULTS

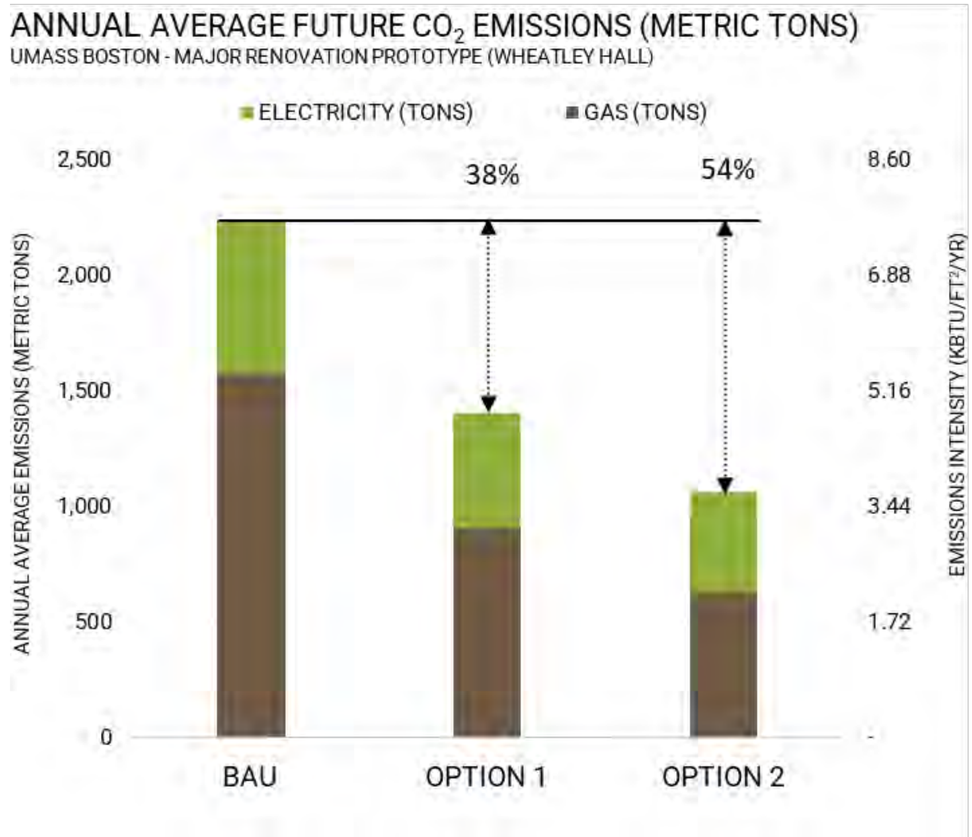


Figure 61: Annual greenhouse gas emissions comparison for Wheatley Hall – with 2050 emissions factors

The figure above shows the annual GHG emissions comparison between the business-as-usual (BAU) scenario and the two design options for Wheatley Hall. Option 1 shows 38% while Option 2 shows 54% savings in annual utility cost. As described in the previous sections, space heating energy reduction results in gas emissions savings while energy reductions in space cooling, fan, and lighting energy use result in electricity emissions reductions. On-site renewables included in both options provide a 2.5 - 3% reduction in emissions (emissions savings are included in the graph).

Note that this analysis assumes the predicted electricity emissions factors for the year 2050 which is projected to be a third of the current electricity emissions factor. See Appendix F for assumed emission rates.

CONSTRUCTION COST COMPARISON

The equipment costs detailed by Vermeulens reflect a conceptual cost estimate. Each equipment type cost is isolated to show the relative cost impact for each equipment option considered. The figure below represents the relative cost for each equipment option when compared to Business-as-usual case.

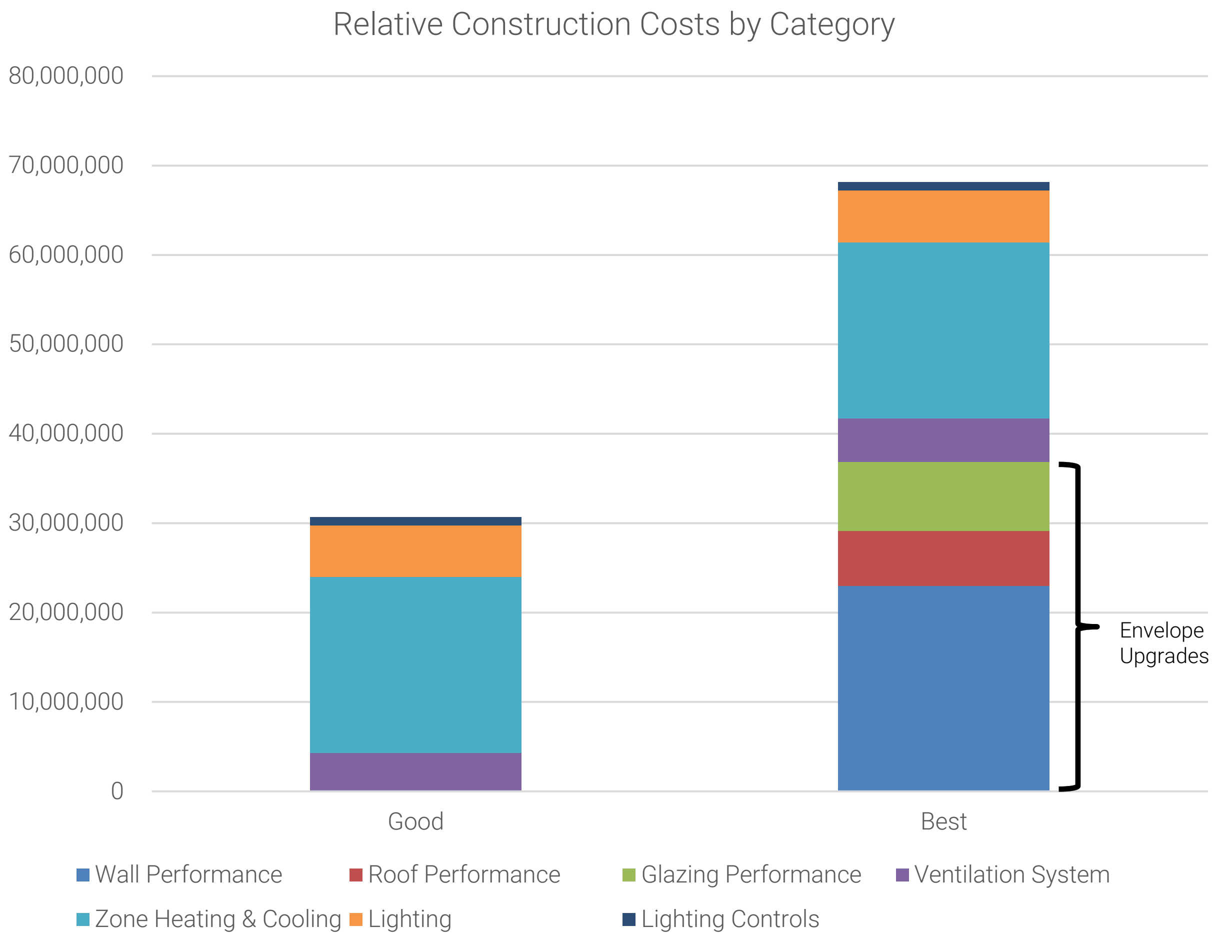


Figure 62: Relative construction costs associated with each equipment category of each equipment configuration option

All options have a first cost premium compared to the Business-as-usual. The original strategy was to source baseline costs from UMB's Sightlines database. However, the costs are significantly less than similar cost items in the Good and Best cases. Given the current analysis, the Good option is a $30M premium and the Best option is a $70M premium. Envelope and decoupled heating/cooling and ventilation are the biggest cost drivers.

LIFE CYCLE COST RESULTS

A relative 30-year net present value life cycle cost analysis (LCCA) provides a long-term capital cost comparison between two (2) options compared to the Business-as-usual baseline. The LCCA utilizes the modeled annualized energy usage and monthly peak demand to estimate the operating costs of each equipment configuration option. Additionally, it incorporates the construction cost and maintenance cost. The analysis shows the premium (not total) associated with each parameter for each option.

The relative analysis takes into consideration the premiums associated with each option within each category. The electric utility costs factor the energy [kWh] usage and the monthly peak demand [kW] of the energy models into the rates provided by CES to calculate anticipated operating costs. The included construction costs are estimated by Vermeulens and reflect the conceptualized purchase and installment price. The associated equipment maintenance costs are reflective of the manufacturer's recommended equipment maintenance, historical maintenance costs, and are inclusive of labor and replacement parts. The maintenance cost breakout by equipment type is listed in Appendix F.

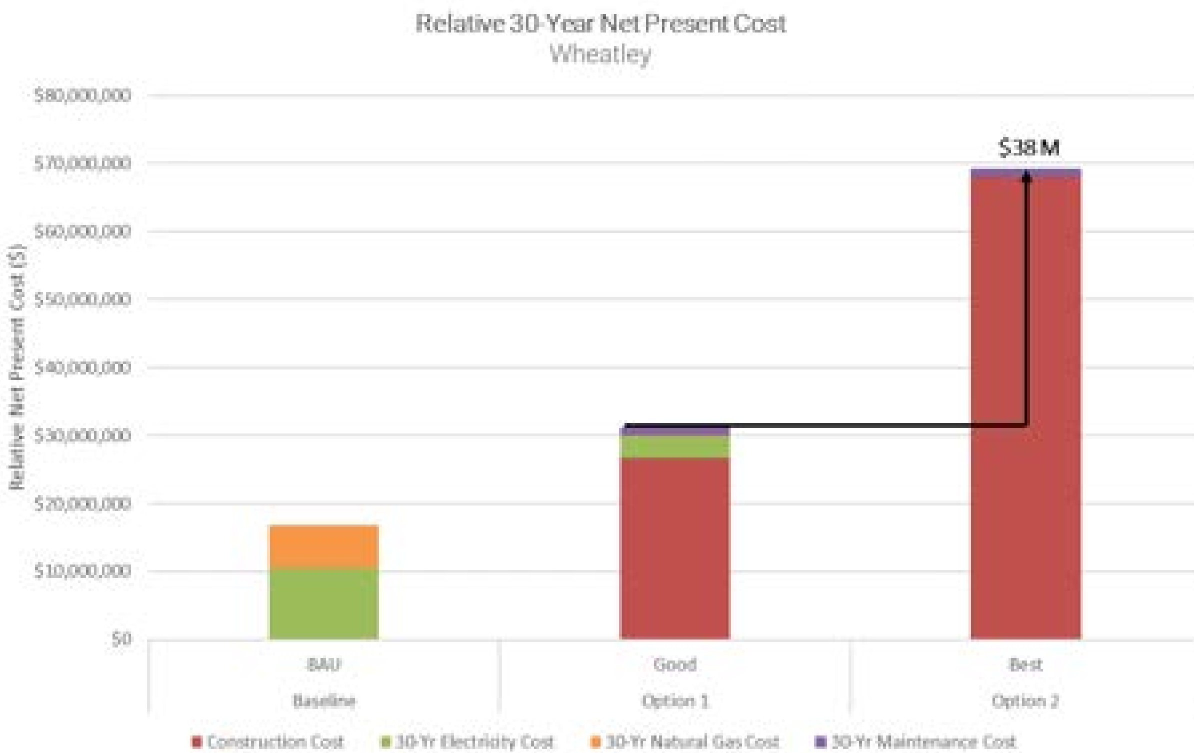


Figure 63: 30-Year Net Present Value Costs of each main equipment configuration

Overall, construction cost is the most influential parameter in the analysis. Envelope and decoupled heating/cooling and ventilation are the biggest cost drivers. Relative energy and maintenance costs are less of a factor. The best case is the most energy efficient. Therefore, the business-as-usual case and good option have a premium operating cost.

RECOMMENDATIONS SUMMARY

	Wheatley Hall		
	BAU	Option 1	Option 2
Energy Use (MMBTU)			
Electricity (MMBTU)	32,000	24,000	21,000
Gas (MMBTU)	30,000	17,000	12,000
EUI	210	139	112
EUI With PV	209	134	107
Energy Savings		36%	49%
Utility Cost ($)			
Electricity Cost ($)	$ 0.83 M	$ 0.6 M	$ 0.55 M
Electricity Demand ($)	$ 0.63 M	$ 0.49 M	$ 0.41 M
Total Electricity Cost ($) (Demand + Supply + Delivery)	$ 1.46 M	$ 1.1 M	$ 0.95 M
Gas Cost ($)	$ 0.30 M	$ 0.17 M	$ 0.120 M
Energy Cost ($)	$ 1.77 M	$ 1.28 M	$ 1.07 M
PV Offset ($)	$ (13,000)	$ (73,000)	$ (73,000)
Energy Cost Intensity ($/sf/yr)	$ 6	$ 4.4	$ 3.7
Energy Cost Savings		31%	43%
Green House Gas Emissions (Tons)			
Electricity (Tons)	665	500	435
Gas (Tons)	1,570	900	625
GHG Emissions (Tons)	2,235	1,400	1,060
PV Offset (Tons)	(6)	(33)	(33)
GHG Intensity (kg/sf/yr)	7.6	4.8	3.6
GHG Emissions Savings		38%	54%

Figure 64: Summary metrics for site energy, utility cost and GHG emissions- Wheatley Hall

	BAU	Good	Best
Construction Cost	✓✓✓	✓✓	✓
Energy Cost	X	✓	✓✓
Maintenance Cost	✓	✓	✓
Life Cycle Cost	✓✓	✓✓	✓
Resiliency	✓	✓	✓✓
Flexibility	✓	✓	✓✓
Familiarity	✓	✓	✓

✓✓✓, ✓✓, ✓ Better relative to others (multiple instances represent better)
X Worse performance or does not meet goals

Figure 65: Wheatley Hall options advantages and disadvantages

	Summary
Construction Cost	The business-as-usual case is the least first cost/capital cost given it assumes equipment would only be replaced in kind. Therefore, it ranks higher in this category. The Best option has the highest first cost given the included envelope upgrades.
Energy Cost	The options have lower energy costs compared to the baseline. Therefore, they are ranked higher in this category. The Best option ranks the highest given further reduced energy consumption as a result of the scoped envelope upgrades.
Maintenance Cost	There are no significant differences as it relates to maintenance costs between each of the scenarios.
Life Cycle Cost	The Business-as-usual case has the lowest life cycle cost. Construction cost is the most influential parameter.
Resiliency	There are no significant differences between resiliency between each of the scenarios. Building specific considerations as described in the “Campus Resiliency” section which can be unlocked as part of the major renovation.
Flexibility	Triple glazing in the Best option unlocks the ability for greater programming flexibility given the expected reduction of fin tube needs at the glazing.
Familiarity	There are no significant differences as it relates to familiarity between each of the scenarios. The Best Option is scoped with dual-wheel enthalpy technology. While there are no instances of this type of technology on campus, the campus has instances of single wheel units. The operation of a dual-wheel unit is unique but doesn’t warrant a downgrade in this category.

Figure 66: Wheatley Hall options advantages and disadvantages summary

Based on the current analysis Wheatley Hall, “Good” is expected to be the most cost-effective option given that the project is expected to undergo a major renovation. This option includes air-side energy recovery and decoupled heating/cooling and ventilation. This results in an annual energy reduction of 38%, annual energy cost reduction of 31%, and annual emissions reduced of 36% compared to the Business-as-usual. Recent Stretch Code updates may affect this analysis. Initial calculations show the Best option is expected to reduce the current cost premium ~30% given future plant construction cost savings.

COMPREHENSIVE ENERGY PROJECT – INTEGRATED SCIENCE CENTER

The Integrated Science Center is the primary lab building on campus. This building was selected by the key stakeholder group to serve as a framework for similar building type comprehensive energy projects given its Building score in Phase I. Comprehensive energy projects afford the university a great opportunity to reduce energy consumption on campus such that central plant solution can be resized in the future.

BASELINE – REPLACE IN KIND

The baseline option reflects a business-as-usual approach, where key energy efficiency equipment and functions continue not to operate.

ALTERNATIVE – COMPREHENSIVE ENERGY PROJECT

This approach consists of three types of projects: proper system functionality, low hanging fruit energy conservation measures (ECMs), and deep energy retrofits/electrification:

Measure	Equipment
Proper System Functionality	• Solar thermal domestic hot water • Heat recovery chiller • Konvekta system • Airflow setbacks
Low Hanging Fruit ECMs	• Fluorescent to LED lighting conversion • Air change rate reduction • Lab process load adjustments
Deep Energy Retrofit/Electrification	• Konvekta Heat Pump • Electric Water Heaters

Figure 67: ISC comprehensive energy projects

- **Proper system functionality:** There are four key systems/functions which are not currently functioning properly: solar thermal domestic hot water, heat recovery chiller, Konvekta system, and airflow setbacks. The solar thermal domestic hot water system is key to providing renewable domestic hot water to the building. This system is currently not functioning. Therefore, the natural gas water heaters are required to provide the full load. The heat recovery chiller is also not functioning. The heat recovery chiller is key to providing heating and cooling during periods of simultaneous loads. This is particularly significant in the summer for providing cooling and reheat. The Konvekta system is not functioning properly. The Konvekta system is key to providing preheat in the winter time by recovering heating energy from the exhaust air handling units. Lastly, the labs were designed to setback when the zones are unoccupied as determined by occupancy sensor status (not schedule-based). During occupied mode, zones would target six (6) air change rates. During unoccupied modes, zones would target four (4) air change rates. This is a key function to reducing heating, cooling, and fan energy consumption in the building.
- **Low hanging fruit ECMs:** Low hanging fruit ECMs are energy efficiency measures are expected to be cost effective and have low payback periods. There are three key measures in this bucket: LED fixture replacement, air change rate reduction, building control upgrades, and lab process load adjustments. It is conservatively assumed that half of the fixtures in the building are fluorescent. This measure assumes that the fixture would be replaced in its entirety with an equivalent LED fixture. LED lighting is more efficient and has a longer life reducing the need for replacement. Building control upgrades consistent with the Van Zelm RCx report (dated 6/16/22) are low hanging fruit: OAT reset, DAT reset, dewpoint setpoint adjustment, room temperature setpoint adjustment. Lab process loads can be reviewed for reduced freezer setpoint and 80 fpm fume hood. Some samples need not be stored in -80°F. Instead, they can be stored at conditions of -70°F which has been shown to reduce energy consumption on average by 36%, while maintaining the same long-term viability of the biological reagents. It is recommended that standard lab practice be adjusted to evaluate the needs of specimens to reduce process equipment energy consumption.[17] Furthermore, as fume hoods come to the end of life, it is recommended to replace with low flow alternatives targeting no lower 80 fpm. Note that filtered fume hoods could also be reviewed for some labs. However, many of the labs in

[17] https://green.harvard.edu/news/harvards-hoekstra-lab-wins-national-green-labs-competition

this facility are chemistry labs where filtered fume hoods would not typically be recommended. Recommend opportunities are studied further.

Lastly, occupant engagement programs like “shut the sash” can be deployed using existing information from the building management system with simple directions outside of labs. The goal for a shut the sash program is, if students are leaving their labs for the day, then it will prompt them to look to see if they perhaps left a fume hood open. As lab are renovated, fume hoods with auto sash closers can also support this same goal. Also, circuit-level metering can help enable energy competitions between individual labs. Traditional submetering may quantify the energy consumed by a panelboard with a mix of end use loads. Circuit level metering enable metering of the individual circuits. This can enable easy allocation of loads by labs and future proof competitions as labs are renovated. Low cost rewards like a pizza party or an annual trophy can help big cost energy savings. As a short term strategy, “shut the sash” displays can be deployed where fume hood exhaust airflow (cfm) is available through the building management system. Displays are recommended to be deployed as part of any future lab renovation. Furthermore, it is recommended that circuit-level metering should be deployed as part of lab fitouts to enable future competitions. At a minimum, space in electrical rooms should be allotted for circuit-level metering modules during renovations as these devices can be deployed aftermarket.

- **Deep energy retrofits/electrification:** the air handling units in this building are expected to be in need of replacement in 2034. This provides an opportunity to provide coils capable of frosting and “supercharging” the Konvekta system with heat pumps. This exhaust source heat pumps boost the effectiveness of the Konvekta system and allow it to consistently provide 65 °F supply air without external preheat. This project would require additional square footage for heat pumps and associated electrical switchgear. Also, the natural gas water heaters are anticipated to near the end of their life by 2030. This provides an opportunity to electrify this system with electric resistance water heaters. This project would replace the water heaters in their existing location and require associated electrical infrastructure.

OPTIONS DESCRIPTION/MATRIX

Description	Business-as-usual	Comprehensive Energy Project
Wall Performance	Existing conditions only: Assumed R-13 Estimated 60% WWR	Same as BAU
Roof Performance	Existing conditions only: White roof Assumed R-20	Same as BAU
Glazing Performance	Existing conditions only: Double-pane 1-3/4" clear laminated insulating glass 3" Insulated shadowbox 3" insulated glass panel Punch Windows Assumed U-0.45	Same as BAU
Ventilation System	Replace AHUs due to end of service life as noted (by 2050). Existing Konvekta. (2) 80,000 cfm 100% OA (lab) (2) 50,000 cfm 100% OA (lab) (1) 30,000 cfm 100% OA (vivarium) General info: AHU (VFD, energy recovery) OA: 100% Heating: GHW (Konvekta) Cooling: CHW 8 ACH (constant - controls issue)	Same as BAU AHU Replacement '+Konvekta Heat pump (7) 110 ton modules konvekta heat pumps 4/2 ACH Assume 3 weeks of work for mechanical subcontractor, controls contractor, and vendor for HRCH Assume 3 weeks of work for mechanical subcontractor, balancer, and controls contractor for ACH
Zone Heating and Cooling	Existing conditions only: Chilled beams (HHW/CHW) VAVs HHW reheat Radiant panel	Same as BAU
Plant Heating	Existing conditions only: Plant HHW HHW-to-HHW exchanger Building Distribution pumps (VFD) Back-up vivarium boilers (gas)	Same as BAU
Plant Cooling	Existing conditions only: Plant CHW Building Distribution pumps (VFD) HRCH (200 Ton - not functioning) Back-up vivarium chiller	HRCH (200 Ton - works correctly) Assume 3 weeks of work for mechanical subcontractor and vendor
Lighting	Existing conditions only: Primarily fluorescent. Some LED	LED (assume 50% of fixture replacement)
Lighting Controls	Existing conditions only: Occupancy sensors Daylight sensors	Same as BAU
Plumbing Water Heating	Replace DHW heaters due to end of service life as noted (by 2050). Existing Konvekta. (2) 565 MBH 125 gal gas water heater (similar to PVI Durawatt) General: Solar with gas fired backup	(2) 162kW 125 gal electric water heater (similar to PVI Durawatt)
Electrical Service	Existing conditions only: Primary: (2) 2500kVA XFRM Secondary: (2) 3200A MAIN	Provide (2) new 15kVA feed from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switchces Provide (1) new 2500 kVA 4000A, 480/277 volt service switchboard. Provide (2) new 1000A switchgear to serve 480V loads.
Process Equipment	Lab, -80F, fume hood, autoclaves	Reduced freezer setpoint, 80 fpm fume hood
Solar	36 evacuated tube solar HW panels (not functioning)	(Functioning correctly) Assume 3 weeks of work for plumbing subcontractor and vendor

Figure 68: ISC options matrix

ENERGY RESULTS

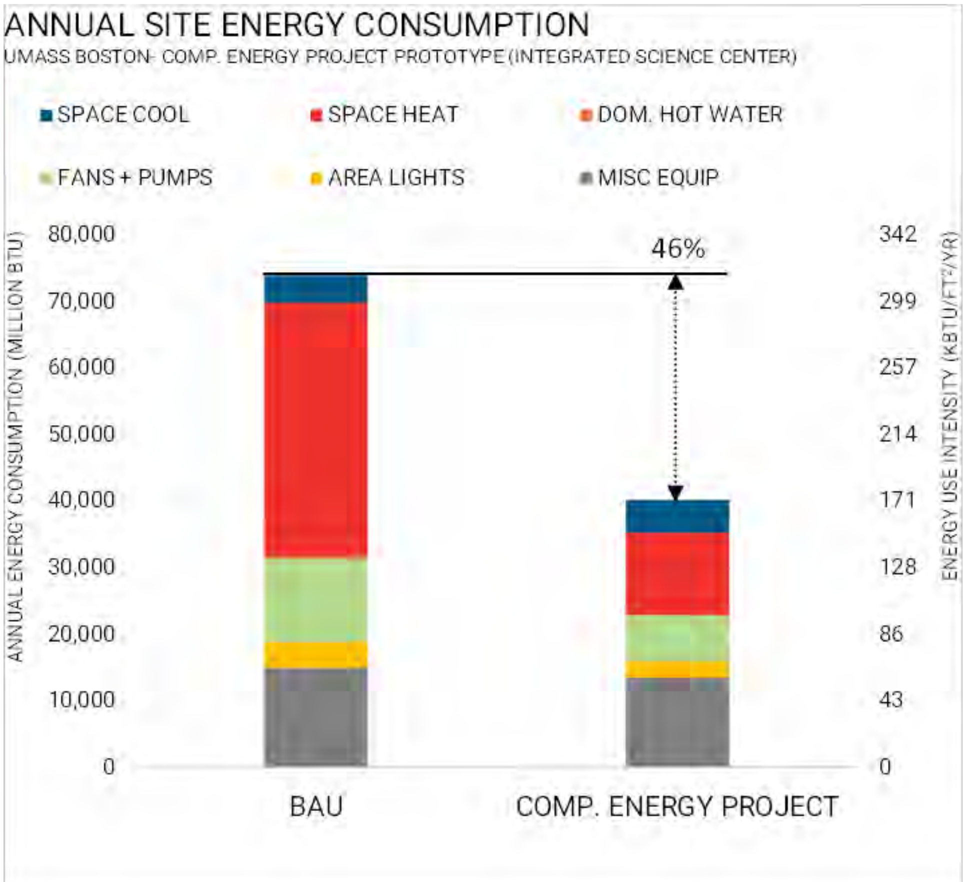


Figure 69: Annual site energy use comparison for Integrated Science Center

The figure above shows the site energy use comparison between the business-as-usual (BAU) scenario and the comprehensive energy project under consideration for the Integrated Science Center. Note that this analysis assumes that the hot water and chilled water is delivered from the existing central plant and accounts for the efficiency of the central plant to estimate the site energy use. The comprehensive energy project shows a 46% reduction in annual site energy consumption compared to the BAU case. These can be primarily attributed to space heating energy and ventilation fan energy use savings. Revisiting the current building operations and allowing for a lower ventilation air change requirement for the labs, implementing an unoccupied setback in lab ventilation rates, and reducing the face velocity for lab fume hoods show a significant reduction in both space heating and fan energy use. Correct operation of the existing heat recovery chiller further reduces the space heating energy with recovered 'free' heat when the building sees simultaneous heating and cooling loads. Lastly, replacing fluorescent lighting fixtures with all LED fixtures and daylight dimming controls results in lighting energy use reduction. Based on preliminary estimates, the Integrated Science Center roof has the potential to include a PV array (~80 KW) that can potentially offset less than 1% of the site energy use (energy savings are included in the graph).

ENERGY COST RESULTS

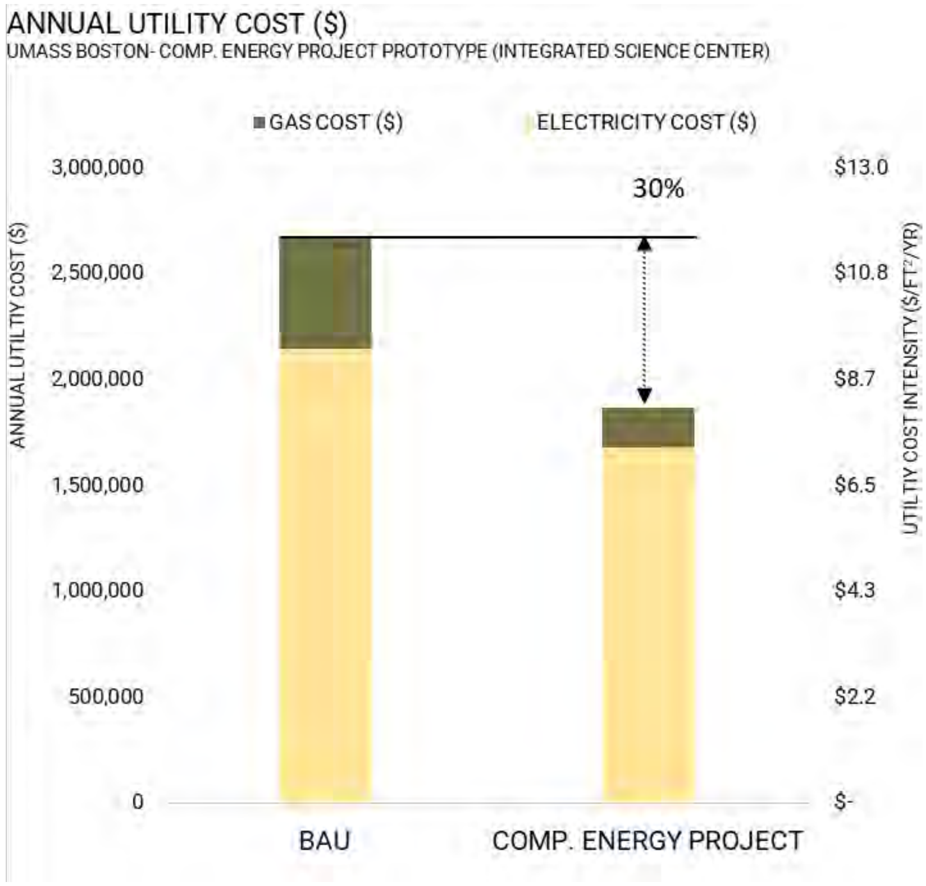


Figure 70: Annual utility cost comparison for Integrated Science Center – with 2022 rates

The figure above shows the utility cost comparison between the business-as-usual (BAU) scenario and the comprehensive energy project under consideration for the Integrated Science Center. The retro-commissioning opportunities and the building operations changes identified in the previous section could potentially show a 30% reduction in energy cost compared to the current design. Utility cost savings in gas is primarily from the space heating energy savings with the unoccupied setbacks and the recommended lower air change requirements in labs. Electricity cost reduction can be mainly attributed to the savings in fan, and lighting energy use. With limited area available on the roof, the 80KW PV array can potentially offset nearly 1% of the total utility cost (cost savings are included in the graph).

Note that this analysis assumes the 2022 utility rate structure and accounts for the electricity demand charges. See Appendix F for assumed rate structures.

EMISSIONS RESULTS

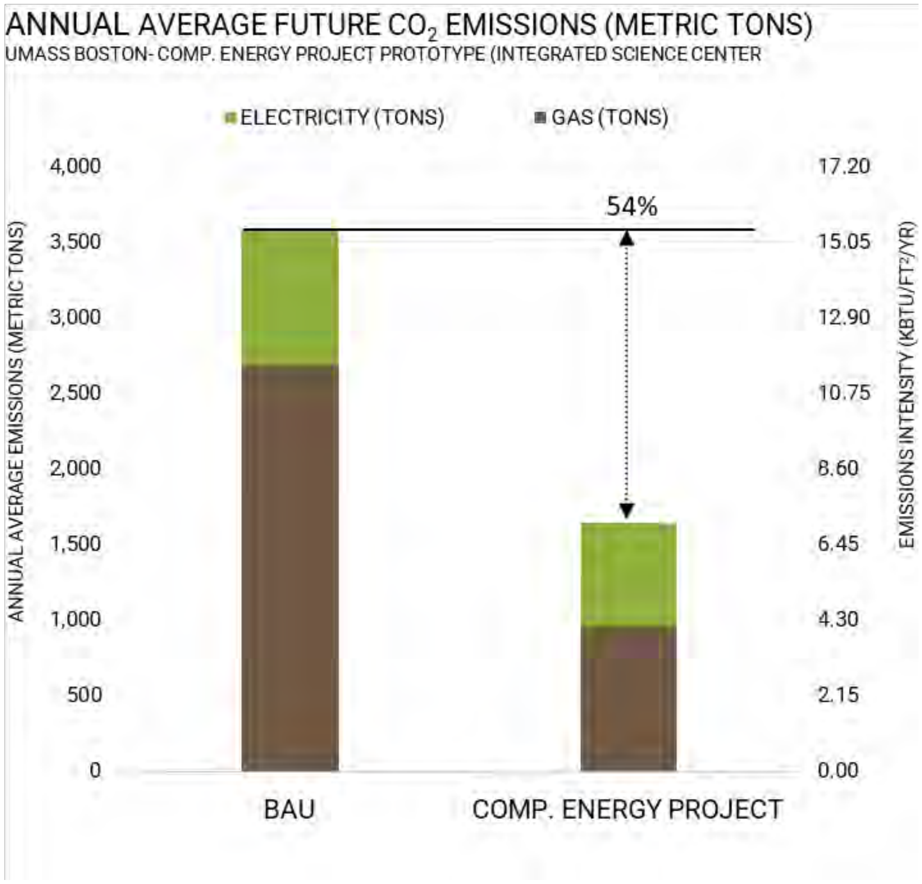


Figure 71: Annual greenhouse gas emissions comparison for Integrated Science Center – with 2050 emissions factors

The figure above shows the annual GHG emissions comparison between the business-as-usual (BAU) scenario and the comprehensive energy project under consideration for the Integrated Science Center. On-site renewables provide less than a 1% reduction in emissions. With all the measures included, the comprehensive energy project demonstrates a 54% reduction in emissions.

Note that this analysis assumes the predicted electricity emissions factors for the year 2050 which is projected to be a third of the current electricity emissions factor. See Appendix F for assumed emission rates.

CONSTRUCTION COST COMPARISON

The equipment costs detailed by Vermeulens reflect a conceptual cost estimate. Each equipment type cost is isolated to show the relative cost impact for each equipment option considered. The figure below represents the relative cost for each equipment option when compared to the Business-as-usual case.

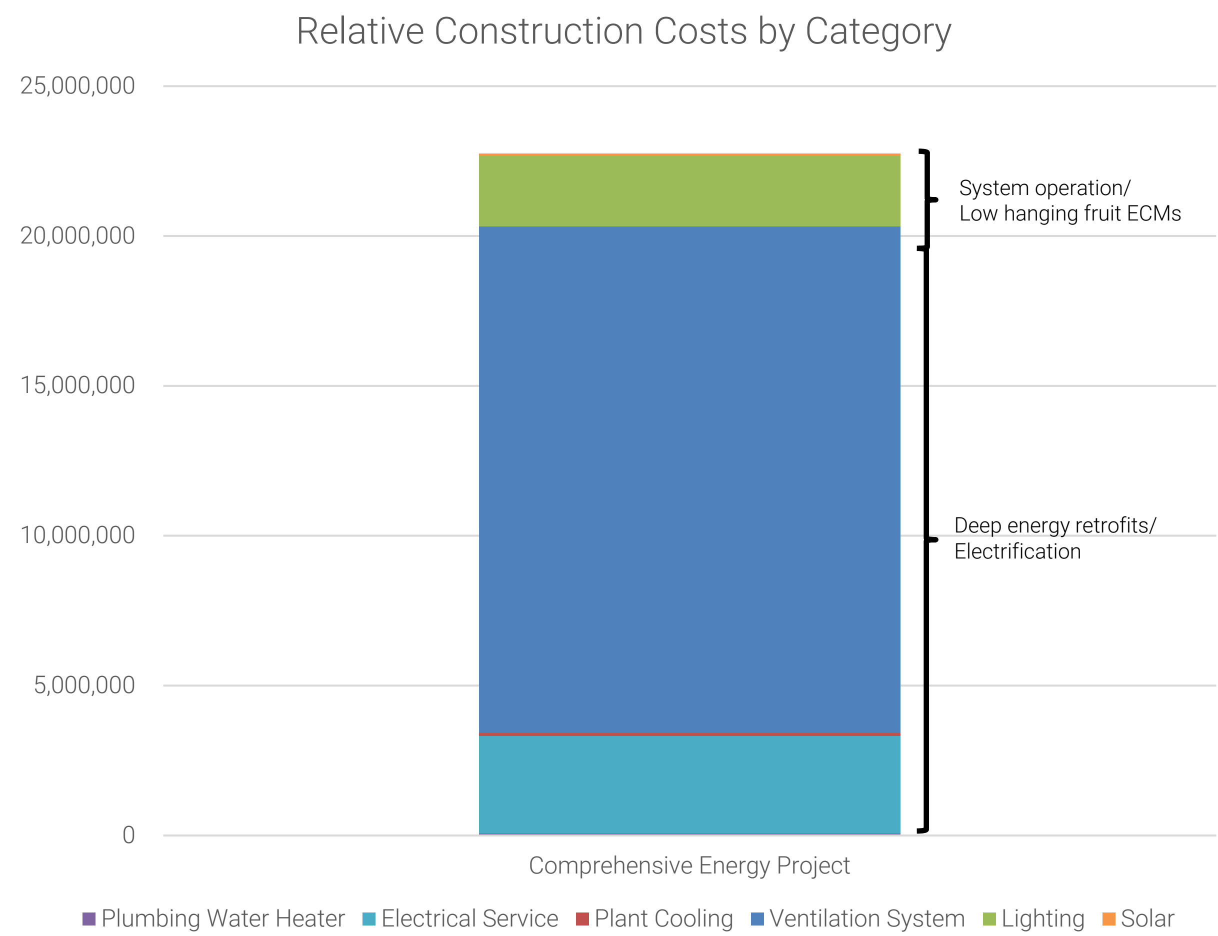


Figure 72: Net construction costs associated with each equipment category of each equipment configuration option

The Comprehensive Energy Project has a $23M cost premium compared to the Business-as-usual. The highest cost premium is the heat pumps and associated electrical equipment. It is highly recommended that system functionality and low hanging fruit ECMs are pursued as soon as possible given an immediate payback. Deep energy retrofits and electrification strategies are recommended at the end of life of the associated equipment. See Appendix H for more cost details.

LIFE CYCLE COST RESULTS

A relative 30-year net present value life cycle cost analysis (LCCA) provides a long-term capital cost comparison between the Business-as-usual baseline and Comprehensive Energy Project. The LCCA utilizes the modeled annualized energy usage and monthly peak demand to estimate the operating costs of each equipment configuration option. Additionally, it incorporates the construction cost and maintenance cost. The analysis shows the premium (not total) associated with each parameter for each option.

The relative analysis takes into consideration the premiums associated with each option within each category. The electric utility costs factor the energy [kWh] usage and the monthly peak demand [kW] of the energy models into the rates provided by CES to calculate anticipated operating costs. The included construction costs are estimated by Vermeulens and reflect the conceptualized purchase and installment price. The associated equipment maintenance costs are reflective of the manufacturer's recommended equipment maintenance, historical maintenance costs, and are inclusive of labor and replacement parts. The maintenance cost breakout by equipment type is listed in Appendix F.

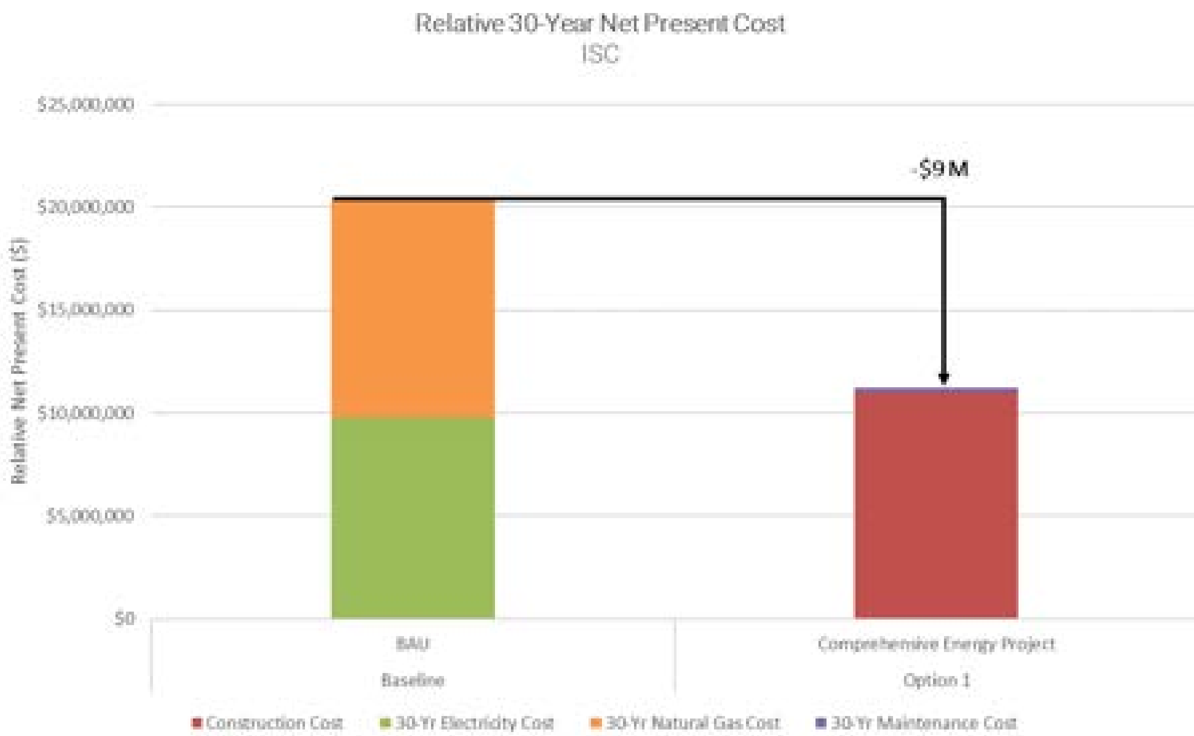


Figure 73: 30-Year Net Present Value Costs of each main equipment configuration

Overall, energy cost is the most influential parameter in the analysis. Proper operation of key equipment and functions result in significant energy reductions. Construction and maintenance costs are less of a factor. The highest cost premium is the heat pumps and associated electrical equipment.

RECOMMENDATIONS SUMMARY

	Integrated Science Center	
	BAU	Option 1
Energy Use (MMBTU)		
Electricity (MMBTU)	43,000	32,800
Gas (MMBTU)	50,650	18,000
EUI	320	174
EUI With PV	320	172
Energy Savings		**46%**
Utility Cost ($)		
Electricity Cost	$ 1.12 M	$0.85 M
Electricity Demand	$ 1.02 M	$ 0.82 M
Electricity Cost ($)	$ 2.14 M	$ 1.68 M
Gas Cost ($)	$ 0.53 M	$ 0.19 M
Energy Cost	$ 2.67 M	$ 1.86 M
PV Offset ($)	-	$ (14,000)
Energy Cost Intensity ($/sf/yr)	$ 11.5	$ 8.1
Energy Cost Savings		**31%**
Green House Gas Emissions (Tons)		
Electricity (Tons)	900	700
Gas (Tons)	2,700	960
GHG Emissions (Tons)	3,600	1,660
PV Offset (Tons)	-	(6.4)
GHG Intensity (kg/sf/yr)	15.5	7.1
GHG Emissions Savings		**54%**

Figure 74: Summary metrics for site energy, utility cost and GHG emissions- Integrated Science Center

Multiple energy projects were evaluated for the Integrated Science Center to reduce energy consumption. These efforts will result in reduced energy consumption, emissions, and right sizing of central plant equipment. There are several systems that are currently not functioning properly: airflow setbacks, heat recovery chiller, Konvekta, and solar thermal systems. Correction of these systems is estimated to result in significant energy reductions particularly heating energy. Also, there are several low hanging energy conservation measure opportunities: LED conversations and lower air-change-rates (ACH). recommended deep energy retrofit project is "supercharging" the Konvekta system with a heat pump. Lastly, local natural gas water heaters could be replaced with electric alternatives at end of life. This results in an annual energy cost savings of 30% and $9M 30-year net present cost savings of compared to the Business-as-usual.

CAMPUS RESILIENCY

Resilience strategies are based on a variety of factors including a building's condition and vulnerability to climate hazards which can vary, even across the UMass Boston campus. Key considerations for four building and site scenarios including new construction, major renovation, and an energy and resilience retrofit are summarized in the figure below. A more comprehensive list of general building adaptation strategies is also provided.

New Utility Plant
New Construction

- Building and critical infrastructure located above design flood elevation
- Generator has capacity for cooling
- Redundant heating plant capacity
- Heating plant fuel diversity
- Light colored roof

Wheatley Hall
Major Renovation

- Building and critical infrastructure located above design flood elevation
- Future summer design criteria: 91°F/73°F
- Light colored roof

Site PE/G
New Construction

- Locate new building outside the extents of flooding or above design flood elevation
- Future summer design criteria: 91°F/75°F

Residence Halls
Energy & Resilience Retrofit

- Relocate mechanical equipment above design flood elevation
- Assessment for retrofitting dry floodproofing

Figure 75: Key resilience strategies for UMass Boston buildings

RESILIENCE FRAMEWORK FOR NEW BUILDINGS

The design of new campus buildings is the ideal time to incorporate resilience strategies to limit operational disruptions from climate hazards. Precipitation, coastal flooding, and extreme heat are of concern for UMass Boston and Figure 75 provides a menu of strategies that can improve resilience to flooding and temperature increase.

> ***What is Design Flood Elevation (DFE)?***
>
> DFE is the minimum elevation that should be used for buildings to protect against flooding. DFE is determined from the base flood elevation (BFE) plus an additional one or two feet of freeboard.
>
> Climate Ready Boston recommends adding one foot of freeboard above the 2070 1% water surface elevation to develop the DFE. Depending on the criticality of the building or system, ASCE recommends two feet of freeboard.

Site selection for new buildings should strive to avoid areas within the extent of flooding, however if unavoidable, the building should reflect the design flood elevation (DFE) to protect against flooding. The City of Boston requires the use of the DFE to determine the floor elevation in new buildings within the Coastal Flood Resilience Overlay District.[18] While the UMass Boston campus is not included within the overlay, this practice is recommended to reduce flood risk and potential damage. Special attention should be given to pedestrian access and utility penetrations through the building envelope below the DFE. Critical equipment should also be elevated, examples include generators and transformers which may sit adjacent to the building. Key concepts include dry floodproofing, where the building is sealed to the DFE and strengthened to resist hydrostatic and hydrodynamic pressure from floodwaters. Alternatively, wet floodproofing allows water through the space and does not require structural strengthen and is suitable for areas such as parking or storage. Materials that are resistant to water damage should be used below the DFE and for other areas of the building envelope. Many strategies for addressing extreme heat differ from those of precipitation and storm surge, and relate to insulation, energy efficiency, redundancy, and landscape solutions.

RESILIENCE FRAMEWORK FOR EXISTING BUILDINGS

The natural cycles of repair and replacement are opportunities to incorporate resilience strategies into existing buildings. Building retrofits should be future-looking to adapt to climate conditions expected in the years to come. In addition to improving resiliency, the strategies proposed can also improve energy efficiency, reduce fossil fuel usage, and improve quality of life for university community members that work and live in these buildings.

While more challenging than new buildings, retrofits should also prioritize elevating critical equipment above the DFE where possible to limit water damage and operational disruptions. Other flood protection strategies could be employed to address components that remain within the DFE, possibly including deployable external barriers. The resilience strategies provided in the table below could be considered during maintenance and upgrades to improve the building's resilience to precipitation, storm surge, and extreme heat.

If major renovations are not expected to occur, building-specific vulnerability assessments can identify appropriate recommendations for individual buildings. For example, Residence Hall East and West have critical heating and cooling equipment located on the first floor which may be impacted by flooding in addition to emergency egress issues, but specific flood proofing strategies cannot be recommended at this time without a more comprehensive analysis. Structural assessments and flood path analyses would be important to understanding which resilience solutions would be safe and effective to maintain operations of the residence halls.

[18] Article 25A – Coastal Flood resilience Overlay District. Boston Planning & Development Agency.

SUMMARY OF RESILIENCE STRATEGIES

The table below provides a range of strategies for enhanced resiliency of buildings through the implementation of systematic building component improvements. Below are the best practices for structure/enclosure, building systems, and site to provide a more comprehensive overview of how to apply resiliency measures. The cost of resiliency implementation depends on a variety of factors. The symbol "$" is a high-level representation of cost and therefore $=low (i.e. a design decision with minimal impact on project cost), $$=medium, $$$=high cost (i.e. requires changes which impact cost compare to building not expected to flood). Recommendations in this table are consistent with recommendations in the City of Boston's Coastal Flood Resilience Design Guidelines and the Department of Housing and Community Development's Resilient Design Specification.

Additional programmatic recommendations include conducting a more detailed climate vulnerability assessment to evaluate building and infrastructure adaptation possibilities. A campus wide hydrologic and hydraulic (H/H) study could also provide a better understanding of the extreme precipitation exposure.

Limitations

Every building is different and the recommendations below may not be suitable for all buildings. This is a summary of common best practices and before being implemented on a building, it is recommended that an architect and/or structural engineer be consulted.

Strategy	Climate Hazard			Cost
	Precipitation	Storm Surge	Extreme Heat	
Structure and Envelope				
Flood damage resistant materials should be continuous from the lowest point in the building up to the Design Flood Elevation (DFE).				$$
Openings including those for HVAC, electrical, plumbing, etc. should be located above the design flood elevation.				$
High thermal performance masonry with attention to managing moisture and permeability.				SS
Design roof drainage to prevent water infiltration and structural failures. Improving roof insulation at the eaves of sloped roofs will reduce the freeze-thaw cycling of ice and snow on the roof that leads to ice dams.				$
Use a light colored "cool roof' to reduce roof temperatures compared to standard built up asphalt, rubber, black EPDM, or other dark roofs.				$$
Shading devices, operable windows, and screens can be integrated into the design to help reduce temperature-related climate impacts, including overheating during heat waves.				$$
Windows play an important role in minimizing the negative effects of climate hazards like extreme heat and flooding, by providing daylighting, improved thermal performance, enabling emergency egress, and providing building occupant comfort.				$
Interiors				
Install slip resistant waterproof flooring such as textured tile in common areas to both resist flood water damage and to help prevent injury during egress in the event floors become wet.				$$
Ground floors that are used for residential, classroom, or utility space and located below the design flood elevation can be repurposed to parking, access, or storage space and wet floodproofed.				$$$
Ground floors with high ceilings can be reconstructed to elevate portions above design flood elevations.				$$$
Raise elevator components above the design flood elevation and mitigate flooding in elevator pits by waterproofing the interior of the pit and installing sump pumps.				$$$

Systems				
Design generator capacity to include cooling center room in critical buildings or a permanent exterior electrical connection so that temporary generators can be connected to emergency circuits.				$$$
Locate critical equipment such as electrical equipment, conduits, panels, wiring, etc. above design flood elevation.				$$
Locate HVAC equipment above design flood elevation.				$$$
Sump pumps can be installed to remove water from below-grade areas and drain to a landscaped area outside of the building.				$$
Seal penetrations through outside walls, especially where service runs underground.				$$
Site				
Deployable flood barriers can serve as an additional strategy beyond the building.				$$$
Use light colored pavement (high albedo) and open grid pavement to help reduce heat impacts. Open grid and permeable pavements help absorb stormwater. Some materials will require modified maintenance practices.				$$
When planning landscaping, consider the potential flood mitigation and cost savings opportunities that Low Impact Development (LID) or green infrastructure may present. LID techniques, such as implementation of bioswales or rain gardens (for stormwater management) also have co-benefits including area beautification and localized temperature moderation.				$$

Figure 76: Building Adaptation Strategies

ON-SITE SOLAR PV

Permitting Requirements

Solar permitting can be complex. However, in the case of these onsite projects, the permitting pathways would be quite straightforward. Because the campus locations are previously developed, the university will not have to go through the overly onerous permitting pathways. Our research and experience indicate that any rooftop system will be "As of Right Development" – meaning that as long as the design is to code, the municipality will approve.

Utility Tariffs

Massachusetts has a very developed solar market. It is on its third large-scale incentive program. The current incentive program in Massachusetts is called the Solar Massachusetts Renewable Target (SMART) program. This program incentivizes solar across a variety of factors including geography, context to the built environment (i.e., on farm land, on a building, on a parking lot, etc…), and which entity receives the value of power (i.e., the site host, low-income community recipients, municipalities, etc…). The program's goal is to support the buildout of solar across the state in a responsible and equitable manner.

The SMART program would allow UMB to build solar on its roofs and derive an incentive for any kWh generated. The electricity could be exported to the grid or could be used by UMB for its operations. The electricity from the solar can participate in Net Meter Crediting (NMC), meaning that if UMB elects to use the solar power for its operations, they can benefit from retail electricity rates for all electricity generated even if the solar is exported to the grid. NMC is simply the grid power and solar power net – meaning the meter rolls up when grid power is drawn while it is rolled back when solar power is exported. This means the value of electricity generated from solar is of higher value than electricity procured from the grid. More details about the value of the projects and solar incentives are provided in the next section of the report outlining project economics.

Interconnection

The process for building a grid-tied distributed energy project requires requesting approval from the local utility or regional transmission operator (RTO) to install a generating station on their utility distribution system. The main goal of the process is to align operating expectations, standards and requirements between the electrical distribution company and the third-party generators. In general, this means building an energy asset that operates at the same voltage as the point of interconnection and uses technology that has been vetted and approved by the utility. This likely means the technology has been vetted by third-parties like UL and the Institute of Electrical and Electronics Engineers Standards Association. These organizations define operating parameters and perform testing such that distributed energy facilities that interconnect with a utility's are pursuant to the current generator interconnection standard and operate in parallel with the utility's distribution system. The requirements by market change infrequently and are defined in the interconnection application paperwork. Interconnection Engineers are very familiar with the requirements and will be able to design distributed energy systems and points of interconnection that adhere to the utility's requirements.

Solar PV Design Assumptions

All project designs in this analysis use industry standard assumptions. Every site will have design considerations that might shift standard practices; however, we have designed the projects using today's best practices. These include:

- Four-foot setbacks from all roof edges;
- Rooftop racking that is set to a 10-degree tilt and oriented along the roof edge – there are many racking providers, our preferred is PanelClaw, Claw FR.
- Fully ballasted, if possible, meaning that rooftop installs avoid mechanical attachments to support system stability.

PV Assumptions	
Module Type	Premium (19%)
Array Type	Fixed (roof mount)
System Losses	11.42%
Array Tilt	10°
Array Azimuth	230°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%

Figure 77: PV Assumptions

Review of existing and new proposed locations for PV installation

Building solar projects in urban markets can be challenging. Rooftops are often small in comparison to the overall building size (i.e., a tower has a small footprint based on the useable area of the building) and crowded because HVAC equipment needs to be located typically on the rooftop. Currently, the campus has utilized 1 MW out of the allowable 5 MW capacity of installed PV system. Several locations for new PV installation have been identified to maximize renewable generation on site. The figure below shows the locations of the proposed new PV installations and as well as the existing PV locations on the UMB campus.

Figure 78: PV Locations

Existing PV

Proposed PV

The table below indicates the existing PV capacity currently installed on the UMB campus. With an installed PV capacity of 1 MW, the existing PV shows a generation potential of ~1,247 MWH annually.

Existing Solar PV on UMB campus		
	PV Capacity (KW)	Annual Generation Potential (MWH)
Wheatley	74	90
University Hall	304	371
Parking Garage	644	786
Total Existing PV	1,022	1,247

Figure 79: Existing Solar PV Capacities and Generation Potential

The table below provides a qualitative assessment for the potential PV locations. This assessment looks at the availability of large contiguous roof area, buildings under consideration for roof replacement, favorable azimuth of the existing roofs. Since the future projected growth is currently being identified and subject to change, the table excludes the PV generation potential from the roofs of new construction buildings.

Based on this study, it is recommended that UMB prioritizes Clark, Wheatley, Quinn buildings for new PV installation. It is recommended to consider the additional PV load and the existing roof condition.

PV Location Assessment			
Building	Contiguous roof area / overshadowing	Planned Roof Replacement	Favorable azimuth for solar PV layout
Clark Building	✓✓✓	✓✓✓	✓✓✓
Wheatley Hall	✓✓✓	✓✓✓	✓✓✓
Quinn Building	✓✓✓	✓✓✓	✓✓✓
Campus Center	✓✓	X	✓✓
McCormack Hall	✓	X	✓✓
Healey Library	✓✓	X	✓✓✓
Service & Supply building	✓✓✓	X	✓✓
Integrated Science Complex	X	X	X
Residence Hall	X	X	✓

Figure 80:Solar PV Qualitative Assessment

The table below provides a list of potential locations for new PV installation on the UMB campus, the PV capacity and the generation potential for the existing buildings. The total available area on the existing building equates to roughly 3.9 MW PV capacity system that could potentially generate 4,804 MWH of electricity annually, offsetting nearly 8% of the total electricity consumption of the existing campus.

Potential New PV Installations on UMB campus		
Building	PV Size (KW)	Annual Generation Potential (MWH)
Clark Building	924	1,128
Wheatley Hall	343	419
Quinn Building	304	370
Campus Center	770	939
McCormack Hall	763	931
Healey Library	359	438
Service & Supply building	149	182
Integrated Science Complex	287	350
Residence Hall	39	48
Total	3,938	4,804

Figure 81: New Solar PV Capacities and Generation Potential

Electrical Interconnection Requirements

Behind the meter solar PV interconnection requirements are typically limited to point of interconnection voltage and amperage. The voltage of the inverters proposed are 480V. If the point of interconnection differs a transformer would need to be installed to either step down or step up the voltage. This is easily engineered.

Amperage limitations are a bit more complex and are typically limited by language in the National Electrical Code (NEC) 705.12(B)(2)(3). This section defines the 120% rule which articulates how many amps can be backfed through electrical service equipment. The amperage of the solar project at the point of interconnection has to be less than 120% of the Main Busbar Rating less the Amperage of the Main Breaker Rating. For instance, if the solar project were 100 Amps, the Busbar rating 800 Amps and the main breaker 800 Amps, the project could move forward: 120% * 800 – 800 = 160. This is greater than the 100 Amps of the solar PV project.

Given the points of interconnection and system sizes are yet to be defined, it is difficult to provide more detailed guidance than voltage and amperage considerations.

Scenario Planning for Renewables

The tradeoffs between developing a renewable project for self-ownership versus contracting a third-party to own and operate are based on considerations surrounding cost of capital, opportunity costs, operational expertise and risk tolerance. In general, self-developing and owning the project outright will provide the most value over time. This is because all of the value-streams associated with the project can be internalized by UMB. If a third-party owner is used, that party will need to generate return on their investment and therefore the value streams will be spread between UMB and the third-party distributed energy system owner.

If UMB wanted to own the distributed energy assets outright, they could pay a renewable energy developer to construct the asset for them. Over the life of the asset, UMB would have to manage operations, maintain the systems, and submit regulatory filings. In general, entities that do not have technical facilities teams will opt to work with a third-party owner.

Third-party ownership of distributed energy assets can come in multiple different forms. The most common are Power Purchase Agreements (PPA), Net Credit Purchase Agreements (NCPA) or equipment eases. In this structure, the third-party distributed energy asset owner would construct the solar project or ESS on UMB's campus and for that right will offer immediate value to UMB. The savings stem from the solar company selling power or credits generated by power being sent to the local electrical grid at a rate lower than UMB's current utility rates. Therefore, UMB would get immediate savings without investing any capital, hence the payback is instantaneous but savings from grid power are shared by UMB and the third-party developer.

As of now, all solar projects in the country have 4 main value-streams: the value of the electricity they generate, the federal investment tax credit (ITC - currently set to 30% since the passage of the Inflation Reduction Act but can be more if American equipment is used, this would also impact the cost of development),accelerated depreciation, and the value of the RECs (which is not addressed in the current analysis).

If UMB does not have taxable income, then third-party ownership of the systems would make more sense as a third-party owner would have the financial structures in place to efficiently utilize the ITC. Cumulative cash flow chart has been provided for the rooftop solar projects. These illustrate the value proposition for self-development verse working with a third-party owner.

Scenario 1: UMB Owned Solar Project

PV Project	PV Size (KW)	Annual Generation Potential (MWH)
Total	3,938	4,804
First cost	$11.8 M	
Operations & Maintenance ($/KW)	$15	
IRA solar tax credit	$3.5 M	
Solar incentive payment ($/KWH)	$0.06/KWH	
Grid utility cost ($/KWH)	$0.09 for the first year; escalation rates provided by CES	
20 year savings	$6.288 M	

Figure 82: Owned Cost and Savings Metrics

Scenario 2: Third party ownership via power purchase agreement

PV Project	PV Size (KW)	Annual Generation Potential (MWH)
Total	3,938	4,804
First cost	$0	
Operations & Maintenance ($/KW)	$0	
Utility cost differential per year via PPA	$0.02/KWH	
Annual utility cost savings	$96,000	
20 year savings	$1.92M	

Figure 83: Third Party Owned Cost and Savings Metrics

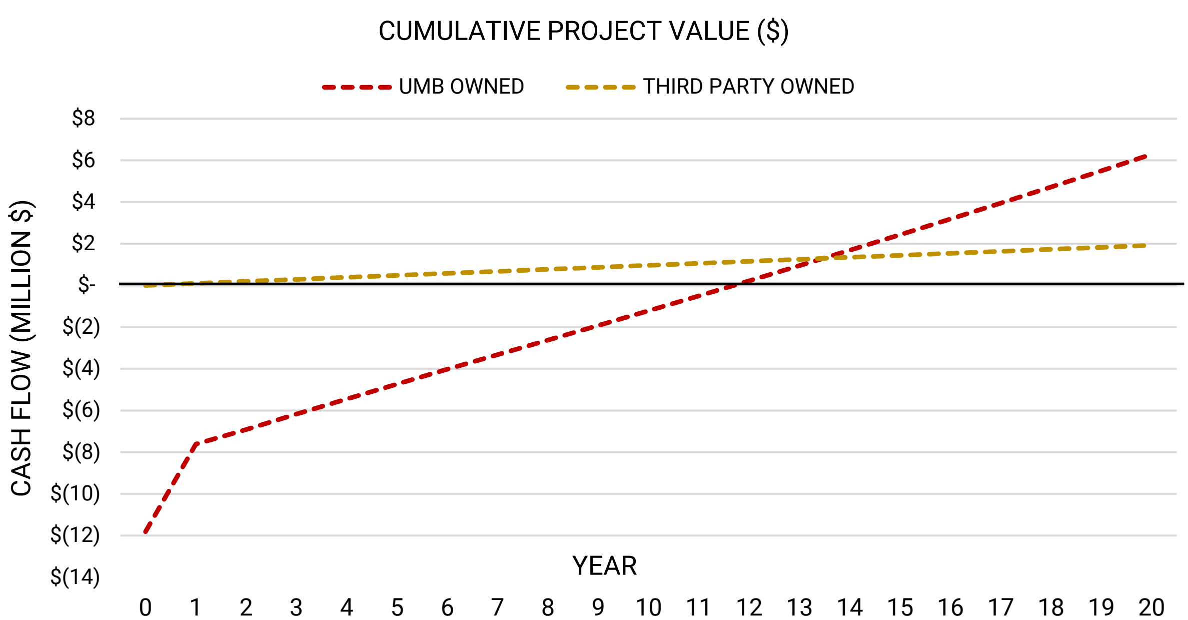


Figure 84: Owned vs Third Party Owned Cost Comparison

The property's utility rate is significantly low at $0.09/kWh . Assuming that the project is able to participate in Block 8 of the MA SMART incentive program, the project would also be eligible for an additional $0.059/kWh of incentives. Therefore, for every kWh the solar project generates, it will create about $0.14/kWh of value. The project will cost about $11.8 million to develop and install; however, it will pay back within 12 years and generate over $6.288 million in savings over the 20-year useful life of the PV system, should they opt to own the system. Nearly 40% of the value is the MA SMART incentive. UMB would be relinquishing its rights to the RECS generated from the system. Other RECS could be procured to layer in additional environmental benefits. A third-party developer would be able to offer UMB a PPA of about $0.02/kWh less expensive than the grid-purchased electricity, creating an annual savings of around $96,000 and a savings of $1.9M over 20-years. This scenario does not require any upfront investment from UMB.

Solar project paired with energy storage system provides energy cost savings and additional incentive savings. An ESS of 1,000 KWH storage; 500 KW of rated capacity will cost around $1.1 million to install. The ESS is eligible to receive a 30% rebate under the Inflation Reduction Act of 2023, thus reducing the first cost by $332,000. Considering the purchased electricity is significantly greater than the renewable energy generated, it is assumed that the ESS would primarily be used for demand response and not for electricity export. The project can participate in Eversource's (the local utility company) Connected Share demand response program. This program provides a $200/kW demand response incentive. The ESS can utilize its entire capacity to support demand response, it can also receive around $100,000 in additional income per summer. Additionally, the battery storage can help mitigate the demand cost with the future electrification strategy The ESS can potentially payback in less than 7 years. However, finding a location to house the energy storage systems will be particularly challenging while adhering to the regulations around ESS installation.

ESS Project	ESS Size (KW)
Total	500
First cost	$1.1M
IRA tax credit	$332,000
Annual demand response incentive	$100,000
Payback period	<7 years
20 year savings	$1.29M

Figure 85: Owned Battery Cost and Savings Metrics

In summary, it is recommended that UMB max out the 5 MW allowance of PV capacity utilizing the roofs of the existing buildings. UMB-owned solar project pays back within 12 years and yields $6.28M in utility cost savings and solar incentives. If UMB has taxable income to absorb the IRA tax credit, it is recommended to pursue a solar project. Third-party-owned PV assets can be beneficial in case of funding allocation constraints. Additionally, owning and managing PV could be a potential added burden to the UMB facility and could require specialized personnel making Third-party owned PV projects more lucrative to UMB. Installing an ESS is recommended as it can support campus participation in demand response programs with greater flexibility. Additionally, the ESS could be used to negotiate lower utility rates, resulting in additional utility savings as the central plant undergoes electrification.

4 – CAPITAL IMPLEMENTATION PLAN

SUMMARY

The goal of the implementation plan is to provide UMB with actionable, cost-effective energy efficiency, electrification, and resiliency projects in alignment with Executive Order 594 and Executive Order 569. This is achieved through three types of projects: new, resilient central plant; all electric new construction and major renovations; and comprehensive energy projects. Projects are scheduled to target high emitters and align with asset end of life in order to maximize cost effectiveness. Multiple versions of the plan were reviewed with key stakeholders to build consensus on project scope and timing.

The new central plant incorporates electrified technologies such as high-temperature heat pumps, seawater heat pumps, air-to-water heat pumps, and geothermal heat pumps. Air source heat pumps are identified as the primary means of electrification. Relocating the central plant to a more resilient location/elevation is proposed to ensure the critical operation remains functional during potential disruptions and natural disasters. New construction and major renovations will connect to the central plant so that they're fully electrified, eliminating the need for additional gas capacity.

A low temperature hot water system is the most cost-effective alternative. Campus systems are currently designed for high temperature hot water. In the short term following the boiler upgrades, buildings should be stressed tested to understand the maximum temperature required. Buildings systems such as air handling units, fan coil units, and variable air volume terminal units will incorporate low temperature coils so that the plant can transition to low temperature hot water in the future.

Energy reduction is planned through major renovation and comprehensive energy projects. Major renovations are the best opportunities to reduce energy consumption. This is a holistic approach to building system renewal. Comprehensive energy projects focus on proper building operation, low-cost energy conservation measures, and deep energy retrofits. A key focus is on regular retrocommissioning to ensure ongoing proper operation.

Enhancing the resiliency of campus operations is a crucial consideration. Future improvements on the UMB campus should incorporate resiliency and adhere to the City of Boston's Climate Resilient Design Guidelines and the Resilient Massachusetts Action Team's Climate Resilience Design Standards and Tool. This ensures that all projects align with industry best practices and withstand the potential impacts of climate change.

Conformance with the implementation plan is estimated to result in the following outcomes:

- 34% energy usage reduction.
- 86% fossil fuel emissions reduction (100% excluding P3 and process natural gas)
- 20% reduction in operating costs (70% increase including growth and escalation)
- 7% increase in total capital spending between 2023 and 2050 ($345M increase above the $4.1B baseline costs)

CENTRAL ENERGY PLANT STRATEGY

This section of the report provides a summary of the selected central plant option. The Alternatives Analysis options were reviewed with key stakeholders. After review, UMB agreed on the seawater heat pump option (Option 1C) given the planned seawater pump house overhaul. Concurrent with this process, the energy code changed. Therefore, the overall strategy changed to accommodate these new requirements and achieve an increased electrification load. In order to achieve this, the central plant is intended to use air source, geothermal, and seawater heat pumps for heating. A test well is recommended prior to work to confirm geothermal performance criteria assumptions. The strategy is to phase the build out of a new central plant to proactively expand as new construction and major renovations are planned. New construction and major renovations will be fully electrified and not require any additional gas capacity. Close coordination is recommended during capital planning such that project budgets are inclusive of project building costs and central plant upgrades.

This analysis accounts for the future weather and growth of the campus per a draft of the Campus Master Plan Update 2022 (dated 2/23/23). It assumes that all buildings on the campus will be connected to the campus district energy system for heating hot water, chilled water, and domestic hot water except for the Calf Pasture P3. See Appendix E for all assumptions.

The underlying concept behind the central plant electrification options are heat recovery, repurposing waste heat from cooling as useful thermal energy for heating buildings and processes. Existing energy data and future energy modeling confirm the campus has year-round heating and cooling loads.

Although the fundamental principle of using waste heat from cooling to provide useful heat for HVAC loads is relatively straightforward, some unique types of equipment are required to integrate this solution into the existing campus utilities. Currently, heating hot water is distributed throughout campus at temperatures as high as 190°F for heating. Conventional heat recovery chillers can only generate hot water up to around 140°F. To overcome this limitation, the options utilize a two-stage approach, where waste heat is collected from auxiliary heat recovery condensers fitted to the cooling chillers at an intermediate temperature (approximately 80°F) and heat pumps are used to boost the temperature to hot water and/or steam. The high temperature heat pumps are piped and valved in such a way that they can operate as a traditional water-cooled chiller in the summertime. This strategy cuts down on the number of equipment needed. The heat recovery loop also includes a large thermal buffer tank to allow the heat pumps to operate without having to exactly match instantaneous cooling demand. The heat recovery loop can also be used to add external heat into the system through air-source or ground-source heat pumps. Natural gas boilers are scoped for heating during extreme conditions (below 8°F) and as back-up. Note that this is a risk given possible rising natural gas operational costs due to electrification. Prior to implementation, it is recommended that current technologies be reviewed to meet or exceed the scoped technologies. This may include alternatives to natural gas boilers for heating backup.

While the central focus of the study is electrification, the options include replacing most of the central heating and cooling infrastructure (boilers, chillers, pumps), as much of the equivalent equipment in the existing plant is aging and will need to be replaced before 2040. The necessity for deferred maintenance provides a good opportunity to upgrade equipment for heat recovery and electrification. This also affords UMB an opportunity to move the existing central plant equipment out of its current location into a new location given that the current equipment may be below the future flood risks. Regardless, a new central plant will be required as future growth is expected to exceed the current plant capacity.

Note that increased electrical demand in this option is not expected to necessitate a utility service upgrade.

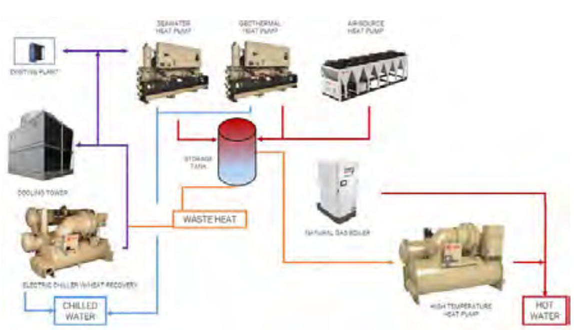


Figure 86: Central Energy Plant Conceptual Diagram

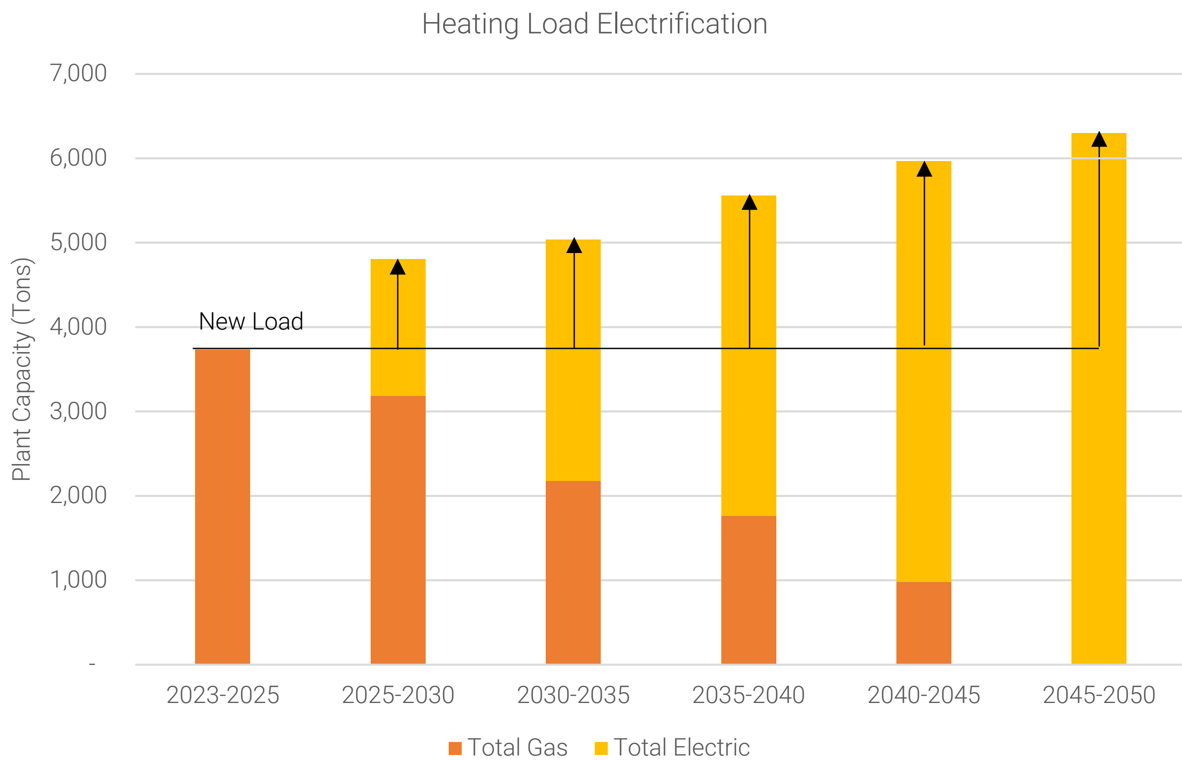


Figure 87: Heating Load Breakdown by Utility

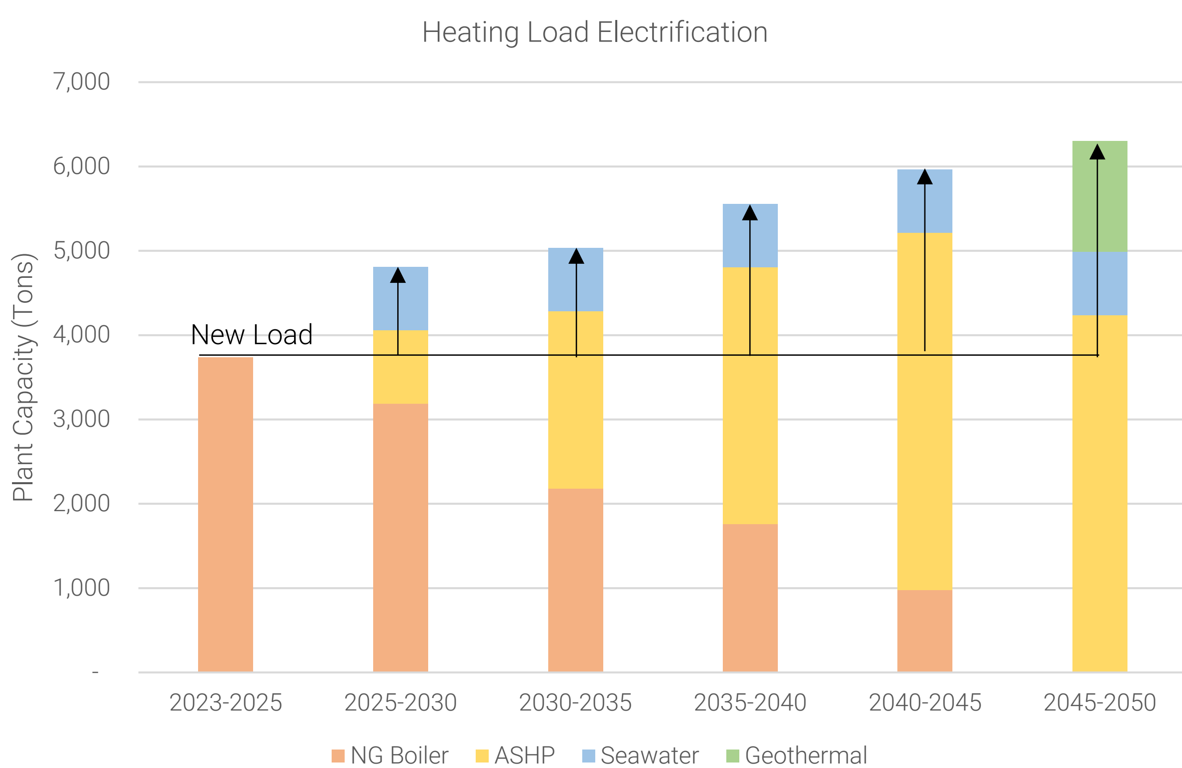


Figure 88: Heating Load Breakdown by Electrification Strategy

Selected Option Seawater/ASHP/Geo	
CHW Chillers	Replace (1) existing 2,000 ton centrifugal chillers at new CUP similar to Trane CentraVac with full heat recovery Replace (1) existing 2,000 ton centrifugal chillers at new CUP similar to Trane CentraVac Replace (1) new 1,000 ton centrifugal chillers at new CUP similar to Trane CentraVac with full heat recovery Replace (1) new 1,000 ton centrifugal chillers at new CUP similar to Trane CentraVac Provide new (2+1) 25 HP primary pump and (2) 15 HP primary pump
Cooling Towers	Replace (1) existing 2,000 ton cooling tower at new CUP New (2) 2,000 ton cooling tower at new CUP Provide (3+1) 100 HP primary pumps
Seawater Exchange	Preventative maintenance (3) 37,500 MBH HXs and (1) 18,750 MBH HX (3) 250 Ton screw heat pump similar to Trane RTWD Provide (3) 2 HP HHW primary pumps and provide (3) 5 HP CHW primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank
High Temperature Heat Pumps	Install (3) 600 Ton screw high temperature cascading heat pump (@150F HWS) similar to Trane CentraVac Provide (3) 15 HP HHW primary pumps and provide (3) 25 HP CHW primary pumps Install (3) 1200 Ton centrifugal high temperature cascading heat pump (@150F HWS) similar to Trane CentraVac Provide (3) 15 HP HHW primary pumps and provide (3) 25 HP CHW primary pumps
Heat Recovery Loop	Install 20" Heat Recovery Supply and Return loop in New CUP Install (6) 50 HP pumps for heat recovery loop
Thermal Storage	Provide 400,000 gallon heat recovery thermal storage tank Approx (25' diameter x 30' height)
GSHP / Geo	(6) 250 Ton screw heat pump similar to Trane RTWD Closed Loop Vertical Borefield 525 Boreholes at 500 ft depth Provide (2) 15 HP HHW primary pumps and provide (2) 20 HP CHW primary pumps Provide (4) 100 HP geothermal primary pumps Heat pumps configured to charge heat recovery loop and thermal storage tank
Air-to-water Heat Pumps	(33) 230 Ton Air-to-Water heat pumps similar to Trane ACX Provide (33) 7.5 HP pump package Heat pumps configured to charge heat recovery loop and thermal storage tank

	Selected Option Seawater/ASHP/Geo
Natural Gas Boilers	(Backup only) Replace (10) 8000 MBH natural gas hot water boilers at new CUP similar to Cleaver Brooks Clearfire Provide (10) 10 HP primary pumps and (5) 85 HP secondary pumps
Electrical Service	Provide (2) new 15kVA feeds from point in system upstream of existing CUP primary switches Provide (1) 15kV padmounted switches Provide (2) new 3000/3360 kVA 13.8kV:480/277V transformers outside new CUP Provide (2) new 5000A switchgear to serve 480V loads Note: no service upgrades expected (4x15kV capacity with only 10MW currently in use)
Space Requirements	Approx 21,000 sf new CUP, including 8,000 sf double-height space

Figure 89: Central Energy Plant Detailed Scope

IMPLEMENTATION TIMELINE

Figure 90: 2023-2025 Campus Map

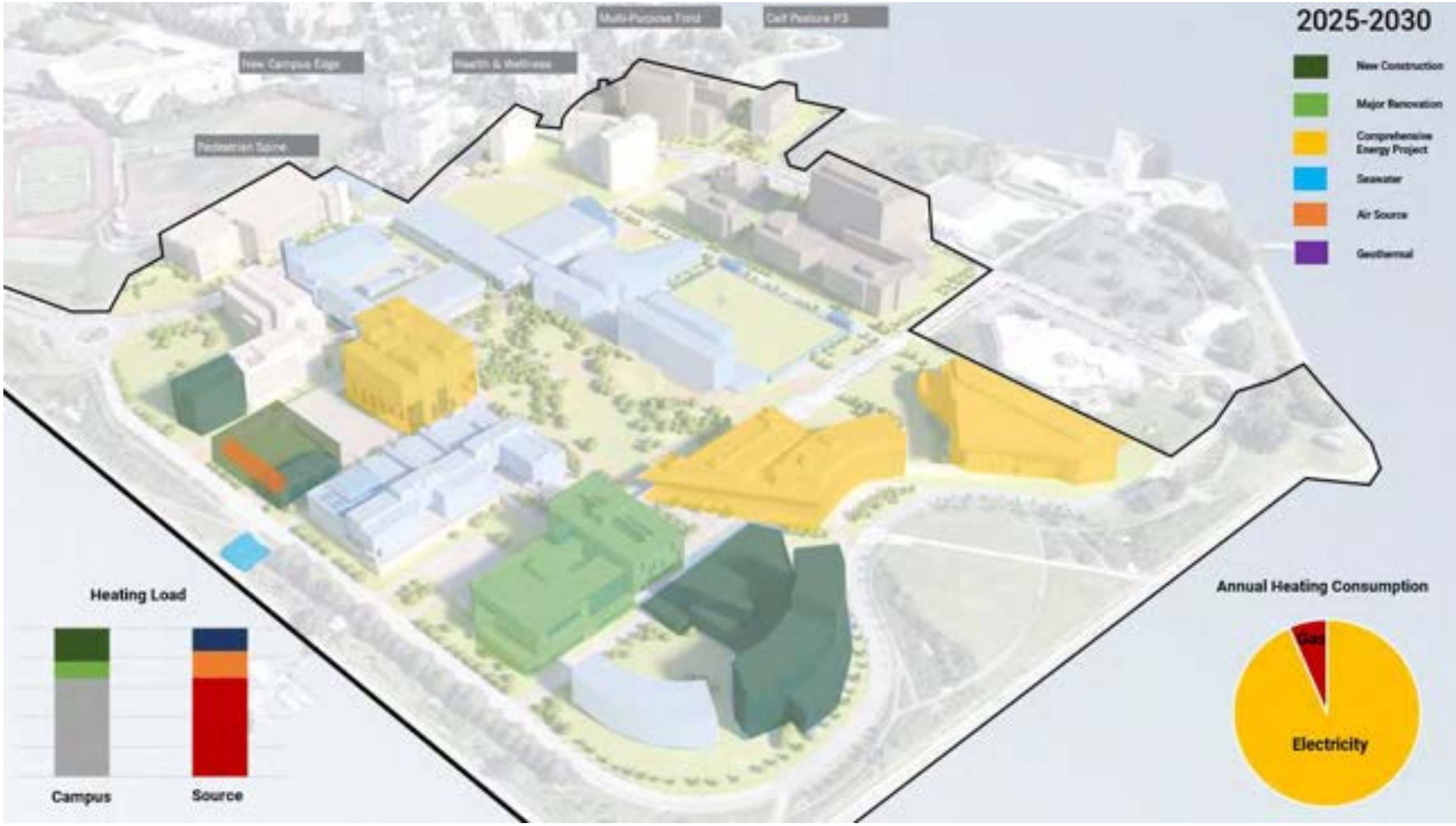


Figure 91: 2025-2030 Campus Map

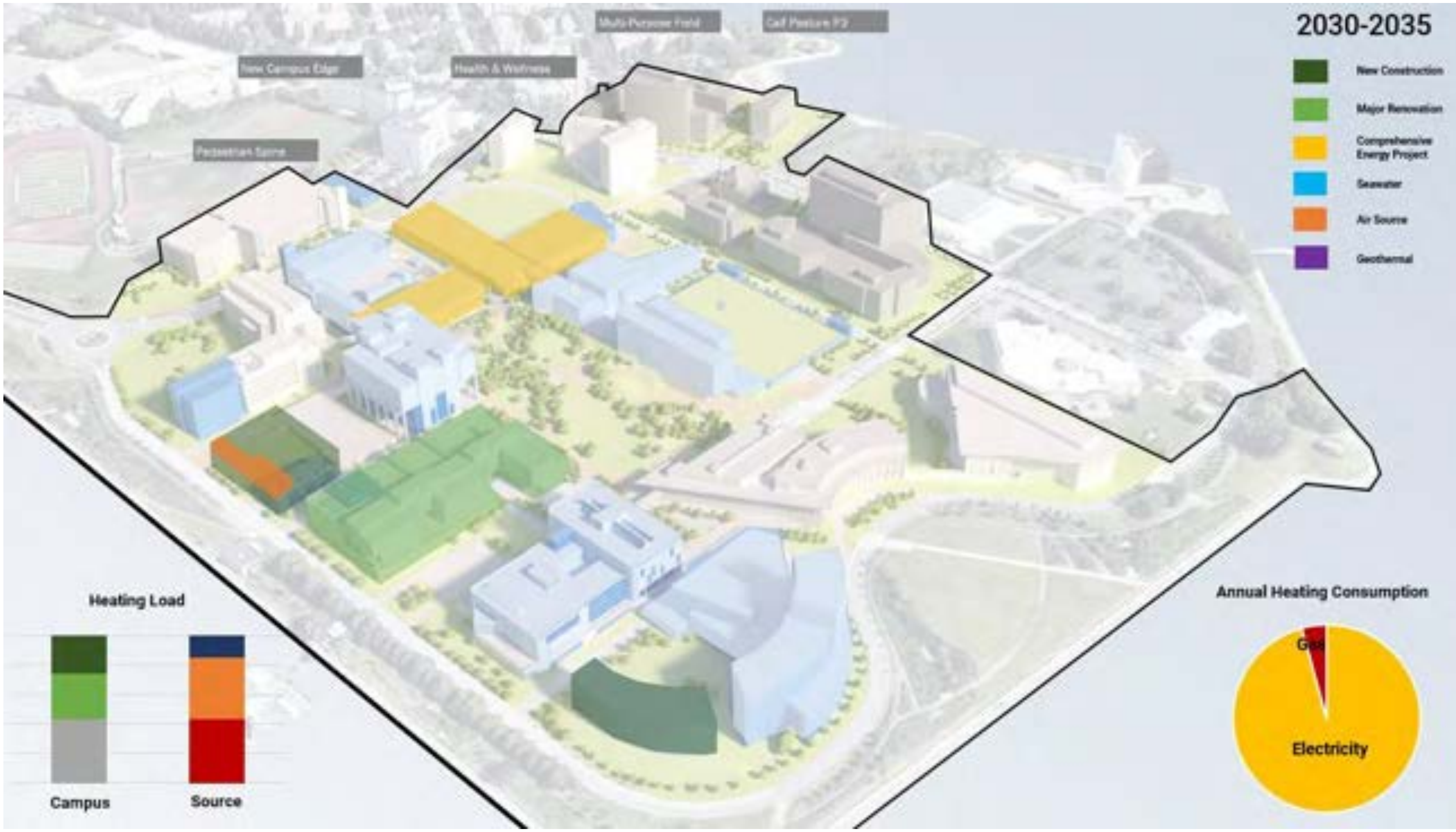


Figure 92: 2030-2035 Campus Map

Figure 93: 2035-2040 Campus Map

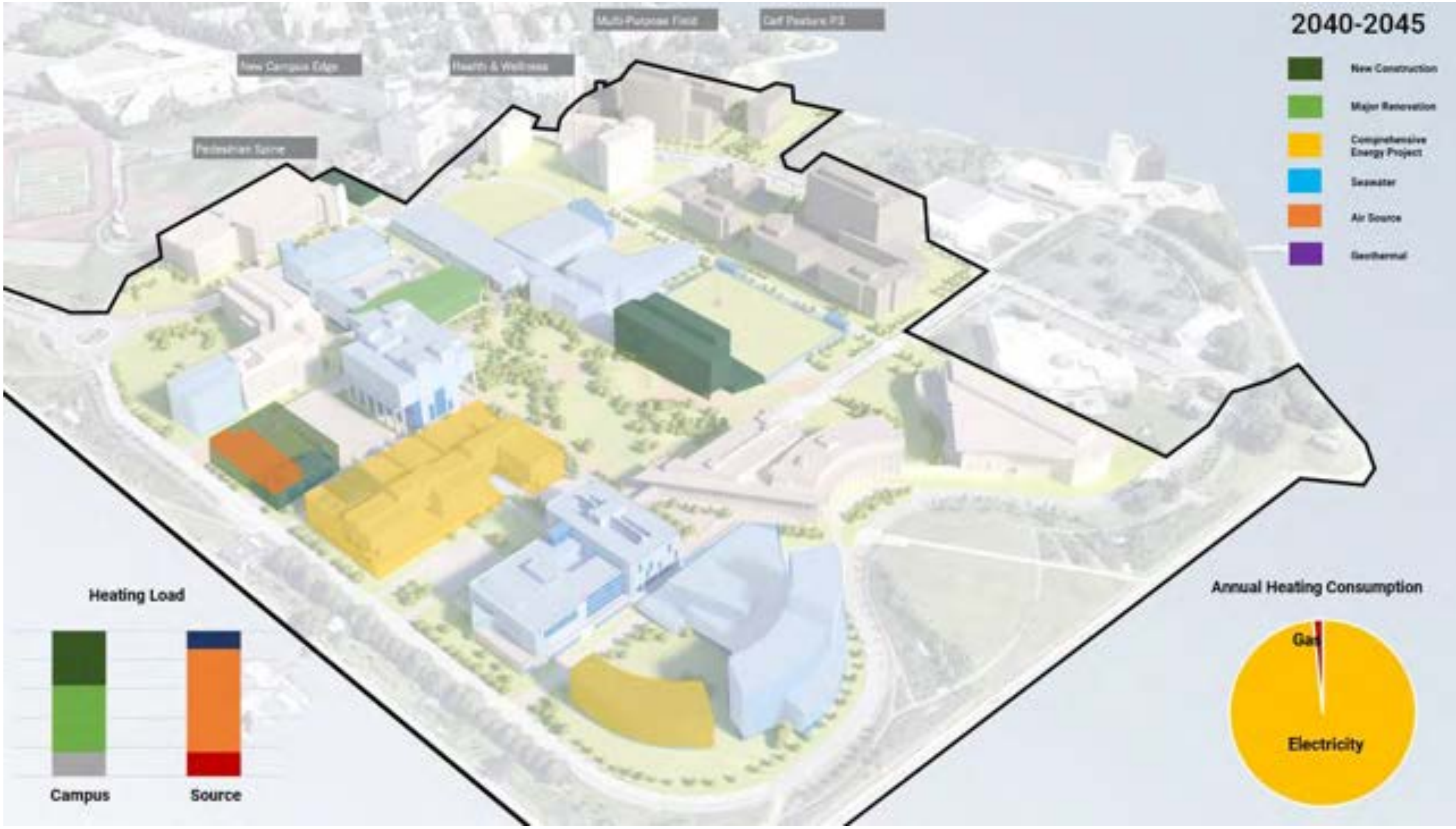


Figure 94: 2040-2045 Campus Map

Figure 95: 2045-2050 Campus Map

BUILDING(S)	PROJECT TYPE	PROJECT DESCRIPTION	2023-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Seawater pump house	Major Renovation	HX/pumps overhaul, cooling tower addition, and dredging						
ISC	Comprehensive Energy Project	Proper operation, low barrier, Energy Audit/RetroCx, LED conversion						
McCormack Hall	Comprehensive Energy Project	Energy Audit/RetroCx						
Wheatley Hall	Comprehensive Energy Project	Energy Audit/RetroCx, AHU upgrade						
Healey	Comprehensive Energy Project	AHU upgrade						
CUP	Comprehensive Energy Project	Energy Audit/RetroCx						
Various	Low Temperature Conversion	Low Temperature Conversion						
CUP	New Construction	New CUP building, seawater and air source heat pumps		Key boiler and early geothermal decision				
Wheatley Hall	Major Renovation	Major Renovation						
Healey	Comprehensive Energy Project	Energy Audit/RetroCx						
University Hall	Comprehensive Energy Project	Energy Audit/RetroCx, LED conversion						
Quinn	Comprehensive Energy Project	Proper operation, low barrier, Energy Audit/RetroCx						
Campus Center	Comprehensive Energy Project	Low barrier, Energy Audit/RetroCx, AHU upgrade, LED conversion, lighting controls, electric kitchen, WH replacement,						
Various	Low Temperature Conversion	Low Temperature Conversion						
Academic Building D	New Construction	New Construction						
ISC Addition	New Construction	New Construction						
CUP	New Construction	Air source heat pump expansion						
McCormack Hall	Major Renovation	Major Renovation						
Clark Athletic	Comprehensive Energy Project	Low barrier, Energy Audit/RetroCx, AHU upgrade, LED conversion, lighting controls						
Quinn	Comprehensive Energy Project	Low barrier, Energy Audit/RetroCx						
Various	Low Temperature Conversion	Low Temperature Conversion						
Academic Building E	New Construction	New Construction						
CUP	New Construction	Air source heat pump expansion						
Healey	Major Renovation	Major Renovation						
University Hall	Comprehensive Energy Project	Energy Audit/RetroCx						
Campus Center	Comprehensive Energy Project	Energy Audit/RetroCx						
Service and Supply	Comprehensive Energy Project	Energy Audit/RetroCx						
Wheatley Hall	Comprehensive Energy Project	Energy Audit/RetroCx						
ISC	Comprehensive Energy Project	Energy Audit/RetroCx, AHU upgrade						
Various	Low Temperature Conversion	Low Temperature Conversion						
Recreation/Health & Wellness B	New Construction	New Construction						
CUP	New Construction	Air source heat pump expansion						
Quinn	Major Renovation	Major Renovation						
McCormack Hall	Comprehensive Energy Project	Energy Audit/RetroCx						
Clark Athletic	Comprehensive Energy Project	Energy Audit/RetroCx						
Academic Building E	Comprehensive Energy Project	Energy Audit/RetroCx						
Various	Low Temperature Conversion	Low Temperature Conversion						
Campus Support Building	New Construction	New Construction						
Academic/Admin Building C	New Construction	New Construction						
CUP	New Construction	Geothermal heat pump expansion						
Service and Supply	Major Renovation	Major Renovation						
Clark Athletic	Major Renovation	Major Renovation						
University Hall	Comprehensive Energy Project	Energy Audit/RetroCx						
Recreation/Health & Wellness B	Comprehensive Energy Project	Energy Audit/RetroCx						
Various	Low Temperature Conversion	Low Temperature Conversion						
Academic Building A	New Construction	New Construction						
Athletic Center Addition	New Construction	New Construction						

Figure 96: Energy Master Plan Recommended Schedule

FINANCIAL INVESTMENT

The capital expenditure (CAPEX) estimates the cost over next ~25 year master plan. Costs are bucketed into two categories: baseline and decarbonization. Baseline capital are costs that UMB is anticipated to incur regardless of option given major equipment end of life. Decarbonization capital are projects and cost premiums that reduce emissions on campus in alignment with Executive Order 594. Referenced costs are sourced from ermeulens’ conceptual cost estimate. Escalation is then applied based on the timing of projects.

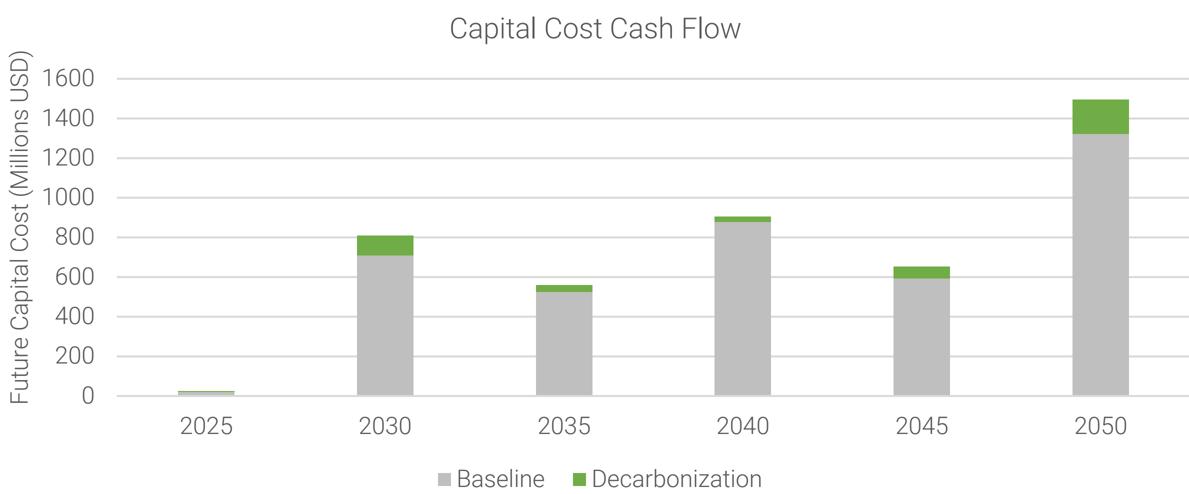


Figure 97: CAPEX over time

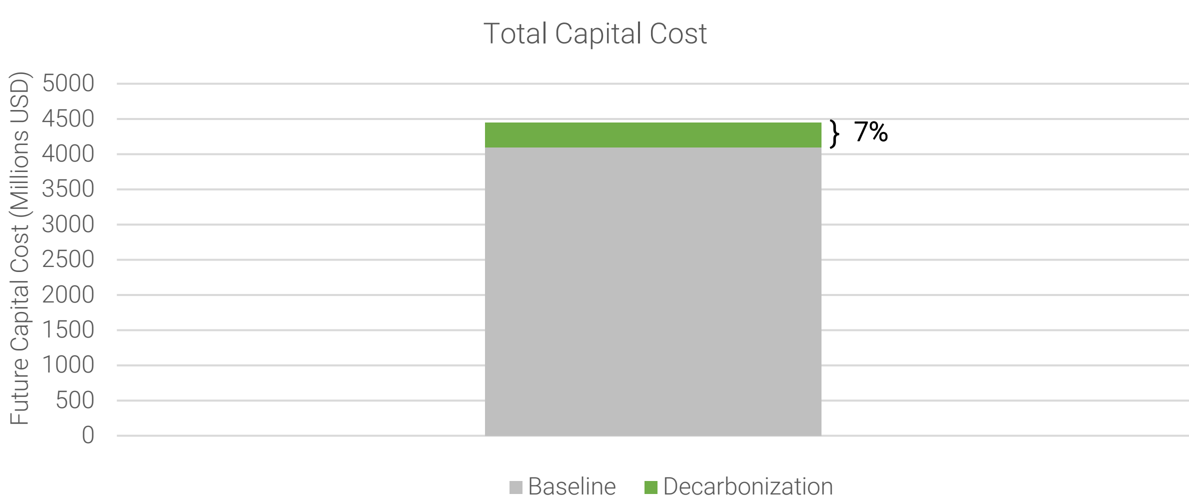


Figure 98: Total CAPEX

ENERGY, EMISSIONS, EUI RESULTS

The figure below shows the estimated annual energy use for the UMB campus across the different periods of the implementation timeline. The campus is projected to demonstrate a 40% reduction in annual energy use by 2050 compared to the 2023 energy use with maximum savings unlocked during the 2025-2035 period. The annual energy use is broken into electricity and gas consumption. The figure indicates the impact of gradual electrification of the campus central plant system as the gas consumption diminishes significantly during the 2045-2050 period. The small amounts of gas indicated in the figure below can be primarily attributed to the process gas assumed to be required in laboratory buildings and gas kitchens assumed to be used in Residence Hall#1. As laboratory technology evolves, laboratory equipment using process gas can be substituted for electric counterparts in the future. The Residence Hall#1 is not owned or operated by UMass Boston and the lease for the building expires in 2050, thus changing the system to an all-electric food service is outside the scope of this study.

The dark red line in the graph below identifies the energy reductions attributed to existing building renovation projects and the central plant decarbonization efforts. Improvements in energy efficiency at the central plant and from major renovations results in a 53% energy use reduction by 2050 compared to the current scenario.

New construction projects are anticipated to be high-performance buildings meeting the stringent energy codes and add 400,000 ft^2 of gross floor area and approximately 23,000 MMBTU of energy use to the campus between 2025-2035. Between 2035-2050, an additional 330,000 ft^2 of floor area will be added to the campus. The new high-performance buildings benefit from the efficiency of the fully electrified central plant, and adds 21% energy to the campus's annual energy use by the year 2050. The graph clearly identifies that energy savings from major renovations and plant electrification far outweighs the limited energy increase from high-efficiency new construction.

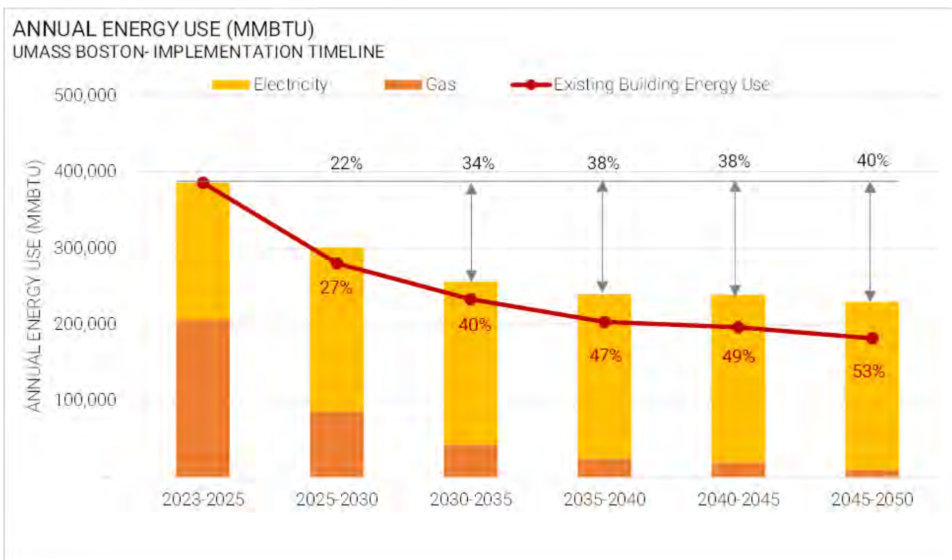


Figure 99: Annual Energy Use Across the Implementation Timeline (2023-2050)

The purpose of the figure below is to illustrate the compliance path with Executive Order 594 (EO 594). It shows the energy use intensity (EUI) of the campus as it changes from 2023 to 2050 and compares it to the historic EUI of the campus in the year 2004, which is defined as the baseline for EO 594. As per EO 594, the campus masterplan should demonstrate a 20% reduction in EUI by 2025 and a 25% reduction in EUI by 2030 compared to the baseline year 2004. Currently, the 2023-2025 campus EUI is 48% higher than the baseline EUI; this is a non-compliant condition. As the renovation projects are implemented, and the plant is electrified, the campus shows 1% higher EUI during the 2025-2030 period; this is also a non-compliant condition. By 2040, the campus EUI is predicted to be 25% lower compared to the 2004 baseline EUI; although compliance thresholds for 2040 are yet to be determined, it can be inferred that the campus will be short of complying with the increasing stringency in EO 594 EUI reduction thresholds. The campus, with a fully electrified central plant, shows a 34% reduction in EUI by 2050 compared to the EO 594 baseline EUI. It is recommended that UMB discuss the impact of increased growth on energy use with DCAMM and request exceptions or alternative compliance requirements.

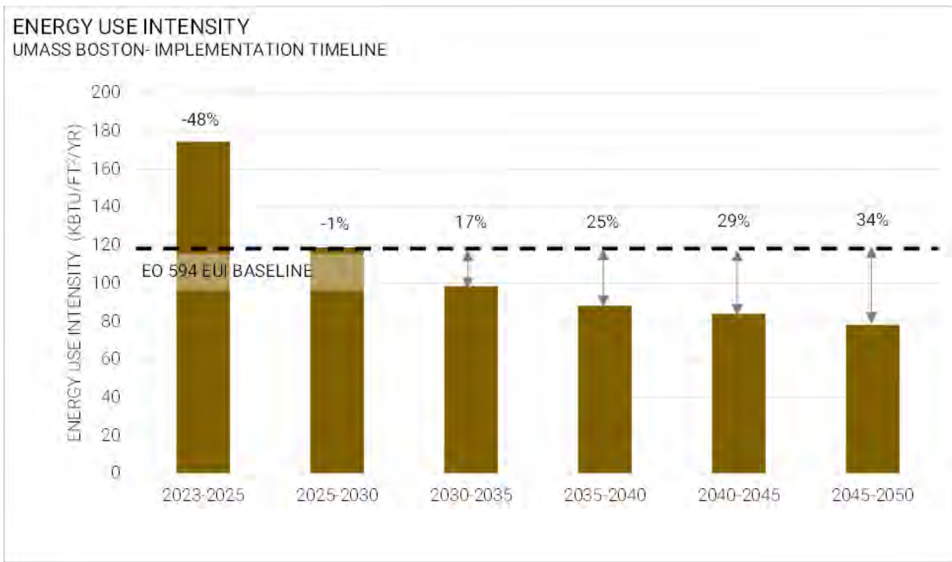


Figure 100: EO 594- Energy Use Intensity Reduction Compliance Across the Implementation Timeline (2023-2050)

EO 594	EUI Reduction Percentage for EO 594 Compliance	Campus EUI Reduction Percentage	Complies (Y/N)
2025	20%	(- 48%)	N
2030	25%	(- 1%)	N
2040	TBD	25%	TBD
2050	TBD	34%	TBD

Figure 101: EO 594 EUI compliance requirements

The figure below shows the annual energy cost for the UMB campus across the different periods of the implementation timeline. The utility rates assumed for the future years take cost escalation into account for both gas and electricity (supply and demand). With an increase in the campus electrical demand as a result of plant electrification, construction of new buildings, and escalating electricity cost, the analysis shows a 70% increase in annual energy cost by 2050 compared to the current energy cost.

The dark red line indicated on the graph demonstrates the utility cost of the existing buildings with planned renovations and campus electrification excluding utility cost escalation and new construction. Without these costs, the existing buildings show a 20% reduction by 2050 compared to the current utility cost. A reduction in annual utility cost (w/o escalation) illustrates the significance of existing building renovation projects as well as campus electrification projects in contributing to cost control.

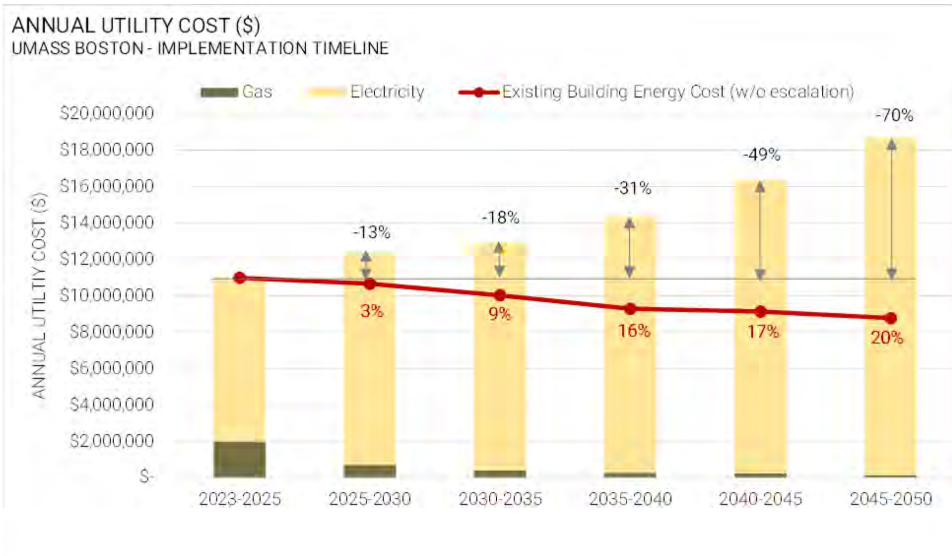


Figure 102: Annual Energy Cost Across the Implementation Timeline (2023-2050)

The figure below shows the annual greenhouse gas emissions for the UMB campus across the different periods of the implementation timeline. The GHG emissions for the campus reduce from 2025 through 2050 at which time a 75% reduction compared to current emissions is shown. The majority of this reduction is due to the Massachusetts Clean Energy Standard (CES). The dark red line indicates the emissions of the existing building and campus electrification efforts.

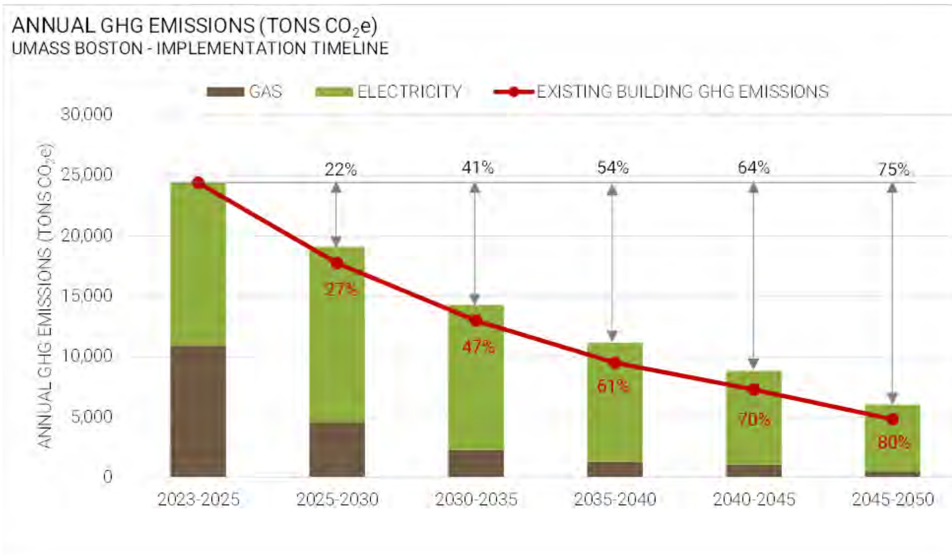


Figure 103: Annual GHG Emissions Across the Implementation Timeline (2023-2050)

The figure below shows the comparison of campus emissions reduction with and without accounting for the Massachusetts Clean Energy Standard. The increase in emissions from the planned campus growth is compensated significantly by emissions reductions from the campus renovation projects and plant electrification efforts. Without accounting for the cleaner grid, the campus shows a 30% reduction in emissions in 2050 compared to the current campus emissions. An additional 45% of emissions reduction can be attributed to the anticipated cleaner MA electrical grid.

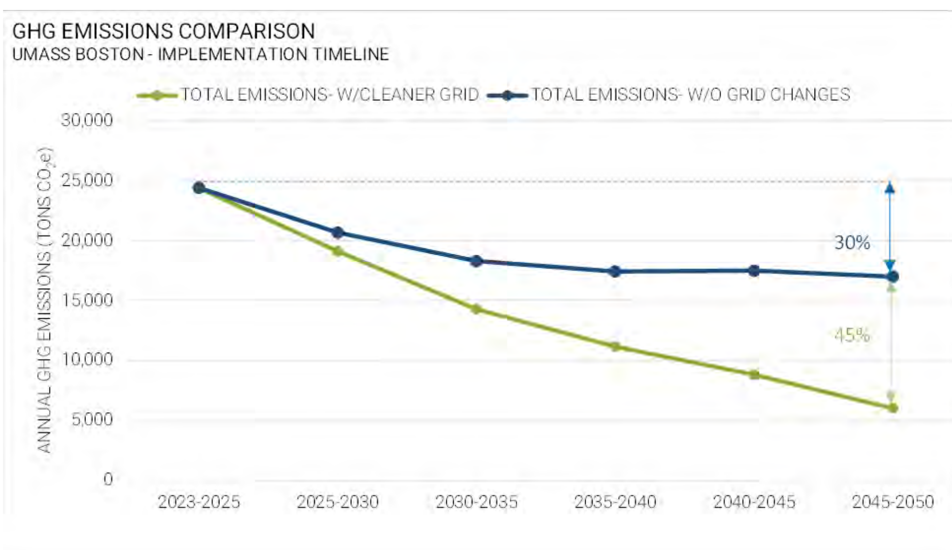


Figure 104: GHG Emissions Comparison With and Without Clean Grid Across the Implementation Timeline (2023-2050)

The purpose of the figure below is to illustrate the compliance path with Executive Order 594 (EO 594). It shows the fossil fuel emissions of the campus as it changes from 2023 to 2050 and compares it to the historic emissions of the campus in the year 2004 which is defined as the baseline for EO 594. Per EO 594, the campus should demonstrate a 20% reduction in fossil fuel emissions by 2025, a 35% reduction by 2030, a 60% reduction by 2040, and a 95% reduction by 2050 compared to the baseline year.

Currently, the 2023-2025 fossil fuel emissions are 200% higher than the baseline emissions. The campus is predicted to comply with EO 594's 2040 fossil fuel emissions reduction goal by demonstrating more than 60% reduction in emissions by 2040. As the plant gets fully electrified in 2050, the campus achieves an 86% reduction in emissions, however a 95% reduction is required. The remaining natural gas consumption is related to process end uses in the labs and Residence Hall commercial kitchen.

It is recommended that UMB discuss compliance exceptions with DCAMM for the 2025 and 2030 years considering the current fossil fuel emissions are 200% higher than that of the baseline year and the projects to electrify the heating plant are under development. UMB should also discuss negotiate the kitchen electrification for Residence Hall #1 and seek an exception for process natural gas use in the labs.

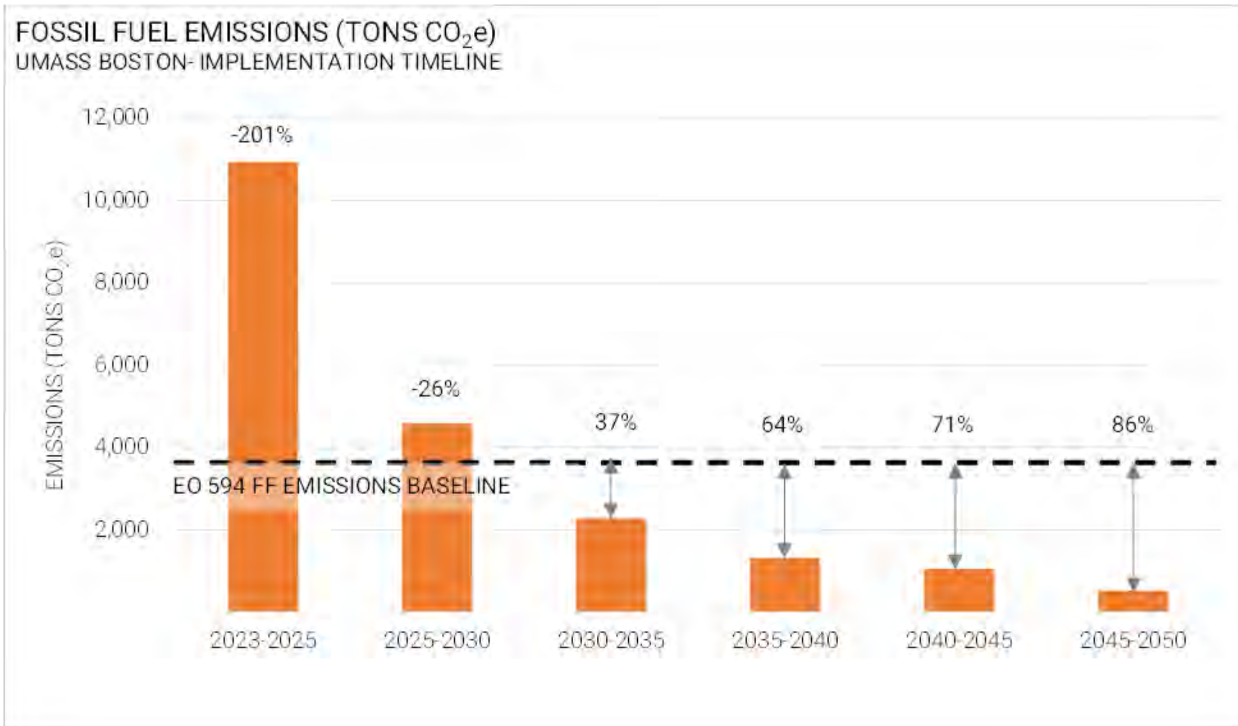


Figure 105: EO 594- Fossil Fuel Emissions Reduction Compliance Across the Implementation Timeline (2023-2050)

EO 594	Fossil Fuel Emissions Reduction Percentage for EO 594 Compliance	Campus Fossil Fuel Emissions Reduction Percentage	Complies (Y/N)
2025	20%	(- 201%)	N
2030	35%	(- 26%)	N
2040	60%	64%	Y
2050	95%	86%	Y*

**100% and compliant excluding process end uses in the labs and Residence Hall commercial kitchen*

Figure 106: EO 594 Fossil Fuel Emissions Compliance Requirements

APPENDICES

APPENDIX A – WORK PLAN

UNIVERSITY OF MASSACHUSETTS BOSTON
ENERGY AND CARBON MASTER PLAN
PROJECT MANAGEMENT PLAN

Contents

Introduction

The Project

The University of Massachusetts Boston (UMB) conducted a competitive procurement for planning and consulting services to develop a comprehensive Alternative Energy Master Plan (ECMP). The ECMP effort grew out of a multi-year strategic planning process and in support of campus sustainability objectives, legislative mandates, and university commitments. The ECMP will assist UMB in achieving interim carbon reduction goals with the ultimate goal of carbon neutrality by 2050 while aligning multiple stakeholder groups across the campus.

BR+A Consulting Engineers (BR+A) was awarded the contract for the ECMP in April 2021 and is responsible for leading the development of the plan, engaging partner firms Atelier Ten, Weston and Sampson, and Vermeulens.

The Work Plan

The enclosed project Work Plan supports the planning, execution, monitoring & control, and closeout of UMB's ECMP effort. The Work Plan spells out the project objectives, scope, schedule, roles and responsibilities, communication methods, and risk tracking. The Work Plan is a "living document" in that it should be reviewed and updated as necessary for the duration of the project.

Work Plan Use Guidelines

The Work Plan will remain in Microsoft Word format and be stored in a Project SharePoint file accessible by the Project Team. Comments may be added to the Work Plan by the ECMP Project Team but should be added in a manner where they are identifiable. Listed below is the standard guidelines for Work Plan comments and edits:

1. Both the author and the content must be visible
2. For ease of recognition, Microsoft Word Review functions should be used to add comments in the review pane
3. Tracked changes are acceptable for in-text edits
4. The author of a tracked change must not approve their own changes, the Project Manager is solely responsible for accepting tracked changes and resolving comments.
5. Rejected changes shall be discussed as necessary during bi-weekly meetings

Goals

The stated goals of the ECMP are as follows:

1. Forecast the campus' hourly and annual energy demands over the next decade under a Business-as-Usual case in which the campus maintains its current level of energy efficiency, and identify any expected shortfalls in campus utility infrastructure capacity and service.
2. Forecast greenhouse gas emissions from campus operations and UMB's energy investment and purchasing costs through 2050 under the Business-as-Usual case in which the campus maintains its current energy systems and sources.
3. Evaluate reliability and resiliency risks in campus utilities and operations considering the campus' proximity to the ocean and vulnerability to sea level rise and storm surge and increased research activities dependent on reliable power and temperature control.
4. Identify, evaluate, and compare energy efficiency, infrastructure and purchasing options that enable UMB to meet the long-term EO 594, ACPUCC, and Baker-Polito Administration emissions goals (Carbon neutral by 2050) in a reliable, cost effective manner.
5. Specify the physical infrastructure, operating systems, and costs for UMB to implement the recommended energy investment and purchasing strategy to meet its emissions, cost, reliability, and resiliency objectives. Compare emissions, cost, and resiliency outcomes between the Business-as-Usual case and the recommended alternative case.

Project goals were reviewed by the Project Team during the kickoff meeting on October 18th 2021. While no additional goals were identified, UMB emphasized the importance of the following:

1. EO 594 has replaced EO 484 detailing energy and emission targets
2. State facilities including UMASS Boston are not subject to the City of Boston Energy Disclosure Ordinance carbon emissions intensity (CEI) targets and/or expected carbon neutral zoning
3. State Clean Energy and Climate Plan updates expected in March 2022 detailing existing building emission targets.
4. Assumptions regarding EV charging expansion for faculty, students, staff, and visitors should be reviewed with UMB so that baseline energy consumption estimates can be updated accordingly.

Scope and Deliverables

The ECMP project is defined by the following phases, tasks, and deliverables:

Phase	Task	Description	Deliverables
I	Default Case Analysis	+ Kick-off meeting to build consensus on goals, roles/responsibilities, and schedule	+ Phase 1 Interim Report
		+ High-level assessment of existing major campus energy-related systems and campus utility distribution infrastructure, using a numerical rating system	
		+ Analyze building-level energy demands, onsite generation performance, and campus-level energy performance.	
		+ Forecast building and campus heating, cooling and electrical load, energy consumption, and GHG emissions under Business-As-Usual (BAU) scenario through 2050 in approximately 10-year increments	
		+ Provide narrative, costs, and life cycle costs, outlining infrastructure replacement, upgrades and increased capacity requirements to reliably serve campus operations through.	
		+ Develop a plan to engage UMB stakeholders throughout the process. Engagement plans should include targeted meetings with established groups (DCAMM, DOER, Utility), outreach to faculty and students, and online mechanisms for soliciting, collecting, and sharing stakeholder input.	
		+ Identify gaps between projected outcomes and mandated targets in Executive Order 594	

Phase	Task	Description	Deliverable
II	Alternative Analysis	+ Perform a high-level energy audit, similar to ASHRAE Level 1, with a primary focus on major drivers of thermal energy and electrical demand. Outline a potential range of deep energy retrofit solutions that accompany renovations vs. more targeted upgrades.	+ Phase 2 Interim Report
		+ Develop whole-campus electrification options, each targeting carbon neutral and enhanced resilience, spanning a range of potential integrated solutions.	
		+ Develop an energy reliability and resiliency strategy for the campus that details the general location, configuration, and vulnerabilities of utility services and compares the options and costs to harden the campus' energy infrastructure to ensure campus operations are resilient based on the campus' waterfront location and risks posed by sea level rise and extreme weather events including storm surge.	
		+ Evaluate onsite capacity for development of additional renewable energy sources	
		+ Provide a summary of potential off-site renewable energy procurement options and associated advantages of each.	
III	Investment Plan	+ Develop investment plans for preferred alternative case. This will include a schedule of capital and operating costs for each and prioritized list of energy projects to achieve the desired outcomes under each case.	+ Draft ECMP + Final ECMP
		+ Draft and final report for Master Plan, primarily focusing on the investment plan for the approved solution.	

Scope Boundaries

The following is a list of scope boundaries:

#	Included / Excluded	Related Tasks	Boundary	Guidance
1	Included	ECMP	The East and West Residence Halls are provided with steam and chilled water from the UMB central plant. The facilities are operated by a third party as part of a 40-year contract. UMB students occupy the building. This facility WILL be included as part of the carbon master plan.	
2	Excluded	ECMP	UMass Board of Trustees and the UMass Building Authority (UMBA) voted to designate Accordia Partners to build a mixed-use urban innovation campus on the Bayside Site. The future energy and carbon associated with this development will NOT be included in the scope of the project. Central plant alternatives developed as part of the carbon master plan will NOT account for future loads of this development.	
3	Excluded	Alternatives Analysis	UMB leases a portion of 150 Mount Vernon Street from a 3rd party. This facility will NOT be included in the carbon master plan scope.	

Project Schedule

Baseline project schedule shown below for reference, task duration and sequence match that of the proposed project schedule. The start date is based on the kickoff meeting task. The project schedule is to be updated throughout the project and addressed during bi-weekly team meetings.

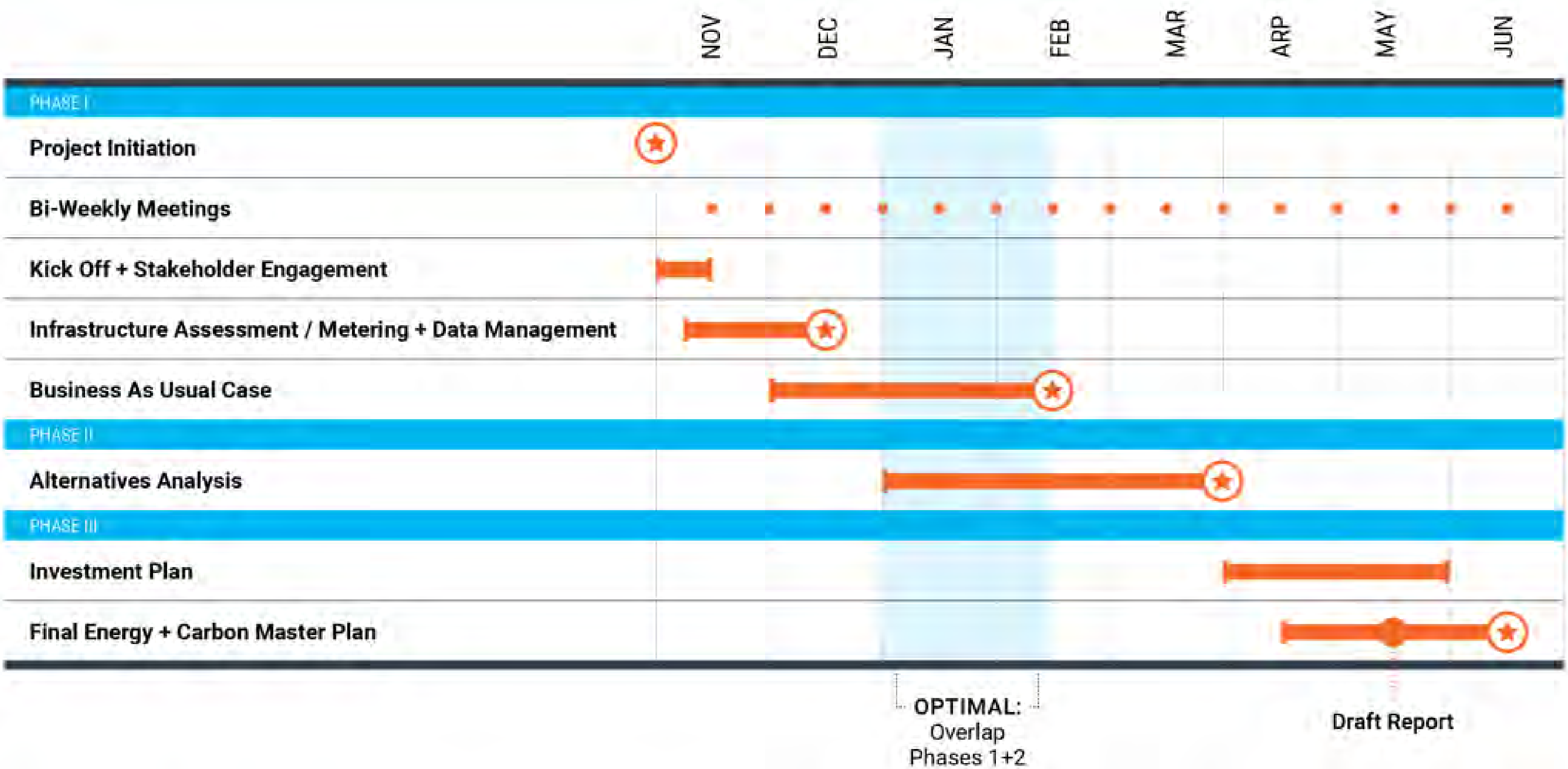


Figure 1 - Project Schedule

Roles and Responsibilities

Project Team

BR+A have assembled a team of specialists each of which brings a unique skillset to the project. The principal roles are:

The Client – ECMP Project Team, University of Massachusetts Boston

Project Manager/ Consultant – BR+A

In addition to the key roles above, other specialists will be involved during the lifecycle of the project. Refer to the Organizational Chart below. The group of specialists may be further developed or refined during the project and the organizational chart shall be updated accordingly.

The Project Directory lists the personnel comprising the current Project Team and relevant information such as agency/company, title, phone number, and email address.

Project Governance

Figure 2 - Organizational Chart

Communication

Efficient and effective communication is integral to the success of the project. As such, the Project Team must be intentional in communicating matters related to the Client's objectives, project design, information requests, contractual/ administrative issues, as well as the resolution of any problems that may arise.

It is the responsibility of each and every member of the Project Team to ensure that information, as it is created or identified, is properly coordinated and communicated to members of the team to whom the information is relevant. Equally, information must be communicated in ways which reflect its importance or urgency.

If there is any doubt as to the status or urgency of information or to whom it should be issued, the matter should be referred to the Project Manager.

All formal communication with and instructions by the Client will be directed through the Project Manager. The Project Manager will transmit all relevant information, instructions, and approvals to the consultant team.

Informal communication is expected to occur between the Client and the consultant team. It is important that a record of any informal communications expressing key information, instructions and approvals from the Client be provided to the Project Manager and circulated to other members of the consultant team as appropriate.

All written communication (email or hard copies) between the consultant team shall be copied to the Project Manager.

Communication between members of the consultant team shall be unrestricted. Each party shall ensure that all other members of the team are kept fully informed of all matters relating to the project.

Verbal Communication

The most common means of communication; may be in person, via web meeting platform, or telephone. Verbal communication should be confirmed in writing or by email when possible. Unnecessary written correspondence is discouraged.

External Communication

The Project Manager will develop relationships with DOER, DCAMM, and other agencies as necessary to ensure project objectives are met and input is received.

Electronic Transmittals

Documents should be transmitted as attachments to emails rather than being embedded in the text of the message whenever possible.

Meetings

Meeting are a central method of communication in the project. In all cases meetings shall be planned and coordinated to ensure efficiency and effectiveness:

1. Meetings shall be coordinated in advance to ensure maximum participation and minimum disruption to scheduled activities
2. Meeting invitations shall be extended electronically via Microsoft Outlook for ease of tracking attendance and integration with electronic calendars

3. Invitations shall be directed to key individual based on the intent of the meeting. Additional attendees may be added as “optional” as necessary
4. Meeting agenda shall be disseminated to attendees at minimum 2 days before the scheduled meeting and convey the intent and topics of discussion
5. Meeting notes shall be taken by BR+A and disseminated to all attendees no later than 2 days after the meeting
6. Meeting notes shall clearly list any action items for tracking

Tools

The Project Team will utilize several tools to manage the project.

SharePoint

SharePoint web-based collaborative platform that integrates with Microsoft Office. It should be used as a document management and storage system for the duration of the project and house key project documents relevant to the Project Team.

RFI Log

The Project Manager shall use an RFI Log to track information requests submitted to the Client. The Client shall use the RFI Log to view and manage requests. The RFI Log may be transmitted electronically when necessary and shall be located in the SharePoint Client folder. See Appendix A for the RFI log.

Teams

Teams is a web-based communication platform developed by Microsoft. Teams offers a communal workspace as well as a forum for audio and video meetings. Teams will primarily be used as a meeting venue with the Client.

Communication Plan

Goal	Method	Responsible	Audience
Obtain site-specific data, documentation	RFI	Michael Swenson	ECMP Project Team, Energy Manager
Obtain site-specific knowledge	Virtual meeting, survey, phone	Michael Swenson	FM, Office of Sustainability, ECMP Project Team
Project status update	Web-based meeting	Michael Swenson	Project Team
Stakeholder engagement	Web-based meeting, electronic survey	Michael Swenson	Project Team, Stakeholders
Interim deliverable dissemination	Email, SharePoint access	Michael Swenson	ECMP Project Team
Interim deliverable feedback	Email, web-based meeting	ECMP Project Team	Project Manager

Table 2 - Communication Plan

Approvals

The following deliverables will require feedback and approval by the Client:

1. Project Management Plan
2. Phase I Interim Report (2-week review period)
3. Phase 2 Interim Report (2-week review period)
4. Complete Report Draft (4-week comment period)

Risk and Issue Management Plan

The risk register is a management tool that logs potential risks to the project, primarily driven by Health and Safety, cost, project delays or any other risks that may be relevant to the successful completion of the project.

The objectives of risk management are:

1. To identify risks to the project before they occur
2. Eliminate risks whenever possible
3. Develop management plans and contingencies to mitigate the impact of risks should they occur
4. Mitigate the impact of a risk occurring

APPENDIX B – DATA OMISSIONS AND ANOMALIES

Energy metering data was reviewed for omissions and anomalies. Metering issues include data not available, data incomplete, and suspect data. Below is a chart summarizing the buildings affected, issues, and next steps to ensure a complete data set.

Table 27: Building data issues and next steps

Affected Building	Issue	Next Steps
Healey Library	Last year BTU not available.	Defer to model assumptions for heating consumption.
Quinn Administration Building	EUI flag. Last year BTU cooling meter appears unrealistic based on building use and equipment (4 kBtu/sf) EUI flag. Last year BTU heating meter appears unrealistic based on building use, equipment, and electric heating (41 kBtu/sf)	Defer to model assumptions for cooling and heating consumption.
Clark Building	EUI flag. Last year BTU cooling meter appears unrealistic based on building use and equipment (300 kBtu/sf)	Defer to model assumptions for cooling consumption.
Integrated Science Complex	Last year BTU not available.	Defer to model assumptions for heating consumption.
Residence Hall	Metering information unreliable based on discussion with UMASS Boston (J. O'day).	Defer to model assumptions for cooling consumption.

APPENDIX C– BUILDING SCORES

Building Name	Score Weighting Factors				
	25%	25%	25%	25%	
	Building Priority Scores				
	Energy Use Intensity Score	EUI Target Score	Combustion Emissions Score	Facility Condition Score	Combined Score (0-100)
Campus Center	44	89	100	100	83
McCormack Hall	100	0	78	88	66
Integrated Science Complex	89	78	22	75	66
Wheatley Hall	56	56	89	63	66
Healey Library	67	67	56	0	47
University Hall	78	22	44	25	42
Clark Building	33	44	33	50	40
Residence Hall #1	11	100	0	38	37
Service	0	33	67	0	25
Quinn Building	11	11	11	13	11

Below is the raw data used to determine the individual scores.

Building Name	Building Values			
	Energy Use Intensity (kBtu/sf-yr)	% off EUI Target	Combustion Emissions (lbs CO2-yr)	Facility Condition ($)
Campus Center	174	66%	576,261,176	55,360,000
McCormack Hall	224	64%	9,654,571	36,050,000
Integrated Science Complex	252	17%	300,142,557	38,475,000
Wheatley Hall	176	59%	401,631,153	28,130,000
Healey Library	136	54%	38,294,217	23,841,000
University Hall	208	62%	186,030,000	167,000
Clark Building	223	36%	163,096,222	9,217,000
Residence Hall #1	101	38%	197,730,000	0
Service	110	66%	1,885,595	19,771,000
Quinn Building	110	35%	2,418,039	8,584,000

APPENDIX D – ASHRAE EQUIPMENT LIFE EXPECTANCY

All End of Life estimates for mechanical equipment delineated in the tables above are reflective of the ASHRAE Equipment Life Expectancy Chart by equipment type.

ASHRAE Equipment Life Expectancy chart

ASHRAE is the industry organization that sets the standards and guidelines for most all HVAC-R equipment.
For additional info about ASHRAE the website is www.ashrae.org .

Equipment Item	Median Years
Air conditioners	
Window unit	10
Residential single or Split Package	15
Commercial through-the wall	15
Water-cooled package	15
Heat Pumps	
Residential air-to-air	15
Commercial air-to-air	15
Commercial water-to-air	19
Roof-top air conditioners	
Single-zone	15
Multi-zone	15
Boilers, hot water (steam)	
Steel water-tube	24 (30)
Steel fire-tube	25 (25)
Cast iron	35 (30)
Electric	15
Burners	21
Furnaces	
Gas- or oil-fired	18
Unit heaters	
Gas or electric	13
Hot water or steam	20
Radiant Heaters	
Electric	10
Hot water or steam	25
Air terminals	
Diffusers, grilles, and registers	27
Induction and fan coil units	20
VAV and double-duct boxes	20
Air washers	17
Ductwork	30
Dampers	20
Fans	
Centrifugal	25
Axial	20
Propeller	15
Ventilating roof-mounted	20
Coils	
DX, water, or steam	20
Electric	15
Heat Exchangers	
Shell-and-tube	24
Reciprocating compressors	20
Packaged chillers	
Reciprocating	20
Centrifugal	23
Absorption	23
Cooling towers	
Galvanized metal	20
Wood	20
Ceramic	34
Air-cooled condensers	20
Evaporative condensers	20
Insulation	
Molded	20
Blanket	24
Pumps	
Base-mounted	20
Pipe-mounted	10
Sump and well	10
Condensate 15	
Reciprocating engines	20
Steam turbines	30
Electric motors	18
Motor starters	17
Electric transformers	30
Controls	
Pneumatic	20
Electric	16
Electronic	15
Valve actuators	
Hydraulic	15
Pneumatic	20
Self-contained	10

APPENDIX E – CAMPUS GROWTH ASSUMPTIONS

View Spreadsheet

APPENDIX F – LIFE CYCLE COST ASSUMPTIONS

Life Cycle Cost Rates	
Discount Rate[1]	4.50%
Electricity Escalation Rate[2]	2.00%
Natural Gas Escalation Rate[2]	3.00%
Potable Water Escalation[3]	6.00%
Maintenance Escalation Rate	3.00%
One-Time Costs Escalation Rate	3.00%
Study Period (years)	30

[1] Per email from Shaun Curry 4/29/22
[2] CES energy projections dated 10/27/21 (average)
[3] https://www.bwsc.org/business-customers/rates (average)

Water Rates	
	Per 1000 Gallons
2022	$10.736

*https://www.bwsc.org/sites/default/files/2020-01/rates_2019.pdf (average)

Emissions Assumptions		
	Electricity	Steam
2019	85.4 kg/MMBtu	66.4 kg/MMBtu
2050	20.8 kg/MMBtu	

* Per City of Boston Building Emission Reduction and Disclosure Ordinance (link). Note that the assumption at this time is that the grid will not be 100% renewable by 2050.

Estimated Annual Maintenance Cost Reference Table		
Unit	U.S Dollar Amount	Equipment Type
$/ea	$1,500	AHU+EAHU+Konvekta Energy Recovery
$/ea	$500	Air Handling Units - hydronic
$/ea	$1,200	Air-to-water Heat Pumps
$/ea	$400	CHW Chillers
$/ton	$10	Cooling Towers
$/ea	$1,700	DOAS + ERW
$/ea	$1,500	Electric Boilers
$/ea	$200	Exhaust Fans
$/ea	$250	Exhaust Fans and Heat Recovery
$/ton	$1,200	Exhaust-source heat pump
$/ea	$95	Fan Coil Units
$/ea	$600	GSHP / Geo
$/ea	$600	Heat Recovery Chiller
$/ea	$400	Heat Recovery Chillers - cascading hp
$/ea	$250	high plume dilution exhaust fans
$/ea	$3,000	Natural Gas Boilers

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Natural Gas (Main Account)

*All prices presented are in nominal dollars
*Current usage profile:

16%	14%	16%	9%	4%	2%	1%	3%	4%	6%	12%	12%

Volumetric Natural Gas Charges ($/MMBtu)

CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average $/MMBtu	Weighted $/MMBtu
2022	$8.02	$8.02	$8.02	$8.02	$9.57	$9.57	$9.57	$9.57	$9.57	$9.57	$16.50	$16.50	$10.21	$10.38
2023	$16.50	$16.50	$16.50	$16.50	$5.95	$5.95	$5.95	$5.95	$5.95	$5.95	$10.70	$10.70	$10.26	$12.89
2024	$10.70	$10.70	$10.70	$10.70	$4.55	$4.55	$4.55	$4.55	$4.55	$4.55	$8.51	$8.51	$7.26	$8.88
2025	$8.51	$8.51	$8.51	$8.51	$4.79	$4.79	$4.79	$4.79	$4.79	$4.79	$8.58	$8.58	$6.66	$7.74
2026	$8.58	$8.58	$8.58	$8.58	$4.91	$4.91	$4.91	$4.91	$4.91	$4.91	$8.81	$8.81	$6.79	$7.87
2027	$8.81	$8.81	$8.81	$8.81	$5.04	$5.04	$5.04	$5.04	$5.04	$5.04	$9.03	$9.03	$6.96	$8.07
2028	$9.03	$9.03	$9.03	$9.03	$5.18	$5.18	$5.18	$5.18	$5.18	$5.18	$9.27	$9.27	$7.15	$8.28
2029	$9.27	$9.27	$9.27	$9.27	$5.32	$5.32	$5.32	$5.32	$5.32	$5.32	$9.51	$9.51	$7.33	$8.49
2030	$9.51	$9.51	$9.51	$9.51	$5.46	$5.46	$5.46	$5.46	$5.46	$5.46	$9.75	$9.75	$7.52	$8.71
2031	$9.75	$9.75	$9.75	$9.75	$5.60	$5.60	$5.60	$5.60	$5.60	$5.60	$10.00	$10.00	$7.72	$8.94
2032	$10.00	$10.00	$10.00	$10.00	$5.75	$5.75	$5.75	$5.75	$5.75	$5.75	$10.26	$10.26	$7.92	$9.17
2033	$10.26	$10.26	$10.26	$10.26	$5.90	$5.90	$5.90	$5.90	$5.90	$5.90	$10.53	$10.53	$8.13	$9.41
2034	$10.53	$10.53	$10.53	$10.53	$6.06	$6.06	$6.06	$6.06	$6.06	$6.06	$10.80	$10.80	$8.34	$9.66
2035	$10.80	$10.80	$10.80	$10.80	$6.22	$6.22	$6.22	$6.22	$6.22	$6.22	$11.08	$11.08	$8.56	$9.91
2036	$11.08	$11.08	$11.08	$11.08	$6.39	$6.39	$6.39	$6.39	$6.39	$6.39	$11.37	$11.37	$8.78	$10.16
2037	$11.37	$11.37	$11.37	$11.37	$6.56	$6.56	$6.56	$6.56	$6.56	$6.56	$11.66	$11.66	$9.01	$10.43
2038	$11.66	$11.66	$11.66	$11.66	$6.73	$6.73	$6.73	$6.73	$6.73	$6.73	$11.97	$11.97	$9.25	$10.70
2039	$11.97	$11.97	$11.97	$11.97	$6.91	$6.91	$6.91	$6.91	$6.91	$6.91	$12.28	$12.28	$9.49	$10.98
2040	$12.28	$12.28	$12.28	$12.28	$7.10	$7.10	$7.10	$7.10	$7.10	$7.10	$12.59	$12.59	$9.74	$11.26
2041	$12.59	$12.59	$12.59	$12.59	$7.28	$7.28	$7.28	$7.28	$7.28	$7.28	$12.85	$12.85	$9.98	$11.54

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Natural Gas (Main Account)

*All prices presented are in nominal dollars
*FY23 Budget MDCQ: 2275 therms (May-Oct), 11000 therms (Nov-Apr)

Determination of Maximum Daily Contract Quantity (MDCQ):

Each season's MDCQ is determined annually. The calculation uses the Customer's billing history for the previous peak and off-peak seasons. The number of therms used in each billing period is adjusted to a 30-day basis. The highest monthly usage for each season is then divided by 21 to determine each season's MDCQ.

National Grid Delivery Demand Charges ($/MDCQ)

CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	$5.34	$5.34	$5.34	$5.34	$1.89	$1.89	$1.89	$1.89	$1.89	$1.89	$5.50	$5.50
2023	$5.50	$5.50	$5.50	$5.50	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$5.66	$5.66
2024	$5.66	$5.66	$5.66	$5.66	$2.01	$2.01	$2.01	$2.01	$2.01	$2.01	$5.83	$5.83
2025	$5.83	$5.83	$5.83	$5.83	$2.07	$2.07	$2.07	$2.07	$2.07	$2.07	$6.01	$6.01
2026	$6.01	$6.01	$6.01	$6.01	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$6.19	$6.19
2027	$6.19	$6.19	$6.19	$6.19	$2.20	$2.20	$2.20	$2.20	$2.20	$2.20	$6.37	$6.37
2028	$6.37	$6.37	$6.37	$6.37	$2.26	$2.26	$2.26	$2.26	$2.26	$2.26	$6.56	$6.56
2029	$6.56	$6.56	$6.56	$6.56	$2.33	$2.33	$2.33	$2.33	$2.33	$2.33	$6.76	$6.76
2030	$6.76	$6.76	$6.76	$6.76	$2.40	$2.40	$2.40	$2.40	$2.40	$2.40	$6.96	$6.96
2031	$6.96	$6.96	$6.96	$6.96	$2.47	$2.47	$2.47	$2.47	$2.47	$2.47	$7.17	$7.17
2032	$7.17	$7.17	$7.17	$7.17	$2.55	$2.55	$2.55	$2.55	$2.55	$2.55	$7.39	$7.39
2033	$7.39	$7.39	$7.39	$7.39	$2.62	$2.62	$2.62	$2.62	$2.62	$2.62	$7.61	$7.61
2034	$7.61	$7.61	$7.61	$7.61	$2.70	$2.70	$2.70	$2.70	$2.70	$2.70	$7.84	$7.84
2035	$7.84	$7.84	$7.84	$7.84	$2.78	$2.78	$2.78	$2.78	$2.78	$2.78	$8.07	$8.07
2036	$8.07	$8.07	$8.07	$8.07	$2.87	$2.87	$2.87	$2.87	$2.87	$2.87	$8.32	$8.32
2037	$8.32	$8.32	$8.32	$8.32	$2.95	$2.95	$2.95	$2.95	$2.95	$2.95	$8.56	$8.56
2038	$8.56	$8.56	$8.56	$8.56	$3.04	$3.04	$3.04	$3.04	$3.04	$3.04	$8.82	$8.82
2039	$8.82	$8.82	$8.82	$8.82	$3.13	$3.13	$3.13	$3.13	$3.13	$3.13	$9.09	$9.09
2040	$9.09	$9.09	$9.09	$9.09	$3.22	$3.22	$3.22	$3.22	$3.22	$3.22	$9.36	$9.36
2041	$9.36	$9.36	$9.36	$9.36	$3.32	$3.32	$3.32	$3.32	$3.32	$3.32	$9.64	$9.64

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Grid Electricity (Main Account)

*All prices presented are in nominal dollars
*Current usage profile:

9%	9%	8%	8%	8%	8%	9%	9%	9%	8%	8%	8%

	Volumetric Grid Electricity Charges ($/MWh)											Average	Weighted
CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	$/MWh	$/MWh
2022	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60	$19.60
2023	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87	$27.87
2024	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06	$28.06
2025	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38	$28.38
2026	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28	$29.28
2027	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05	$29.05
2028	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20	$26.20
2029	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59	$26.59
2030	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86	$26.86
2031	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13	$27.13
2032	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40	$27.40
2033	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67	$27.67
2034	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95	$27.95
2035	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23	$28.23
2036	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51	$28.51
2037	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80	$28.80
2038	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09	$29.09
2039	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38	$29.38
2040	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67	$29.67
2041	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97	$29.97

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Grid Electricity (Main Account)

*All prices presented are in nominal dollars
*Billed demand is based on the campus' maximum 15-minute grid demand across all on-peak hours in a billing cycle:
On-peak hours from June through September: 9am - 6pm all weekdays
On-peak hours from October through May: 8am - 9pm all weekdays

	Eversource Distribution & Transmission Demand Charges ($/kW-mo)											
CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	$23.39	$23.39	$23.39	$23.39	$23.39	$30.21	$30.21	$30.21	$30.21	$23.39	$23.39	$23.39
2023	$24.09	$24.09	$24.09	$24.09	$24.09	$31.04	$31.04	$31.04	$31.04	$24.09	$24.09	$24.09
2024	$25.23	$25.23	$25.23	$25.23	$25.23	$32.28	$32.28	$32.28	$32.28	$25.23	$25.23	$25.23
2025	$25.99	$25.99	$25.99	$25.99	$25.99	$33.14	$33.14	$33.14	$33.14	$25.99	$25.99	$25.99
2026	$26.77	$26.77	$26.77	$26.77	$26.77	$34.03	$34.03	$34.03	$34.03	$26.77	$26.77	$26.77
2027	$27.58	$27.58	$27.58	$27.58	$27.58	$34.95	$34.95	$34.95	$34.95	$27.58	$27.58	$27.58
2028	$28.42	$28.42	$28.42	$28.42	$28.42	$35.90	$35.90	$35.90	$35.90	$28.42	$28.42	$28.42
2029	$29.28	$29.28	$29.28	$29.28	$29.28	$36.88	$36.88	$36.88	$36.88	$29.28	$29.28	$29.28
2030	$30.13	$30.13	$30.13	$30.13	$30.13	$37.80	$37.80	$37.80	$37.80	$30.13	$30.13	$30.13
2031	$31.00	$31.00	$31.00	$31.00	$31.00	$38.75	$38.75	$38.75	$38.75	$31.00	$31.00	$31.00
2032	$31.91	$31.91	$31.91	$31.91	$31.91	$39.74	$39.74	$39.74	$39.74	$31.91	$31.91	$31.91
2033	$32.85	$32.85	$32.85	$32.85	$32.85	$40.75	$40.75	$40.75	$40.75	$32.85	$32.85	$32.85
2034	$33.82	$33.82	$33.82	$33.82	$33.82	$41.81	$41.81	$41.81	$41.81	$33.82	$33.82	$33.82
2035	$34.83	$34.83	$34.83	$34.83	$34.83	$42.89	$42.89	$42.89	$42.89	$34.83	$34.83	$34.83
2036	$35.88	$35.88	$35.88	$35.88	$35.88	$44.02	$44.02	$44.02	$44.02	$35.88	$35.88	$35.88
2037	$36.96	$36.96	$36.96	$36.96	$36.96	$45.19	$45.19	$45.19	$45.19	$36.96	$36.96	$36.96
2038	$38.09	$38.09	$38.09	$38.09	$38.09	$46.39	$46.39	$46.39	$46.39	$38.09	$38.09	$38.09
2039	$39.25	$39.25	$39.25	$39.25	$39.25	$47.64	$47.64	$47.64	$47.64	$39.25	$39.25	$39.25
2040	$40.46	$40.46	$40.46	$40.46	$40.46	$48.93	$48.93	$48.93	$48.93	$40.46	$40.46	$40.46
2041	$41.71	$41.71	$41.71	$41.71	$41.71	$50.27	$50.27	$50.27	$50.27	$41.71	$41.71	$41.71

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Grid Electricity (Main Account)

*All prices presented are in nominal dollars
*Current usage profile:

9%	9%	8%	8%	8%	8%	9%	9%	9%	8%	8%	8%

	Volumetric Grid Electricity Charges ($/MWh)												Average	Weighted
CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	$/MWh	$/MWh
2022	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30
2023	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30	$69.30
2024	$133.43	$136.24	$92.22	$62.93	$57.28	$59.27	$64.27	$64.71	$57.78	$63.83	$80.23	$97.32	$80.79	$81.21
2025	$104.98	$107.89	$90.22	$59.52	$56.29	$58.49	$62.89	$63.74	$58.27	$63.06	$76.15	$90.50	$74.33	$74.58
2026	$100.42	$103.36	$85.97	$56.33	$55.90	$58.47	$62.28	$63.54	$59.74	$63.34	$72.79	$84.65	$72.23	$72.49
2027	$99.74	$102.77	$85.75	$56.54	$56.20	$58.70	$62.44	$63.59	$59.69	$63.23	$72.57	$84.33	$72.13	$72.38
2028	$98.76	$101.78	$84.95	$56.03	$55.69	$58.28	$62.08	$63.25	$59.40	$63.10	$72.05	$83.57	$71.58	$71.83
2029	$97.46	$100.43	$83.76	$55.10	$54.68	$57.15	$60.92	$62.31	$58.45	$62.15	$70.88	$82.24	$70.46	$70.71
2030	$97.76	$100.83	$84.44	$56.21	$55.86	$58.36	$62.19	$63.77	$59.93	$63.88	$71.89	$82.66	$71.48	$71.72
2031	$98.35	$101.42	$85.18	$57.12	$56.78	$59.30	$63.17	$64.77	$60.90	$64.91	$72.70	$83.35	$72.33	$72.57
2032	$99.45	$102.52	$86.42	$58.54	$58.21	$60.75	$64.65	$66.27	$62.36	$66.43	$74.01	$84.55	$73.68	$73.92
2033	$100.57	$103.65	$87.68	$59.97	$59.66	$62.22	$66.16	$67.80	$63.86	$67.99	$75.34	$85.77	$75.06	$75.29
2034	$101.71	$104.80	$88.97	$61.43	$61.13	$63.72	$67.69	$69.35	$65.37	$69.56	$76.70	$87.02	$76.46	$76.69
2035	$102.88	$105.97	$90.28	$62.92	$62.63	$65.24	$69.25	$70.93	$66.91	$71.17	$78.09	$88.29	$77.88	$78.12
2036	$104.08	$107.17	$91.62	$64.43	$64.16	$66.79	$70.83	$72.53	$68.48	$72.80	$79.50	$89.59	$79.33	$79.56
2037	$105.30	$108.40	$92.99	$65.96	$65.71	$68.36	$72.44	$74.16	$70.07	$74.45	$80.93	$90.91	$80.81	$81.04
2038	$106.55	$109.65	$94.38	$67.52	$67.28	$69.96	$74.07	$75.81	$71.69	$76.13	$82.39	$92.26	$82.31	$82.54
2039	$107.82	$110.92	$95.79	$69.11	$68.89	$71.58	$75.74	$77.50	$73.34	$77.84	$83.88	$93.63	$83.84	$84.07
2040	$109.12	$112.23	$97.24	$70.72	$70.52	$73.23	$77.42	$79.21	$75.01	$79.58	$85.39	$95.03	$85.39	$85.62
2041	$110.44	$113.56	$98.71	$72.37	$72.17	$74.91	$79.14	$80.94	$76.71	$81.34	$86.94	$96.45	$86.97	$87.20

UMass Boston
Energy Master Plan
20-Year Energy Price Forecast
Grid Electricity (Main Account)

*All prices presented are in nominal dollars
*Billed demand is based on the campus' hourly load during the ISO New England annual peak demand hour, cap tag resets each June.

Installed Capacity Demand Charges ($/kW-mo)

CY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	$6.56	$6.56	$6.56	$6.56	$6.56	$5.32	$5.32	$5.32	$5.32	$5.32	$5.32	$5.32
2023	$5.32	$5.32	$5.32	$5.32	$5.32	$2.80	$2.80	$2.80	$2.80	$2.80	$2.80	$2.80
2024	$2.80	$2.80	$2.80	$2.80	$2.80	$3.47	$3.47	$3.47	$3.47	$3.47	$3.47	$3.47
2025	$3.47	$3.47	$3.47	$3.47	$3.47	$4.20	$4.20	$4.20	$4.20	$4.20	$4.20	$4.20
2026	$4.20	$4.20	$4.20	$4.20	$4.20	$5.25	$5.25	$5.25	$5.25	$5.25	$5.25	$5.25
2027	$5.25	$5.25	$5.25	$5.25	$5.25	$6.30	$6.30	$6.30	$6.30	$6.30	$6.30	$6.30
2028	$6.30	$6.30	$6.30	$6.30	$6.30	$7.35	$7.35	$7.35	$7.35	$7.35	$7.35	$7.35
2029	$7.35	$7.35	$7.35	$7.35	$7.35	$8.40	$8.40	$8.40	$8.40	$8.40	$8.40	$8.40
2030	$8.40	$8.40	$8.40	$8.40	$8.40	$8.48	$8.48	$8.48	$8.48	$8.48	$8.48	$8.48
2031	$8.48	$8.48	$8.48	$8.48	$8.48	$8.57	$8.57	$8.57	$8.57	$8.57	$8.57	$8.57
2032	$8.57	$8.57	$8.57	$8.57	$8.57	$8.65	$8.65	$8.65	$8.65	$8.65	$8.65	$8.65
2033	$8.65	$8.65	$8.65	$8.65	$8.65	$8.74	$8.74	$8.74	$8.74	$8.74	$8.74	$8.74
2034	$8.74	$8.74	$8.74	$8.74	$8.74	$8.83	$8.83	$8.83	$8.83	$8.83	$8.83	$8.83
2035	$8.83	$8.83	$8.83	$8.83	$8.83	$8.92	$8.92	$8.92	$8.92	$8.92	$8.92	$8.92
2036	$8.92	$8.92	$8.92	$8.92	$8.92	$9.01	$9.01	$9.01	$9.01	$9.01	$9.01	$9.01
2037	$9.01	$9.01	$9.01	$9.01	$9.01	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10
2038	$9.10	$9.10	$9.10	$9.10	$9.10	$9.19	$9.19	$9.19	$9.19	$9.19	$9.19	$9.19
2039	$9.19	$9.19	$9.19	$9.19	$9.19	$9.28	$9.28	$9.28	$9.28	$9.28	$9.28	$9.28
2040	$9.28	$9.28	$9.28	$9.28	$9.28	$9.37	$9.37	$9.37	$9.37	$9.37	$9.37	$9.37
2041	$9.37	$9.37	$9.37	$9.37	$9.37	$9.47	$9.47	$9.47	$9.47	$9.47	$9.47	$9.47

APPENDIX G – DETAILED COMPREHENSIVE ENERGY PROJECTS

	Proper Operation	Low Hanging Fruit ECMs	Deep Energy Retrofit
Campus Center	n/A	• Static pressure reset • Air-side economizers • LED conversion • Occupancy and daylight lighting controls	• Air-side energy recovery • Kitchen exhaust controls • Electric kitchen equipment
Clark Athletic Center	n/A	• AHU scheduling • Air-side economizers	• Air-side energy recovery
ISC	• Solar thermal domestic hot water • Heat recovery chiller • Konvekta system • Airflow setbacks	• LED lighting conversion • Air change rate reduction • Lab freezers -80->-70F	n/A
University Hall	n/A	• AHU scheduling • Static pressure reset • Air-side economizers • LED conversion • Occupancy and daylight lighting controls • Air change rate reduction (occupancy sensor based) • Lab freezers -80->-70F • Filtered fume hoods (recommendation)	• Air-side energy recovery
Wheatley Hall	• Ineffective coil conditioning • Simultaneous heating/ cooling • Low/high DAT • Overrides • Alarms • Failed/inaccurate sensors • Possible insufficient outside air • Possible insufficient supply air	• Economizer	*
McCormick Hall	• Ineffective coil conditioning • Simultaneous heating/ cooling • Low/high DAT • Overrides • Failed/inaccurate sensors • Alarms	• Economizer	*
Healey Library	• Ineffective coil conditioning • Low/high DAT • Overrides • Failed/inaccurate sensors • Alarms	• Economizer	*
Quinn Building	• VAV-01-20 leaking by • Failed/inaccurate sensors • Pump operation mismatch	• Economizer	*
Service and Supply	• Ineffective coil conditioning • Low/high DAT • AHU pump operation mismatch • Overrides • Alarms	• Economizer	*

*Expected major renovation

APPENDIX H – DETAILED COST ESTIMATE

21067 UMB Energy & Carbon MP

ALT #	ALTERNATES DESCRIPTION	QUANTITY	UNIT	RATE	TOTAL
	Baseline: CHW Chillers				
	chillers, replace 2000 ton each	8,000	tns	800.00	6,400,000
	chillers, 2000 ton each	4,000	tns	800.00	3,200,000
	primary chilled water pumps, 3200gpm, 100hp	7	no	95,000.00	665,000
	secondary chilled water pumps, 6400gpm, 270hp	4	no	150,000.00	600,000
	VFDs	11	no	25,000.00	275,000
	piping, chilled water	1,700	lf	925.00	1,572,500
	equipment connections	23	no	20,000.00	460,000
	controls	102	pts	2,500.00	255,000
	electrical connections	17	no	30,000.00	510,000
	miscellaneous removals, demolition	100,000	ls	1.00	100,000
	description	0		0.00	0
	Markups	14,037,500	%	0.58	8,141,750
	TOTAL				22,179,000
	Baseline: Cooling Towers				
	cooling towers, replace 2500 ton each	5,000	tns	325.00	1,625,000
	cooling towers, 2500 ton each	7,500	tns	325.00	2,437,500
	condenser water pumps, 6000gpm, 180hp	6	no	125,000.00	750,000
	VFDs	11	no	20,000.00	220,000
	piping, condenser water	1,300	lf	1,200.00	1,560,000
	equipment connections	11	no	20,000.00	220,000
	controls	66	pts	2,500.00	165,000
	electrical connections	11	no	30,000.00	330,000
	miscellaneous removals, demolition	100,000	ls	1.00	100,000
	description	0		0.00	0
	Markups	7,407,500	%	0.58	4,296,350
	TOTAL				11,704,000
	Baseline: Seawater Exchange				
	heat exchangers, preventative maintenance (TBD)	3	no	50,000.00	150,000
	heat exchangers, replace, 18750mbh (TBD)	1	no	500,000.00	500,000
	piping connections	2	no	20,000.00	40,000
	miscellaneous removals, demolition	25,000	ls	1.00	25,000
	description	0		0.00	0
	Markups	715,000	%	0.58	414,700
	TOTAL				1,130,000
	Baseline: Natural Gas Boilers				
	boilers, gas, 800bhp each	80,350	mbh	28.00	2,249,789
	boilers, gas, 400bhp	13,392	mbh	28.00	374,965
	boilers, gas, 800bhp each	107,133	mbh	28.00	2,999,718
	piping, hot water	1,000	lf	600.00	600,000
	piping, gas	400	lf	250.00	100,000
	equipment connections	8	no	12,500.00	100,000
	controls	32	pts	2,500.00	80,000
	electrical connection	8	no	3,000.00	24,000
	miscellaneous removals, demolition	25,000	ls	1.00	25,000
	description	0		0.00	0
	Markups	6,553,472	%	0.58	3,801,014
	TOTAL				10,354,000
	Baseline: Electrical Service				
	15kV feeds in ductbank	500	lf	450.00	225,000
	pad mounted switches	1	no	125,000.00	125,000
	pad mounted transformers, 3000kva	2	no	275,000.00	550,000
	switchgear, 5000A each	10,000	A	120.00	1,200,000
	feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
	concrete pads	500	sf	30.00	15,000
	miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
	description	0		0.00	0
	Markups	3,323,000	%	0.58	1,927,340
	TOTAL				5,250,000
	Baseline: Space Requirements				
	foundations	6,000	sf	30.00	180,000

structure	6,000	sf	100.00	600,000
enclosure	7,199	sf	125.00	899,930
fitout (partitions, doors, finishes, MEP)	6,000	sf	60.00	360,000
description	0		0.00	0
Markups	2,039,930	%	0.58	1,183,159
TOTAL				3,223,000
Baseline Alternate: Electric Boilers				
boilers, electric	17,060	mbh	36.00	614,160
piping	200	lf	450.00	90,000
equipment connections	2	no	12,500.00	25,000
controls	8	pts	2,500.00	20,000
electrical connection	2	no	10,000.00	20,000
miscellaneous removals, demolition	10,000	ls	1.00	10,000
description	0		0.00	0
Markups	779,160	%	0.58	451,913
TOTAL				1,231,000
Baseline Alternate: Natural Gas Boilers				
boilers, gas, 800bhp each	53,566	mbh	28.00	1,499,859
boilers, gas, 400bhp	13,392	mbh	28.00	374,965
boilers, gas, 800bhp each	107,133	mbh	28.00	2,999,718
piping, hot water	700	lf	600.00	420,000
piping, gas	350	lf	250.00	87,500
equipment connections	7	no	12,500.00	87,500
controls	28	pts	2,500.00	70,000
electrical connection	7	no	3,000.00	21,000
miscellaneous removals, demolition	25,000	ls	1.00	25,000
description	0		0.00	0
Markups	5,585,542	%	0.58	3,239,615
TOTAL				8,825,000
Baseline Alternate: Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	2	no	125,000.00	250,000
pad mounted transformers, 3000kva	4	no	275,000.00	1,100,000
switchgear, 5000A each	20,000	A	120.00	2,400,000
feeders, 5000A in ductbank	600	lf	3,860.00	2,316,000
concrete pads	1,000	sf	30.00	30,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
description	0		0.00	0
Markups	6,371,000	%	0.58	3,695,180
TOTAL				10,066,000
Baseline Alternate: Space Requirements				
foundations	9,000	sf	30.00	270,000
structure	9,000	sf	100.00	900,000
enclosure, 30'	8,348	sf	125.00	1,043,552
fitout (partitions, doors, finishes, MEP)	9,000	sf	60.00	540,000
description	0		0.00	0
Markups	2,753,552	%	0.58	1,597,060
TOTAL				4,351,000
Option 1: Chillers				
chillers, replace 2000 ton each	8,000	tns	800.00	6,400,000
chillers, 1600 ton each, w/heat recovery	1,600	tns	1,250.00	2,000,000
chillers, 800 ton each, w/heat recovery	800	tns	1,250.00	1,000,000
primary chilled water pumps, 3400gpm, 110hp	6	no	100,000.00	600,000
secondary chilled water pumps, 5600gpm, 240hp	4	no	140,000.00	560,000
VFDs	10	no	25,000.00	250,000
piping, chilled water	1,600	lf	800.00	1,280,000
equipment connections	23	no	20,000.00	460,000
controls	96	pts	2,500.00	240,000
electrical connections	16	no	30,000.00	480,000
miscellaneous removals, demolition	100,000	ls	1.00	100,000
description	0		0.00	0
Markups	13,370,000	%	0.58	7,754,600
TOTAL				21,125,000
Option 1: Cooling Towers				
cooling towers, replace 2500 ton each	5,000	tns	325.00	1,625,000

cooling towers, 2500 ton each	5,000	tns	325.00	1,625,000
condenser water pumps, 4000gpm, 120hp	5	no	115,000.00	575,000
VFDs	9	no	20,000.00	180,000
piping, condenser water	1,000	lf	925.00	925,000
equipment connections	9	no	20,000.00	180,000
controls	54	pts	2,500.00	135,000
electrical connections	9	no	30,000.00	270,000
miscellaneous removals, demolition	100,000	ls	1.00	100,000
description	0		0.00	0
Markups	5,615,000	%	0.58	3,256,700
TOTAL				8,872,000
Option 1: Heat Recovery Chillers				
heat pump, 22000mbh each	44,000	mbh	210.00	9,240,000
heat pump, 5000mbh each	10,000	mbh	250.00	2,500,000
heat exchanger, plate & frame, 22000mbh	1	no	150,000.00	150,000
pumps, 3000gpm, 90hp	3	no	80,000.00	240,000
pumps, 1500gpm, 90hp	6	no	80,000.00	480,000
pumps, 700gpm, 20hp	6	no	25,000.00	150,000
VFDs	16	no	17,500.00	280,000
piping, chilled water, heat recovery	4,000	lf	800.00	3,200,000
equipment connections	20	no	20,000.00	400,000
controls	80	pts	2,500.00	200,000
electrical connections	20	no	25,000.00	500,000
description	0		0.00	0
Markups	17,340,000	%	0.58	10,057,200
TOTAL				27,397,000
Option 1: Heat Recovery Loop				
piping, heat recovery loop	2,000	lf	800.00	1,600,000
description	0		0.00	0
Markups	1,600,000	%	0.58	928,000
TOTAL				2,528,000
Option 1: Thermal Storage				
thermal storage tank, 400000 gallon	400,000	gal	3.25	1,300,000
description	0		0.00	0
Markups	1,300,000	%	0.58	754,000
TOTAL				2,054,000
Option 1: GSHP / Geo				
heat pump, 300 ton each	1,200	tns	1,750.00	2,100,000
geothermal wells, 500'	289	no	30,000.00	8,670,000
geothermal wells, horizontal piping premiums	289	no	3,000.00	867,000
pumps, geothermal, 750gpm, 35hp	5	no	30,000.00	150,000
pumps, primary, 750gpm, 15hp	5	no	17,500.00	87,500
VFDs	10	no	12,500.00	125,000
piping, geothermal/heat recovery	2,800	lf	600.00	1,680,000
equipment connections	14	no	20,000.00	280,000
controls	56	pts	2,500.00	140,000
electrical connections	14	no	15,000.00	210,000
description	0		0.00	0
Markups	14,309,500	%	0.58	8,299,510
TOTAL				22,609,000
Option 1: Air-to-Water Heat Pumps				
heat pumps, air to water, 230 tons each	3,910	tns	3,000.00	11,730,000
pumps, 1000gpm, 20hp	3	no	25,000.00	75,000
pumps, 2000gpm, 35hp	3	no	30,000.00	90,000
VFDs	6	no	12,500.00	75,000
piping	2,900	lf	600.00	1,740,000
equipment connections	23	no	20,000.00	460,000
controls	92	pts	2,500.00	230,000
electrical connections	23	no	15,000.00	345,000
description	0		0.00	0
Markups	14,745,000	%	0.58	8,552,100
TOTAL				23,297,000
Option 1: Building DHW Considerations				
DHW heater, 100kw, 600 gallon each	2	no	125,000.00	250,000
piping	100	lf	175.00	17,500

electrical connections	2	no	10,000.00	20,000
miscellaneous removals, demolition	10,000	ls	1.00	10,000
description	0		0.00	0
Markups	297,500	%	0.58	172,550
TOTAL				470,000
Option 1: Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 3000kva	2	no	275,000.00	550,000
switchgear, 5000A each	10,000	A	120.00	1,200,000
feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
concrete pads	500	sf	30.00	15,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
Markups	3,323,000	%	0.58	1,927,340
TOTAL				5,250,000
Option 1: Space Requirements				
foundations	15,000	sf	30.00	450,000
structure	15,000	sf	100.00	1,500,000
enclosure, 30'	12,258	sf	125.00	1,532,190
fitout (partitions, doors, finishes, MEP)	15,000	sf	60.00	900,000
description	0		0.00	0
Markups	4,382,190	%	0.58	2,541,670
TOTAL				6,924,000
Option 1b: Heat Recovery Chillers				
heat pump, 170 ton each	850	tns	1,750.00	1,487,500
pumps, 300gpm, 10hp	12	no	15,000.00	180,000
piping	3,250	lf	300.00	975,000
equipment connections	29	no	12,500.00	362,500
controls	116	no	2,500.00	290,000
electrical connections	29	no	7,500.00	217,500
description	0		0.00	0
Markups	3,512,500	%	0.58	2,037,250
TOTAL				5,550,000
Option 1b: GSHP / Geo				
heat pump, 300 ton each	600	tns	1,750.00	1,050,000
geothermal wells, 500'	145	no	30,000.00	4,350,000
geothermal wells, horizontal piping premiums	145	no	3,000.00	435,000
pumps, geothermal, 750gpm, 35hp	3	no	30,000.00	90,000
pumps, primary, 750gpm, 15hp	3	no	17,500.00	52,500
VFDs	6	no	12,500.00	75,000
piping, geothermal/heat recovery	1,600	lf	600.00	960,000
equipment connections	8	no	20,000.00	160,000
controls	32	pts	2,500.00	80,000
electrical connections	8	no	15,000.00	120,000
description	0		0.00	0
Markups	7,372,500	%	0.58	4,276,050
TOTAL				11,649,000
Option 1b: Air-to-Water Heat Pumps				
heat pumps, air to water, 230 tons each	4,370	tns	3,000.00	13,110,000
pumps, 1000gpm, 20hp	4	no	25,000.00	100,000
pumps, 2000gpm, 35hp	3	no	30,000.00	90,000
VFDs	7	no	12,500.00	87,500
piping	3,300	lf	600.00	1,980,000
equipment connections	26	no	20,000.00	520,000
controls	104	pts	2,500.00	260,000
electrical connections	26	no	15,000.00	390,000
description	0		0.00	0
Markups	16,537,500	%	0.58	9,591,750
TOTAL				26,129,000
Option 1b: Building Coil Replacements				
University Hall	150,000	sf	0.00	0
Campus Center	370,324	sf	0.00	0
Residence Hall	260,000	sf	0.00	0
ISC	231,110	sf	0.00	0
Clark	119,144	sf	0.00	0

replace AHU coils, University Hall	225,000	cfm	2.50	562,500
replace AHU coils, Campus Center	254,000	cfm	2.50	635,000
replace AHU coils, Residence Hall	68,100	cfm	2.50	170,250
replace AHU coils, ISC	340,000	cfm	2.50	850,000
replace AHU coils, Clark	150,010	cfm	2.50	375,025
replace VAV coils, University Hall	125	no	575.00	71,875
replace VAV coils, Campus Center	309	no	575.00	177,447
replace VAV coils, Residence Hall	17	no	575.00	9,775
replace VAV coils, ISC	514	no	575.00	295,307
replace FCU coils, Clark	578	no	575.00	332,222
new piping connections	1,542	no	600.00	925,175
replace other terminal equipment, University Hall	150,000	sf	0.75	112,500
replace other terminal equipment, Campus Center	370,324	sf	0.75	277,743
replace other terminal equipment, Residence Hall	260,000	sf	0.75	195,000
replace other terminal equipment, ISC	231,110	sf	0.75	173,333
replace other terminal equipment, Clark	119,144	sf	0.75	89,358
description	0			0
Markups	5,252,510	%	0.58	3,046,456
TOTAL				8,299,000

Option 1b: Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 3000kva	2	no	275,000.00	550,000
switchgear, 5000A each	10,000	A	120.00	1,200,000
feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
concrete pads	500	sf	30.00	15,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
Markups	3,323,000	%	0.58	1,927,340
TOTAL				5,250,000

Option 1b: Space Requirements				
foundations	12,000	sf	30.00	360,000
structure	12,000	sf	100.00	1,200,000
enclosure, 30'	10,845	sf	125.00	1,355,613
fitout (partitions, doors, finishes, MEP)	12,000	sf	60.00	720,000
description	0		0.00	0
Markups	3,635,613	%	0.58	2,108,656
TOTAL				5,744,000

Option 1c: Seawater Exchange				
heat exchangers, preventative maintenance (TBD)	3	no	50,000.00	150,000
heat exchangers, replace, 18750mbh (TBD)	1	no	500,000.00	500,000
piping connections	2	no	20,000.00	40,000
miscellaneous removals, demolition	25,000	ls	1.00	25,000
chillers, 1000 ton each w/heat recovery	3,000	tns	1,250.00	3,750,000
heat pump, 300 ton each	900	tns	1,750.00	1,575,000
pumps, 1600gpm, 50hp	14	no	40,000.00	560,000
VFDs	14	no	12,500.00	175,000
piping	4,000	lf	600.00	2,400,000
equipment connections	20	no	20,000.00	400,000
controls	80	no	2,500.00	200,000
electrical connections	20	no	10,000.00	200,000
description	0		0.00	0
Markups	9,975,000	%	0.58	5,785,500
TOTAL				15,761,000

Option 1c: Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 3000kva	2	no	275,000.00	550,000
switchgear, 5000A each	10,000	A	120.00	1,200,000
feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
concrete pads	500	sf	30.00	15,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
Markups	3,323,000	%	0.58	1,927,340
TOTAL				5,250,000

Option 1c: Space Requirements				

foundations	17,000	sf	30.00	510,000
structure	17,000	sf	100.00	1,700,000
enclosure, 30'	13,033	sf	125.00	1,629,095
fitout (partitions, doors, finishes, MEP)	17,000	sf	60.00	1,020,000
description	0		0.00	0
Markups	4,859,095	%	0.58	2,818,275
TOTAL				7,677,000

Option 2: GSHP / Geo				
heat pump, 300 ton each	1,800	tns	1,750.00	3,150,000
geothermal wells, 500'	434	no	30,000.00	13,020,000
geothermal wells, horizontal piping premiums	434	no	6,000.00	2,604,000
pumps, geothermal, 750gpm, 35hp	7	no	30,000.00	210,000
pumps, primary, 750gpm, 15hp	7	no	17,500.00	122,500
VFDs	14	no	12,500.00	175,000
piping, geothermal/heat recovery	4,000	lf	800.00	3,200,000
equipment connections	20	no	20,000.00	400,000
controls	80	pts	2,500.00	200,000
electrical connections	20	no	15,000.00	300,000
description	0		0.00	0
Markups	23,381,500	%	0.58	13,561,270
TOTAL				36,943,000

Option 2: Air-to-Water Heat Pumps				
heat pumps, air to water, 230 tons each	3,450	tns	3,000.00	10,350,000
pumps, 1000gpm, 20hp	4	no	25,000.00	100,000
pumps, 2000gpm, 35hp	2	no	30,000.00	60,000
VFDs	6	no	12,500.00	75,000
piping	2,700	lf	600.00	1,620,000
equipment connections	21	no	20,000.00	420,000
controls	84	pts	2,500.00	210,000
electrical connections	21	no	15,000.00	315,000
description	0		0.00	0
Markups	13,150,000	%	0.58	7,627,000
TOTAL				20,777,000

Option 2: Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 3000kva	2	no	275,000.00	550,000
switchgear, 5000A each	10,000	A	120.00	1,200,000
feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
concrete pads	500	sf	30.00	15,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
Markups	3,323,000	%	0.58	1,927,340
TOTAL				5,250,000

Option 2: Space Requirements				
foundations	15,000	sf	30.00	450,000
structure	15,000	sf	100.00	1,500,000
enclosure, 30'	12,258	sf	125.00	1,532,190
fitout (partitions, doors, finishes, MEP)	15,000	sf	60.00	900,000
description	0		0.00	0
Markups	4,382,190	%	0.58	2,541,670
TOTAL				6,924,000

Wheatley: Wall Performance (Best)				
build new exterior wall outboard of existing	117,359	sf	125.00	14,669,850
description	0		0.00	0
Markups	14,669,850	%	0.58	8,508,513
TOTAL				23,178,000

Wheatley: Roof Performance (Best)				
remove existing roofing	73,349	sf	6.00	440,096
new roofing system	73,349	sf	50.00	3,667,463
description	0		0.00	0
Markups	4,107,558	%	0.58	2,382,384
TOTAL				6,490,000

Wheatley: Glazing Performance (Best)				
remove existing windows	29,340	sf	15.00	440,096
new triple glazed windows and perimeter repair	29,340	sf	225.00	6,601,433
description	0		0.00	0
Markups	7,041,528	%	0.58	4,084,086
TOTAL				11,126,000

Wheatley: Ventilation System (Good)				
new DOAS system, 60000cfm each	120,000	cfm	18.00	2,160,000
ductwork, piping	120,000	cfm	15.00	1,800,000
controls	80	pts	2,000.00	160,000
electrical connections	2	no	15,000.00	30,000
description	0		0.00	0
Markups	4,150,000	%	0.58	2,407,000
TOTAL				6,557,000

Wheatley: Ventilation System (Best)				
new DOAS system, 60000cfm each	120,000	cfm	21.00	2,520,000
ductwork, piping	120,000	cfm	15.00	1,800,000
controls	80	pts	2,000.00	160,000
electrical connections	2	no	15,000.00	30,000
description	0		0.00	0
Markups	4,510,000	%	0.58	2,615,800
TOTAL				7,126,000

Wheatley: Zones Heating & Cooling (Good)				
fan coil units	587	no	5,000.00	2,933,970
supply VAV boxes w/reheat coil	244	no	2,300.00	562,344
piping for above	85,085	lf	65.00	5,530,533
controls	3,912	pts	900.00	3,520,764
electical connections	831	no	300.00	249,387
misc demolition	293,397	sf	4.00	1,173,588
Markups	13,970,587	%	0.58	8,102,941
TOTAL				22,074,000

Wheatley: Lighting (Good)				
remove existing lights	293,397	sf	1.00	293,397
LED fixtures (reuse existing wiring)	293,397	sf	12.00	3,520,764
description	0		0.00	0
Markups	3,814,161	%	0.58	2,212,213
TOTAL				6,026,000

Wheatley: Lighting Controls (Good)				
occupancy & daylight sensors	293,397	sf	2.00	586,794
description	0		0.00	0
Markups	586,794	%	0.58	340,341
TOTAL				927,000

ISC: Ventilation System (BAU)				
remove AHUs	290,000	cfm	1.50	435,000
AHUs	290,000	cfm	20.00	5,800,000
piping	500	lf	450.00	225,000
piping connections	5	no	20,000.00	100,000
controls	400	pts	2,000.00	800,000
electrical connections	5	no	15,000.00	75,000
description	0		0.00	0
Markups	7,435,000	%	0.58	4,312,300
TOTAL				11,747,000

ISC: Ventilation System (Alternative)				
remove AHUs	290,000	cfm	1.50	435,000
AHUs	290,000	cfm	20.00	5,800,000
piping	500	lf	450.00	225,000
piping connections	5	no	20,000.00	100,000
controls	400	pts	2,000.00	800,000
electrical connections	5	no	15,000.00	75,000

heat pumps	770	tns	3,500.00	2,695,000
piping	1,400	lf	200.00	280,000
equipment connections	7	no	10,000.00	70,000
controls	56	pts	2,000.00	112,000
electrical connections	7	no	5,000.00	35,000
mechanical subcontractor	120	hrs	175.00	21,000
balancing subcontractor	120	hrs	175.00	21,000
controls subcontractor	120	hrs	175.00	21,000
description	0		0.00	0
Markups	10,690,000	%	0.58	6,200,200
TOTAL				16,890,000

ISC: Plant Cooling (Alternative)				
mechanical subcontractor	120	hrs	175.00	21,000
balancing subcontractor	120	hrs	175.00	21,000
controls subcontractor	120	hrs	175.00	21,000
description	0		0.00	0
Markups	63,000	%	0.58	36,540
TOTAL				100,000

ISC: Lighting (Alternative)				
remove existing lights	231,110	sf	0.50	115,555
LED fixtures (reuse existing wiring)	231,110	sf	6.00	1,386,660
description	0		0.00	0
Markups	1,502,215	%	0.58	871,285
TOTAL				2,373,000

ISC: Plumbing Water Heater (Alternative)				
water heater, electric	2	no	15,000.00	30,000
electrical connections	2	no	5,000.00	10,000
description	0		0.00	0
Markups	40,000	%	0.58	23,200
TOTAL				63,000

ISC: Electrical Service (Alternative)				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 2500kva	1	no	240,000.00	240,000
switchgear, 4000A each	4,000	A	120.00	480,000
switchgear, 1000A each	2,000	A	120.00	240,000
feeders, 4000A	150	lf	3,100.00	465,000
feeders, 1000A	300	lf	775.00	232,500
concrete pads	250	sf	30.00	7,500
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
Markups	2,065,000	%	0.58	1,197,700
TOTAL				3,263,000

ISC: Solar (Alternative)				
plumbing subcontractor	120	hrs	175.00	21,000
vendor	120	hrs	175.00	21,000
description	0		0.00	0
Markups	42,000	%	0.58	24,360
TOTAL				66,000

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ALTERNATES DESCRIPTION	QUANTITY	UNIT	RATE	TOTAL
CHW Chillers				
chillers, 2000 ton each, w/heat recovery	2,000	tns	875.00	1,750,000
chillers, 1000 ton each, w/heat recovery	1,000	tns	875.00	875,000
chillers, 2000 ton each	2,000	tns	800.00	1,600,000
chillers, 1000 ton each	1,000	tns	800.00	800,000
primary chilled water pumps, 25hp	3	no	30,000.00	90,000
primary chilled water pumps, 15hp	2	no	17,500.00	35,000
VFDs	5	no	10,000.00	50,000
piping, chilled water	1,200	lf	750.00	900,000
equipment connections	13	no	20,000.00	260,000
controls	54	pts	2,500.00	135,000
electrical connections	9	no	30,000.00	270,000
miscellaneous removals, demolition	100,000	ls	1.00	100,000
description	0		0.00	0
Markups	6,865,000	%	0.58	3,981,700
TOTAL				10,847,000
Cooling Towers				
cooling towers, 2000 tons each	6,000	tns	325.00	1,950,000
condenser water pumps, 100hp	4	no	100,000.00	400,000
VFDs	7	no	20,000.00	140,000
piping, condenser water	700	lf	1,200.00	840,000
equipment connections	7	no	20,000.00	140,000
controls	42	pts	2,500.00	105,000
electrical connections	7	no	30,000.00	210,000
miscellaneous removals, demolition	100,000	ls	1.00	100,000
description	0		0.00	0
Markups	3,885,000	%	0.58	2,253,300
TOTAL				6,138,000
Seawater Exchange				
heat exchangers, preventative maintenance (TBD)	4	no	50,000.00	200,000
heat pump, 250 tons each	750	tns	1,750.00	1,312,500
piping	300	lf	400.00	120,000
piping connections	3	no	20,000.00	60,000
controls	24	pts	2,500.00	60,000
electrical connections	3	no	15,000.00	45,000
miscellaneous removals, demolition	25,000	ls	1.00	25,000
description	0		0.00	0
Markups	1,822,500	%	0.58	1,057,050
TOTAL				2,880,000
High Temperature Heat Pumps				
heat pumps, 12500mbh each	28,800	mbh	250.00	7,200,000
heat pumps, 22200mbh each	43,200	mbh	210.00	9,072,000
pumps, 15hp	6	no	17,500.00	105,000
pumps, 25hp	6	no	30,000.00	180,000
VFDs	12	no	10,000.00	120,000
piping	2,400	lf	800.00	1,920,000
equipment connections	19	no	20,000.00	380,000
controls	76	pts	2,500.00	190,000
electrical connections	19	no	25,000.00	475,000
description	0		0.00	0
Markups	19,642,000	%	0.58	11,392,360
TOTAL				31,034,000
Heat Recovery Loop				
pumps, 50hp	6	no	45,000.00	270,000
VFDs	6	no	12,500.00	75,000
piping	1,200	lf	600.00	720,000
equipment connections	6	no	20,000.00	120,000
controls	24	pts	2,500.00	60,000
electrical connections	6	no	15,000.00	90,000
description	0		0.00	0
Markups	1,335,000	%	0.58	774,300
TOTAL				2,109,000

Thermal Storage				
thermal storage tank, 400000 gallon	400,000	gal	3.25	1,300,000
description				0
description	0		0.00	0
Markups	1,300,000	%	0.58	754,000
TOTAL				2,054,000
GSHP / Geo				
heat pump, 250 ton each	1,500	tns	1,750.00	2,625,000
geothermal wells, 500'	525	no	30,000.00	15,750,000
geothermal wells, horizontal piping premiums	525	no	3,000.00	1,575,000
pumps, 15hp	2	no	17,500.00	35,000
pumps, 20hp	2	no	25,000.00	50,000
pumps, 100hp	4	no	100,000.00	400,000
VFDs	8	no	12,500.00	100,000
piping, geothermal/heat recovery	2,000	lf	600.00	1,200,000
equipment connections	14	no	20,000.00	280,000
controls	56	pts	2,500.00	140,000
electrical connections	14	no	15,000.00	210,000
description	0		0.00	0
Markups	22,365,000	%	0.58	12,971,700
TOTAL				35,337,000
Air To Water Heat Pumps				
heat pumps, air to water, 230 tons each	7,590	tns	3,000.00	22,770,000
pumps, 7.5hp	33	no	10,000.00	330,000
VFDs	33	no	5,000.00	165,000
piping	6,600	lf	300.00	1,980,000
equipment connections	66	no	10,000.00	660,000
controls	264	pts	2,500.00	660,000
electrical connections	66	no	7,500.00	495,000
description	0		0.00	0
Markups	27,060,000	%	0.58	15,694,800
TOTAL				42,755,000
Natural Gas Boilers				
boilers, gas, 8000mbh each	88,000	mbh	28.00	2,464,000
pumps, 10hp	10	no	12,500.00	125,000
VFDs	10	no	5,000.00	50,000
piping, hot water	2,500	lf	600.00	1,500,000
piping, gas	500	lf	250.00	125,000
equipment connections	20	no	12,500.00	250,000
controls	80	pts	2,500.00	200,000
electrical connection	20	no	3,000.00	60,000
description	0		0.00	0
Markups	4,774,000	%	0.58	2,768,920
TOTAL				7,543,000
Electrical Service				
15kV feeds in ductbank	500	lf	450.00	225,000
pad mounted switches	1	no	125,000.00	125,000
pad mounted transformers, 3000kva	2	no	275,000.00	550,000
switchgear, 5000A each	10,000	A	120.00	1,200,000
feeders, 5000A in ductbank	300	lf	3,860.00	1,158,000
concrete pads	500	sf	30.00	15,000
miscellaneous removals, demolition, site repair	50,000	ls	1.00	50,000
description	0		0.00	0
Markups	3,323,000	%	0.58	1,927,340
TOTAL				5,250,000
Space Requirements				
foundations	21,000	sf	30.00	630,000
structure	21,000	sf	100.00	2,100,000
enclosure	11,651	sf	125.00	1,456,426
fitout (partitions, doors, finishes, MEP)	21,000	sf	60.00	1,260,000
description	0		0.00	0
Markups	5,446,426	%	0.58	3,158,927
TOTAL				8,605,000