University of Massachusetts Lowell Alternative Energy Master Plan

June 30, 2021

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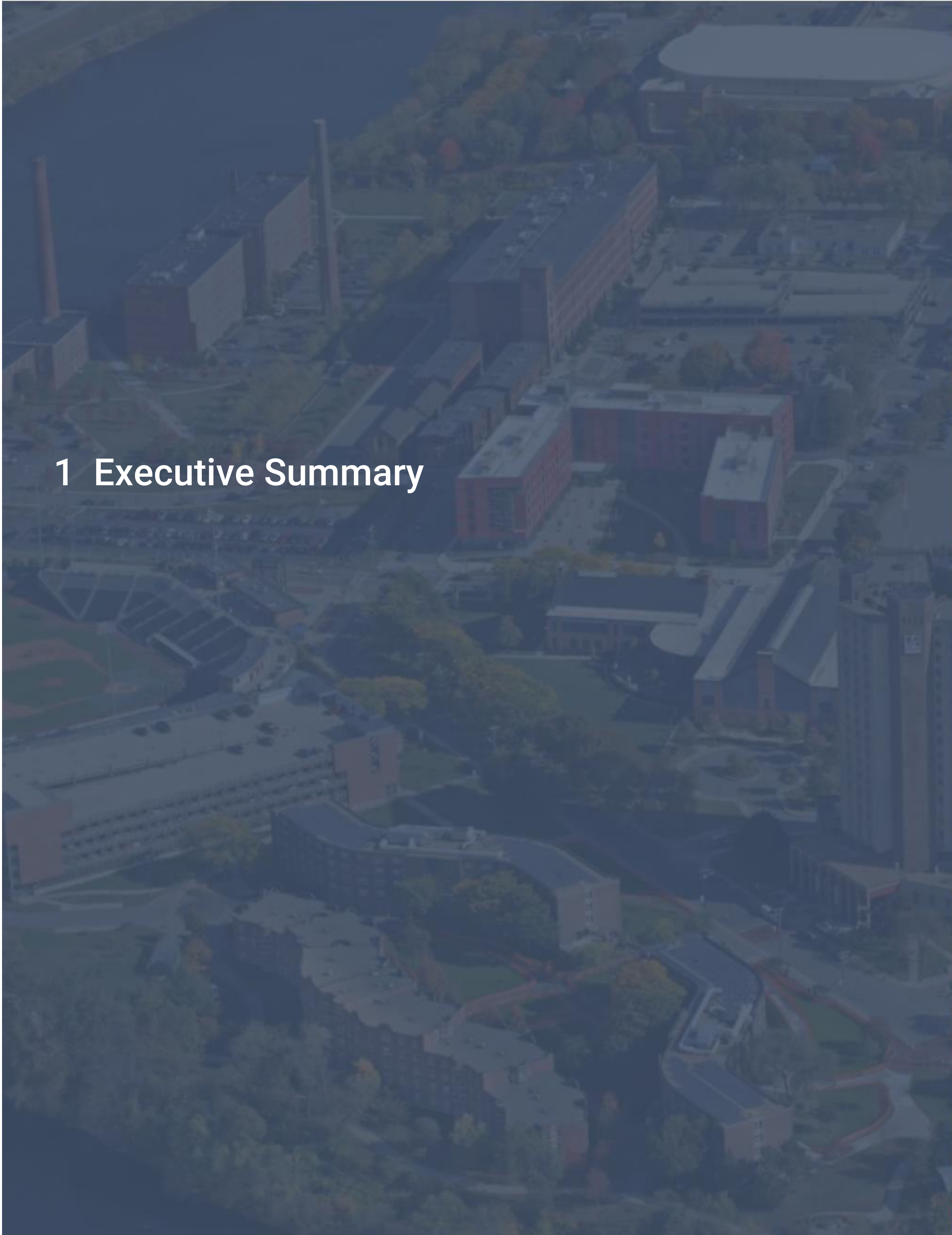


Executive Summary

The University of Massachusetts at Lowell (UML) has set an ambitious goal to achieve carbon neutrality by 2050. To progress toward this goal, UML collaborated with BR+A Consulting Engineers and Anser Advisory, building on previous success, to develop this Alternative Energy Master Plan (AEMP). The AEMP effort grew out of a multi-year strategic planning process and in support of campus sustainability objectives, legislative mandates, and university commitments. The AEMP will assist UML in achieving interim carbon reduction goals with the ultimate goal of carbon neutrality by 2050 while aligning multiple stakeholder groups across the campus. This report was developed through comprehensive engagement with many stakeholders, including the Office for Sustainability; Facilities Operations and Services; Planning, Design, and Construction; Business Development (E2i); Research and Innovation; DOER; DCAMM; National Grid; and representatives from UML Academics.

Plan Goals

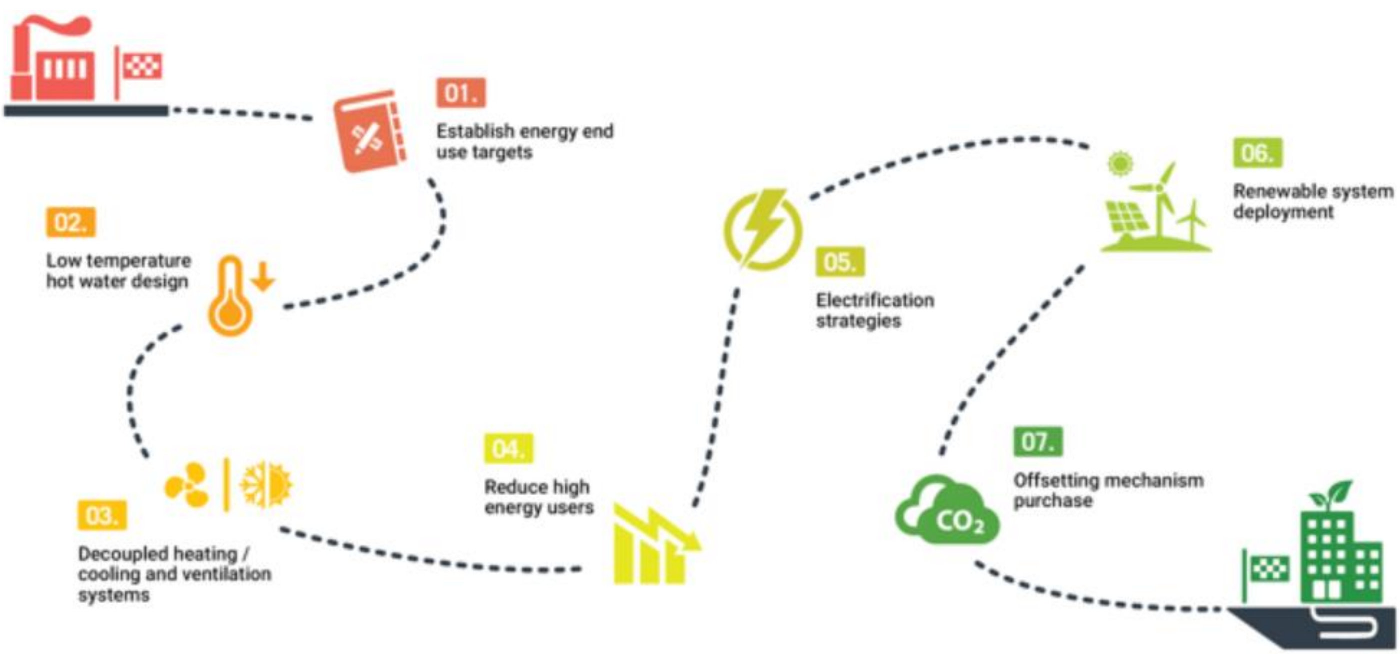
The University of Massachusetts Lowell (UML) has six primary goals in developing a comprehensive campus Alternative Energy Master Plan:

1. Evaluate UML's existing energy and metering, data management systems, and data governance practices to establish accurate usage and demand baselines, and to analyze onsite electricity and steam production, building-level performance, and campus-level energy performance on an ongoing basis;
2. Forecast the primary campus' annual energy demands between 2020 and 2050;
3. Identify, scope and estimate specific energy sources and/or energy savings opportunities that can meet the campus' growth over the next 30 years in a resilient, cost effective, and sustainable manner;
4. Identify and design energy sources and energy savings opportunities that can enable UML to meet the sustainability targets mandated under Executive Order 484 and the campus' carbon neutrality goals under the American College & University President's Climate Commitment in a reliable, cost effective manner;
5. Identify physical infrastructure, operating systems (mechanical, administrative, etc.), advantages and constraints for each identified location, and costs in order for UML to implement or upgrade recommended energy strategies to meet the campus' resiliency, utility cost, and sustainability objectives; and
6. Propose mechanisms for stakeholder engagement (students, faculty, staff, and broader community) throughout the planning process that offers opportunities for students and faculty to engage in planning, hands-on projects, and activities associated with the renewable energy goals.

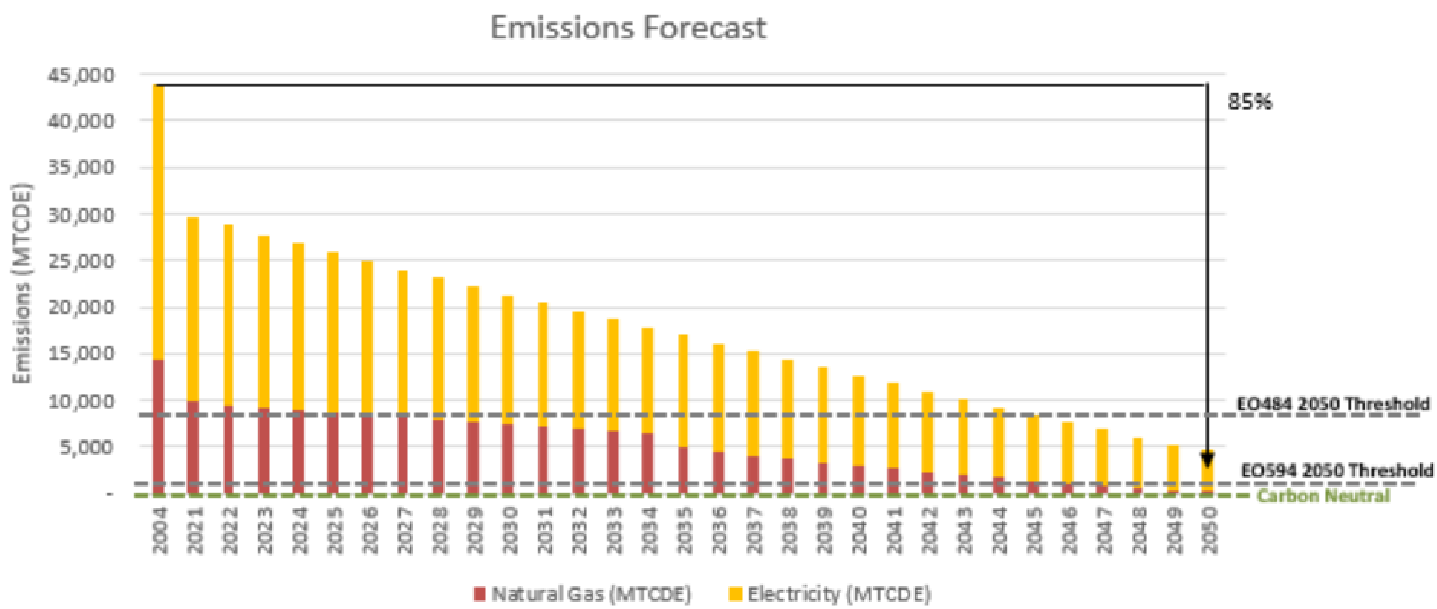
Roadmap to Carbon Neutral

This proven roadmap to carbon neutral builds on UML's successful Alternative Energy Project (AEP) load reduction, then applies electrification technologies to shift off of fossil fuels, and then offsets the remaining energy consumption with renewables:

1. **Energy efficiency.** The roadmap starts with developing a set of energy targets. Energy conservation measures (ECMs) are then applied to meet these targets prioritizing those buildings with the highest scores. Investment in energy efficiency reduces loads and thereby reducing the size and cost of plant and electrification infrastructure.
2. **Electrification.** After sufficient load reduction is achieved, then proven alternative energy measures (AEMs) are applied to further reduce energy consumption and reliance on fossil fuels for heating. The North Plant will be transitioned from a steam-based heating system to a low-temperature hot water heating system. The South and East campus buildings will rely on standalone, electrified plants.
3. **Renewables.** After all the energy is squeezed out of the campus, a carbon offset purchase would be required to meet carbon neutrality if the Massachusetts electricity grid is powered by anything less than 100% renewable energy. After review with UML, onsite solar PV can be deployed to reduce operating costs, but is not a critical strategy to reducing emissions given current regulation on renewable energy credit (REC) ownership and the critical role that the sale of RECs play in the economic feasibility of these types of projects.

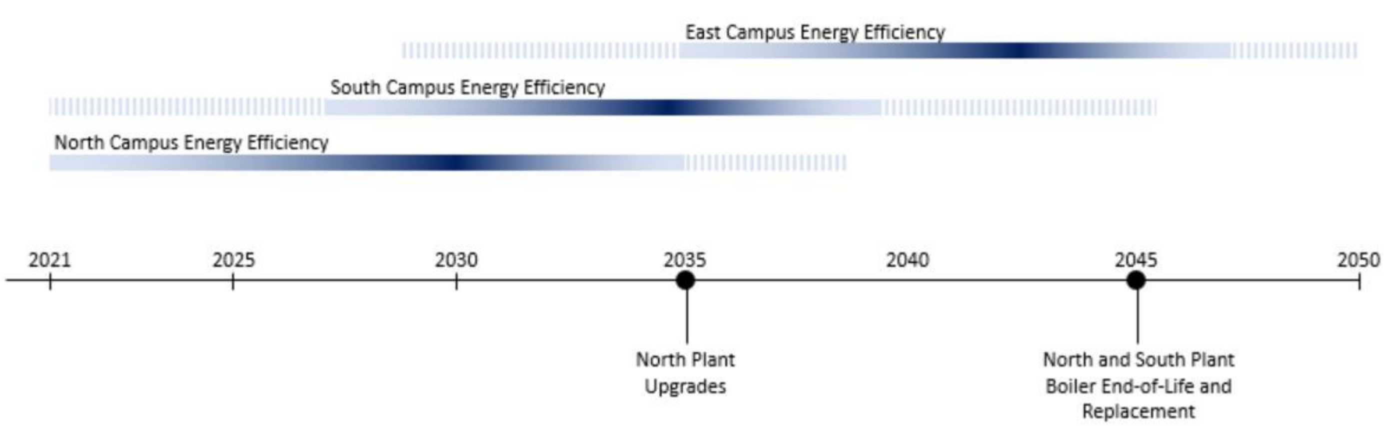


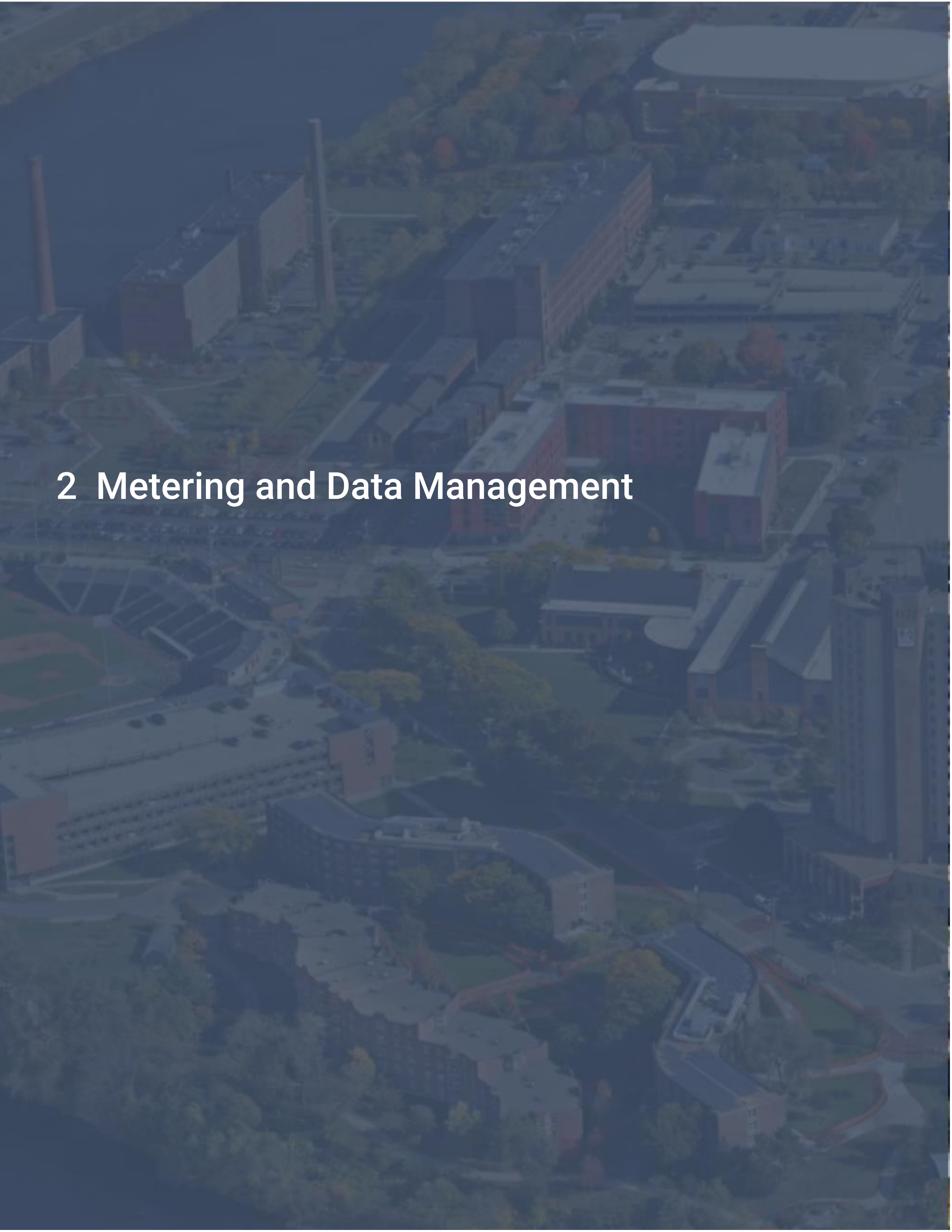
The Selected Scenario results in significant reductions in energy and emissions. This creates a pathway towards carbon neutrality by 2050 as well as achievement of Executive Order 594 and Executive Order 484 requirements. The Selected Scenario is estimated to reduce building emissions 85% compared to emissions in 2004. About half of this reduction is the result of grid emission reductions.



Implementation Timeline

The timing of energy efficiency and alternative energy projects are prioritized based on building score and expected central plant infrastructure useful life. Energy efficiency projects for buildings on the North Campus are prioritized in order to reduce loads ahead of new central plant upgrades. The South Campus building energy efficiency and alternative energy projects would be prioritized next ahead of retiring the South Plant central plant assets while maximizing their useful life. Buildings on the East Campus would also consist of standalone heat pump heating/cooling plants.





2 Metering and Data Management

Metering and Data Management

Energy Metering Overview

Metering is not only a means for billing energy consumption. It serves as a powerful tool to identify where UML should make alternative energy investments that offer the most cost effective solution. BR+A aggregated metering information from multiple sources in order to identify these opportunities. Buildings are prioritized based on key criteria: actual energy use intensity, energy consumption change over time, target energy use intensity (based on building type), combustion energy consumption, and facility condition. Buildings that rank highest in these criteria are assumed as ideal candidates to pilot alternative energy projects. A candidate from each of the core building use types (lab, office/classroom, residential) has been recommended for UML evaluation and sign-off. Olney Hall is the candidate for lab, Ball Hall is the candidate for office/classroom, and Sheehy Hall is the candidate for residential.

Data Management Overview

Adequate data management is critical for tracking carbon goals, identifying energy waste, and fostering a living lab campus. Metering data must be usable and easily accessible to track UML's 2050 carbon neutral goal and the impact of alternative energy projects. UML currently uses several metering platforms. BR+A recommends centralizing metering under a single platform to streamline carbon reporting efforts.

Building management system (BMS) trend data helps to identify systems not operating at their optimal efficiency. Current UML BMS trend data intervals and sampling storage practices are limited such that trend data cannot be used as a tool to troubleshoot issues. Near term changes to reduce trend intervals and increase the maximum number of samples for all building types can help UML Facilities better understand how their buildings are operating. Impacts to network traffic and storage requirements should be reviewed on a project-by-project basis with UML Information Technology. Cloud-based automated fault detection systems can help reduce BMS or on-site storage requirements, as well as support UML Facilities in identifying energy waste problems and solutions.

More granular metering and monitoring practices can also help foster a living lab campus. Implementation of alternative energy projects offer opportunities for faculty, students, and staff to confirm proper operation, verify energy savings, and, in some cases, improve system operation. As alternative energy projects are implemented, end-use energy submetering should be explored to better understand energy increases. In office/classroom buildings, a physical energy dashboard can empower occupants to change their behavior in the spaces they use. In residential buildings, web-based dashboards can help inform students on how their dorm building "stacks up" against one another. In lab spaces, deployment or future-proofing for circuit-level metering can unlock opportunities to conduct energy competitions at the individual lab level as well as expand research on lab consumption loads. These practices are intended to be cost-effective with more granular living lab deployment prioritizing high energy building types.

Energy Metering Analysis

BR+A reviewed and aggregated building-by-building, campus-by-campus, and whole campus energy metering information into an Excel-based tool in order to understand how energy and carbon are used on campus. Building information such as use type, built/renovation date, energy meter data, and facility condition information was obtained from UML. With this information, energy use intensity, energy consumption change over time, total combustion energy, and a facility condition rating were calculated. Buildings were scored/ranked based on usage and aging systems. Buildings that rank highest in these criteria are assumed as the ideal candidates to pilot alternative energy projects.

In the absence of building end-use submetering, typical energy end-use profiles were applied to each building based on use type and system type. This helped the team understand how each building may use energy for heating, cooling, pump, fan, domestic hot water, interior lighting, and plug loads. This information can then be used as part of the Alternative Analysis phase to prioritize projects that target the highest end-uses. Also, this information was organized by campus – North, South, and East – to better understand energy loads and, therefore, potential opportunities for energy recovery and centralized plant solutions.

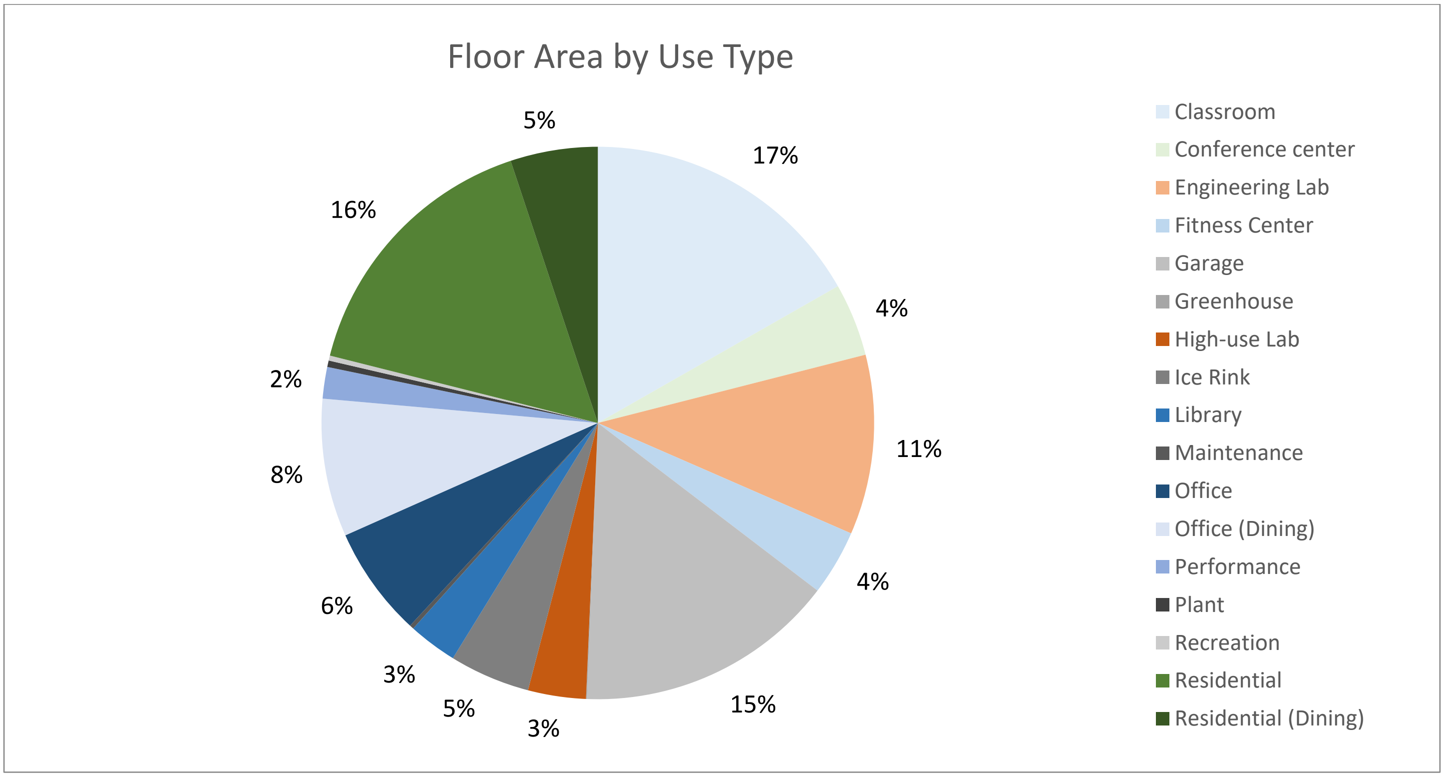
Whole campus energy data was reviewed for change over time and utility energy breakdowns. Patterns in energy change over time data will help inform the 30 Year Forecast phase of the project. Breakdowns of total campus energy into electricity and natural gas will help inform the 30 Year Forecast and the Alternatives Analysis. Grid electricity from renewable sources is anticipated to increase based on the Massachusetts (MA) Clean Energy Standard (CES). This will help reduce emissions on campus. This will be reflected in the 30 Year Forecast. A discussion is required between UML, BR+A, and Anser to understand how the MA CES may influence project prioritization as part of the Alternatives Analysis phase.

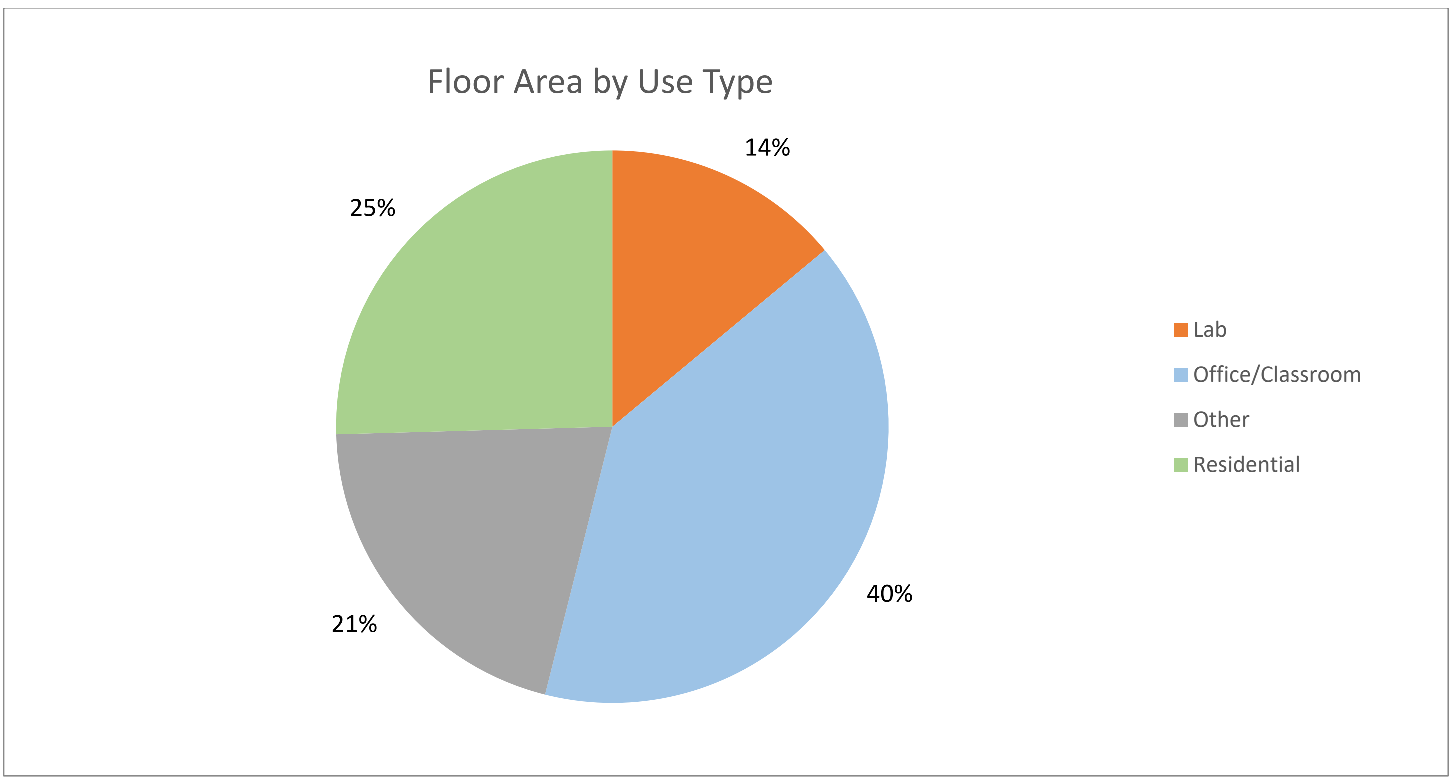
Building Use Types

Buildings of similar space type are anticipated to have similar energy and carbon emissions. Therefore, it's important to define each building's use type to enable an apples-to-apples comparison and identify the highest consumers. First, buildings were defined by their use type: office, classroom, high-use lab, engineering lab, residential, fitness center, performance, garage, plant, library, greenhouse, maintenance, ice rink, recreation, and conference center. The use type with the greatest square footage is classroom. High-use labs are anticipated to be exhaust driven and have high outside air requirements resulting in higher energy consumption than engineering labs where air may be recirculate recirculated. Residential and office were further defined if they contained commercial cooking, as their energy consumption/carbon emissions are anticipated be higher than a building without. These space types were rolled up into three core use types based on anticipated energy end-use breakdown and anticipated alternative energy projects: lab, office/classroom, and residential. The core use type with the greatest square footage is office/classroom.

Buildings with unique energy end-use breakdowns and/or low energy consumers are organized into an "Other" category. Use types organized into "Other" include garage, greenhouse, maintenance, and ice rink. High consumers will require specialized alternative energy project approaches. Buildings defined as "plant' (North Power Plant and South Power Plant) were omitted from this list as to not duplicate steam energy consumption metered at the building level.

Appendix C contains a list of how each building was defined.

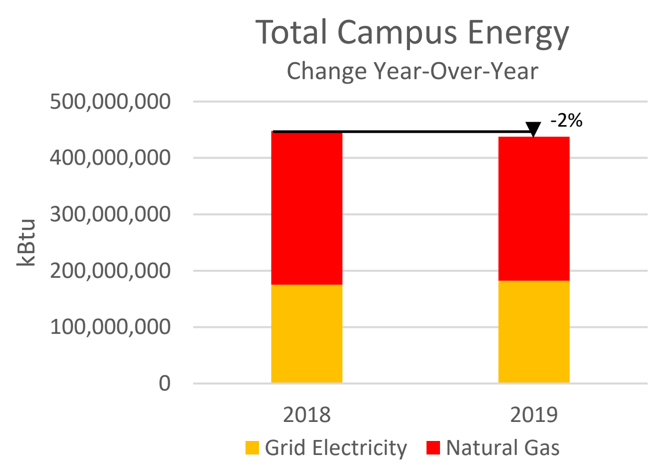

Floor Area by Use Type
5%
17%
16%
4%
2%
11%
8%
4%
6%
3%
5%
3%
15%
Classroom
Conference center
Engineering Lab
Fitness Center
Garage
Greenhouse
High-use Lab
Ice Rink
Library
Maintenance
Office
Office (Dining)
Performance
Plant
Recreation
Residential
Residential (Dining)

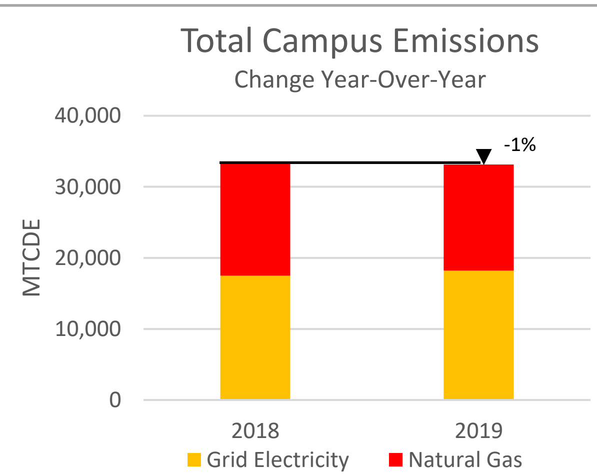

Floor Area by Use Type
14%
25%
40%
21%
Lab
Office/Classroom
Other
Residential

Campus Energy and Emissions

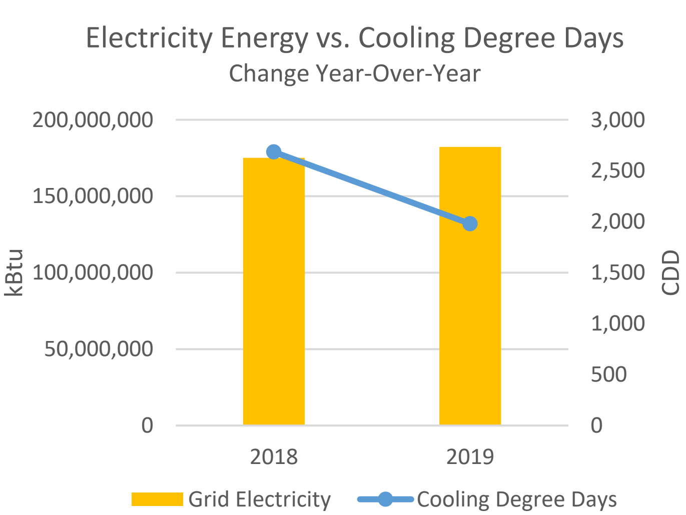
The intent of analyzing total campus metered energy data is to develop a baseline for the "30-Year Forecast" phase. The charts below compare total energy and total emissions year-over-year. The raw data used to develop this analysis was provided by UML via Competitive Energy Solutions' reports. Reports were limited to only providing total campus energy from 2017 (partial), 2018, 2019, and 2020 (partial). For the purposes of this analysis, 2020 data was omitted given assumed non-normal operation as a result of COVID-19.

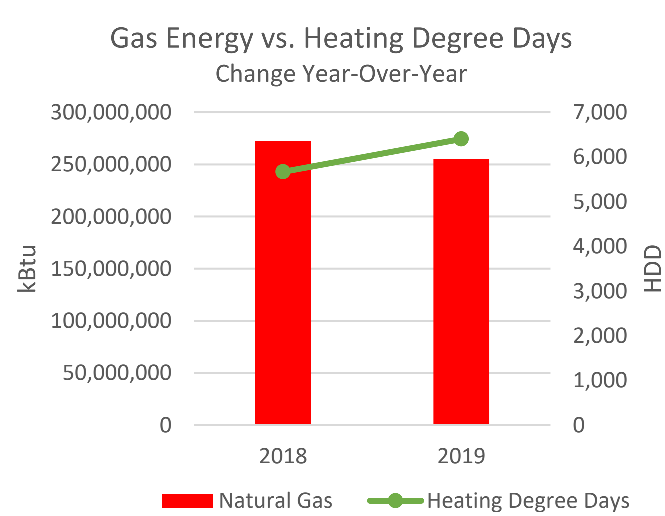
Total campus energy and emissions are relatively consistent between 2018 and 2019. Energy was converted to carbon emissions using the following factors: 682 lbs/MWh electricity and 117 lbs/MMBtu natural gas. Natural gas energy is the largest utility end use. Grid electricity is the largest utility emission end use. However, a more detailed end use breakdown is required in order to better anticipate how alternative energy projects should be prioritized. This can be found under the "Building-by-building Energy and Emissions" section.



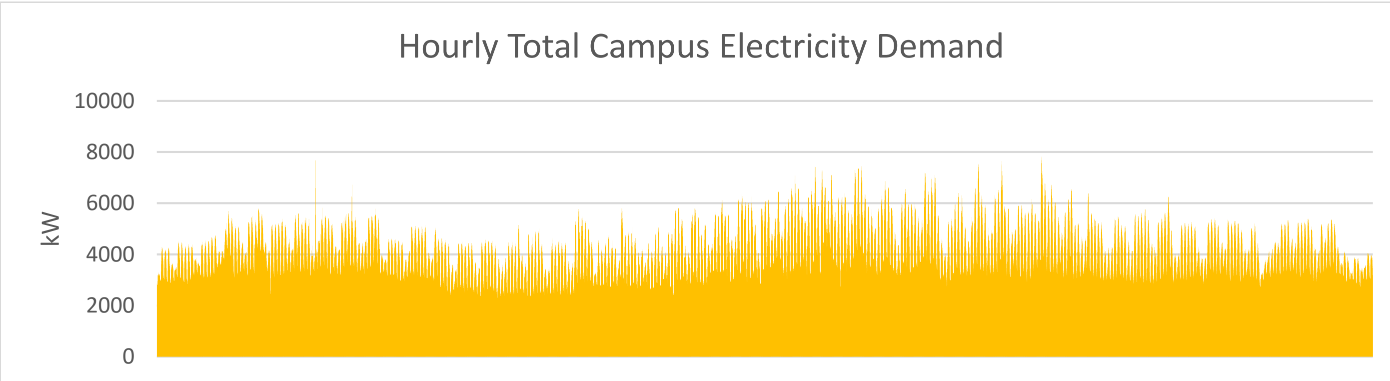


The charts below compare grid electricity energy and natural gas consumption year-over-year as it relates to cooling and heating degree days. Degree days are the number of hours during the year when heating or cooling is expected. The hypothesis is that grid electricity is correlated by cooling degree days (CDD) and natural gas is correlated to heating degree days (HDD). However, the data shows an inverse relationship. Grid electricity energy consumption increased even though CDD decreased 36%, and natural gas energy consumption decreased even though heating degree days increased 11%. This conclusion will have to be further reviewed with UML to better understand the relationship between campus energy consumption and weather.





The chart below shows the hourly electricity demand of the entire Lowell Campus in 2019. The coincidental peak electricity demand of the campus is approximately 8 MW. The peak demand occurred on September 23rd and is approximately 1MW. This is likely driven by student move-in and weather (near design cooling day: 88°F max). Note that some high intensity buildings (i.e. Perry Hall, Pinanski Hall, and 110 Canal) do not have electricity demand information. Additional research will have to be conducted in order to estimate peak electricity demand in these buildings.

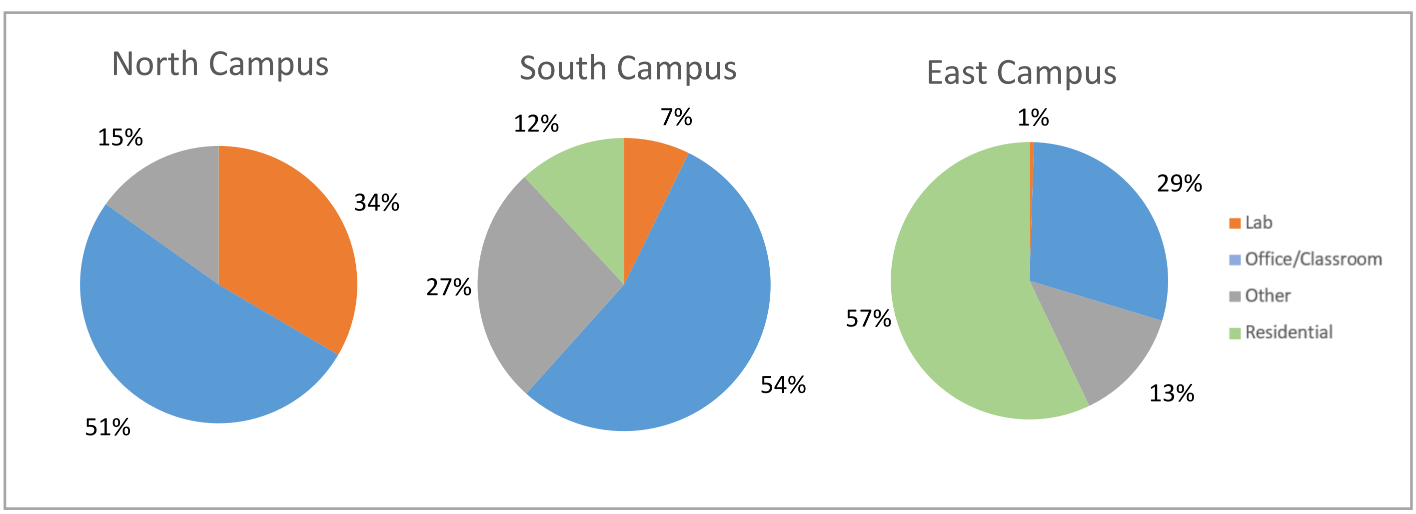


The UML 2012 Climate Action Plan established target goals for Scope 1 and 2 emissions by 2020 and 2030. The table below compares these targets to CY19 emissions for stationary and purchased electricity only. For the purposes of this comparison, it's assumed that the target goals used the same stationary (33.8%) and purchased electricity (27.1%) emission end use breakdown factors. A more detailed analysis showing this breakdown as well as emission factor assumptions would be needed to verify these findings. This delta between CY19 and FY2030 will help the team better understand how projects can be prioritized in order to meet the interim 2030 goal.

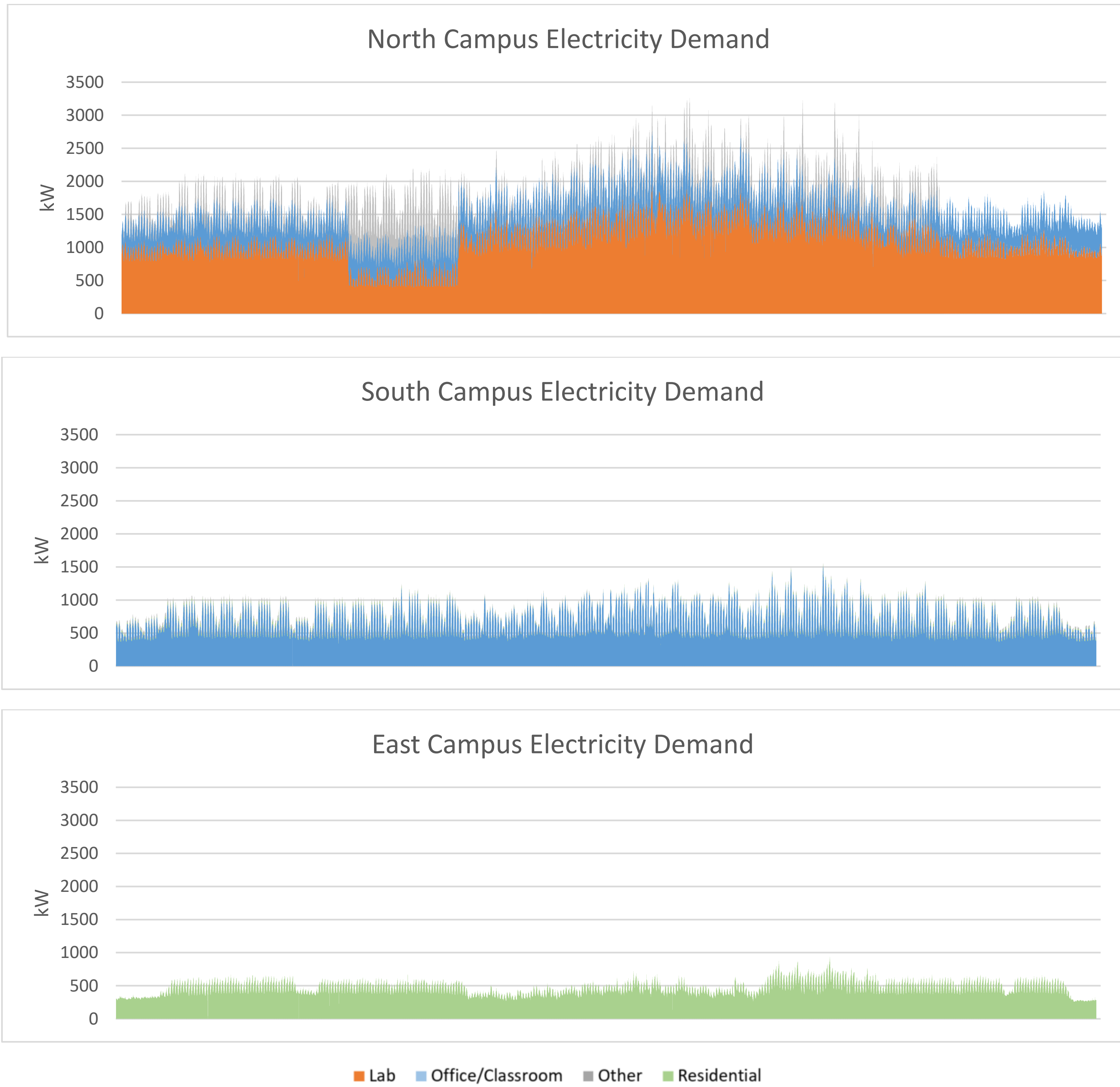
Time Frame	FY2011 (actual)	CY19 (actual)	FY2020 (target)	FY2030 (target)
Scope 1+2 Emissions	34,567 MTCDE	33,146 MTCDE	36,884 MTCDE	28,684 MTCDE

Campus-by-Campus Energy and Emissions

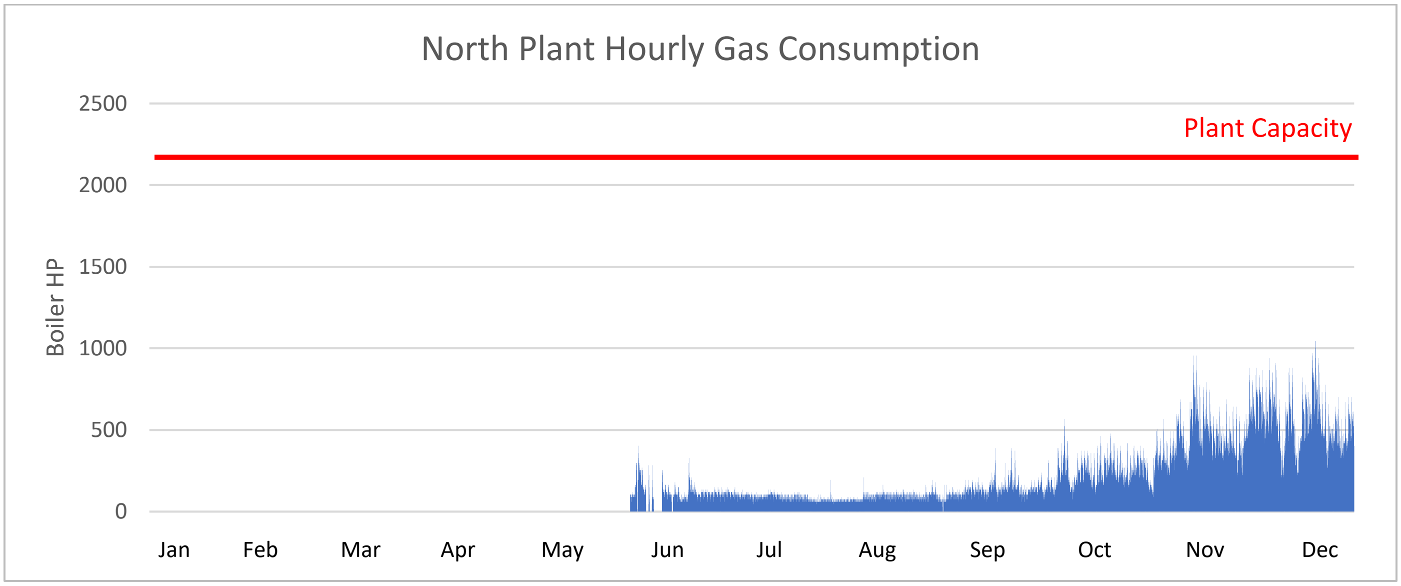
The Lowell Campus has three distinct campuses: North Campus, South Campus, and East Campus. The North Campus is primarily office/classroom, but has the largest presence of lab space on campus. The South Campus is primarily office and classroom, and the East Campus is primarily residential. The charts below do not include "satellite buildings" that are relatively near any of the three campuses. The charts below show the core use type breakdown of each campus.

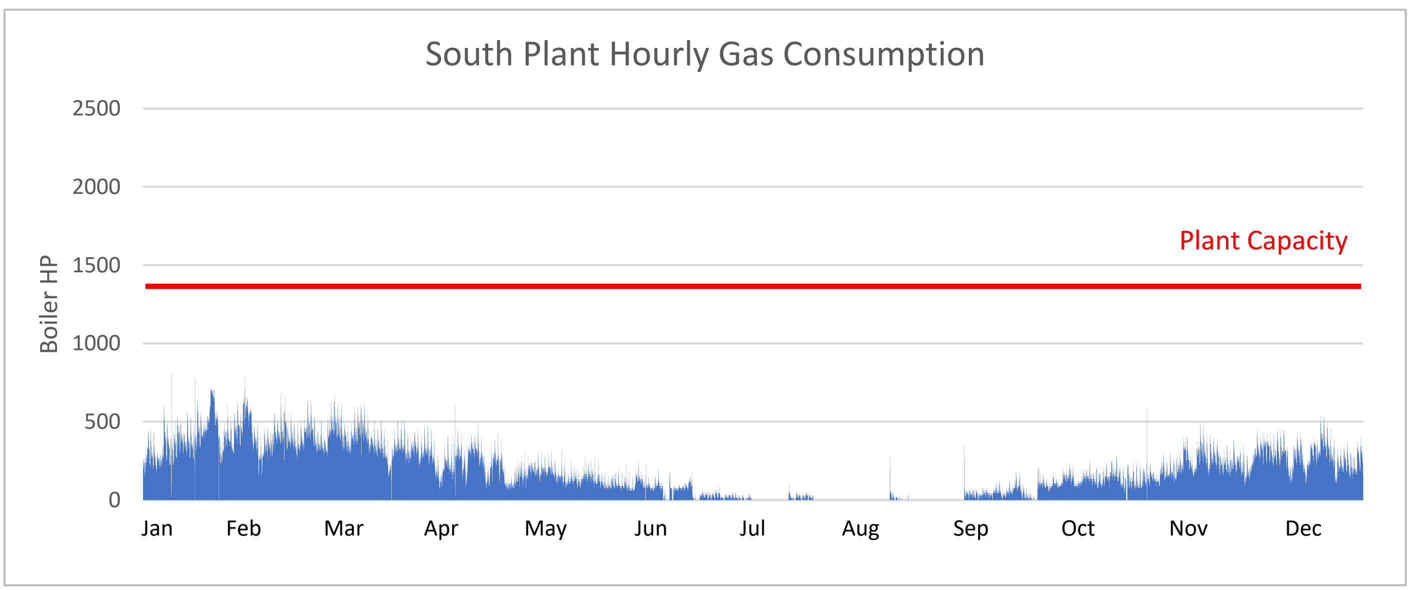


The charts below show the hourly electricity demand of each campus in 2019 broken down by core use type. The raw data used to develop this analysis was provided by UML via Hatch Data. The North Campus has the highest electricity demand of the three campuses, primarily driven by labs. The coincidental peak demand of the North Campus occurred on July 31st and is approximately 3.3MW. This is likely driven by coincidental loads in labs and weather (near design cooling day: 88°F max). The demand of the South Campus is driven by office/classroom. The coincidental peak demand occurred on September 21st and is approximately 1.5MW. This is likely driven by student presence on campus and weather (near design cooling day: 88°F max). The demand of the East Campus is driven by residential. The peak demand occurred on September 23rd and is approximately 1MW. This is likely driven by student presence on campus and weather (near design cooling day: 85°F max).



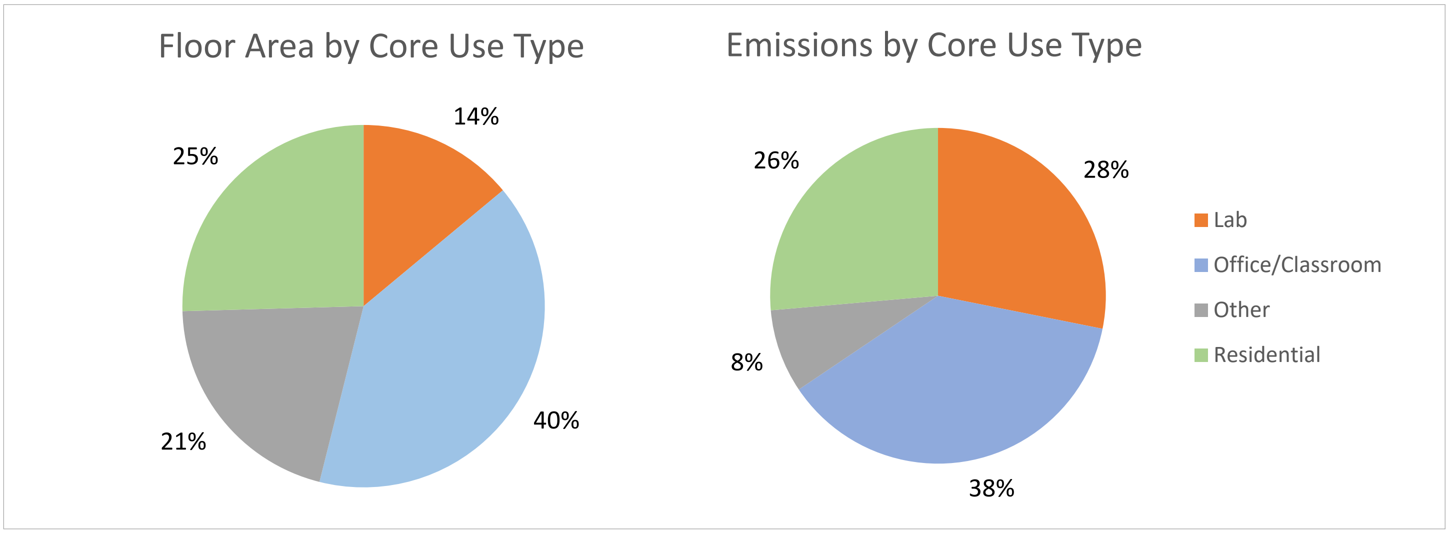
The charts below show the hourly gas consumption for the North Plant and South Plant in 2019. The raw data used to develop this analysis was provided by UML via Hatch Data. The data for the North Plant's first half of the year is not available. Similar data gaps exist in the 2018 data. However, it is still assumes that the North Campus has a higher gas demand than the south campus, primarily driven by labs and increased, treated outside air. The peak hourly consumption of the North Campus occurred on December 20th and is approximately 1,045 boiler HP. The peak hourly consumption of the South Campus occurred on January 9th and is approximately 806 boiler HP. Both instances are expected to be weather dependent. The peak hourly consumption is significantly less than the estimated maximum plant capacity at both the North Plant and South Plant.



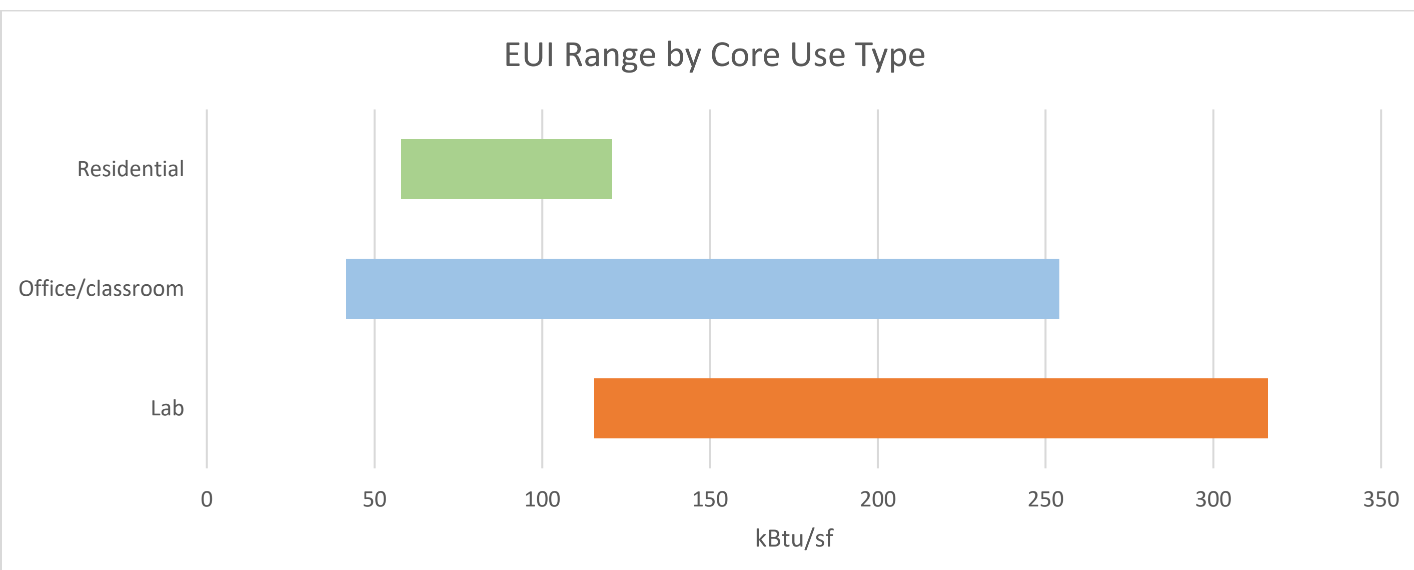


Building Use Energy and Emissions

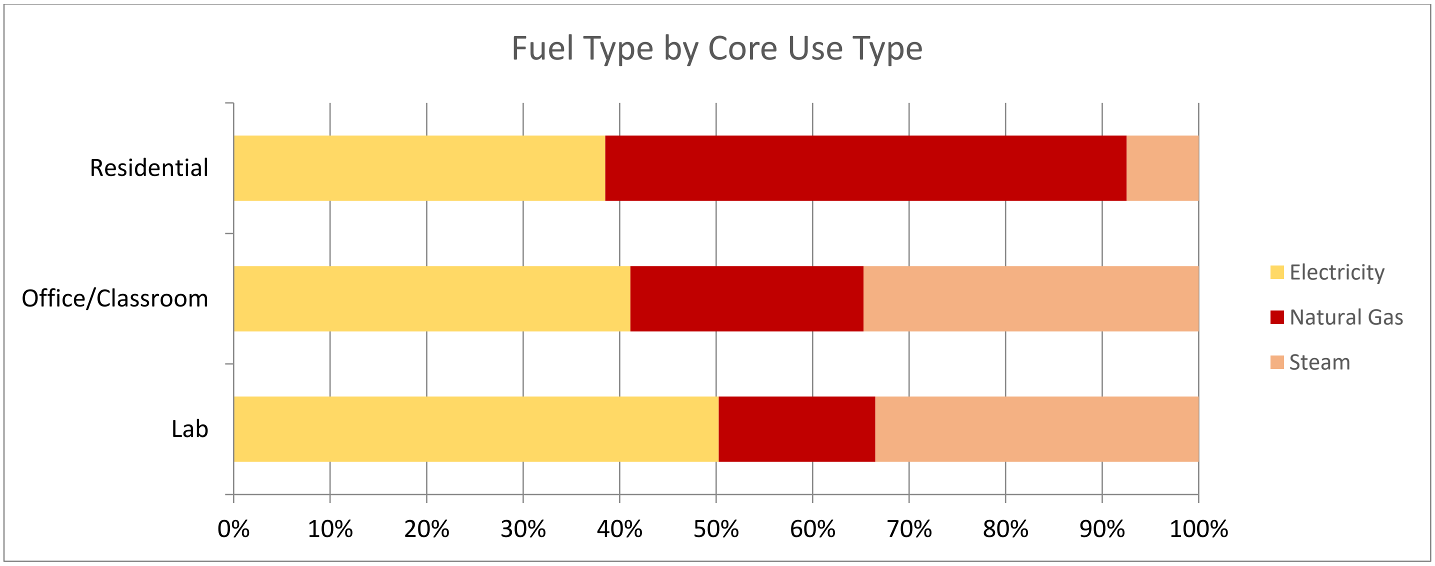
The charts below compare core use type floor area as a percentage of total campus floor area and core use type emissions as a percentage of total campus emissions. Steam energy consumption has been adjusted to apply an 80% average boiler efficiency. This efficiency should be confirmed by UML. As noted above, the core use type with the greatest square footage is office/classroom. Office/classroom also contributes to the greatest number of emissions. However, lab emissions constitute almost a third of emissions even though labs makes up 14% of floor area. This data suggests that alternative energy projects should initially prioritize lab core use types as part of the Alternatives Analysis.



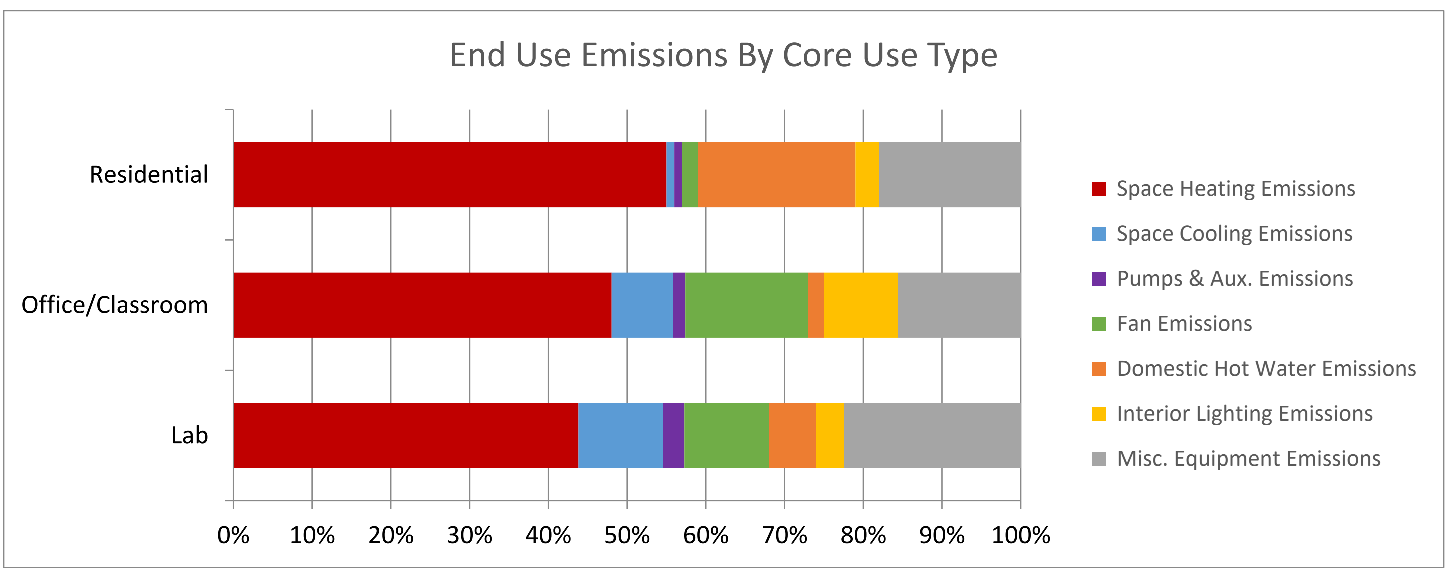
The charts below compare the ranges of energy use intensity (EUI) as a function of core use type. In general, lab spaces are the most dense energy consumers followed by office/classroom. Lab EUI ranges from 115 to 316 kBtu/sf. Office/classroom EUI ranges from 41 to 254 kBtu/sf. Residential EUI ranges from 58 to 120 kBtu/sf. Higher EUI residential buildings contain dining facilities. Outliers have been removed from this part of the analysis. See "Data Omissions and Anomalies" for more details.



The chart below compares core use type fuel mix breakdown. The raw data used to develop this analysis was provided by UML via Hatch Data and the cumulative spreadsheet. Energy consumption by fuel type was aggregated for each building of each core use type in order to develop these profiles. The highest fuel type use in residential buildings is natural gas. The highest fuel type use for office is steam. This suggests that alternative energy projects should initially target natural gas reduction in residential and steam reduction in office/classroom. A closer look at estimated end-use breakdowns is required to understand more specifically what projects should be targeted in labs.



The chart below compares core use type end use emissions. The raw data used to develop this analysis was provided by UML via Hatch Data and the cumulative spreadsheet. End use breakdowns were estimated using typical end use breakdowns for core use type adjusted for UML building specific electricity-natural gas fuel mix. The highest energy end use for every core use type is space heating. This is to be expected given UML's climate. This data suggests that alternative energy projects should initially prioritize space heating reduction.

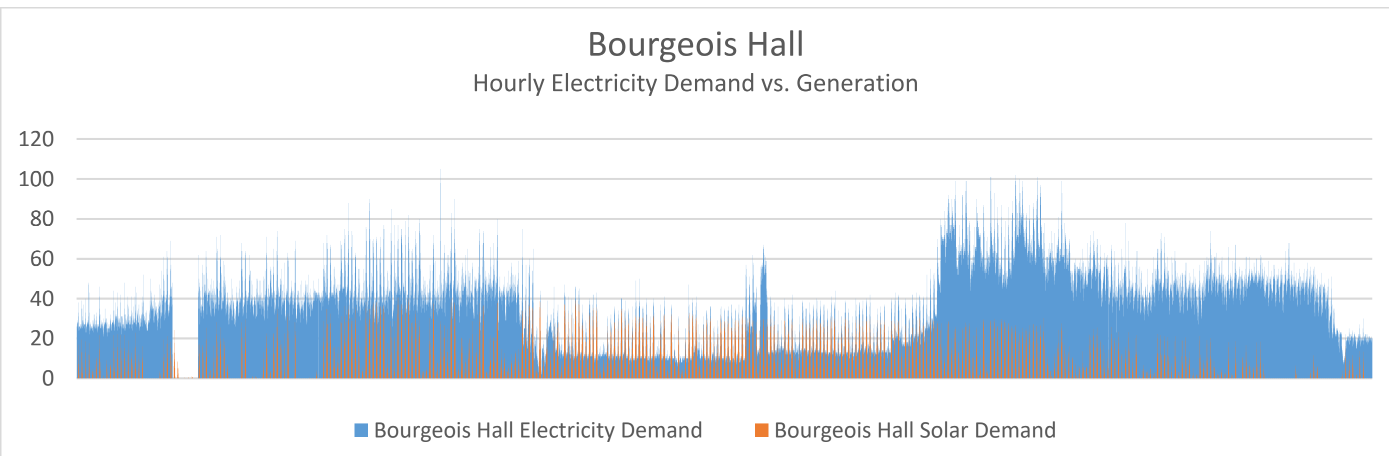


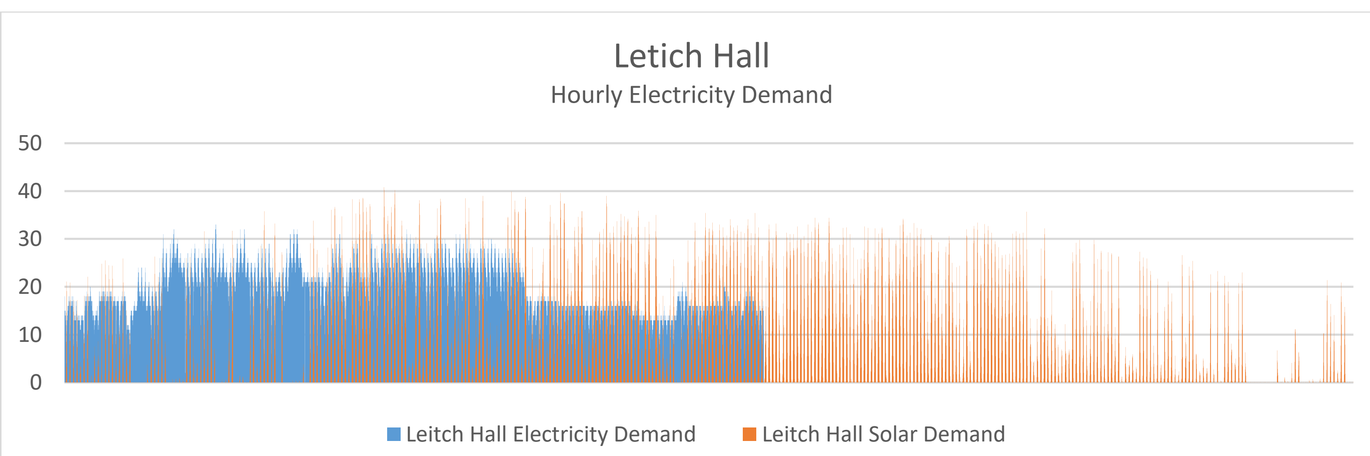
Solar Photovoltaic Generation

Solar photovoltaic (PV) electricity generation offset approximately 1% of campus electricity consumption in 2019. There are five solar PV arrays on campus: Bourgeois Hall (51kW), Costello Athletic Center (61kW), Dugan Hall (82kW), Leitch Hall (49kW), and South Parking Garage (154kW). The table below details these buildings' electricity consumption and generation. South Parking Garage energy consumption is not available. See "Data Omissions and Anomalies" for more details.

Building/Area	Electricity Consumption (kBtu)	Electricity Generation (kBtu)	Percentage Generation
Bourgeois Hall	1,096,613	147,808	12%
Costello Athletic Center	927,728	250,714	21%
Dugan Hall	2,519,844	280,569	10%
Leitch Hall	283,957	163,230	37%
South Parking Garage	n/A	784,521	n/A
Total Campus	137,511,835	1,626,842	1%

The table graphs below compare hourly 2019 building electricity demand to solar PV generation. These analyses help to better understand microgrid and battery storage opportunities. For example, Bourgeois Hall solar generation rarely exceeds building demand. Therefore, this candidate may be a lower priority for microgrid and/or battery storage. Inversely, Leitch Hall's solar generation often exceeds its building demand in the summer. This may be a higher priority candidate for microgrid and/or battery storage particularly given its variable building use. Similar profiles can be found in Appendix D for Costello Athletic Center and Dugan Hall.





Building Rankings

Prioritizing the highest energy consumers for projects is the more cost effective strategy to achieving load reductions on campus. These buildings are ideal for pilots. The pilot 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 pilot 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. Buildings with a higher EUI are ranked higher. Below is a summary of the highest ranked buildings in this key criteria. These rankings should be revisited once data omissions and anomalies are resolved, particularly those involving Pinanski Hall and UMASS Lowell Research Institute.

Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Ames Building		100 ^	0 ✓	96 ^	60 —	46 —	100 ^	72 ^
Saab ETIC		98 ^	0 ✓	36 ✓	88 ^	0 ✓	100 ^	58 —
McGauvran Center		96 ^	0 ✓	94 ^	79 ^	12 ✓	100 ^	68 ^

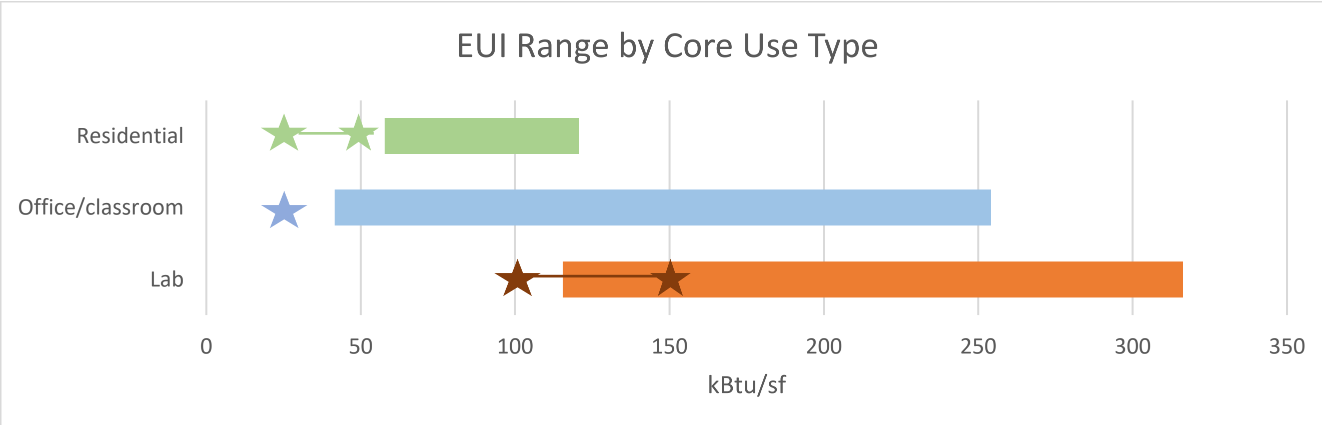
^ High priority — Medium priority ✓ Low priority ? Incomplete/anomaly

Energy Change Over Time – Energy change over time can be an indicator that system operation may becoming less efficient and/or that operational "band-aids" are leading to energy waste. Buildings with an energy increase between 2018 and 2019 are ranked higher. If a building decreased its energy use between 2018 and 2019, then a score of "0" was assigned under this key criteria. Below is a summary of the highest ranked buildings in this key criteria.

Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Wannalancit Business Center		54 —	100 ^	64 —	62 —	22 ✓	100	55 —
Concordia Hall		62 —	96 ^	76 ^	54 —	98 ^	0 ✓	74 ^
East Parking Garage		12 ✓	94 ^	2 ✓	0 ✓	22 ✓	0 ✓	13 ✓

^ High priority — Medium priority ✓ Low priority ? Incomplete/anomaly

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 based on our experience and The U.S. Department of Energy's Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS) data. The higher a building's 2019 EUI is from the target, the higher it is ranked. Below is a summary of the EUI ranges across core end uses relative to their associated EUI targets as well as highest ranked buildings in this key criteria. More information is required to better understand how maintenance facilities are used on campus. This will be reviewed during BR+A's site visits.



Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Ames Building		100	0	96	60	46	100	72
McGauvran Center		96	0	94	79	12	100	68
Ball Hall		75	0	92	81	94	100	85

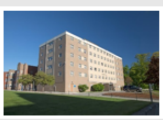
High priority Medium priority Low priority ? Incomplete/anomaly

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. Therefore, it's more important to prioritize electrification strategies. Buildings with the highest carbon emissions from natural gas and/or steam rank higher. Below is a summary of the highest ranked buildings in this key criteria.

Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Olney Hall		92 ^	0 ✓	42 —	96 ^	74 —	100 ^	73 ^
Fox Hall		79 ^	0 ✓	60 —	94 ^	22 ✓	100 ^	62 —
University Crossing		63 —	0 ✓	48 —	92 ^	22 ✓	0 ✓	50 —

^ High priority — Medium priority ✓ Low priority ? Incomplete/anomaly

Facility Condition – Deferred maintenance may make decision-making easier when it comes to implement load reduction strategies. Buildings were reviewed for recent renovations, AEP projects, and Sightlines. Using this information, a "facility condition" score was established. Buildings were subjectively scored on a scale from 0-4 if exterior improvements appeared to be needed, 0-3 if building system improvements appear to be needed, and a 0-1 score if the building appeared to be architectural importance. Buildings with a higher score suggest a greater need for improvements. A total score was calculated for each building Buildings with a greater total score are ranked higher. Below is a summary of the highest ranked buildings in this key criteria. Building facility scores will be revisited during BR+A's upcoming site visits.

Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Sheehy Hall		54 ?	46 ?	74 ?	65 ?	98 ^	0 ✓	67 —
Concordia Hall		67 —	96 ^	84 ^	62 —	98 ^	0 ✓	74 ^
Ball Hall		85 ^	0 ✓	92 ^	87 ^	94 ^	100 ^	85 ^

^ High priority — Medium priority ✓ Low priority ? Incomplete/anomaly

Precinct Priority – Centralizing heating and cooling operations improves efficiency, resiliency, and reliability. Buildings that are best suited for central plants given relative location to other buildings, critical operations, anticipated alternative energy strategies based on core end use, and/or coincidental loads rank higher in this category. Buildings that met this criteria were ranked with a score of 100 in this key criteria. See Appendix E for a list of building scores.

In summary, buildings with the highest average score are anticipated to be the best candidates for pilot alternative energy projects. Weight factors were applied to each key criteria in order to establish an overall score for each building. Weight factors for energy change over time and precinct priority are lower given data omissions and to prevent skewing of data. Weight factors should be reviewed by UML at this stage to align with goal priority. Below is a summary of the office/classroom, residential, and lab building with the highest average score in each core use building type. Sheehy has replaced Concordia as a pilot building after review with UML. See Appendix E for a list of all building scores.

Building		Energy Consumption	Energy Change	EUI Target	Combustion Total	Facility Condition	Precinct Plant	Overall Score
Ball Hall		85 ^	0 ∨	92 ^	87 ^	94 ^	100 ^	85 ^
Concordia Hall		67 —	96 ^	84 ^	62 —	98 ^	0 ∨	74 ^
Olney Hall		92 ^	0 ∨	42 —	96 ^	74 —	100 ^	73 ^

^ High priority — Medium priority ∨ Low priority ? Incomplete/anomaly

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. Buildings have been omitted from the analysis until issues are resolved (unless otherwise noted). Issues resolved will be included as part of the Final Report.

Affected Building	Issue	Next Steps
110 Canal	Missing natural gas meter data.	UML to follow up. Natural gas may be included as part of lease. If so, UML to provide proxy building. Not 100% UML occupancy. Not in scope of project.
175 Cabot	EUI flag. Calculated EUI is unrealistic based on building use (<2 kBtu/sf).	UML to confirm gas data is not available. Leased. Not in scope of project.
Allen House	No meter information available (electricity nor steam)	After review with UML, BR+A to develop energy profile based buildings of similar type from benchmarking database.
Ames Textile	EUI flag. Calculated EUI is high even though cleanroom (1036 kBtu/sf).	Review with UML as part of next phase. Allocated 20% to Ames of Ames/ Wannalancit meters.
Alumni Hall	No meter information available (electricity nor natural gas)	Assumed to be metered as part of Lydon Library
Coburn Hall	Building underwent major renovation such that one complete year of data is not available.	Energy model data recommended for use as proxy.
Costello Athletic Center	One complete year of data is not available.	Available 2018 and 2019 is relatively consistent month-over-month. 2018 and 2019 data stitched together to create complete profile. EUI still lower than expected (~16 kBtu/sf). BR+A to develop energy profile based buildings of similar type from benchmarking database.
Cumnock Hall	Missing steam meter data. Missing 2018 electricity data.	Use Mahoney Hall as proxy per UML for steam. Review with UML as part of next phase for electricity.
Dandeneau Hall	Missing steam meter data	Interim solution is to use Southwick as proxy. UML to follow up on omission.
Durgin Hall	Negative steam meter values	UML to review steam meter calibration. Values (-288) have been zeroed out for the purposes of this analysis.
Falmouth Hall	EUI flag. Calculated EUI is unrealistic based on building use (11 kBtu/sf).	Use Kitson as proxy.
Graduate and Professional Studies Center	EUI flag. Calculated EUI is unrealistic based on building use (25 kBtu/sf).	BR+A to develop energy profile based on proxy building.
O'Leary Library	Negative steam meter values. Significant steam spikes in energy consumption during summer months.	UML to review steam meter calibration and setup. Values (-288) have been zeroed out for the purposes of this analysis
Perry Hall	One complete year of data is not available.	Energy model data used as proxy (DMI, 11/9/17).
Pinanski Hall	No meter information available (electricity nor steam)	BR+A to develop energy profile based on proxy building.
Rist Urban Agriculture Farm	No meter information available (electricity only anticipated)	Building omitted based on anticipated low energy impact and limited alternative energy projects
Sheeney Hall	One complete year of data is not available.	Use Concordia as proxy.
UMass Lowell Research Institute	No meter information available (electricity nor steam)	Leased. Not in scope of project.
Weed Hall	One complete year of steam data is not available. Missing 2018 electricity data.	BR+A to develop energy profile based buildings of similar type from benchmarking database.

[1] Boston Building Energy Reporting and Disclosure Ordinance. https://www.boston.gov/departments/environment/building-energy-reporting-and-disclosure-ordinance

Data Management Analysis

BR+A reviewed data management practices related to metering and building management system (BMS) trend data. UML currently uses several sources to manage and store energy metering data. Each source was examined for capability of current and potential future needs. Also, reports from the BMS were generated for all buildings to understand trend data intervals and sampling, as well as trended system parameters. Below are recommendations to improve current practices to support tracking carbon goals, identifying energy waste, and fostering a living lab campus.

Metering Data Management

UML currently uses several sources to manage and store energy metering data: Hatch Data, ALSOENERGY PV Platform for solar photovoltaic generation, Automated Logic Controls (ALC) for select building metering, and an Excel spreadsheet for select building metering ("Cumulative Report" spreadsheet).

Hatch Data compiles the majority of large building energy metering data. It stores building electricity consumption and demand data as well as condensate and natural gas data. Data can be tracked at 15 minute intervals and has data for most buildings dating back to 2017. The platform also offers diagnostic tools to identify and offer solutions to energy anomalies. The software does not appear to integrate with UML work order management (CAMIS-Tririga) in order to centralize work order related tasks.

ALSOENERGY PV Platform is used to store solar photovoltaic generation data. Data for all five solar PV arrays is centralized in this platform. Data can be tracked at 15 minute intervals and has data for most buildings dating back to 2017. Actual generation is compared to an estimated generation target. The software does not integrate with sources of building energy consumption or demand data.

Automated Logic Controls (ALC) is UML's building management system. Electricity demand metering is provided for most buildings. This appears to be redundant with Hatch Data efforts. In general, newer buildings have expanded end use metering capabilities such as BTU meters for heating hot water, chilled water, condenser water, and domestic hot water as well as electricity consumption for cooling tower fans, ventilation fans, and pumps through VFD integration. In general, the software does not "push" this BTU meter information to Hatch Data or another software for automated analytics.

An Excel-based spreadsheet manual (referenced as the "Cumulative Report") is used to log energy metering data for select buildings. This spreadsheet is manually populated with electricity, natural gas, and water data. Data is available in monthly intervals dating back to 2012.

Centralizing metering records under a single platform will streamline carbon tracking and reporting efforts. Centralization under an energy tracking and analysis system (like Hatch) and linking BMS submeters from the building management system can help shift required meter data storage to the cloud, enable automated energy analysis/fault detection in order to reduce the need for manual analysis, and automate carbon accounting. In the near term, submeter trending, whether through the BMS or a centralized platform, is recommended given that, in general, newer buildings have this capability. Moving forward, development of a building management system standard, inclusive of metering requirements for construction projects, can help ensure that sufficient end use metering is comprehensive and trended appropriately to better support facilities and carbon tracking. As alternative energy projects are pursued, this standard will help support measurement and verification of these efforts.

See Appendix F for list of buildings and their associated metering capabilities.

BMS Trend Data Management

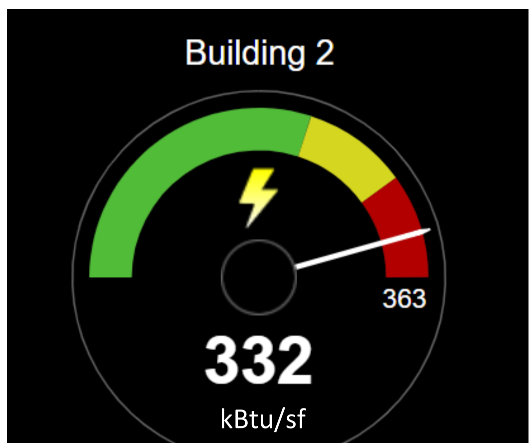
Automated Logic Controls (ALC) is UML's building management system (BMS). BMS trend data is available for most HVAC systems: boilers, chillers, air handling units, pumps, and fans. However, points are typically trended at 15-minute intervals with maximum sampling storage of 1-4 days. In general, these practices are not sufficient to properly review system operation, identify wasted energy/carbon instances, and support troubleshooting. In the near term, storage retainage is recommended to be increased to at least 36 months as recommended as part of ASHRAE 90.1-2016. Moving forward, development of a building management system standard inclusive of trend parameters, intervals, and storage will help to better support facilities, streamline efforts as part of UMASS' Turnkey Existing Building Commissioning Services, and enable the necessary information to maximize automated fault detection and diagnostics (AFDD). As alternative energy projects are pursued, this standard will help monitor technologies to ensure proper operation.

An automated fault detection and diagnostics (AFDD) system can help facilities proactively identify and troubleshoot energy/carbon waste issues. This may include equipment on during unoccupied hours, systems not tracking temperature setpoints, and simultaneous heating and cooling. AFDD not only helps identify issues, but also identifies potential solutions – a piece of equipment left in manual override/"hand," a broken valve actuator, or a programming error. AFDD is a critical component to ensuring proper system operation and minimizing energy/carbon waste, but it is only possible if the proper information is available within the building management system.

Campus Living Lab Opportunities

Acquiring, storing, and managing meter and trend data is the first step towards enabling a living lab campus. A living lab campus may consist of enabling research, behavior change strategies, and energy competitions. Access to metering and trend data can equip faculty, students, and staff with hands-on, real-world research into smart buildings, big data, and the impact of alternative energy projects. Organization of this data can also unlock opportunities to change occupants' behavior around how they use building energy. Below are recommended approaches to the three core building use categories:

Office/classroom Buildings – Office/classroom buildings create most of UML's Scope 1 and Scope 2 emissions. However, a large number of occupants use these buildings as transient spaces. This begs the question: How do you empower occupants – whether office workers are there for eight hours a day or students just stopping in for an hour class – and hold them accountable for the energy that they use while working or studying in the building? A centrally located energy dashboard can help serve this purpose. Energy use intensity targets can be set for existing buildings based on historic data and for new buildings based on energy model estimates. The dashboard would be a clear indicator of how much of an "energy budget" the building has used. To the right is a stock graphic offered by ALC which could be used for this purpose. This effort can also help facilities automate energy management efforts.



Simple graphics to clearly and quickly communicate to occupants if the building is on track towards its energy goal.

Residential Buildings – Residential buildings are generally occupied 24/7. The second highest end use in these buildings is plug loads (see "Building Energy Use and Emissions" section for more information). This end use type is more difficult to manage than other end use loads given that the solution is typically not as simple as switching to, for example, LED lighting or a more efficient boiler. Instead, this end use is typically based on what devices students bring with them and how often they use them. Our recommendation to manage this is through friendly, behavior change energy competitions. Centralizing metering to one platform and making this information accessible to students will unlock the ability to conduct competitions. These competitions could be run by the Office for Sustainability. Identifying and empowering student champions can help increase participation and help manage competitions. Low cost rewards like a pizza party or an annual trophy can help big impact energy savings. These competitions can be rolled up into a more comprehensive housing program, based on the student body's strengths and interests, to ensure students are educated, create habits, and are aware of their impact on their residential building and overall campus. This will in turn help to change their behavior and interaction with other campus buildings. As a near term strategy, data can be organized to enable these types of competitions as much of this data is already available through Hatch Data.

Lab Buildings - Lab buildings are also 24/7 buildings but much more energy dense than residential buildings. As the University seeks to increase research on campus, lab energy and its associated plug use is also expected to increase. Plug loads are typically the second highest end use in lab type buildings (see "Building Energy Use and Emissions" section for more information). 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 and major renovations 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.

Simple displays and directions to show exhaust air flow rates and users' impact in fume hood driven spaces. The graphic above is from Harvard University's Jacobsen Lab.

Summary

This data will provide the foundation for future project phases. Improvements to current data management practices including more granular interval trending and increased sampling storage can better support tracking carbon goals, identifying energy waste, and fostering a living lab campus. The data shows that Olney Hall, Ball Hall, and Sheehy Hall are the best buildings to conduct pilot alternative energy projects given that they score highest compared to other buildings of the same core use type. These buildings will be prioritized as part of the Alternatives Analysis. This preliminary report will be incorporated into the Final Report based on any comments and feedback from UML.

3 30-Year Forecast

30-Year Forecast

It is expected that factors affecting UML's historical energy and emissions data will change. The primary factor that has driven a reduction in energy consumption in the last 5-10 years was the Accelerated Energy Program (AEP). On-campus population growth and campus area growth were the primary factors resulting in an increase in energy consumption. It is expected that these factors will have less influence on energy consumption given that the Accelerated Energy program has ended, on-campus population has slowed, and campus growth is expected to slow given UML's debt ceiling. Therefore, anticipated energy consumption to be relatively flat over the next five years given these factors. The expansion of online learning, COVID's effects on student interest and COVID's impacts on building operations will also be factors. Going forward, it is expected that these changes in operating revenue and on-campus population will continue to play a role. However, it is expected that capital planning's focus will shift from new construction and acquisitions to renovation of existing assets. These renovations are expected to shift less energy intensive office/classroom program to more energy intensive lab program. Renovations are also likely to add cooling in spaces that currently do not have this function. As for emissions, Massachusetts's Clean Energy Standard ('CES') and the states' requirements will lead to a continuously improved electrical grid over time. This will result in reduced emissions from electric consumption. Considering all of these factors and adjusted forecasts from the U.S. Energy Information Administration's ('EIA') Commercial New England data sets, BR+A-Anser anticipate that energy consumption will slowly increase 7% and emissions will decrease 39% over the next 30 years.

Energy forecasts are subject change due to future developments in technologies, demographics, and resources. These factors cannot be accounted for with absolute certainty. Therefore, it is recommended that forecasting is updated on a regular basis to ensure project implementation decisions are made with the most up-to-date information.

30-Year Energy and Emissions Analysis

Overview

BR+A utilized data sets from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) in order to understand the key factors affecting energy in the region. The AEO is published annually in accordance with the Department of Energy Organization Act of 1977. Reports detail trends and projections for energy use and supply in the United States. Regional and building sector-specific data sets are available for estimating future electricity and natural gas consumption. This information was used as a baseline, then UML-specific factors were applied as adjustments.

BR+A reviewed changes over the last ten years in UML's gross area, on-campus population, and operating revenue in order to establish a correlation with changes in energy consumption. Initial findings were reviewed with members of UML's Office for Planning, Design and Construction; and Office of Strategic Analysis and Data Management. Results were inconclusive. Assumptions regarding how these factors will affect future energy consumption were adjusted based on the available data. In addition, members of these offices suggested that additional factors such as increased lab program and expanded cooling operations would play a role in energy changes on campus.

EIA New England Assumptions

The EIA data set that most closely resembles UML's climate and operations is the New England Commercial building sector. Economic growth is the primary driver of energy demand and related CO2 emissions. Data sets show relatively steady economic growth as indicated by an average 1.9% annual increase in gross domestic product over the next 30 years. Gross square footage and population grow steadily at an annual average of 1% and 0.5%, respectively. This correlates with similar trends in electricity and natural gas consumption.

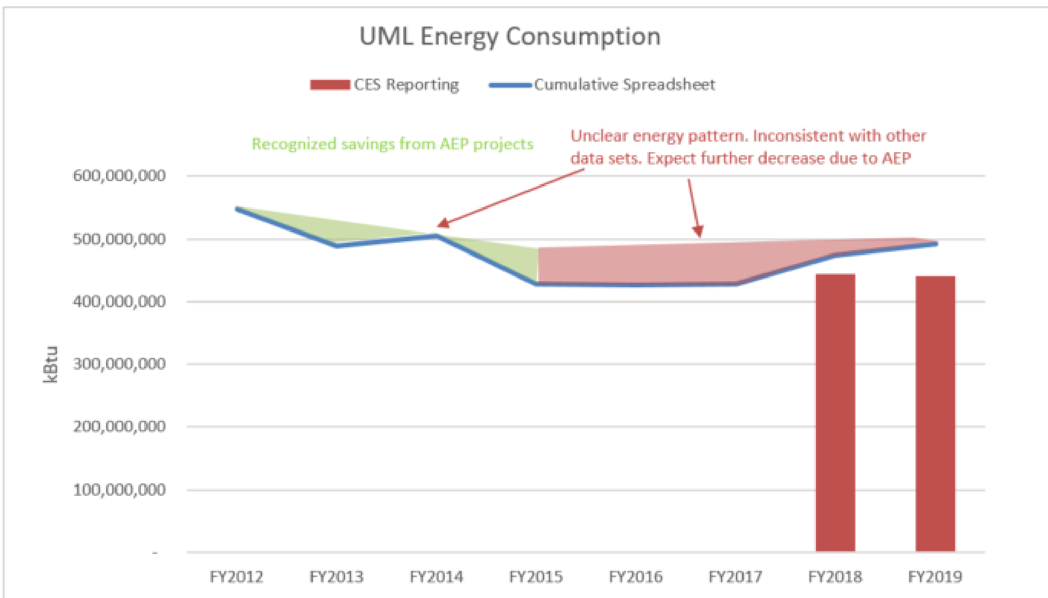
The electricity and natural gas data sets account for continued energy improvements leading up until 2026 as part of the AEP and consistent with EIA's assumption. At that point, economic growth increase is expected to outweigh energy conservation decreases. BR+A estimates that the UML will not experience this same degree of decline due the completion of the Accelerated Energy Program. See "UML-Specific Assumptions" for more details. In addition, electricity consumption/cooling is expected increase as cooling degree days increase, and natural gas consumption/heating is expected to decrease as heating degree days decrease.

In summary, New England Commercial total energy is expected to increase. Electricity consumption is expected to increase 11% between 2020-2050 with an average annual increase of 0.3% Natural gas consumption is expected to increase 6% between 2020-2050 with an average annual increase of 0.1%. High economic growth and low economic growth scenarios are also available to demonstrate a range of how energy consumption could change. The high economic growth scenario accounts for a 2.4% annual GDP growth, and the low economic growth scenario accounts for a 1.4% annual GDP growth. Energy consumption could range 1.5% higher or lower depending on economic growth. Raw data sets can be found in Appendix G.

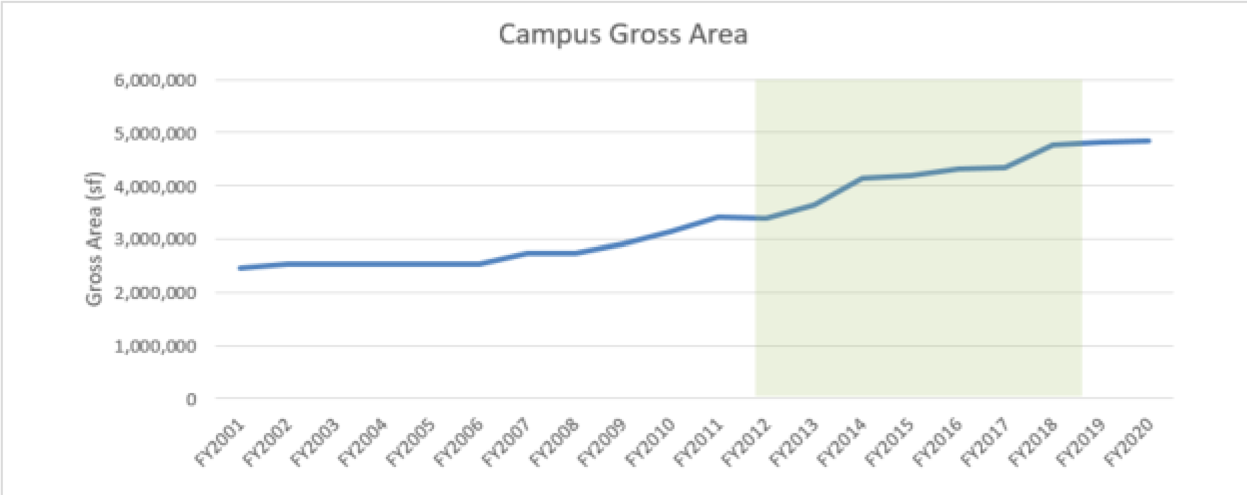
UML-Specific Assumptions

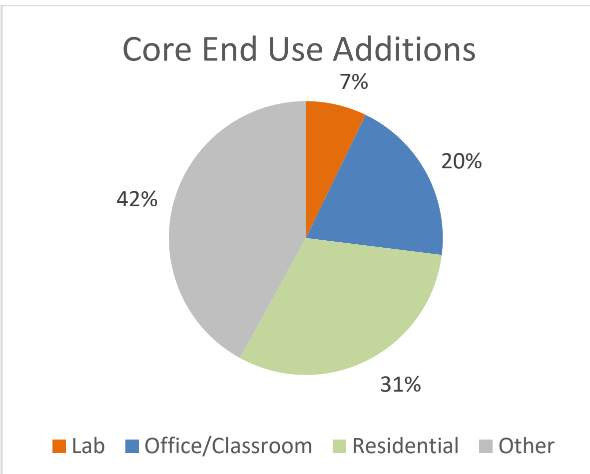
The cumulative spreadsheet was used to aggregate energy data for the last seven (7) years. Year-over-year aggregates are inconsistent with CES reporting. CES reporting is believed to be accurate based on prior reviews with UML. For example, the cumulative spreadsheet shows an increase in energy consumption whereas the CES reporting shows a decrease in energy consumption between FY2018 to FY2019. Note that CES reporting is only available for FY2018 through FY2020. FY2020 has been omitted from the analysis due to skewed data as a result of COVID-related reduced operations.

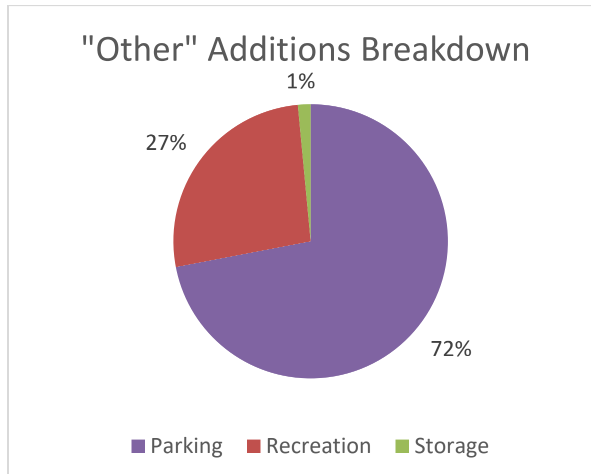
The graph below shows the inconsistent energy trends between FY2012 and FY2019 per the cumulative spreadsheet. The cumulative spreadsheet data shows a downward trend between FY2012 and FY2015. This appears to generally align with BR+A-Anser's understanding of Alternative Energy Project (AEP) implementation and associated energy reduction (except for FY2014). However, the steady and subsequent increase in energy consumption between FY2015 and FY2019 does not align with Alternative Energy Project (AEP) implementation nor BR+A trends of other factors. Therefore, it's expected that this is a data error. See "Data Omissions and Anomalies" for more information and next steps.



Campus area growth is a key factor expected to influence energy consumption. Energy consumption is expected to increase as the campus grows in size. Data provided by the Office for Planning, Design and Construction was used to review changes in gross area over the last twenty (20) years. Over the last ten years, the campus has experienced a surge in area growth; 55% increase with an average annual increase of 5%. Only 2% of this square footage is leased space. This is not included in the UML greenhouse gas inventory and, therefore, is not included in the scope of this project. The majority of the added area falls under the core end use "Other", which is primarily "Parking." See graphs below for more details.

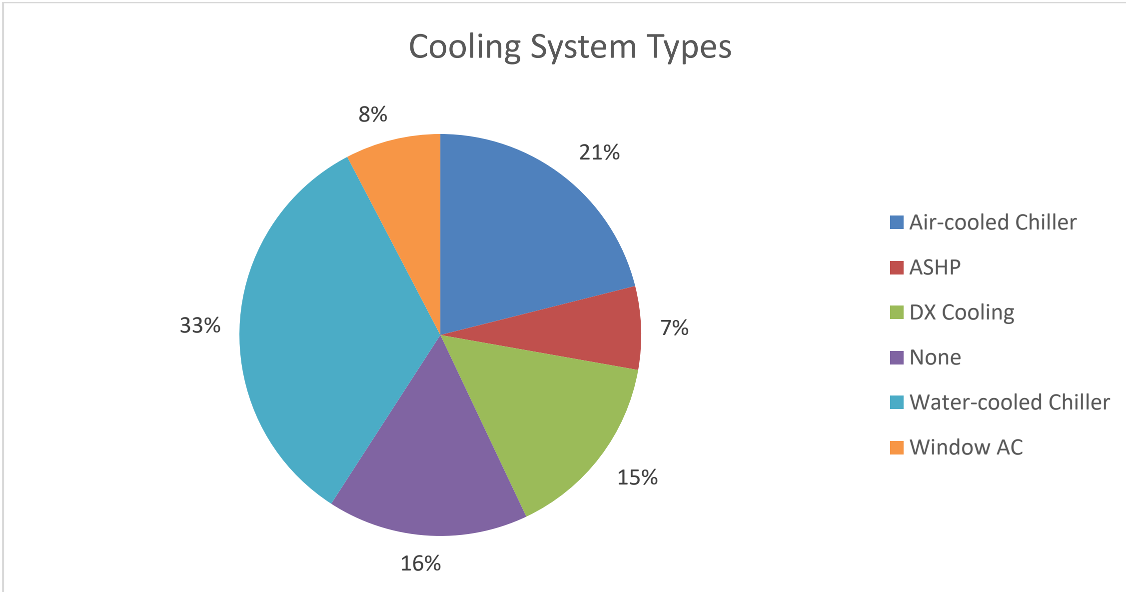


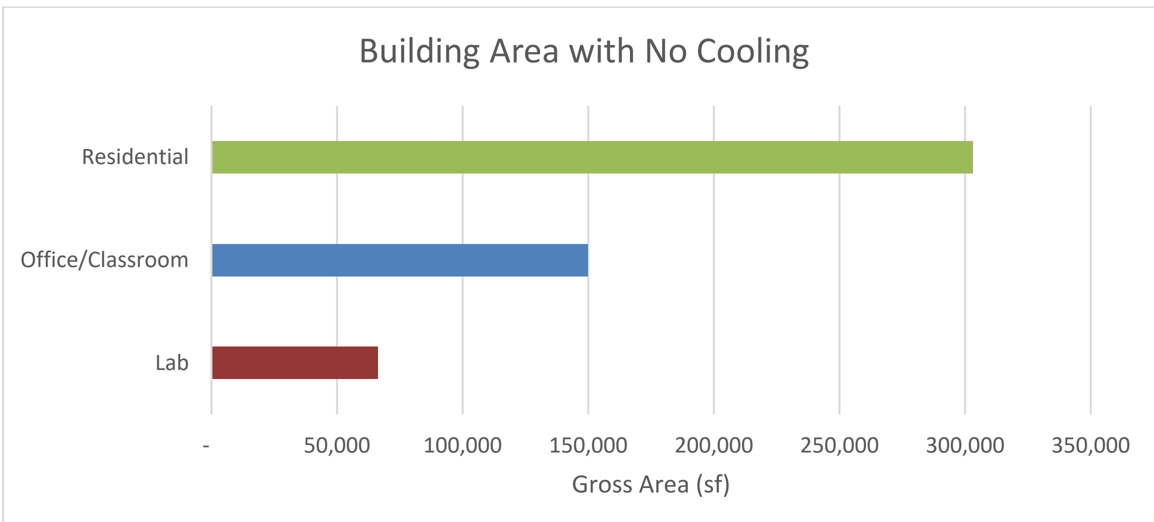




After review with the Office for Planning, Design and Construction, it is not expected that this gross area increase will continue at the same rate as experienced over the last ten (10) years. Instead, it's expected that capital planning's focus will shift from new construction and acquisitions to renovation of existing assets. These renovations are expected to shift less energy intensive office/classroom program to more energy intensive lab program. The energy forecast under "UML 30-Year Forecast" represents a 10% conversion of office space to lab space from FY2025 to FY2050 (~6K sf per year). This represents approximately 6-7% increase in energy consumption due to increased equipment loads and ventilation air changes (fan, heating, and cooling energy). In general, it's expected that energy will increase 3.5% for every 5% conversion of office/classroom to lab.

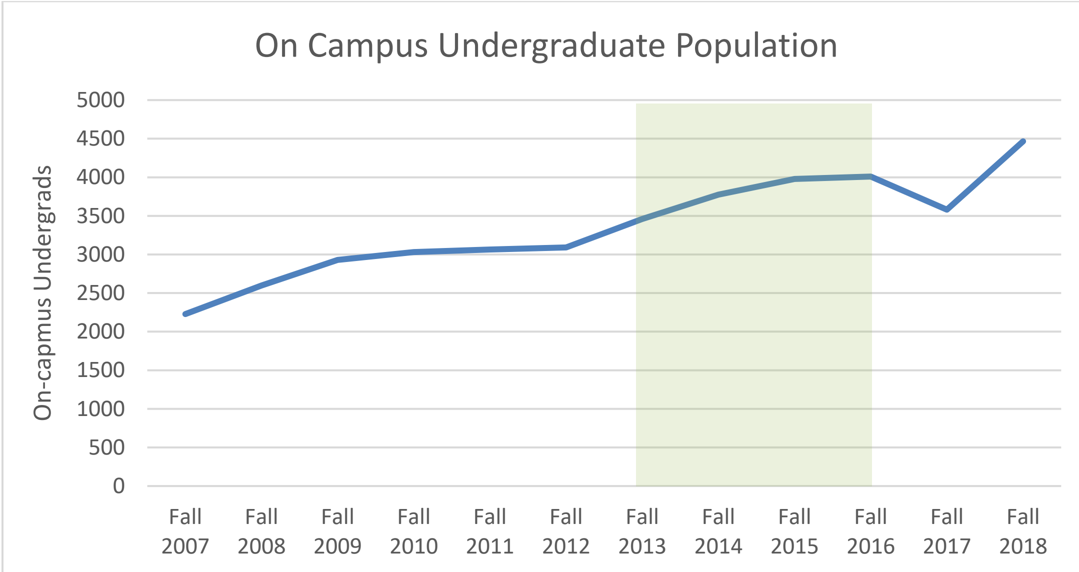
Also, the Office for Planning, Design and Construction noted that added mechanical cooling is expected to be a key factor on campus. Energy consumption is expected to increase in areas where mechanical cooling is added and it did not previously exist. BR+A-Anser reviewed the building management systems and building plans to gain a better understanding of how buildings on campus are cooled. Most of this square footage is in residential buildings. If all square footage currently not cooled is upgraded with mechanical cooling systems, it is expected to increase energy 1-2% from 2025-2050. See Appendix H for a breakdown of how buildings have been organized.



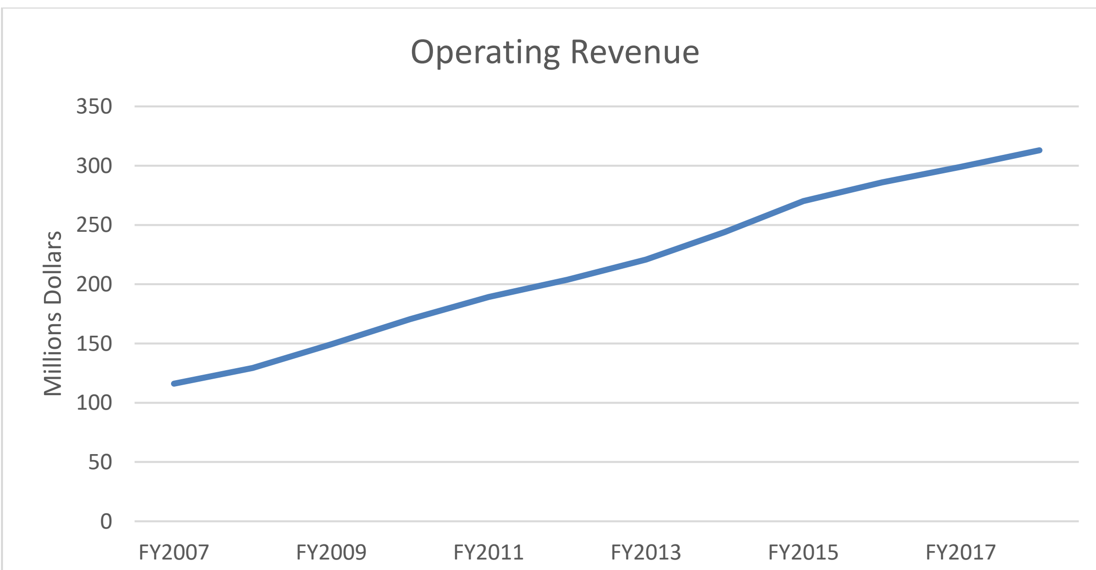


On-campus population growth is another key factor expected to influence energy consumption. Increases in on-campus population is expected to result in increases in energy consumption. The majority of graduate classes are expected to move online in future years. Also, in Fall 2018, graduate students accounted for ~1% of the on-campus student population. Therefore, undergraduate population was the focus of this study. Furthermore, the number of faculty staff is expected to increase to support the increasing student population. Therefore, specific patterns in faculty population are not explicitly detailed in this report. Lastly, the UML reporting data does not include data on support staff such as facilities. Similarly, support staff numbers are expected to increase to support student population

Undergraduate on-campus population growth has slowed in the past seven (7) years. This is represented by a pattern between Fall 2013 and Fall 2016 in which population increase compared to the previous year were 12%, 9% 5%, and 1%, respectively. See graph below for more details. See Appendix I for a table of the information below. After review with the Office of Strategic Analysis and Data Management, it's expected that student population will experience slower growth in the coming years. In the short term, this may be due to student interest may reduce given COVID. In the long term, this may be due to limited space on campus and in the city for expansion. This expected pattern is factored into the energy and emissions forecast by adjusting the EIA baseline to a slower rate of growth (50% adjustment factor). Note that data errors are expected in Fall 2017 and Fall 2018. See "Data Omissions and Anomalies" for more details.

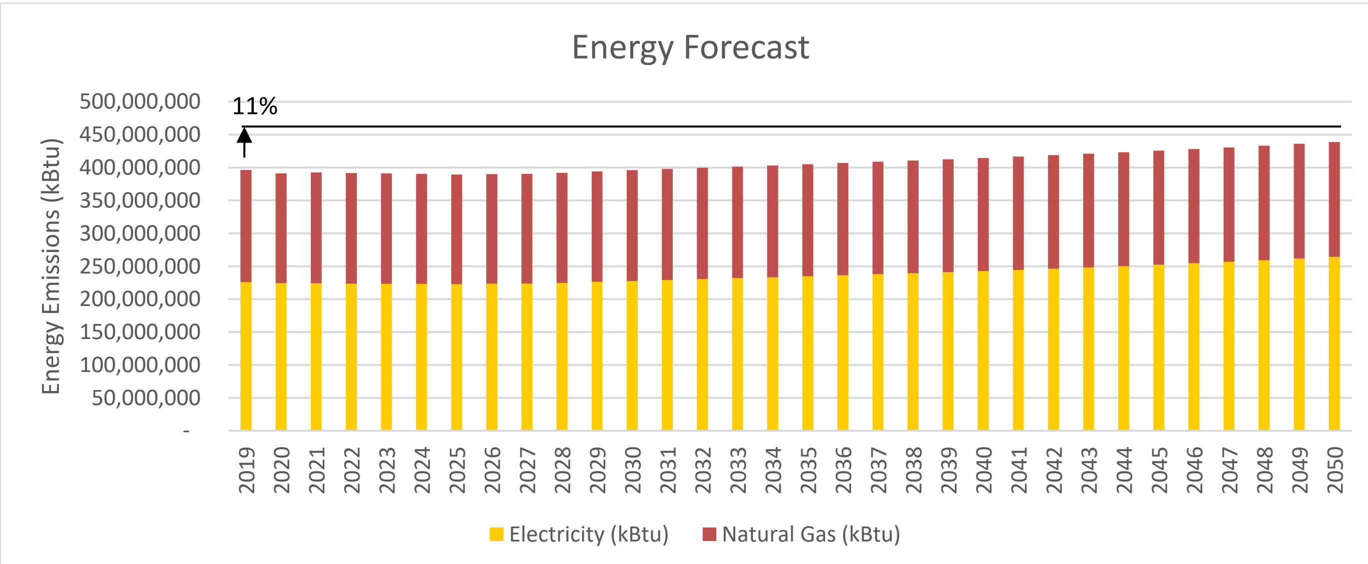


Operating revenue is another key factor expected to influence energy consumption. Increases in operating revenue may allow for building operations to expand resulting in an increase in energy consumption as well as allow for building upgrades that could reduce energy consumption. Operating revenue growth has slowed in the past ten (10) years. In FY2008-2009, growth was 15% and in FY2017-2018 growth was 5%. See graph below for more details. This expected pattern is factored into the energy and emissions forecast by adjusting the EIA baseline to a slower rate of growth (50% Adjustment). See Appendix J for a table of the information below.

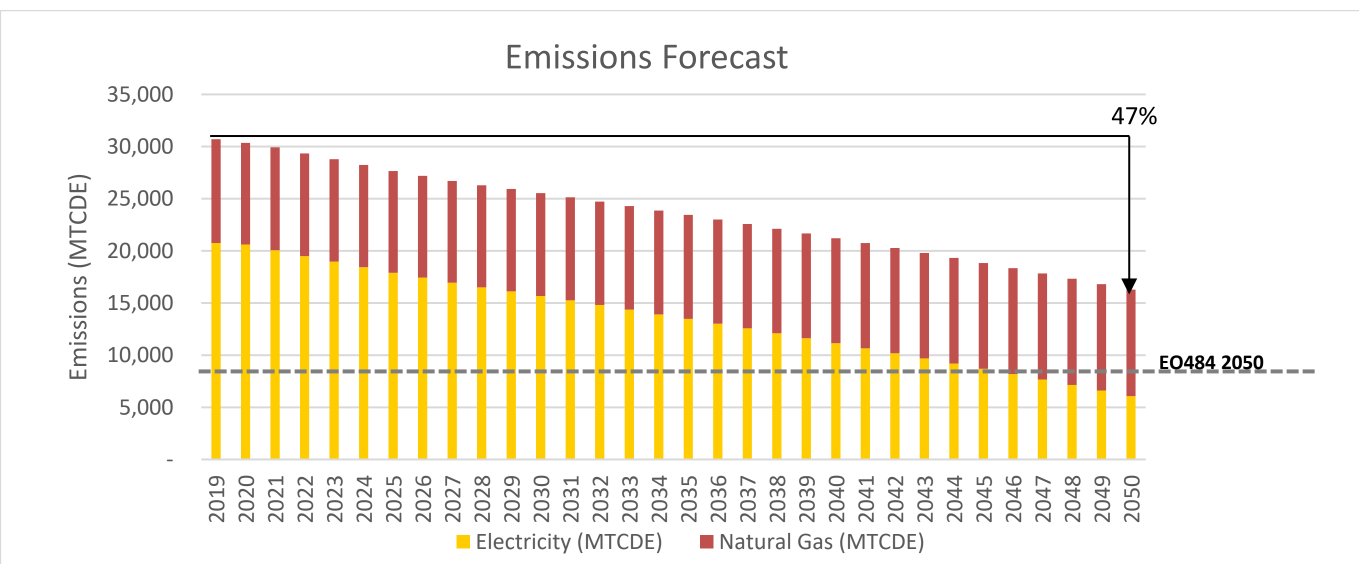


30-Year Energy and Emissions Forecast

Considering all key factors and adjusted forecasts from EIA's Commercial New England energy consumption is estimated to increase 11% over the next thirty (30) years. The baseline year is based on CES reporting for calendar year 2019 normalized for weather. The graph below shows the year-over-year forecast broken down into electricity consumption and natural gas consumption. Electric energy consumption is expected to increase 14% and natural gas consumption is expected to increase 2%. See Appendix K for a table of the information below.



Considering all key factors and adjusted forecasts from EIA's Commercial New England, BR+A-Anser anticipate that emissions will decrease by 47% over the next thirty (30) years. The graph below shows the year-over-year forecast broken down into electricity emissions and natural gas emissions. Electric emissions are expected to decrease 71% as a result of Massachusetts' CES. Natural gas emissions are expected to decrease 2% consistent with energy reduction. At these rates, UML will not meet the EO484 2050 threshold. See Appendix L for a table of the information below and emissions factors.



Data Omissions and Anomalies

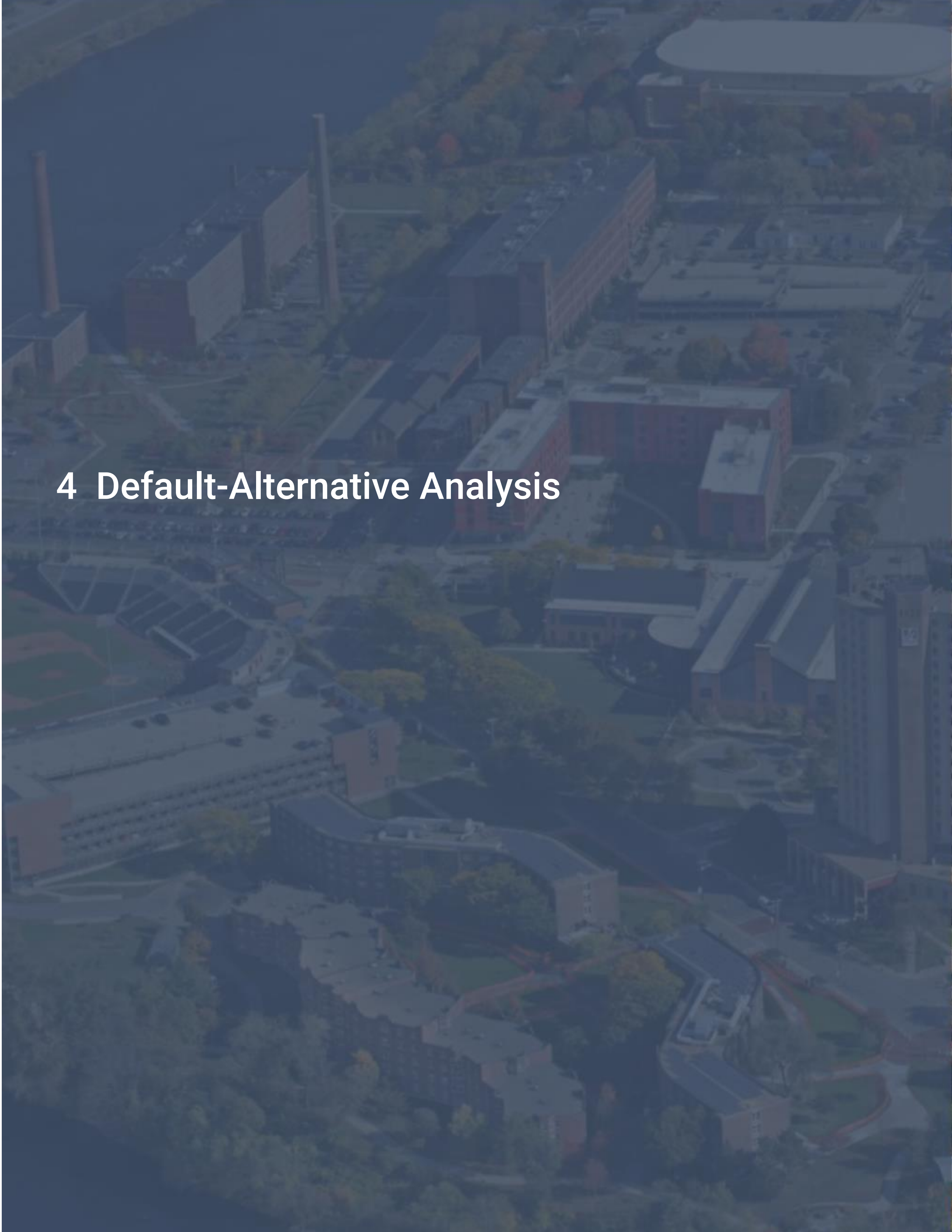
Data was reviewed for omissions and anomalies. Below is a chart summarizing the issues and next steps to ensure an accurate data set. Resolved issues will be included as part of the Final Report to be issues at a later date.

Issue	Next Steps
"Cumulative Report" total energy consumption data is higher than CES reporting and UMASS Sustainability Report. Sustainability Report estimates and CES reports are similar.	UML (D. Abrahamson) to follow up with CES to understand discrepancy. Constellation and 725 Merrimack accounts were identified by CES as the key contributors. Cumulative Report doesn't account for Constellation use (only cost). Discrepancy still exists.
"Enrollment At A Glance" reports on-campus undergraduate population unexpected drops in Fall 2017 followed by an unexpected degree of growth in Fall 2018 (even if Fall 2017 was normalized based on previous years' patterns). This suggests a data error.	UML (S. Barich) to review and follow up. Although our overall count of students enrolling year to year has mostly been on an increase, the growth rate has been on a decline. Raw numbers increasing, how much we increase by (the growth rate) is shrinking as time moves forward. A model of this nature would also assume infinite growth, at some point across the 30 years we would have to acquire new land and build new dorms to keep up with a 7% annual on-campus increase across a 30 year span. I am not sure if that is possible or not. Especially with bullet point number one above and available space in the city for expansion. Finally, I anticipate the impact of COVID to be felt for a few years to come. We might see flat to very little growth in the education sector as well as UML over the next couple of years.

Summary

This forecast discussed above will provide the foundation of the Alternatives Analysis will be based. Considering all of these factors and adjusted forecasts from the U.S. Energy Information Administration's (EIA) Commercial New England, energy consumption is estimated to increase 11% and emissions will decrease 47% over the next thirty (30) years. The increase in energy consumption is expected to be driven by conversion of office/classroom to lab, added mechanical cooling, increased operating revenue and increased on-campus population. Emissions are expected to be impacted primarily by the Massachusetts's Clean Energy Standard. This preliminary report will be incorporated into the Final Report inclusive of any comments from UML.

4 Default-Alternative Analysis



Default-Alternative Analysis

Default Case Overview

The Lowell Campus has three distinct campuses: North Campus, South Campus, and East Campus. The North Campus is primarily office/classroom, but has the largest presence of lab space on campus. The South Campus is primarily office and classroom, and the East Campus is primarily residential. The Default Case assumes that the steam boilers at the North and South plants as well as the main electrical infrastructure will be existing to remain given recent upgrades. The backlog of deferred maintenance will be replace in kind.

Based on this historic energy information, there is spare electricity capacity at the North Campus and South Campus mains. There is anticipated on being approximately 0.3MW of available capacity on the North Campus. There is not enough spare capacity to add Saab Emerging Technologies & Innovation Center and Pulichino Tong Business Center are tied to the North Campus electrical distribution. It is not anticipated these or any other buildings will be tied in at this time. Furthermore, there is anticipated on being approximately 1.7MW of available capacity on the South Campus. For the East Campus, any upgrade projects will have to be evaluated on a building by building basis. Alternative Case projects that include the installation all electric mechanical and plumbing systems in lieu of gas fired equipment, and large installations of electric vehicle-charging stations will likely need upgrades at individual buildings. This will be addressed as part of the Alternative Case. One potential resiliency measure in support of Executive Order No. 594 and the goals of this project is to provide a second utility circuit to each campus, fed from a different utility substation, and configure the incoming service in a main-tie-main configuration, with the tie breaker normally open.

Currently the North Campus peak steam demand is using 47% of the total plant capacity and the South Campus peak steam demand is using 57% of the total plant capacity. The capacity of the two main boilers on the North Campus can handle the full load of the campus, therefore the third, smaller boiler is not needed to be replaced at the end of its term. The age and required upgrades to the steam distribution systems on campus present further incentive to pursue and invest in electrification strategies campus wide and eliminate the use of fossil fuels.

UML contracts with energy suppliers for multi-year, fixed rate contracts. Inflation is expected to be the primary driver of UML electricity and natural gas rates given the smaller impact of renewable energy and retiring assets. Therefore, the average year-over-year change in electricity rates is 3% with a 2050 estimated rate of $0.26/kWh. The average year-over-year change in gas rates is 4% with a 2050 estimated rate of $23.50/Dth.

Alternative Case Overview

Energy efficiency, electrification, and renewable deployment are the key steps in working towards UML's 2050 carbon neutral goal and Executive Order No. 594 energy use intensity (EUI) and emissions goals. Implementation of energy conservation measures (ECMs) reduces, energy, emissions, operating costs, and enable cost effective infrastructure by reducing heating and cooling loads. Measures were identified by using the ASHRAE Level I Audit procedure. Detailed scopes for the pilot buildings (as identified during the "Metering and Data Management" phase) – Ball Hall, Olney Hall, and Sheehy Hall – were developed in order to evaluate energy, emissions, and load impacts. Two scenarios - "Good" and "Best" – were detailed in order to outline the range of opportunities compared to a Default/Business-As-Usual ("BAU") Case. These options are expected to serve as standalone building options in order to provide a comparison to a centralized approach.

Compared to the Default/Business-As-Usual ("BAU") Case, the North Campus, "Good" case is expected to achieve a 47% energy reduction and 35% emissions reduction. Upgrades are expected to be all-electric systems. Based on future electricity emissions rate (as detailed in the "30-Year Forecast), the emissions reduction is expected to be closer to 71%. The North Campus, "Best" case is expected to achieve a 52% energy reduction and 42% emissions reduction. The emissions reduction is expected to be closer to 74% given the implemented electrification strategies and future grid emissions rates (as detailed in the "30-Year Forecast"). The remaining emissions can be offset with renewables sources.

The South Campus, "Good" case is expected to achieve a 47% energy reduction and 35% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast), the emissions reduction is expected to be closer to 70%. The South Campus, "Best" case is expected to achieve a 53% energy reduction and 43% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast"), the emissions reduction is expected to be closer to 74%. The remaining emissions can be offset with renewables sources.

The East Campus, "Good" case is expected to achieve a 41% energy reduction and 26% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast), the emissions reduction is expected to be closer to 68%. The East Campus, "Best" case is expected to achieve a 54% energy reduction and 43% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast"), the emissions reduction is expected to be closer to 75%. The remaining emissions can be offset with renewables sources.

The reductions outlined above are expected to greatly exceed the EUI and emissions goals of Executive Order No. 594. The Investment Phase will detail how these projects can be structured in order to meet these requirement timelines.

Alternative Energy Measures comprised of centralized heating/cooling strategies and on-site renewable energy deployment were reviewed. Alternative Energy Measures were screened for viability given UML's unique campus conditions and key parameters including: construction cost, maintenance cost, energy cost, life cycle cost, system familiarity, emissions, resiliency, and space requirements. The North Campus provides the best opportunity for vetting alternative energy heating/cooling strategies given diversity of space types and associated heating and cooling load diversity. Eighteen (18) North Plant options were developed looking at a variety of technologies to help right-size the plant: ground-source heat pump, air-source heat pump, air-cooled chiller and water-cooled chiller capacities. If centralizing heating and cooling equipment on the North Plant is desired, the option that balances all factors including future flexibility, resiliency, construction cost, operating cost, maintenance is "Good B2 – Light Geo + Air-source + Gas Boilers". The good option also allows flexibility in building retrofits. As buildings are added to the central plant, the required air-source heat pumps and boiler capacity can be added. The geothermal borefield can be completed in two phases, one for the parking lot to the south and one for the parking lot to the north. This option also offers familiarity of gas boilers with the potential of transitioning to biodiesel in the future. Based on decisions made by UML regarding the North Campus, the Team will evaluate the viability of centralized heating/cooling systems on the South Campus. The East Campus is not expected to be an appropriate site for centralized heating/cooling systems given the lack of space type and load diversity; limited space in the urban environment; and relative locations of buildings to one another.

UML's site provides an opportunity for an additional 18,700 MWh/yr to be generated a year from solar PV. 85% of the total PV system capacity and annual production is proposed at parking sites. 84% of the total annual production for systems over 100 kW-DC. Sites under 100 kW are not expected to be cost effective. Given the current SMART program, solar PV can be used by UML as a tool to reduce operational costs but cannot be used to offset emissions given that the utility retains ownership of the renewable energy certificate (REC) under the SMART program. If this incentive program were to change such that owners could have ownership of the RECs, then the RECs could be retired in support of reducing emission and carbon neutrality. However, many owners may opt to sell the RECs as an additional cash flow. While battery energy storage system (BESS) resiliency may help harden UML buildings to the impacts of intermittent power disruptions, they are unlikely to supplant a liquid fuel generator and as such would have limited impact on long term energy and climate targets.

Default Case

Electrical Services Reliability Assessment

Several of the alternative options that are being considered rely on a transitioning from a fossil fuel-based energy source to electrification options, and the addition of electrical vehicle charging stations throughout the campus. Since these solutions will increase the electrical demand of the campus, it is important to identify the capacity of the primary electrical service feeder that is provided from National Grid to each campus.

The North Campus is fed from (2) two 1500KVA, 13.2 KV:4160V pad mounted transformers. These transformers in turn feed the South Campus loop distribution. There are select buildings that are fed with direct utility services from National Grid.

The South Campus is fed from a single National Grid 13.2KV circuit. This circuit serves a 3000/3750KVA, ONAN, 13.2KV: 4160V pad mounted transformer. There are (3) three buildings that are not fed off of the North Campus loop distribution, but rather fed with direct utility services from National Grid. The existing 3000/3750KVA transformer was sized to accommodate the load of these buildings in the future.

On the East Campus, each individual building is fed with an individual National Grid secondary service and there is no centralized electrical distribution infrastructure.

Based on this information the campus electrical capacities are as follows (assuming a power factor of 0.85):

Campus	Electrical Capacity	Peak Demand (Actual)	Peak Demand (All Buildings)
North	2.6 MW (main)	2.3 MW	3.3 MW
South	3.2 MW (main)	1.3 MW	1.5 MW
East	N/A (Decentralized)	N/A (Decentralized)	1 MW

Based on this information, there is not enough spare capacity to add Saab Emerging Technologies & Innovation Center and Pulichino Tong Business Center are tied to the North Campus electrical distribution. It is not anticipated these or any other buildings will be tied in at this time.

Depending on where equipment upgrades are occurring on campus, there could be downstream electrical infrastructure limitations at the building transformer and distribution feeder level. Projects that include the installation of all electric mechanical and plumbing systems in lieu of gas fired equipment, and large installations of electric vehicle-charging stations will likely need upgrades at individual buildings.

There are multiple on-going efforts on campus to increase the electrical resiliency of the electrical distribution system. On the North and South Campuses, the existing distribution network has been upgrade to consist of a loop primary system. This allow for isolating an individual building or cable segment in the event of a failure without affecting other buildings.

Efforts have been made to replace aging medium voltage cable and conduit infrastructure as areas of the campus are upgraded. In many cases, the new medium voltage cable has been rated for 15KV to provide better insulation, and allow for the future transition to campus electrical distribution at 13.2KV.

The existing North and South Campuses are each fed with an individual utility circuit. One potential resiliency measure is to provide a second utility circuit to each campus, fed from a different utility substation, and configure the incoming service in a main-tie-main configuration, with the tie breaker normally open. Should a utility outage occur on one of the incoming lines, the associated primary main breaker is opened and the tie breaker is closed (either manually or through an automatic means), and the campus then operates a single incoming line.

Steam Reliability Assessment

The campus is currently sub-divided into three campuses, North Campus, South Campus, and East Campus. North Campus and South Campus each are served by central plants that include gas fired boilers creating low pressure steam for heating. East campus is not served by a centralized system and relies on building specific systems to deliver heating and, in some instances, cooling. The proposed alternative heating options deviate from the reliance on fossil fuels and transition to electrification options.

Hourly gas consumption data for the North Campus and South Campus was provided by UML via Hatch Data. In 2019, the peak hourly gas consumption is approximately 1,045 boiler HP and 806 boiler HP for North Campus and South Campus, respectively. The plant capacity for the North Campus is approximately 2,200 boiler HP, and 1,400 boiler HP for the South Campus.

North Campus central plant consists of two main boilers which were replaced in 2015, and a third smaller boiler that is near the end of its useful life (expected replacement would be 1-3 years). An underground fuel oil tank on the North Campus will also need replaced within 1-3 years. The South Campus plant consists of three main boilers, all of which were replaced in 2015. Campus steam distribution piping for both North and South campuses are at the end of their life cycle and will need repaired or replaced.

Currently the North Campus peak steam demand is using 47% of the total plant capacity and the South Campus peak steam demand is using 57% of the total plant capacity. The capacity of the two main boilers on the North Campus can handle the full load of the campus, therefore the third, smaller boiler is not needed to be replaced at the end of its term. Additional buildings can utilize the North and South Campus plants without increasing current capacity in the short term as the campus moves towards electrification. Because the central plants are under-utilized currently (based on loads), they present a reliable source for heating as it relates to the equipment. Provided the current loads are not increased drastically in either campus, loss of a single boiler would not necessarily reflect a major campus wide shutdown.

The aging steam distribution system on both the North Campus and South Campus will need extensive maintenance and repair in the coming years if the system is to be kept in place. While the steam boilers currently operating were installed in 2015 and have an expected life of approximately 30 Years, it is the distribution piping that will require replacement. The steam tunnels and concrete trench systems are already in need of replacement within the coming 2-3 years, as well as the preinsulated steam piping. A failure or rupture in a steam distribution pipe will disrupt the large portions of the campus and potentially leaving many buildings unoccupiable in the heating season. Typically, these piping failures are not easy or quickly remedied, presenting a substantial risk to the university should this occur.

Ultimately, the age and required upgrades to the steam distribution systems on campus present further incentive to pursue and invest in electrification strategies campus wide and eliminate the use of fossil fuels.

Current and Future Electricity Rates

BR+A utilized data sets from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) in order to forecast energy costs. The EIA data set that most closely resembles UML's climate and operations is the New England Commercial building sector. Based on this data set, electricity rates are expected to slow +0.30%. This is primarily driven by an expected increase in renewable energy assets. Natural gas is expected to increase +0.50% (not including inflation). This is primarily driven by an expected retirement of nuclear and coal assets thereby focusing electricity generation on natural gas as well as electrification.

UML contracts with energy suppliers for multi-year, fixed rate contracts. The current electricity contract is with Constellation NewEnergy and is in effect until December 1, 2023. The rate is $0.08230/kWh. The current gas contract is with Direct Energy and is in effect until December 1, 2022. The rate is $2.53/Dth. Delivery and other associated costs were compiled from National Grid's publicly available rates. A G-3 and G-43 rate class was used as the basis of this analysis given that is the rate class for UML's larger accounts/accounts for a larger percentage of UML's energy consumption. Below are lists of these assumptions.

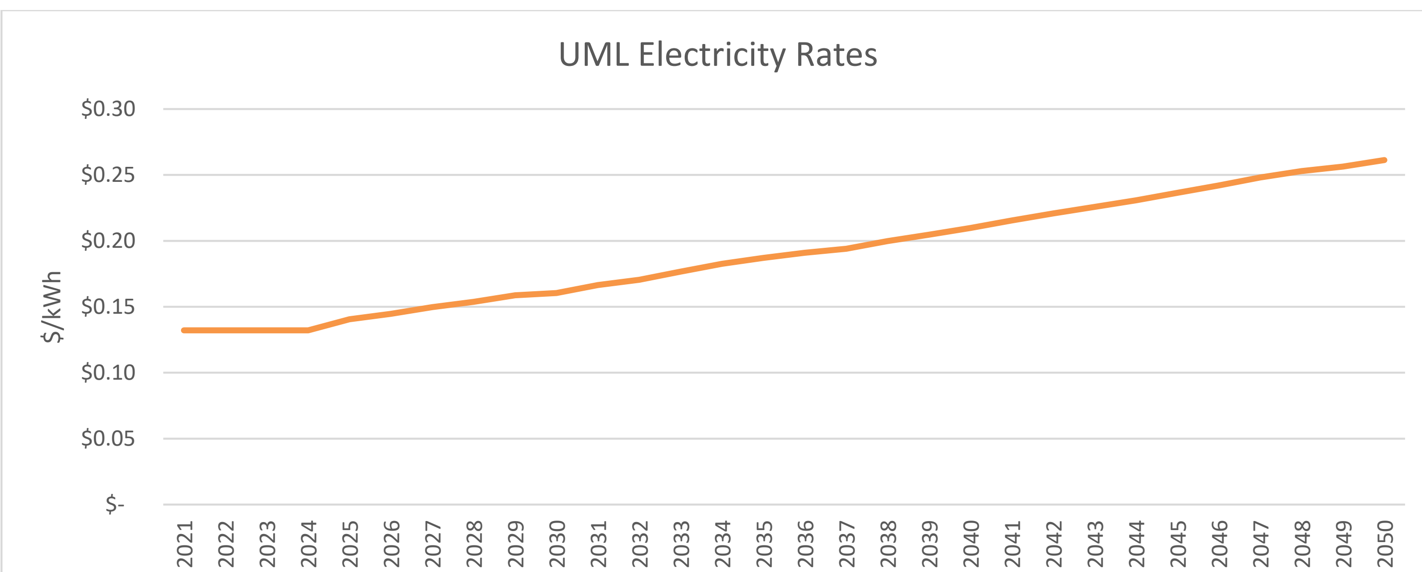
Electricity Rate Assumptions

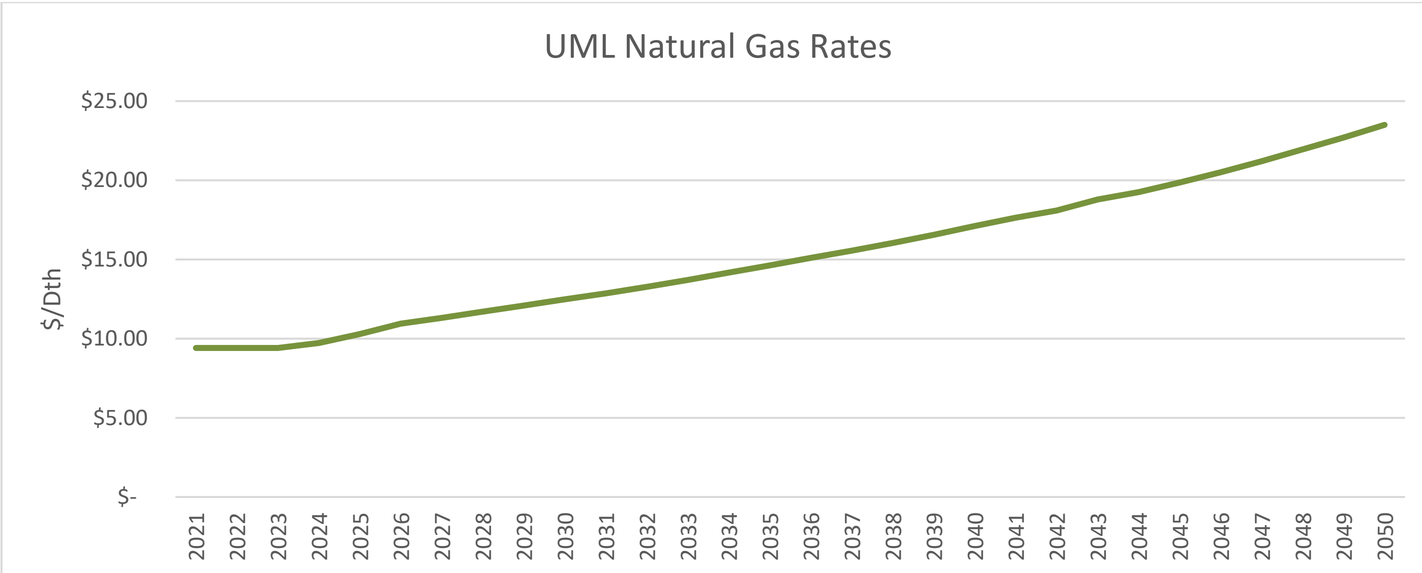
Charge	Rate ($/kWh)
Supply Charge	0.08230
Distribution Charge (Peak Hours)	0.01357
Transmission Charge	0.02714
Transition Energy Charge	-0.00104
Energy Efficiency Charge	0.00967
Renewables Charge	0.00050

Natural Gas Rate Assumptions

Charge	Rate ($/Dth)
Supply Charge	2.530
Gas Adjustment Factor (Peak Hours)	5.826
Local Distribution Adjustment Factor	1.007

Inflation is expected to be the primary driver of UML electricity and natural gas rates given the smaller impact of renewable energy and retiring assets. Therefore, the average year-over-year change in electricity rates is 3% with a 2050 estimated rate of $0.26/kWh. The average year-over-year change in gas rates is 4% with a 2050 estimated rate of $23.50/Dth. Below outlines how the 30-year electricity and natural gas rate rates are estimated to change over the next 30 years.

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Alternative Case

Energy Efficiency Measure Descriptions

Energy efficiency is the first step in working towards UML's carbon neutral goal. ECMs, with the intent to reduce energy and move away from fossil fuels, have been identified through ASHRAE Level 1 audits. Along with reducing energy, ECMs also look to minimize building loads allowing building and campus plants and other mechanical systems to be right-sized and project equipment to be lower cost. A reduction in building load, especially on the heating side, also makes going all-electric even easier as smaller or less equipment means less mechanical space is required. Applying ECMs and transitioning towards building electrification reduces dependency on fossil fuels and moves reliance to the ever greener Massachusetts electric grid ultimately resulting in significant reductions of overall campus energy cost, energy consumption and greenhouse gas emissions.

ECM 1a - Wall Insulation - R-10 continuous insulation

Improve overall exterior wall R-value by R-10.

Measure description

There are two approaches for implementing this measure. The first strategy, over-cladding allows the work to occur while the building is in use, but does not preserve historic character. Over-cladding can be applied to any type of existing facade.

Any over-cladding approach will share common elements:

1. Wall preparation: Depending on the over-cladding system, the required preparation will vary. The labor costs of preparation should be factored into pricing comparisons between systems.
2. Air sealing with a spray on fluid applied air barrier, the permeability of which should be determined for optimal hygrothermal performance of the wall by an approved envelope consultant.
3. Exterior insulation: This can be in the form of a commercially available panelized system, however those tend to be more expensive. A panel system designed for the project that is fabricated offsite may be the most cost-effective in terms of materials and labor and will shorten construction duration. Lastly a site-built approach could also be taken which would entail more challenging quality assurance, higher labor costs and longer construction duration. Exterior insulation used could be moisture resistant wood fiber board as shown in this example (lowest embodied carbon), mineral wool, or even a foam based EIFS type system (highest embodied carbon).
4. Thermally broken clips with girts or rails – There are many different products available each with different thermal performance, structural properties, horizontal or vertical orientation, and range of available depth to accommodate varying insulation thicknesses
5. Lastly cladding – This should be lightweight to minimize the need for additional structural engineering and materials.
6. Optionally, if needed or desired, an interior wall can be furred out which can be insulated or not. Interior insulation options should be analyzed for hygrothermal performance to ensure long-term durability of the final assembly.

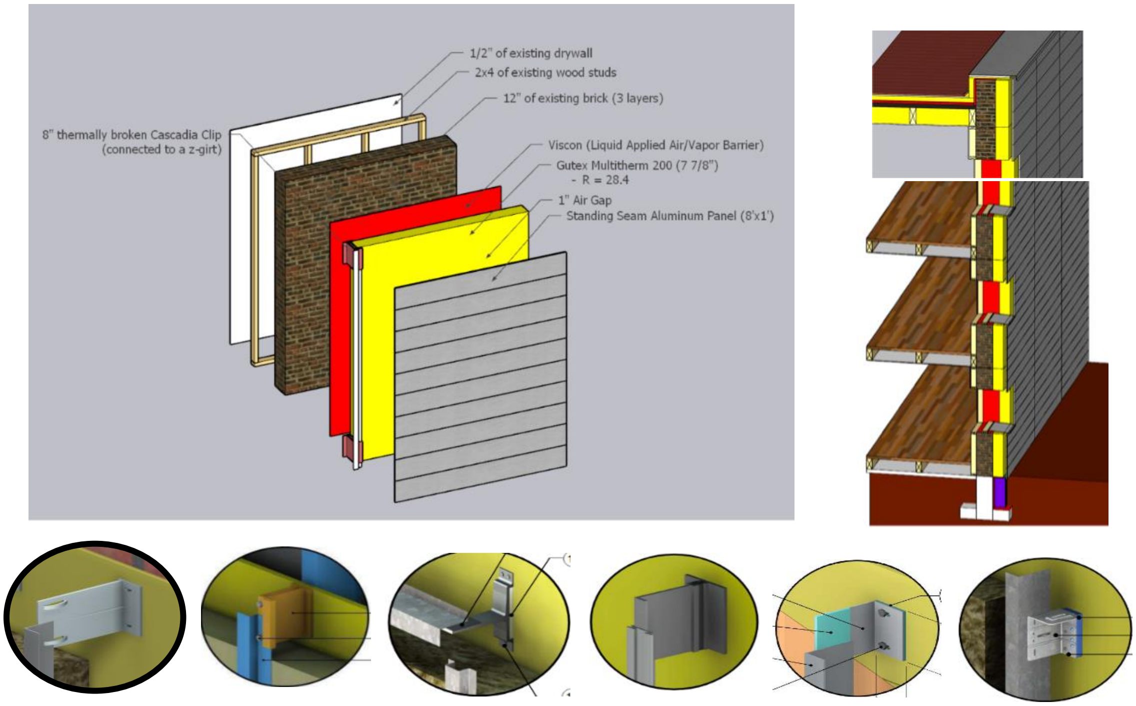


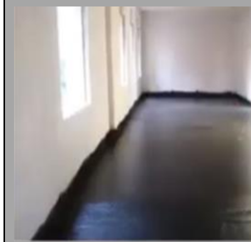
Figure ##: Over-cladding example with thermally broken clip system options

The alternative approach of insulating on the interior is appropriate for historic buildings where the original façade must be preserved.

The key here is to protect the existing masonry from water intrusion, while creating and insulated assembly that allows drying to the interior and the exterior on order to prevent moisture buildup in the brick which will now be colder in winter due to being cut off from interior heat by a layer of insulation, and prevent brick spalling, where trapped moisture inside the brick freezes, expanding and breaking off pieces.

The best strategy for insulating from the interior is shown below. Exterior treatment, air barrier and insulation options should be analyzed for hygrothermal performance to ensure long-term durability of the final assembly.

	Prep the exterior concrete, stucco, stone or masonry wall and treat with silane or siloxane sealer. These sealers penetrate deep into the surface of the existing finish materials where they chemically react to form a hydrophobic barrier of cross-linked silicone resinous membranes within the pores, while remaining vapor permeable. Siloxane improves the ability of masonry to resist cracking, spalling, staining and other damage related to water intrusion. If the existing wall has been properly prepared these coatings can last for five to ten years.

 	Air seal the interior with a permeable air barrier. Gypsum plaster works quite well combined with tapes and airtight paint, but other fluid applied vapor permeable air barriers will also do the job nicely. Air sealing must be done on both walls and the intersections of the intermediate floors to the exterior wall, across the ceiling and slab, at all rough openings and on all service penetrations.
 	Windows can stay flush with exterior and be supported internally as we see above by a wood fiber/polyurethane board. This means the IGU is optimally aligned with the insulation layer in section view. The rough opening is treated with a permeable air barrier flashing, window positioned with nonconductive plastic shims, the shim gap filled with vapor open fibrous insulation, then the window is sealed with airtight to pre-primed gypsum prior to being fixed with steel brackets to inside face of wall.
	In the interior, a steel stud wall is furred out, but offset from the exterior brick wall by at least an inch to allow for fibrous vapor permeable insulation to fill the space between the steel stud and the masonry. The cavity is filled with insulation, then finished off with gypsum wallboard. Since the air barrier is outboard of the steel stud layers, electrical boxes do not need to be air sealed.

In some instances, this approach may improve the overall appearance of the building or eliminate the need for existing façade maintenance. It must be noted that this measure will need further study by an approved envelope consultant to confirm appropriate application of the over-cladding system to prevent moisture issues. Prior to making any changes it will be required to investigate the presence of any toxic materials in the existing façade such as asbestos or PCBs and remediate as necessary.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Age and building type are primary drivers for recommending this measure. Older buildings are typically constructed with insulation only between framing members resulting in thermal bridging and reduced insulation performance or with no insulation at all.

ECM 1b - Wall Insulation - R-30 continuous insulation

Improve overall exterior wall R-value by R-30.

Measure description

See ECM 1a. It must be noted that this measure will need further study by an approved envelope consultant to confirm appropriate application of the over-cladding system to prevent moisture issues. Prior to making any changes it will be required to investigate the presence of any toxic materials in the existing façade such as asbestos or PCBs and remediate as necessary.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Age and building type are primary drivers for recommending this measure. Older buildings are typically constructed with insulation only between framing members resulting in thermal bridging and reduced insulation performance or with no insulation at all.

ECM 2a - Roof Insulation - R-30 continuous insulation

Install additional insulation to improve overall roof R-value by R-30.

Measure description

Add insulation to the roof surface to improve thermal performance. The intent is to increase the existing roof insulation by adding continuous rigid roof insulation to achieve an overall R-value improvement. This measure requires the replacement of the weatherproof roofing membrane. To prevent thermal bridging and maintain anticipated thermal performance it is recommended to avoid mechanical fasteners and instead fully adhere the insulation and roof membrane.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Age, building type, existing roof insulation and condition. Older buildings that have not had a roof replacement are ideal candidates for a new roof with increased insulation levels.

ECM 2b - Roof Insulation - R-50 continuous insulation

Install additional insulation to improve overall roof R-value by R-50.

Measure description

Add insulation to the roof surface to improve thermal performance. The intent is to increase the existing roof insulation by adding continuous rigid roof insulation to achieve an overall R-value improvement. This measure requires the replacement of the weatherproof roofing membrane. To prevent thermal bridging and maintain anticipated thermal performance it is recommended to avoid mechanical fasteners and instead fully adhere the insulation and roof membrane.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Age, building type, existing roof insulation and condition. Older buildings that have not had a roof replacement are ideal candidates for a new roof with increased insulation levels.

ECM 3a - Glazing U-value/SHGC - Double-pane, U-0.30/ SGHC 0.25

Replace existing window assemblies with new utilizing double pane glass achieving an assembly U-value of U-0.30 with thermally-broken metal framing. The window assembly shall aim for a Solar Heat Gain Coefficient value of SHGC-0.25.

Measure description

Replace existing windows with new double pane glazing and thermally-broken metal framing to improve thermal performance by increasing overall thermal resistance. The intent is to remove existing window assemblies and replace with new efficient double-glazed units. Buildings with single pane glazing or older double pane systems have reduced thermal performance and higher solar gain. Replacing them with new high performance assemblies reduces heating and cooling loads. Prior to making any changes it will be required to investigate the presence of any toxic materials in the existing window assemblies such as asbestos or PCBs and remediate as necessary.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Based on building type, age and existing window assembly type/ condition.

ECM 3b - Glazing U-value/SHGC - Triple-pane, U-0.20/SGHC 0.25

Replace existing window assemblies with new utilizing triple pane glass achieving an assembly U-value of U-0.20 with thermally-broken metal framing. The window assembly shall aim for a Solar Heat Gain Coefficient value of SHGC-0.25.

Measure description

Replace existing windows with new triple pane glazing and thermally-broken metal framing to improve thermal performance by increasing overall thermal resistance. The intent is to remove existing window assemblies and replace with new efficient triple-glazed units. Buildings with single pane glazing or older double pane systems have reduced thermal performance and higher solar gain. Replacing them with new high performance assemblies reduces heating and cooling loads. Prior to making any changes it will be required to investigate the presence of any toxic materials in the existing window assemblies such as asbestos or PCBs and remediate as necessary.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Based on building type, age and existing window assembly type/ condition.

ECM 4a - Infiltration - 0.25 cfm/sf

Perform building analysis to identify points of infiltration through the building envelope and repair issues such that infiltration rates do not exceed 0.25 cfm/ sf of envelope area at 0.3 inches w.c. (75 Pa).

Measure description

Reduce existing amounts of air leakage through building envelope by remediating cracks, leaks and other means of unintended ambient air infiltration. The intent is to test the building for air leakage and to seal or repair problems. This requires a blower door test which lowers the inside pressure using temporary fans that pull air out of the building. This process identifies areas of the building that are not sufficiently sealed and require repair. After repair the blower door test can be re-performed to ensure the infiltration criteria set forth has been achieved.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Based on building type, age and existing façade condition.

ECM 4b - Infiltration - 0.10 cfm/sf

Perform building analysis to identify points of infiltration through the building envelope and repair issues such that infiltration rates do not exceed 0.10 cfm/ sf of envelope area at 0.3 inches w.c. (75 Pa).

Measure description

Reduce existing amounts of air leakage through building envelope by remediating cracks, leaks and other means of unintended ambient air infiltration. The intent is to test the building for air leakage and to seal or repair problems. This requires a blower door test which lowers the inside pressure using temporary fans that pull air out of the building. This process identifies areas of the building that are not sufficiently sealed and require repair. After repair the blower door test can be re-performed to ensure the infiltration criteria set forth has been achieved.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, reduced peak heating and cooling and improved overall occupant comfort.

Why is this measure being recommended for this building

Based on building type, age and existing façade condition.

ECM 5a - Air-side Systems - Decoupled systems (low)

Reconfigure or replace existing air handling units such ventilation air is conditioned separately from other building loads.

Measure description

Configure building air handling units such that ventilation load is decoupled from other building loads. Generally speaking a central 100% outdoor air unit with energy recovery shall be sized to only meet ventilation requirements while localized terminal units (fan coils) meet all other heating and cooling loads. The intent is to modify or replace existing air handling units such that they include energy recovery and provide 100% outdoor air for ventilation only and be tied to zonal 4-pipe fan coil units.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, and reduced peak heating and cooling by reducing the amount of outdoor air.

Why is this measure being recommended for this building

Based on building type (residential/office-classroom), age and existing air handling configuration.

ECM 5b - Air-side Systems - Decoupled systems (high)

Reconfigure or replace existing air handling units such ventilation air is conditioned separately from other building loads.

Measure description

Configure building air handling units such that ventilation load is decoupled from other building loads. Generally speaking a central 100% outdoor air unit with energy recovery shall be sized to only meet ventilation and lab make-up air requirements while localized terminal units (fan coils) meet all other heating and cooling loads. The intent is to modify or replace existing air handling units such that they include energy recovery and provide 100% outdoor air for ventilation only and be tied to zonal 4-pipe fan coil units.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption, and reduced peak heating and cooling by reducing the amount of outdoor air.

Why is this measure being recommended for this building

Based on building type (lab), age and existing air handling configuration.

ECM 5c - Air-side Systems - Constant to variable volume (low)

Reconfigure or replace existing air handling units to operate as variable volume. This measure focuses on buildings with lower airflow capacity (low cfm/ ft^2).

Measure description

Upgrade or replace constant volume existing air-handling units with a variable volume air distribution system. This involves providing variable volume airflow via variable frequency drive control and variable flow terminal units. The intent is to upgrade the air distribution system such that it can modulate airflow to meet varying building loads. Reducing air-flow results in lower fan use and less reheating, along with decreased cooling and pump use.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption.

Why is this measure being recommended for this building

Based on building type (non-lab) and existing air handling configuration.

ECM 5d - Air-side Systems - Constant to variable volume (high)

Reconfigure or replace existing air handling units such that they can operate as variable volume. This measure focuses on buildings with higher airflow capacity (high cfm/ ft^2).

Measure description

Upgrade or replace constant volume existing air-handling units with a variable volume air distribution system. This involves providing variable volume airflow via variable frequency drive control and variable flow terminal units. The intent is to upgrade the air distribution system such that it can modulate airflow to meet varying building loads. Reducing air-flow results in lower fan use and less reheating, along with decreased cooling and pump use.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption.

Why is this measure being recommended for this building

Based on building type (lab) and existing air handling configuration.

ECM 5e - Air-side Systems - Airflow setbacks

Provide controls to reduce unoccupied minimum airflows.

Measure description

Provide controls that allow room airflow minimums to reset lower when a space is unoccupied. The intent is to reduce unnecessary airflow in spaces when loads are satisfied and the space is unoccupied. When a space is occupied there is a minimum airflow required to meet ventilation and comfort requirements. When a space is unoccupied as indicated via an occupancy sensor there is no longer a need to meet these requirements. The room will go into an 'unoccupied' setting allowing the airflow minimum to reset to a lower value as long as the loads are satisfied. This is recommended for spaces that are non-critical in nature such as offices, classrooms and conference rooms. This measure also falls under ECMs 10a & 10c but is intended as a standalone measure.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption.

Why is this measure being recommended for this building

Based on building type, space type, and existing controls.

ECM 5f - Air-side Systems - Air quality (Aircuity, particle counters)

Provide controls to reduce unoccupied minimum airflows.

Measure description

Provide controls that allow space airflow design minimums to reset lower when conditions meet air quality monitoring (lab) or particle counter monitoring (cleanroom) setpoints. The intent is to reduce unnecessary airflow in spaces when loads are satisfied and the space meets minimum air quality or particle count set-points. This is recommended for chemical laboratory or cleanroom type spaces.

What metrics are improving

By implementing this measure the building will experience lower heating, cooling, fan and pump energy consumption due to reduced outdoor air and fan operation.

Why is this measure being recommended for this building

Based on building type, space type, age and existing air handlers this approach is recommended.

ECM 6a - Air-side Energy Recovery - 70% (Single Wheel Recovery)

Improve or provide means of recovering energy from building exhaust with a minimum recovery effectiveness of 70%.

Measure description

Install or upgrade to a total enthalpy energy recovery wheel. The intent is to increase the amount of energy recovered from the exhaust air stream to in turn reduce the amount of heating and cooling required. This is recommended only for non-lab type spaces. Enthalpy energy recovery wheels use rotating desiccant wheels to transfer sensible and latent energy from the exhaust air stream to the supply air stream.

What metrics are improving

By implementing this measure the building will experience reduced heating and cooling loads due to the recovery of energy that would otherwise be wasted through the exhaust.

Why is this measure being recommended for this building

Based on building type and space type this approach is recommended.

ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)

Improve or provide means of recovering energy from building exhaust with a minimum recovery effectiveness of 90%.

Measure description

Install or upgrade to an exhaust heat regen system. This system is similar in technology to heat wheel heat recovery using desiccant media but instead uses two alternating cores in lieu of a wheel. This advancement allows one core to recovery exhaust heat while the second preheats the outdoor air. When the second core can no longer preheat, the cores switch. This increases effectiveness of the system by preventing frost on the heat recovery media and eliminating the frost cycle heating that would otherwise be required.

The intent is to increase the amount of energy recovered from the exhaust air stream to in turn reduce the amount of heating and cooling required. This is recommended only for non-lab type spaces.

What metrics are improving

By implementing this measure the building will experience reduced heating and cooling loads due to the recovery of energy that would otherwise be wasted through the exhaust.

Why is this measure being recommended for this building

Based on building type and space type this approach is recommended.

ECM 6c - Air-side Energy Recovery - 50% (Runaround Coil)

Improve or provide means of recovering energy from building exhaust with a minimum recovery effectiveness of 50%.

Measure description

Install or upgrade to a conventional glycol runaround heat recovery system. The intent is to increase the amount of energy recovered from the exhaust air stream to in turn reduce the amount of heating and cooling required. Glycol runaround heat recovery uses a closed loop system with hydronic coils located in the exhaust and supply airstreams. Pumps move the glycol between the coils to transfer sensible heat between the exhaust and supply as needed. This is recommended only for laboratory type spaces where supply and exhaust air streams cannot be mixed.

What metrics are improving

By implementing this measure the building will experience reduced heating and cooling loads due to the recovery of energy that would otherwise be wasted through the exhaust.

Why is this measure being recommended for this building

Based on building type and space type this approach is recommended.

ECM 6d - Air-side Energy Recovery - 70% (DOAS Konvekta + Heat Pump)

Improve or provide means of recovering energy from building exhaust with a minimum recovery effectiveness of 70%.

Measure description

Install or upgrade to a high performance glycol runaround heat recovery system in combination with exhaust source heat-pump chiller. The intent is to increase the amount of energy recovered from the exhaust air to in-turn reduce the amount of heating and cooling required. This technology combines high performance runaround heat recovery coils with an air-source heat pump chiller to maximize system heat recovery effectiveness. Konvekta heat recovery uses specially designed coils along with advance control algorithms to maximize heat transfer between the supply and exhaust airstreams. The heat pump is designed such that it can remove more heat from or reject more heat to the building exhaust air stream and transfer it to where it can pretreat outdoor air more efficiently than the heat recovery coils alone. This is recommended only for laboratory type spaces where supply and exhaust air streams cannot be mixed.

What metrics are improving

By implementing this measure the building will experience lower heating and cooling energy.

Why is this measure being recommended for this building

Based on building type and space type this approach is recommended.

ECM 7a - Water-side Systems - Standalone VRF

Increase cooling energy efficiency by installing advanced VRF systems to provide cooling in lieu of a traditional cooling system.

Measure description

Install or upgrade to efficient Variable Refrigerant Flow (VRF) systems for comfort cooling. The intent is to provide cooling in spaces where the ventilation can be decoupled from cooling loads such as in office and classroom type space. VRF differs from other types of cooling in that it moves refrigerant throughout the building to indoor units located directly in the conditioned space. As the space loads change, VRF has the ability to modulate the refrigerant flow to each indoor unit so that it only consumes enough energy to meet the load. There is also an option that allows for heat recovery for buildings that regularly have simultaneous heating and cooling further enhancing efficiency.

What metrics are improving

By implementing this measure the building will benefit from reduced cooling energy when compared to most alternatives.

Why is this measure being recommended for this building

Based on building type, space type and ease of retrofit this approach is recommended.

ECM 7b - Water-side Systems - Standalone AWHP

Add Air to Water Heat Pump (AWHP) heating system to increase heating efficiency over other electric heating alternatives.

Measure description

Install or upgrade to efficient heat pump heating. The intent is to provide heating using air to water heat pumps in lieu of using electric boilers or electric resistance. AWHP technology uses the refrigerant cycle to remove heat from the ambient air and transfer it to the hot water loop similar in place of a boiler. This process is significantly more energy efficient than using standard electric resistance heating. It also eliminates site carbon emissions in comparison to natural gas heating.

What metrics are improving

By implementing this measure the building will benefit from reduced heating energy when compared to other electric heating alternatives.

Why is this measure being recommended for this building

Based on building type, existing heating source and available outdoor space to locate the AWHP units.

ECM 7c - Water-side Systems - Pump VFDs

Increase pumping energy efficiency by installing variable speed drives on pumps.

Measure description

Install variable speed drives on pumps that currently operate at constant volume to allow pumps to modulate flow based on load. Differential pressure sensors shall also be installed to monitor the pressure across the loop supply and return. Additionally, all 3-way valves on the system shall be converted to 2-way.

What metrics are improving

By implementing this measure the building will benefit from reduced pumping energy.

Why is this measure being recommended for this building

Based on building current pump control, operation and motor horsepower.

ECM 8a - Lighting - LED Conversion

Increase lighting efficiency and appearance by replacing existing inefficient lighting with new LED fixtures.

Measure description

Upgrade all existing lighting to LED lighting fixtures. The intent is to convert any interior lighting fixtures to energy efficient LED where they have not been already. LED lighting is more efficient and has a longer life reducing the need for replacement.

What metrics are improving

By implementing this measure the building will benefit from reduced lighting and cooling energy.

Why is this measure being recommended for this building

Based on existing lighting fixtures.

ECM 8b - Lighting - Occupancy Sensors

Install occupancy sensors to turn off lighting when spaces have been unoccupied after a period of time.

Measure description

Install lighting occupancy sensors. The intent is to add occupancy sensors where not currently installed to control lighting in areas not required to be lit 24 hour a day. These lighting controls automatically turn lighting on when occupancy is detected and turn off lighting after a set time when no longer occupied.

What metrics are improving

By implementing this measure the building will benefit from reduced lighting and cooling energy.

Why is this measure being recommended for this building

Based on existing lighting controls.

ECM 8c - Lighting - Daylight Sensors

Install photocell sensors to limit amount of artificial lighting based on the availability of natural lighting from exterior windows.

Measure description

Install daylighting sensors. The intent is to add daylighting sensors to modulate lighting based on available natural light. Photocells are installed to sense space lighting levels, as natural light through windows and skylights varies the artificial lighting is adjusted to maintain desired lighting levels. This is recommended in spaces where non-critical activities occur.

What metrics are improving

By implementing this measure the building will benefit from reduced lighting and cooling energy.

Why is this measure being recommended for this building

Based on existing lighting controls.

ECM 9a - Plumbing - Low Flow Fixtures

Install new low-flow lavatory, kitchenette sink and shower head units to reduce domestic water consumption and hot water heater energy.

Measure description

Replace existing domestic water fixtures with low-flow units. The intent is to reduce water consumption by using low-flow fixtures. It is suggested that existing fixtures in lavatory sinks, showerheads and kitchenette sinks be examined for rated flow and new low-flow units be installed where appropriate.

What metrics are improving

By implementing this measure the building will benefit from reduced domestic water consumption and reduced hot water heater energy.

Why is this measure being recommended for this building

Based on existing domestic water fixtures, this building offers a good opportunity to reduce water consumption.

ECM 9b - Plumbing - Instantaneous Water Heater

Install new instantaneous domestic hot water heaters in place of existing hot water heaters.

Measure description

Replace existing domestic hot water heater with instantaneous hot water heater. The intent is to eliminate energy consumption during stand-by periods associated with storage tank type hot water heaters. Instantaneous hot water heaters make hot water only when it is called for, otherwise these units do not consume any energy.

What metrics are improving

By implementing this measure the building will benefit from a reduction in hot water heating energy.

Why is this measure being recommended for this building

Based on existing domestic water heater configuration, there is a good opportunity to reduce energy associated with heating domestic hot water.

ECM 9c - Plumbing - Electric Water Heater

Install new electric domestic hot water heaters in place of existing steam fired hot water heaters.

Measure description

Replace existing domestic steam fired hot water heaters with electric hot water heaters. The intent is to reduce emissions associated with using fossil fuels to generate domestic hot water.

What metrics are improving

By implementing this measure the building will benefit from a reduction in fossil fuel emissions.

Why is this measure being recommended for this building

Based on existing domestic water heater configuration, this building offers a good opportunity to reduce fossil fuel emissions associated with heating domestic hot water, this approach is recommended.

ECM 9d - Plumbing - Electric Water Heater with Storage

Install new electric domestic hot water heaters in place of existing hot water heaters.

Measure description

Replace existing domestic hot water heater with electric hot water heater with storage. The intent is to reduce emissions associated with using fossil fuels to generate domestic hot water.

What metrics are improving

By implementing this measure the building will benefit from a reduction in fossil fuel emissions.

Why is this measure being recommended for this building

Based on existing domestic water heater configuration, this building offers a good opportunity to reduce fossil fuel emissions associated with heating domestic hot water, this approach is recommended.

ECM 9e - Plumbing - ASHP Water Heater with Storage

Install new electric ASHP domestic hot water heaters with storage in place of existing electric hot water heaters with storage.

Measure description

Replace existing electric domestic hot water heater with electric Air Source Heat Pump (ASHP) hot water heater with storage. The intent is to reduce electric energy consumption associated with generating domestic hot water. ASHP technology uses the refrigerant cycle to remove heat from the surrounding air and transfer it to the domestic water to raise its temperature. This process is significantly more energy efficient than using a standard electric resistance domestic water heater.

What metrics are improving

By implementing this measure the building will benefit from a reduction hot water heating electric energy.

Why is this measure being recommended for this building

Based on existing domestic water heater configuration, this building offers a good opportunity to reduce energy associated with heating domestic hot water.

ECM 10a - Controls – DDC

Install new DDC controls to maximize automated building control.

Measure description

Install Direct Digital Controls (DDC) to allow for greater controllability of building systems and eliminate the need for manual control. The intent is to reduce energy consumption by monitoring HVAC and other building components and automatically controlling them as required to satisfy building set points. There are many control sequences that can be implemented through the installation of DDC controls, a partial list follows:

- Space temperature scheduling and automatic unoccupied temperature set-back.
- Unoccupied space airflow set-back.
- Air handler:
    - Static pressure reset.
    - Supply air temperature reset.
    - Outdoor air economizer.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Based on existing building having limited to no automated building controllability.

ECM 10b - Controls - Retrocomissioning

Perform retro-commissioning to ensure building is operating as originally designed.

Measure description

Perform Retro-commissioning to improve building performance such that the building operates as originally designed. The intent is to reduce energy consumption by reviewing the original design documents and ensuring the building is operating as intended. Over time building operations can be overridden or adjusted from the original design intent causing excessive energy consumption. The Retro-commissioning procedure will evaluate current building operation to define where it deviates from the original design and restore it. This may also expose issues the building was experiencing requiring the deviations.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Due to the age, energy consumption and apparent operation of the building this measure is recommend for implementation.

ECM 10c - Controls - DDC Sequence Upgrades

New DDC control sequences to maximize automated building control.

Measure description

Provide new sequence of operations for various control points such as temperature setbacks and resets, air-side economizer, water-side economizer and static pressure reset. The intent is to reduce energy consumption by enhancing automated controllability of various building components.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Based on existing building having limited to no automated building control, this approach is recommended.

ECM 11a - Process Loads - Behavior Change

Educate building users on ways to reduce their energy usage.

Measure description

Apply simple behavioral changes to reduce energy without requiring modification to the building or controls. The intent is to promote energy awareness and encourage building users to be conscientious about their energy consumption. This can be accomplished by providing signage around equipment regularly left on (shut the sash, turn off lights/monitors/ lab equipment), requiring occupants to set back thermostat and close windows when leaving for extended periods, having IT support program computers to enter sleep mode automatically and by hosting competitions against others to reduce energy.

What metrics are improving

This approach can reduce heating, cooling, fan, pump, receptacle and lighting energy.

Why is this measure being recommended for this building

Any building can benefit from users practicing smart energy behavior.

ECM 11b - Process Loads - Filtered Fume Hoods

Provide new filtered fume hoods.

Measure description: Provide new filtered fume hoods in lieu of exhausted fume hoods to reduce energy associated with conditioning make-up air. The intent is to reduce energy consumption by reducing the required amount of fume hood exhaust make-up air. Filtered fume hood technology allows for fume hood exhaust to be filtered and safely returned to the lab space rather than being exhausted from the buildng. Traditional exhausted fume hoods exhaust 100% of fume hood from the building which requires conditioned make-up air. Filtered fume hoods have limitations regarding the type of chemicals that can be used within, it is necessary to confirm what chemicals are used in the lab before selecting a filtered hood.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Based on existing building having labs with standard fume hoods or for proposed new fume hoods.

ECM 11c - Process Loads - Low Flow Fume Hoods

Provide new low flow fume hoods.

Measure description

Provide new low-flow fume hoods in lieu of standard flow fume hoods to reduce energy associated with conditioning make-up air. The intent is to reduce energy consumption by reducing the required amount of fume hood exhaust make-up air. Standard flow fume hoods are typically designed to operate with a face velocity of 100 FPM or greater. Low flow fume hoods are designed to operate at 80 FPM or less while safely containing fume hood contents. The face velocity reduction equates to less fume hood exhaust and conditioned make-up air requirements.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Based on existing building having labs with standard fume hoods or for proposed new fume hoods.

ECM 11d - Process Loads - Fume Hood Sash Vacancy Sensors

Provide fume hood sash vacancy sensors.

Measure description

Install fume hood sash vacancy sensors on existing fume hoods to reduce air-flow through the fume hood when hood operator is not present. The intent is to reduce energy consumption by reducing the required amount of fume hood exhaust and make-up air when appropriate. This technology retrofits existing fume hoods with automatically closing sashes to safely reduce fume hood flow when the operator has been away from the front of the hood for a set period of time.

What metrics are improving

By implementing this measure the building will benefit from a reduction in heating, cooling, fan and pump energy.

Why is this measure being recommended for this building

Based on existing building being a lab building with standard flow fume hoods that do not have the ability to automatically reduce the fume hood flow.

ECM 11e - Process Loads - Plug Load Management

Provide controls to reduce plug loads when equipment is not in use.

Measure description

Provide controls which have the ability to turn off non-critical equipment when user is not present. The intent is to reduce energy consumed when receptacle equipment is idle due to occupant inactivity. This measure connects an occupancy sensor with a portion of local receptacles to automatically turn off plugged in equipment when identified as unoccupied. It is important to note that certain equipment such as computers and other components which need a regular power supply not be powered by this system.

What metrics are improving

By implementing this measure the building will benefit from a reduction in receptacle equipment and cooling energy.

Why is this measure being recommended for this building

Based on the existing building having office, conference, breakrooms, classrooms printing/ copying rooms and individual workstations.

ECM 11f - Process Loads - Energy Star Office Equipment

Select Energy Star rated office equipment when purchasing new equipment.

Measure description

When purchasing new office equipment purchase Energy Star rated equipment such as computers, monitors, printers, copiers and appliances. The intent is to reduce receptacle energy consumed during normal operation and when on standby mode. An Energy Star rating means equipment has been independently certified that it meets energy performance in a given product category.

What metrics are improving

By implementing this measure the building will benefit from a reduction in receptacle equipment and cooling energy.

Why is this measure being recommended for this building

Based on the existing building having office, conference, breakrooms, classrooms printing/ copying rooms and individual workstations.

ECM 11g - Process Loads - Energy Star Kitchen Equipment

Select Energy Star rated kitchen equipment when purchasing new equipment.

Measure description

When purchasing new equipment purchase Energy Star rated kitchen equipment such as refrigerators, freezers, dishwashers, griddles and ice makers. The intent is to reduce receptacle energy consumed during normal operation and when on standby mode. An Energy Star rating means equipment has been independently certified that it meets energy performance in a given product category.

What metrics are improving

By implementing this measure the building will benefit from a reduction in receptacle equipment and cooling energy.

Why is this measure being recommended for this building

Based on the existing building having a kitchen or kitchenette.

ECM 12 – Natatorium – High Efficiency Heating and Cooling

Provide new packaged DX air handling unit with condenser heat recovery.

Measure description

Install new air handling unit with packaged DX cooling and condenser heat recovery to serve the Costello pool. The intent of this measure is to provide the natatorium with a new air handling unit which has the capability to control temperature and humidity set-points while recovering waste heat from the condenser. The waste heat is then in turn used to reheat supply air and heat pool water. Outdoor air heat recovery should also be considered when selecting the air-handling unit. A number of manufacturers (Desert Aire, PoolPak, Seresco for example) make units designed specifically for natatorium duties.

What metrics are improving

By implementing this measure the building will experience lower heating consumption due to the recovery and re-use of waste heat.

Why is this measure being recommended for this building

Based on building type, space type, age and existing air handlers this approach is recommended.

Alternative Energy Measures Descriptions

Overview

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 additional off-site renewable energy to offset the remaining energy. 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	-	XXX	✓✓	✓	Fail	Pass
2	Biodiesel boiler	✓	✓	X	X	-	XXX	✓	✓	Fail	Pass
3	Biomass boiler (wood chips)	-	-	✓	X	X	XXX	✓	X	Fail	Fail
4	Electric boiler	✓	✓✓	XXX	XXX	-	XXX	X	✓	Fail	Fail
5	Heat-recovery electric chiller	✓	✓	✓	✓	-	✓✓✓	✓	✓✓	Pass	n/a
6	HP (air-to-water) - large scale	✓	-	X	✓	-	✓✓	X	✓✓✓	Pass	n/a
7	HP (air-to-water) - small scale	✓	-	X	✓	-	✓✓	X	✓✓✓	Pass	n/a
8	GSHP closed loop, horizontal	X	✓✓	✓	-	-	✓✓	X	XXX	Fail	n/a
9	GSHP closed loop, vertical	X	✓✓	✓✓	✓	-	✓✓✓	X	✓	Pass	n/a
10	GSHP open loop	-	XX	✓✓	-	X	✓✓✓	X	✓	Fail	n/a
11	TTES (Tank Thermal Energy Storage)	-	✓✓✓	-	-	-	X	✓	X	Fail	n/a
12	Solar Thermal	X	X	✓	XX	X	✓	-	X	Fail	n/a
13	Photovoltaics	✓	✓✓✓	✓✓✓	✓✓	✓	-	✓	✓	Pass	n/a
14	Battery storage	X	✓✓	✓	✓	X	✓✓	✓✓	✓	Pass	n/a
15	Wind turbine	XX	✓	✓	XX	X	✓	✓	XXX	Fail	n/a

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. 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).

Recommendation
Biodiesel generators (in combination with biodiesel boilers) are offered as a peaking and back-up system for UML consideration. The intent would be to operate the biodiesel generators as a source for back-up power, during periods of electric grid failure. The intent would be to operate the biodiesel boilers as a source of heating for peak winter conditions and as a back-up heating source, during periods of electric grid failure (when the electric heat pump systems would not operate).

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 UMass Lowell.

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).

Recommendation
Biomass boilers are not recommended for UMass Lowell. This is due to the lack of emissions savings and the large area required for a biomass boiler plant.

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.

AEM 5, 6, 7 - Heat-Recovery Electric Chiller and Air-Source Heat Pumps

Heat-recovery electric chillers and air source heat pumps are proven solutions and are recommended as primary systems for UMass Lowell. Therefore, heat recovery electric chillers and air source heat pumps are addressed in detail elsewhere in this report.

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 UMass Lowell. This is a highly efficient and all electric heating and cooling source. 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.

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 UMass Lowell 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.

Recommendation
Thermal energy storage systems should be considered as a component of the alternative energy systems for UMass Lowell. But, they are not a primary element of the systems being considered and therefore should be evaluated in the future, when the system is being fully designed, in preparation for construction.

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 UMass Lowell. 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. Battery systems vary in terms of cost-effectiveness, based on the building demand profile and the SMART incentive program.

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 UMass Lowell. The evaluation of solar PV and batteries is addressed in detail in a separate section of this report.

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 UMass Lowell 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 UMass Lowell. 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 UMass Lowell. These are renewable gas and hydrogen and are outlined below.

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).

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.

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

Recommendation
If UMass Lowell continues to consume natural gas, renewable gas credits may be worth considering, if the 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.

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 UMass Lowell.

Pilot Building Descriptions

Prioritizing the highest energy consumers for projects is the more cost effective strategy to achieving load reductions on campus. These buildings are ideal for pilots. The pilot 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 pilot projects, buildings were ranked across a set of key criteria: energy use intensity, energy change over time, energy use intensity target, combustion emissions, and facility conditions. The data shows that Olney Hall, Ball Hall, and Sheehy Hall are the best buildings to conduct pilot alternative energy projects given that they score highest compared to other buildings of the same core use type. See the “Metering and Data Management Preliminary Report” for more details.

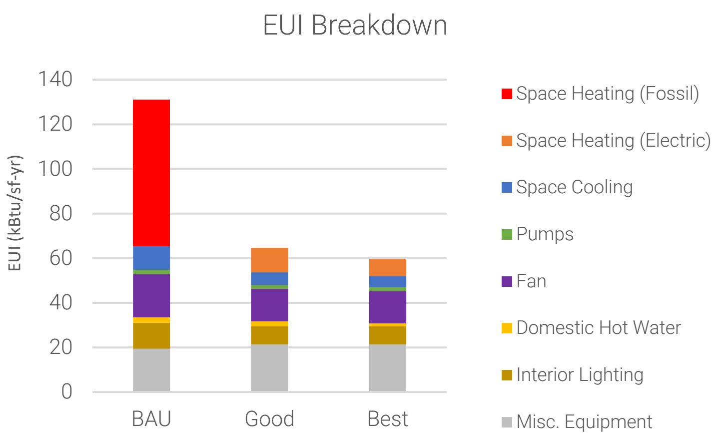
Project profiles and detailed scope descriptions for each pilot building are developed in order to evaluate and quantify energy, emissions, and heating/cooling load impacts. Measures were identified by using the ASHRAE Level I Audit procedure. Two scenarios - “Good” and “Best” – were detailed in order to outline the range of opportunities compared to a Default/Business-As-Usual (“BAU”) Case. The BAU case was defined as the 2019 energy use profiles adjusted for key factor including expanded lab operations, added cooling, and centralized ventilation. Energy end use breakdowns were estimated based building core end use given the lack of campus submetering. Current and future 2050 carbon emissions were quantified using values from the “30-year Forecast Preliminary Report.” Heating and cooling loads were quantified in order to enable evaluation of central vs. decentralized scenarios. Air-side energy recovery and envelope are the key strategies outlined to reduce heating and cooling loads.

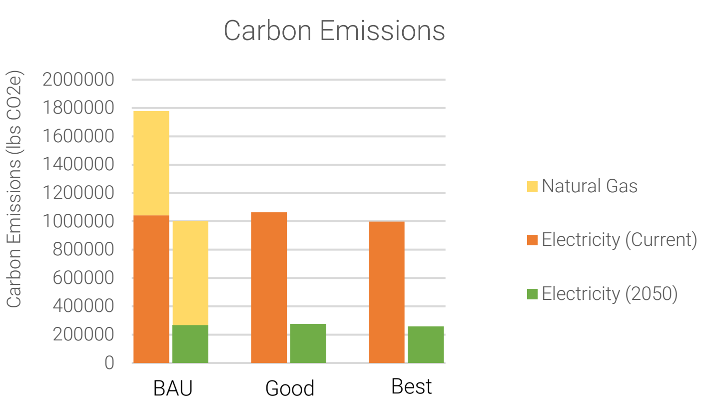
Ball Hall

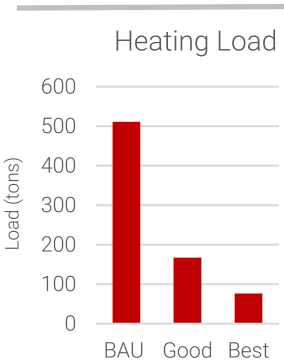
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	92396
Last Major Renovation	1958

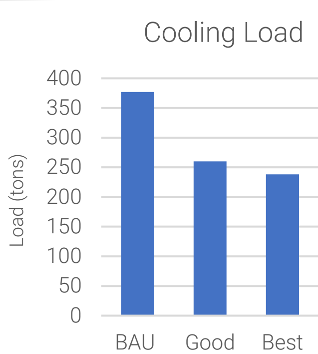
Building Summary

Ball Hall is an office/classroom building with some dry labs on the North Campus. It has the highest building score of any building on campus (73) making it an ideal candidate for energy efficiency upgrades as a pilot project particularly given direct steam systems. The business as usual case assume dry lab and cooling operations will be expanded. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Direct Steam
Air-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

Ball Hall Detailed Options Matrix

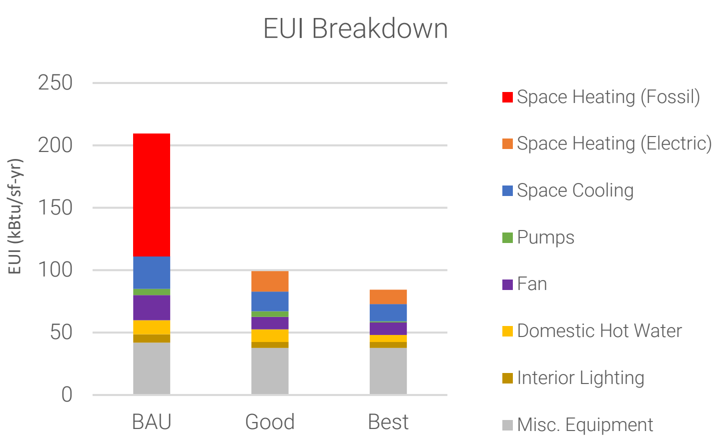
Description	BAU	Good	Best
Target EUI (kBtu/sf-yr)	131	65	60
Architectural			
Wall Performance	Brick (uninsulated exterior) (1950s)	R-10 continuous insulation	R-30 continuous insulation
Roof Performance	Tar/gravel 1" insulation ~R-4	R-30 continuous insulation, white	R-50 continuous insulation, white
Glazing Performance	Single pane window wall Double pane punched	Double glazing curtain walll and punched assembly u-value: 0.3, SHGC: 0.26 Insulate spandrel to wall performance.	Triple glazing curtain walll and punched assembly u-value: 0.20, SHGC: 0.26
HVAC			
Heating/cooling system	Steam-to-hot water (7000 MBH) 60 Ton Air-cooled chiller (new - 3rd and 4th floors only) Window AC Rooftop heat pumps	(6) 30 ton modules air-to-water heat pumps (2) 100 ton air cooled chiller (peak and 50% redundancy) (3) chilled water pumps @ 3 HP (includes 1 on standby) (4) hot water pumps @ 3 HP (includes 2 on standby)	(3) 30 ton air-to-water heat pumps (2) 150 ton air cooled chiller (peak and 50% redundancy) (3) chilled water pumps @ 5.0 HP (includes 1 on standby) (4) hot water pumps @ 2 HP (includes 2 on standby)
Air distribution	AIR HANDLING UNIT - INDOOR (.5-1.25 HP) - univents (DX cooling) - don't always provide fresh air during occupied times	DOAS Single Wheel (70% EF) - Qty. 2 - 20,000 CFM @ 45 MHP each	DOAS Regen (90% EF) - Qty. 2 - 20,000 CFM @ 45 MHP each
	Exhaust fans (constant volume)	Qty. 2 - 20,000 CFM @ 30 MHP each	Qty. 2 - 20,000 CFM @ 30 MHP each
Zone systems	Heat Pumps (1368 MBH cooling/1531 MBH cooling), FCU 2-pipe, FCU 4-pipe	4-pipe FCUs	4-pipe FCUs
Controls	95% DDC Resets in place	Complete DDC Chilled water reset Classroom 326 bypass damper issue Classroom 322 damper misrepresentation (100% OAD, 0% RAD, heat coil 0% OAT 23F, DAT 75F)	Complete DDC Chilled water reset Classroom 326 bypass damper issue Classroom 322 damper misrepresentation (100% OAD, 0% RAD, heat coil 0% OAT 23F, DAT 75F)
Plumbing			
Domestic Hot Water	Gas storage Steam-to-hot water	Electric boiler with recirc	Instantaneous electric DHW
Fixture Flow Rates	0.5 gpm lavatory 1.5 gpm kitchen sink	0.35 gpm lavatory 1.0 gpm kitchen sink	0.35 gpm lavatory 1.0 gpm kitchen sink
Electrical			
Lighting	Fluorescent	LED	LED
EQUIPMENT, INTERNAL LOADS AND DESIGN TEMPERATURE SETPOINTS			
Process equipment	Fume hoods (4)	Filtered fume hoods	Filtered fume hoods
	Lab compressed air		

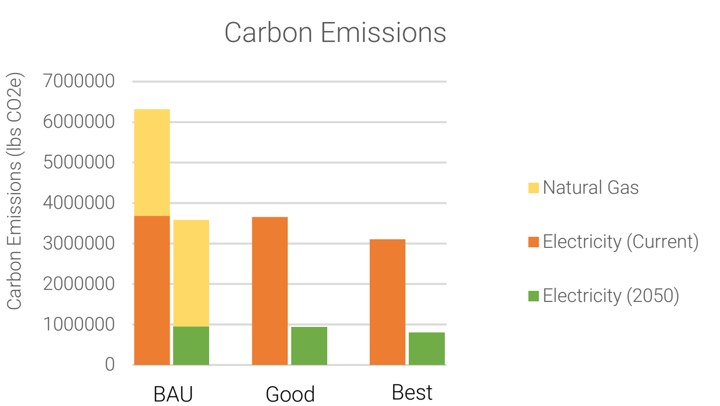
Olney Hall

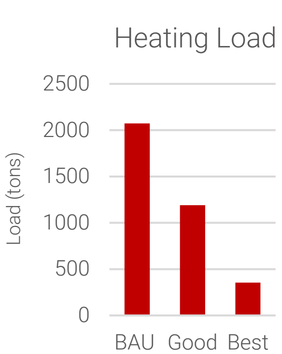
Campus	North Campus
Core End Use	Lab
Square Footage	205550
Last Major Renovation	1974

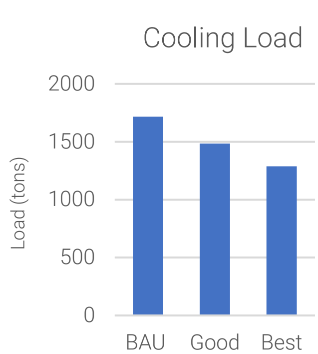
Building Summary

Olney Hall is an lab building on the North Campus. It has a Building Score of 67. This makes it a higher priority for energy efficiency improvements as a pilot project particularly given direct steam systems. The business as usual case assume dry lab and cooling operations will be expanded. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5b - Air-side Systems - Decoupled systems
ECM 5d - Air-side Systems - Constant to variable volume
ECM 5e - Air-side Systems - Airflow setbacks
ECM 6c - Air-side Energy Recovery - 50% (Runaround Coil)
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11c - Process Loads - Low Flow Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 5f - Air-side Systems - Aircuity, particle counters
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)
ECM 9b - Plumbing - Instantaneous Water Heater

Olney Hall Detailed Options Matrix

Description	BAU	Good	Best
Target EUI (kBtu/sf-yr)	210	99	84
Architectural			
Wall Performance	Mass and brick, 1 1/2" spray insulation, ~R-3 noncontinuous (1970s)	R-10 continuous insulation (exterior)	R-30 continuous insulation (exterior)
Roof Performance	Black TPO, 2" rigid R-8 (exterior) (1970s)	R-30 continuous insulation, white	R-50 continuous insulation, white
Glazing Performance	Single pane (fixed and operable)	Double glazing curtain walll and punched assembly u-value: 0.3, SHGC: 0.26	Triple glazing punched assembly u-value: 0.20, SHGC: 0.26
HVAC			
Heating/cooling system	Steam to hot water (original to building) Constant volume pumps	(40) 30 ton modular air-to-water heat pumps (2) 300 ton air cooled chiller (peak and 50% redunancy) (3) chilled water pumps @ 10 HP (includes 1 on standby) (3) hot water pumps @ 10 HP (includes 1 on standby) (6) hot water pumps @ 7.5 HP (includes 3 on standby)	(12) 30 ton modular air-to-water heat pumps (2) 900 ton air cooled chiller (peak and 50% redunancy) (4) chilled water pumps @ 20 HP (includes 1 on standby) (4) hot water pumps @ 7.5 HP (includes 2 on standby)
	Chiller Constant volume pumps		
	Cooling tower		
	Split AC		
	Split AC		
Air distribution	Individual AHUs (constant volume)	DOAS Runaround Coil - Qty. 4 - 66,000 CFM @ 120 MHP each	DOAS Konvekta + Heat Pump Qty. 3 - 70,000 CFM @ 140 MHP each Heat Pump - (7) 30 ton modules (multistack Heat Recovery) DOAS General exhaust through wheel Supply Qty. 1 - 54,000 CFM @ 100 MHP Exhaust Qty. 1 - 54,000 CFM @ 50 MHP
	Individual exhaust fans (constant volume)	Qty. 8 - 33,000 CFM @ 30 MHP each	Lab Exhaust Fans Qty. 6 - 35,000 CFM @ 30 MHP each
	Individual return fans		
Zone systems	Univent system (1-2 per lab)	4-pipe fan coil units	4-pipe fan coil units
Controls	DDC HHW and CHW resets included DAT reset included	Complete DDC Static pressure reset opportunity No effective reheat coil multiple spaces (Lab G2A, G4, G6) - Retro-commissioning opportunity	Complete DDC Static pressure reset opportunity No effective reheat coil multiple spaces (Lab G2A, G4, G6) - Retro-commissioning opportunity
Plumbing			
Domestic Hot Water	Steam to hot water	Electric boiler with recirc	Instantaneous electric DHW
	DHW Boiler		
Fixture Flow Rates	Bathrooom renovation 2.2 gpm	0.35 gpm lavatory 1.0 gpm kitchen sink	0.35 gpm lavatory 1.0 gpm kitchen sink
Electrical			
Interior Lighting	Fluorescent	LED	LED

EQUIPMENT, INTERNAL LOADS AND DESIGN TEMPERATURE SETPOINTS			
Process equipment	Fume hoods (mostly constant)	Filter fume hoods	Filter fume hoods
	Fume hoods (mostly constant)	Low flow fume hoods	Low flow fume hoods
	Lab compressed air		
	Lab compressed air		
	Lab freezer condenser		
	Process chiller		

Sheehy Hall

Campus	South Campus
Core End Use	Residential
Square Footage	62219
Last Major Renovation	1989

Building Summary

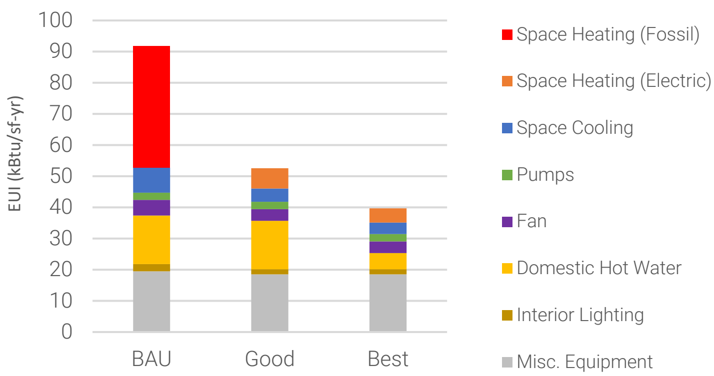
Sheehy Hall is residential building on the South Campus. It has a Building Score of 62. This makes it a higher priority for energy efficiency improvements as a pilot project particularly given direct steam systems. The business as usual case assumes ventilation and cooling will be added. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.

Current
Steam-to-HHW
No cooling
Candidate for envelope improvements

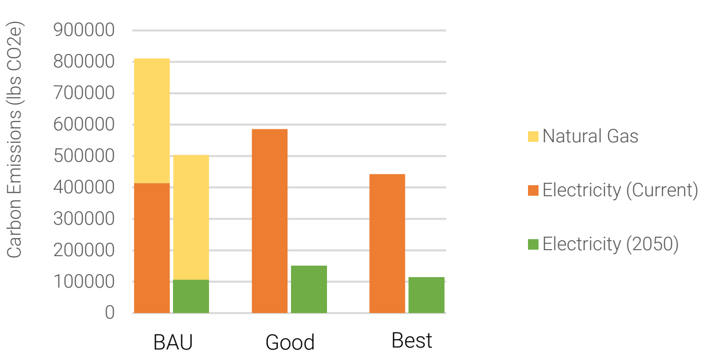
Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7a - Water-side Systems - Standalone VRF
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9e - Plumbing - ASHP Water Heater with Storage

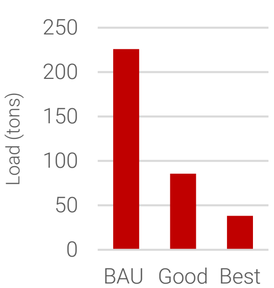
EUI Breakdown



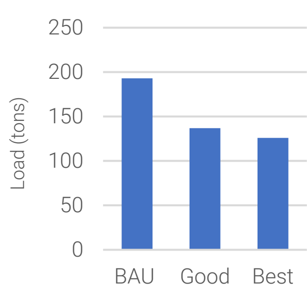
Carbon Emissions



Heating Load



Cooling Load



Description	BAU	Good	Best
Target EUI (kBtu/sf-yr)	92	53	40
Architectural			
Wall Performance	Brick, 4" blanket ~R-10 (1980s)	R-10 continuous insulation	R-30 continuous insulation
Roof Performance	Single-Ply/ EPDM 3" rigid insulation ~R-12 (1980s)	R-30 continuous insulation, white	R-50 continuous insulation, white
Glazing Performance	Single, operable, potentially leaking	Double glazing with Low e double hung (operable) assembly u-value: 0.35, SHGC: 0.26	Triple glazing double hung (operable) assembly u-value: 0.25, SHGC: 0.26
HVAC			
Heating/cooling system	Steam-to-hot water HX	VRF - (9) 16 ton Mitsubishi R2-Series Heat Recovery	VRF - (8) 16 ton Mitsubishi R2-Series Heat Recovery
Air distribution	No make-up air	DOAS Single Wheel (70% EF) w/ hot gas reheat - Qty. 1 - 16,000 CFM @ 30 MHP each	DOAS Regen (90% EF) w/ hot gas reheat - Qty. 1 - 16,000 CFM @ 30 MHP each
Exhaust	Bathroom exhaust	Qty. 1 - 16,000 CFM @ 20 MHP each	Qty. 1 - 16,000 CFM @ 20 MHP each
Zone systems	Perimeter radiation , Danfoss valve controlled	VRF	VRF
Controls	pneumatic	Complete DDC	Complete DDC
Plumbing			
Domestic Hot Water	Steam-to-hot water HX	Electrical water heater with storage	ASHP with storage
Fixture Flow Rates	Bathroom renovation	0.35 gpm lavatory 1.0 gpm kitchen sink 1.0 gpm shower	0.35 gpm lavatory 1.0 gpm kitchen sink 1.0 gpm shower
Electrical			
Lighting	CFL, LED, T12	LED	LED
Lighting Controls	None	Occupancy sensors	Occupancy sensors

North Campus Energy Efficiency Results

Project profiles were developed for each building on the North Campus pilot building are developed in order to evaluate and quantify energy, emissions, and heating/cooling load impacts. Measures were identified by using the ASHRAE Level I Audit procedure. Two scenarios - “Good” and “Best” – were detailed in order to outline the range of opportunities compared to a Default/Business-As-Usual (“BAU”) Case. The BAU case was defined as the 2019 energy use profiles adjusted for key factor including expanded lab operations, added cooling, and centralized ventilation. Energy end use breakdowns were estimated based building core end use given the lack of campus submetering. Current and future 2050 carbon emissions were quantified using values from the “30-year Forecast Preliminary Report.” Heating and cooling loads were quantified in order to enable evaluation of central vs. decentralized scenarios. Air-side energy recovery and envelope are the key strategies outlined to reduce heating and cooling loads.

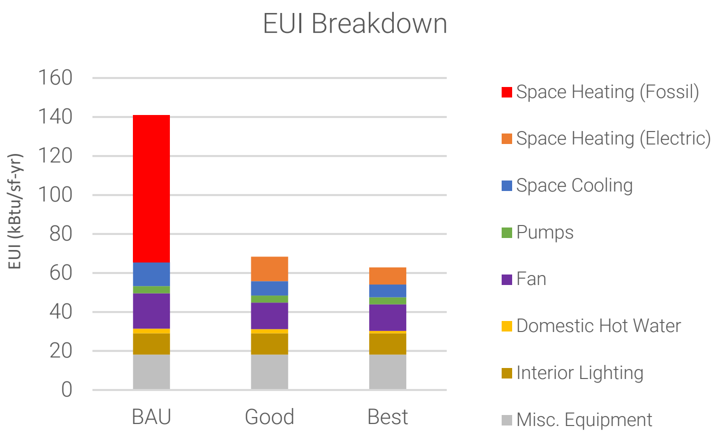
Compared to the Default/Business-As-Usual (“BAU”) Case, the North Campus, “Good” case is expected to achieve a 47% energy reduction and 35% emissions reduction. Based on future emissions rate (as detailed in the “30-Year Forecast), the emissions reduction is expected to be closer to 71%. The North Campus, “Best” case is expected to achieve a 52% energy reduction and 42% emissions reduction. The emissions reduction is expected to be closer to 74% given the implemented electrification strategies and future grid emissions rates (as detailed in the “30-Year Forecast”). The reductions outlined above are expected to greatly exceed the EUI and emissions requirements of Executive Order No. 594. The Investment Phase will detail how these projects can be structured in order to meet these requirement timelines. The remaining emissions can be offset with renewables sources.

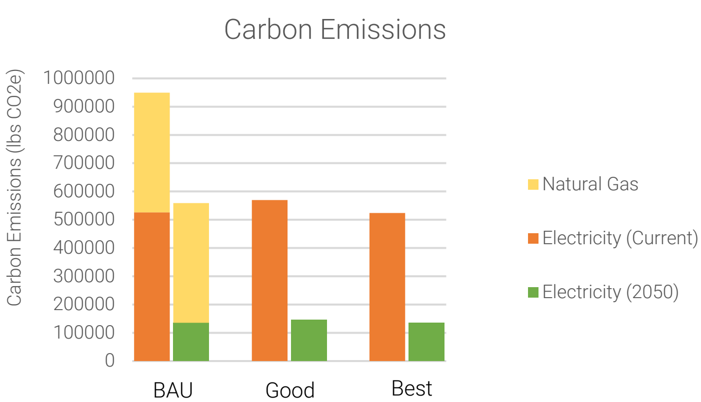
Kitson Hall

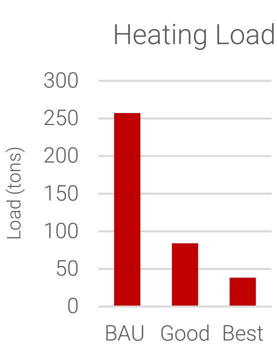
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	46512
Last Major Renovation	1902

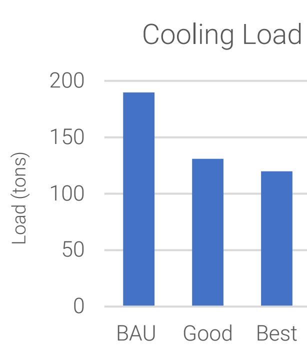
Building Summary

Kitson Hall is an office/classroom building with some dry labs on the North Campus. It has a Building Score of 71. This makes it a high priority for energy efficiency improvements. The business as usual case assume dry lab and cooling operations will be expanded. The EUI reduction in the Good and Best cases are a result of envelope upgrades, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Window AC
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10a - Controls - DDC
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

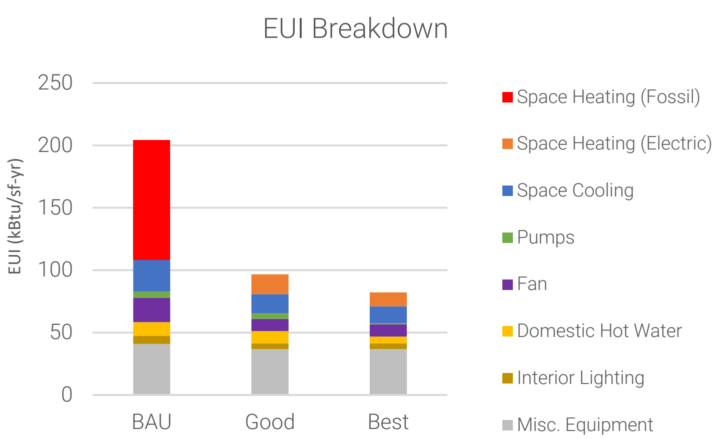
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

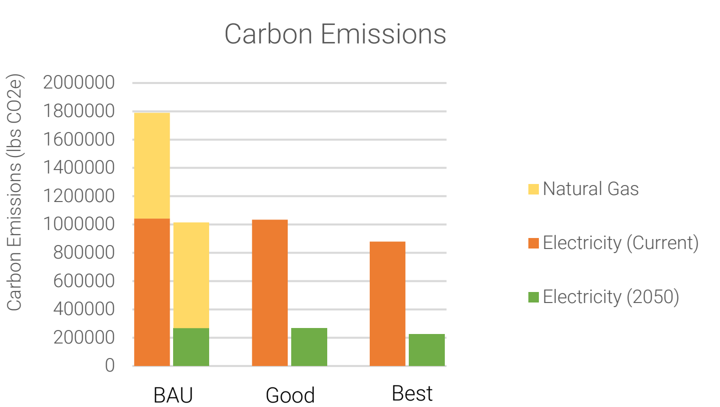
Pinanski Hall

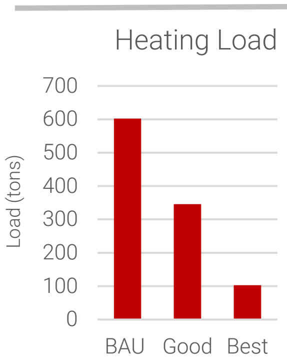
Campus	North Campus
Core End Use	Lab
Square Footage	59696
Last Major Renovation	2019

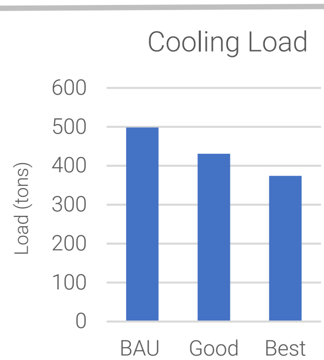
Building Summary

Pinanski Hall is a lab building with on the North Campus. It has a Building Score of 69. This makes it a high priority for energy efficiency improvements. The business as usual case assumed added lab operations. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 6c - Air-side Energy Recovery - 50% (Runaround Coil)
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11f - Process Loads - Energy Star Office Equipment

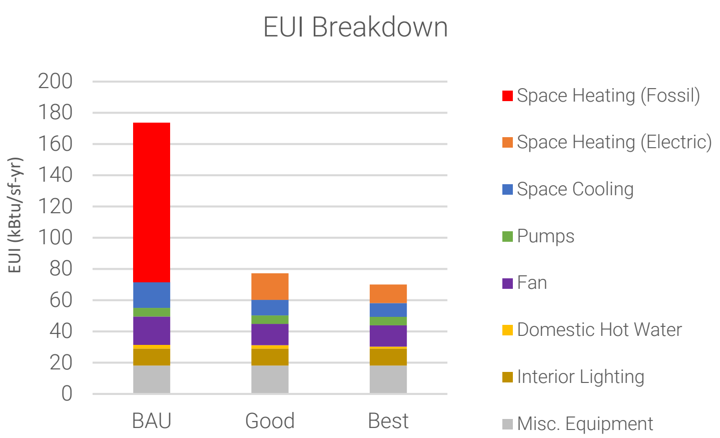
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)
ECM 9b - Plumbing - Instantaneous Water Heater

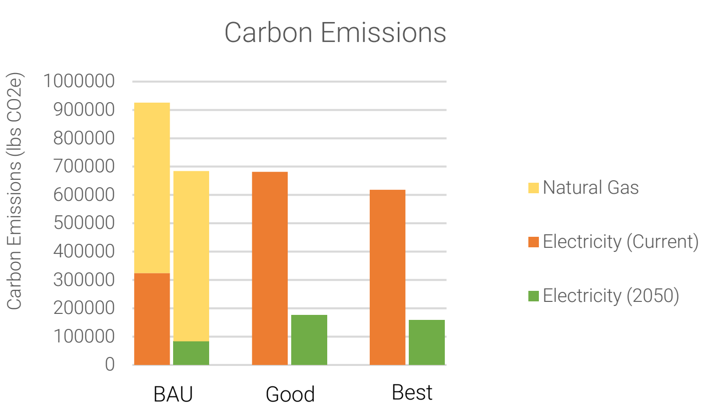
Falmouth Hall

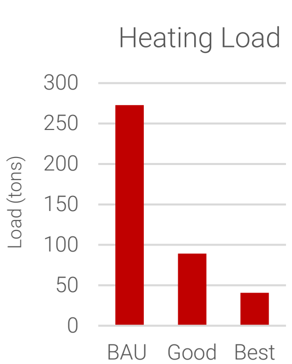
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	49290
Last Major Renovation	1907

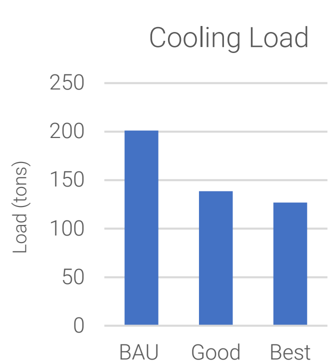
Building Summary

Falmouth Hall is an office/classroom building with some dry labs on the North Campus. It has a Building Score of 67. This makes it a high priority for energy efficiency improvements. The business as usual case assume dry lab and cooling operations will be expanded. The EUI reduction in the Good and Best cases are a result of envelope upgrades, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
DX Cooling
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10a - Controls - DDC
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11c - Process Loads - Low Flow Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

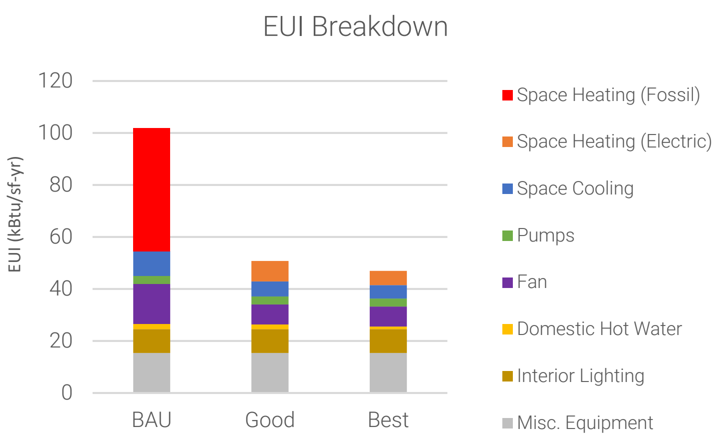
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

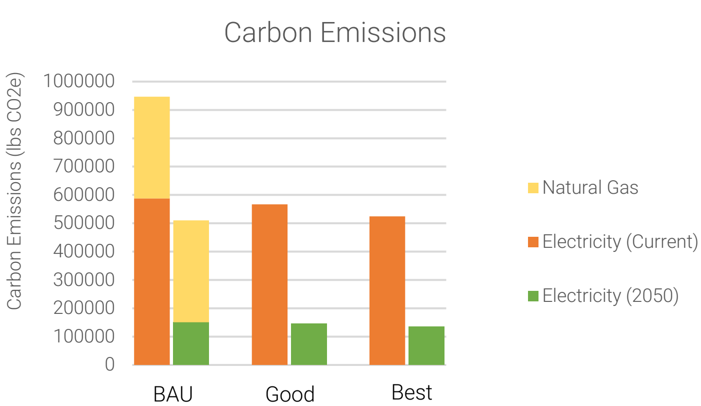
Southwick Hall

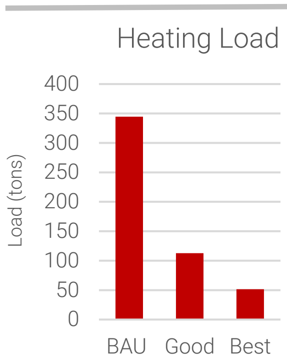
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	62313
Last Major Renovation	1902

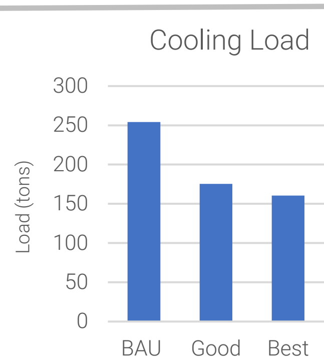
Building Summary

Southwick Hall is an office/classroom building with dining on the North Campus. It has a Building Score of 52. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, high efficiency heating/cooling systems, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
DX Cooling
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment
ECM 11g - Process Loads - Energy Star Kitchen All-Electric Energy Star

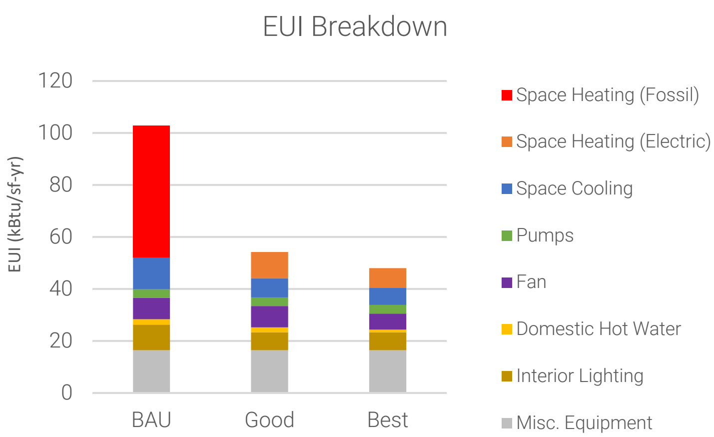
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

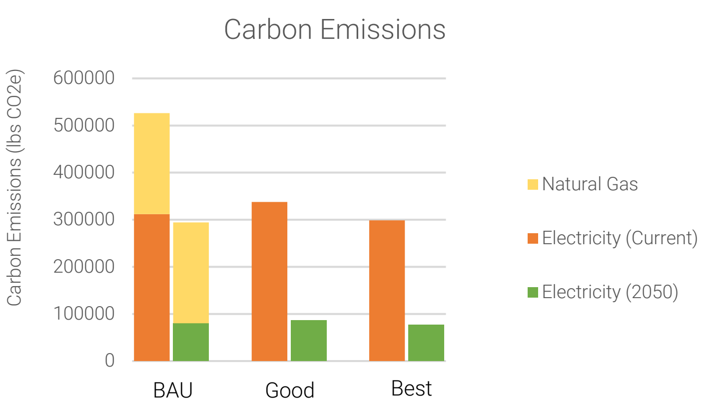
Cumnock Hall

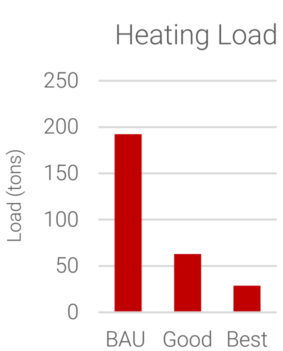
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	34768
Last Major Renovation	1954

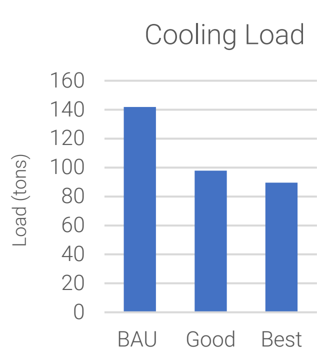
Building Summary

Cumnock Hall is an office building with a dining facility on the North Campus. It has a Building Score of 51. This makes it a medium priority for energy efficiency improvements particularly given direct steam systems. The business as usual case assumed added cooling. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Direct Steam
ASHP
Acceptable envelope; original components

Good
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment
ECM 11g - Process Loads - Energy Star Kitchen All-Electric Energy Star

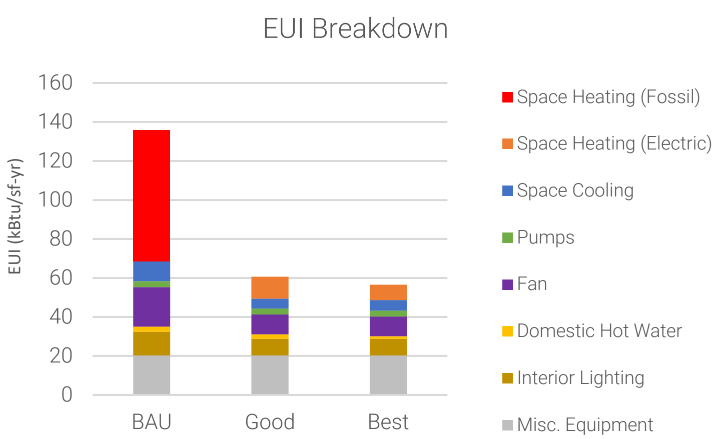
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

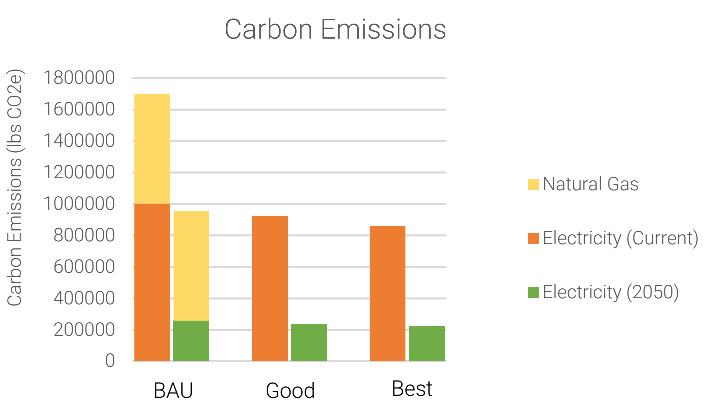
Costello Athletic Center

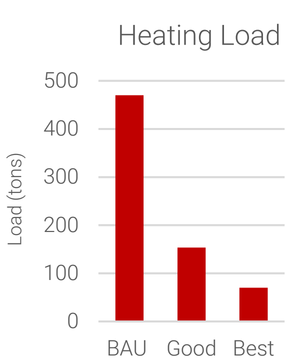
Campus	North Campus
Core End Use	Fitness
Square Footage	84979
Last Major Renovation	1967

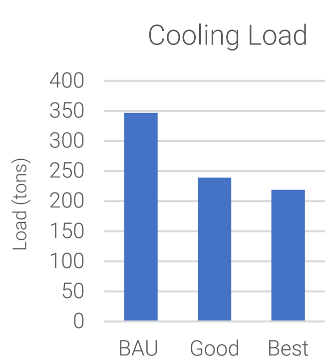
Building Summary

Costello Athletic Center is a fitness building on the North Campus. It has a Building Score of 65. This makes it a high priority for energy efficiency improvements particularly given direct steam systems. The business as usual case assumes cooling will be added. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Direct Steam
No cooling
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10c - Controls - DDC Sequence Upgrades

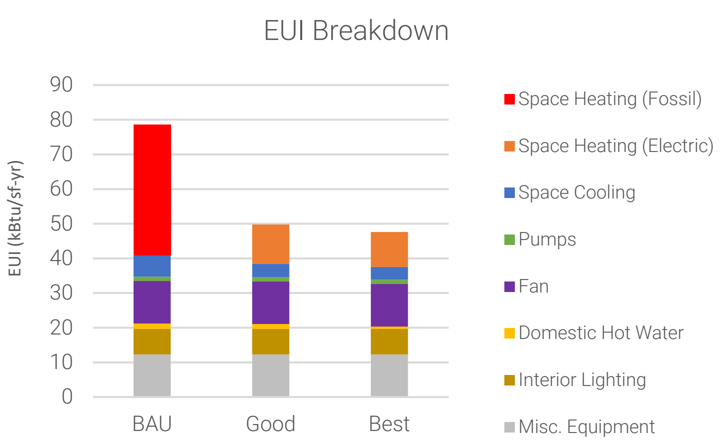
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 9e - Plumbing - ASHP Water Heater with Storage
ECM 12 – Natatorium – High Efficiency Heating and Cooling

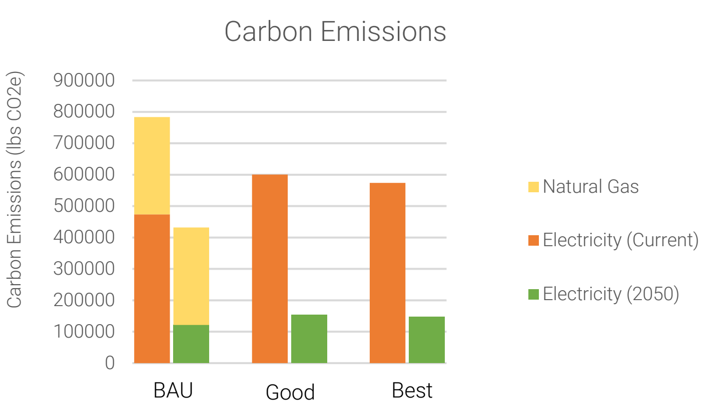
Lydon Library

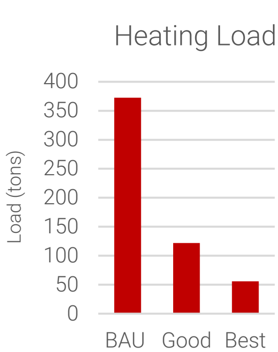
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	67329
Last Major Renovation	2017

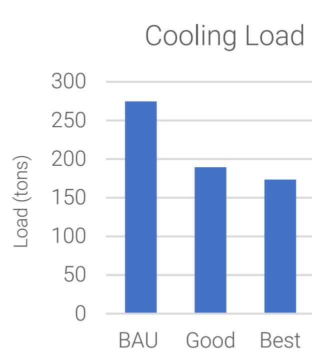
Building Summary

Lydon Library building is an office/classroom building on the North Campus. It has a Building Score of 62. This makes it a higher priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Air-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

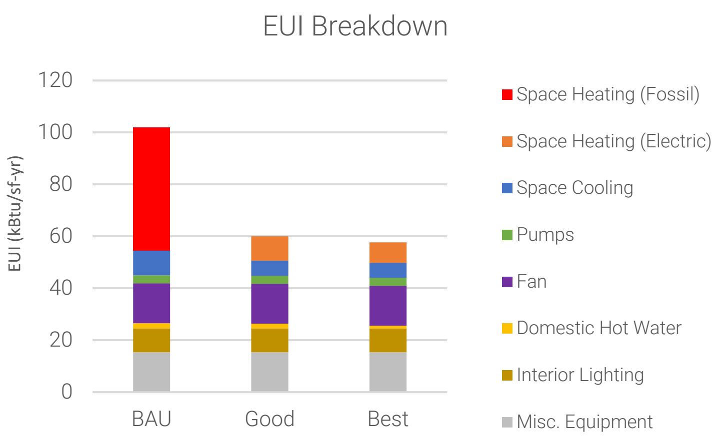
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

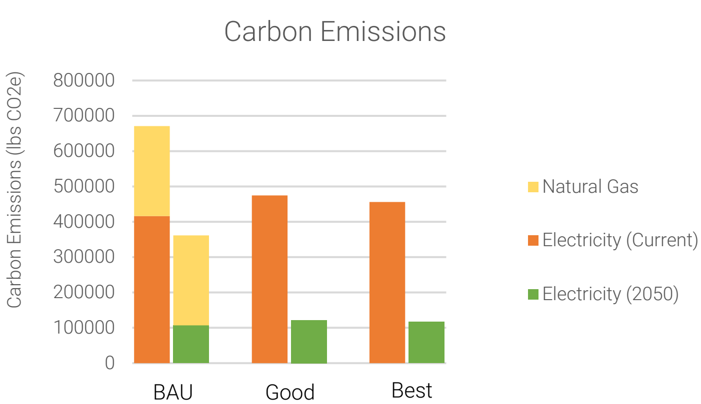
Dandeneau Hall

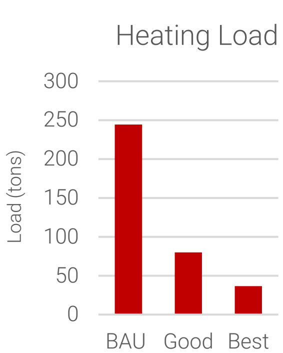
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	44169
Last Major Renovation	2018

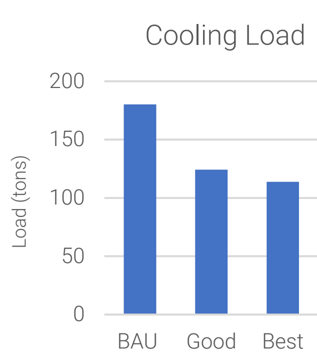
Building Summary

Dandeneau Hall is an office/classroom building with some dry labs on the North Campus. It has a Building Score of 61. This makes it a high priority for energy efficiency improvements. The business as usual case assumed added cooling. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

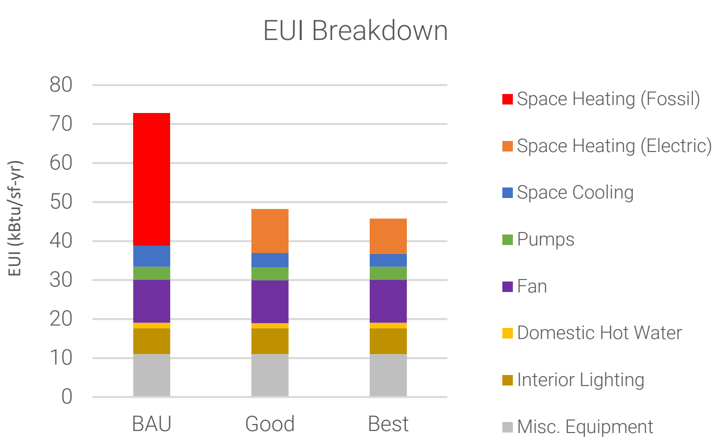
Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

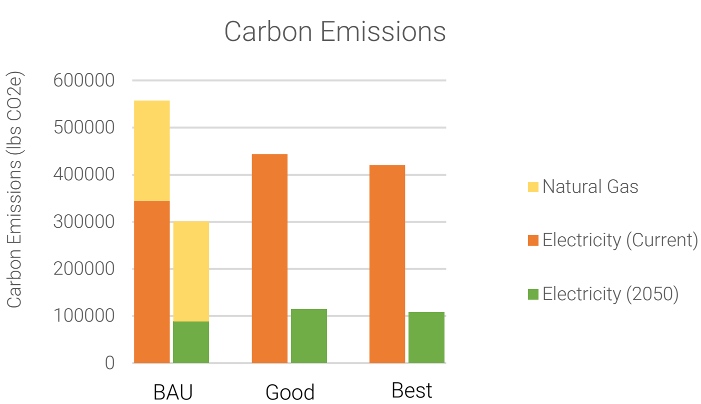
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

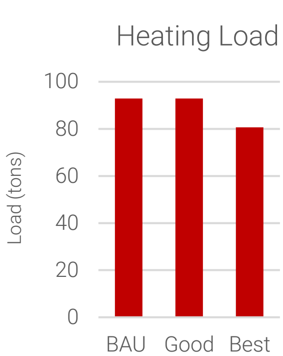
Pulichino Tong Business Center

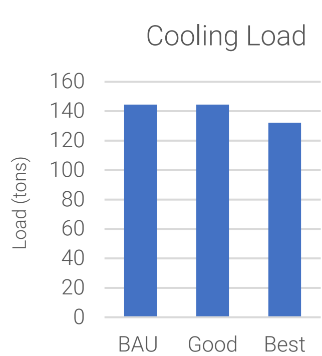
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	51345
Last Major Renovation	2016

Building Summary
Pulichino Tong Business Center (PTB) is an office/classroom building on the North Campus. It has a Building Score of 44. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. Future carbon reduction is in result to electrified heating strategy. Minor envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Water-cooled Chiller
High-quality; new insulation and new windows and doors

Good
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 11f - Process Loads - Energy Star Office Equipment

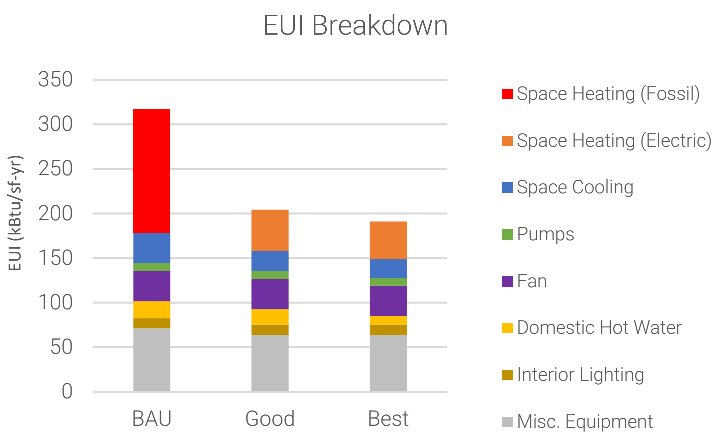
Best
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

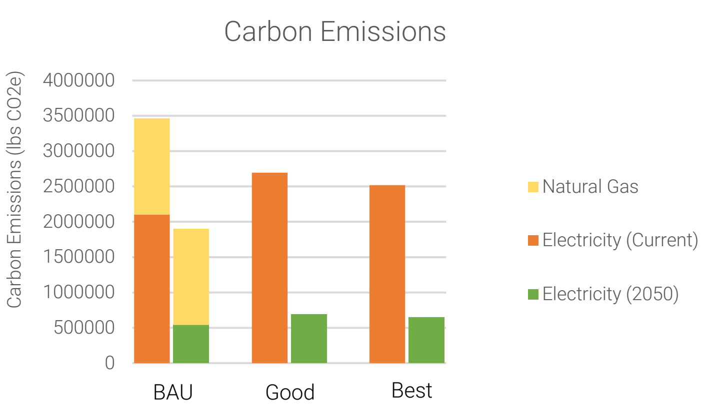
Saab Emerging Technologies & Innovation Center

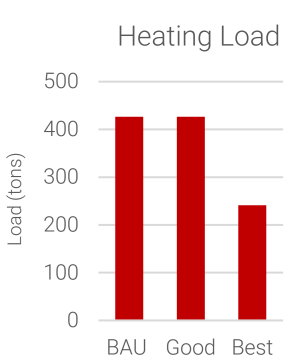
Campus	North Campus
Core End Use	Lab
Square Footage	73637
Last Major Renovation	2012

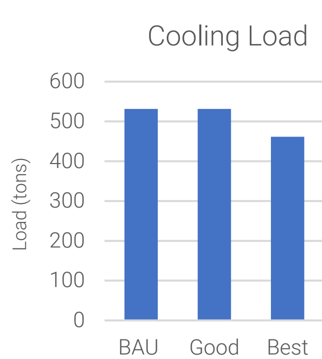
Building Summary

Saab Emerging Technologies & Innovation Center is the most energy intensive lab building located on the North Campus. It has a Building Score of 44. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. Future carbon reduction is in result to electrified heating strategy. Minor envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Water-cooled Chiller
High-quality; new insulation and new windows and doors

Good
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 5f - Air-side Systems - Aircuity, particle counters
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9b - Plumbing - Instantaneous Water Heater

Perry Hall

Campus	North Campus
Core End Use	Lab
Square Footage	50158
Last Major Renovation	2019

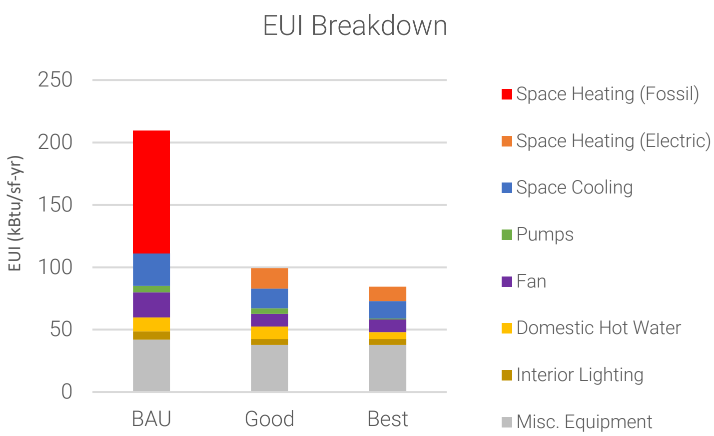
Building Summary

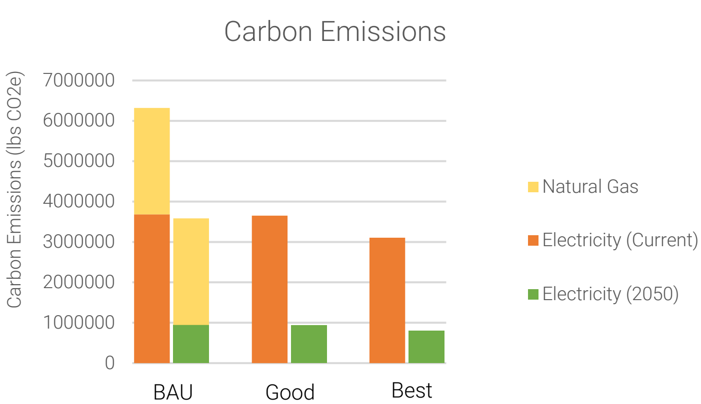
Perry Hall is an office/classroom building with some dry labs on the North Campus. It has a Building Score of 42. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. A current carbon increase would be a result of minor energy efficiency upgrades and electrified heating strategy. Minor envelope upgrades reduce heating and cooling loads.

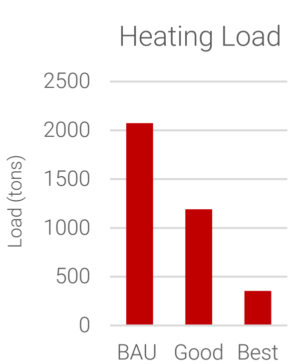
Current
Steam-to-HHW
Water-cooled Chiller
High-quality envelope; new insulation and new windows and doors

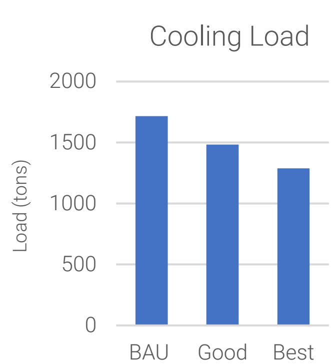
Good
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)
ECM 9b - Plumbing - Instantaneous Water Heater







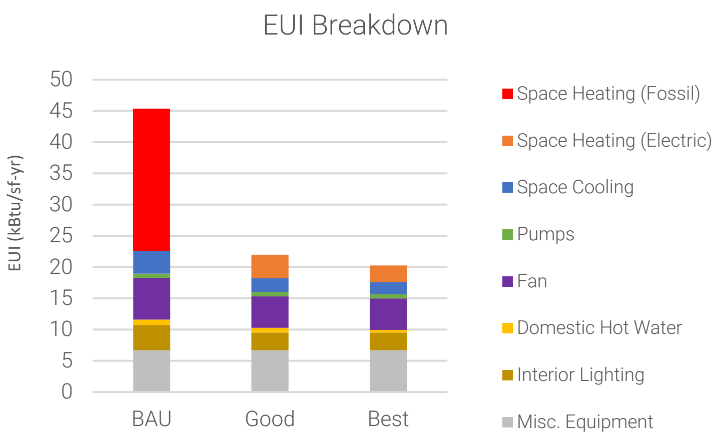


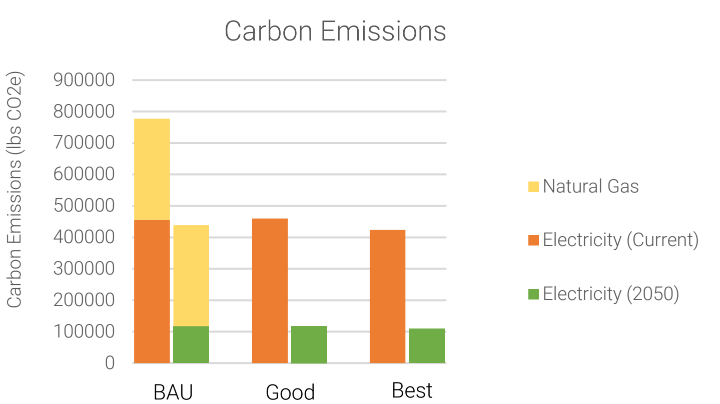
Olsen Hall

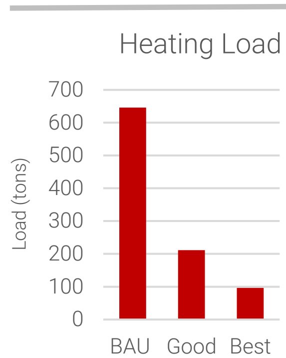
Campus	North Campus
Core End Use	Office/Classroom
Square Footage	116764
Last Major Renovation	2019

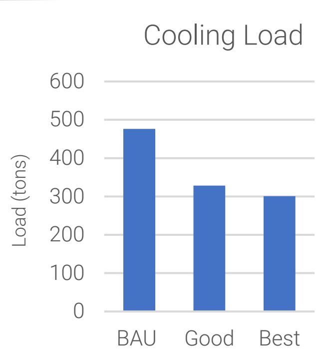
Building Summary

Olsen Hall is an office/classroom building with some wet labs on the North Campus. It has a Building Score of 29, although, the score is expected to be higher due to energy meter data anomalies. Therefore, this building is assumed to be a medium priority for energy efficiency improvements. The business as usual case assumes lab operations will be expanded. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Air-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11c - Process Loads - Low Flow Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

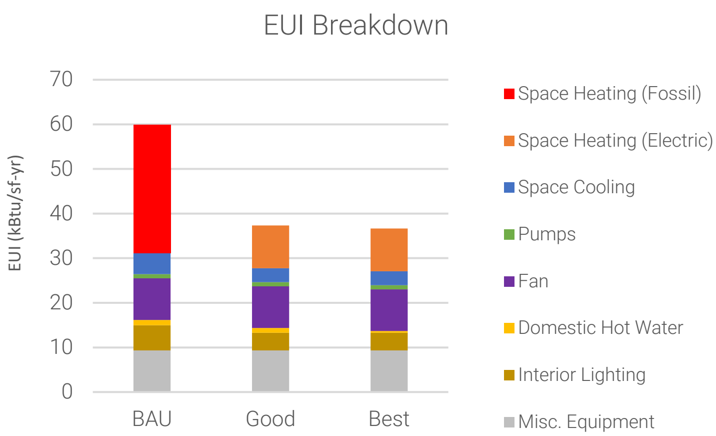
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

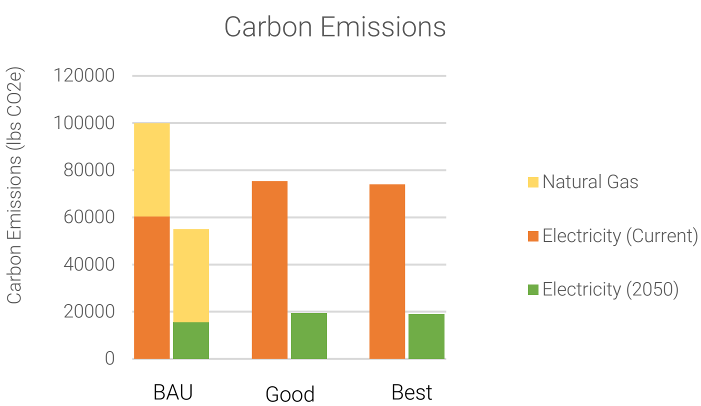
UMass Lowell Bellegarde Boathouse

Campus	North Campus (satellite)
Core End Use	Recreation
Square Footage	11272
Last Major Renovation	2009

Building Summary

UMass Lowell Bellegarde Boathouse is a recreation building on the North Campus. It has a Building Score of 16. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling systems and lighting. Future carbon reduction is in result to electrified heating strategy.





Current
HHW Boiler
Window AC
High-quality; new insulation and new windows and doors

Good
ECM 7a - Water-side Systems - Standalone VRF
ECM 8a - Lighting - LED Conversion
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater

Best
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 9b - Plumbing - Instantaneous Water Heater

North Campus Plant Alternatives

Overview

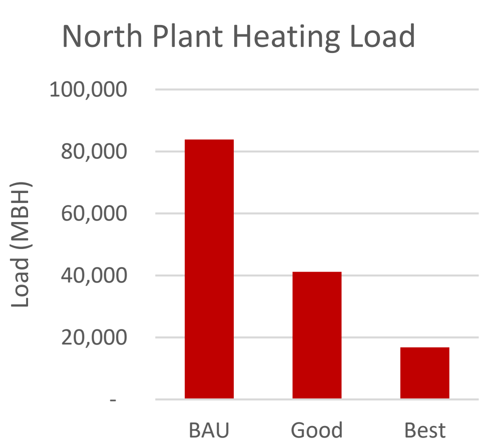
The existing North Plant is a heating only central plant that serves the north campus except the Pulichino Tong Business Center and the Saab Emerging Technologies and Innovation Center. The north plant has three low pressure steam boilers for a total of 2,200 boiler HP of capacity. The aging steam infrastructure in the north campus presents an opportunity to convert to low temperature hot water and chilled water. Steam is a high grade heat source that requires either a fossil fuel or bio fuel to operate, locking the north campus into high grade heat through 2050. Therefore, it is recommended to pursue a low temperature hot water and chilled water distribution to take advantage of ground-source and air-source heat pump technologies, as well as integrate boilers for resiliency.

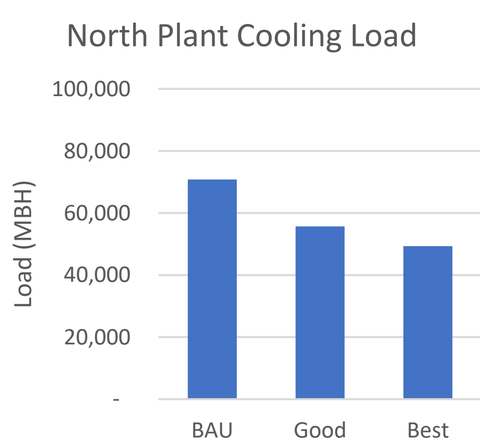
The proposed primary heating and cooling equipment for the central plant were selected based on emission impact, feasibility, resiliency and cost. This includes ground-source heat pumps, air-source heat pumps, biodiesel boilers and gas boilers (for low outdoor air temperatures only and backup). Refer to the alternative energy systems section for more information regarding these systems. This section outlines the peak heating and cooling loads for the "Business As Usual', 'Good', and 'Best' load scenarios and central plant equipment sizing recommended for each option. Each load scenario has six options for consideration.

Plant Heating and Cooling Loads

The North Plant will serve all of the buildings currently served by the existing steam plant as well as the Pulichino Tong Business Center and the Saab Emerging Technologies and Innovation Center. The design heating and cooling loads for the 'Business As Usual', 'Good' and 'Best' cases are shown in the table and charts below. Note that as buildings improve the envelope and air-side energy recovery systems, the buildings require less and less heating and cooling.

	Business As Usual	Good	Best
Heating Load (MBH)	83,900	41,200	16,800
Cooling Load (MBH)	70,800	55,700	49,350





Options Description and Matrix

The team is proposing six options for the north plant consideration. Sizing of the plant depends on energy efficiency improvements made in the buildings the plant serves. These options are outlined in the following tables. The north plant is proposed to serve all of the building currently served by the north plant heating plant as well as the Pulichino Tong Business Center and the Saab Emerging Technologies and Innovation Center. When evaluating the plant options, consider the following:

1. Consider if the buildings should be stand-alone heating and cooling or expand the existing central plant.
2. Which peak load scenario the plant should be designed around.
3. Whether the peak/backup boilers will be biodiesel or gas.
4. Whether the plant will have geothermal or air-source heat pumps or a combination of both.

Best Option

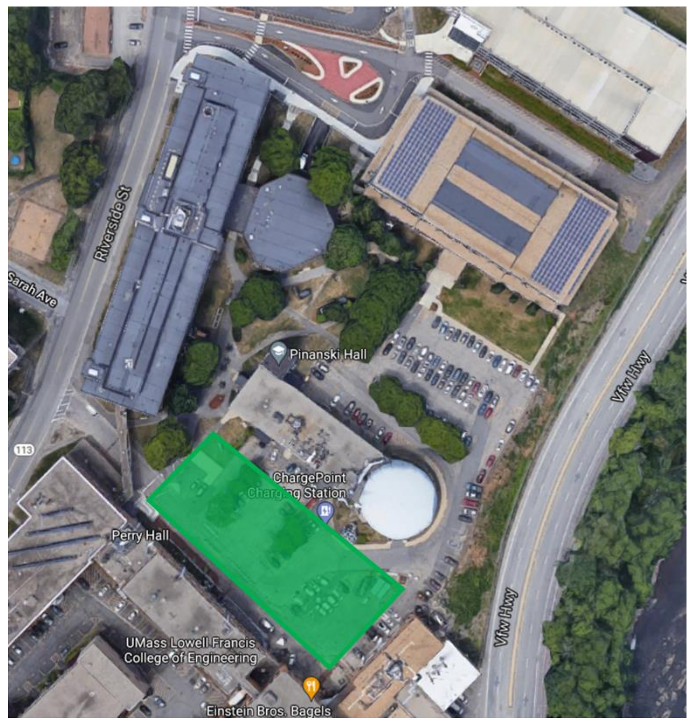
The table below shows the main north plant equipment required if all buildings pursue "BEST" energy conservation measures. Options with "A" include a large geothermal field, "B" includes a medium size geothermal field and "C" includes no geothermal. Options with "1" include biodiesel boilers and options with "2" include natural gas condensing boilers.

	BEST A1 Heavy Geo + Biodiesel	BEST B1 Light Geo + Air-source + Biodiesel	BEST C1 Air-source + Biodiesel	BEST A2 Heavy Geo + Air-source + Gas	BEST B2 Light Geo + Air-source + Gas	BEST C2 Air-source + Gas
Heat Recovery Chillers	(12) 50 Ton modular heat recovery chillers with VFDs and ground connection	(6) 50 Ton modular heat recovery chillers with VFDs and ground connection	None	(12) 50 Ton modular heat recovery chillers with VFDs and ground connection	(6) 50 Ton modular heat recovery chillers with VFDs and ground connection	None
Geothermal Borefield	Closed Loop Vertical Borefield 200 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 100 Boreholes at 500 ft depth	None	Closed Loop Vertical Borefield 200 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 100 Boreholes at 500 ft depth	None
Air-to-Water Heat Pumps	None	(12) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(23) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(23) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(35) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(47) 30 Ton Air-to-Water heat pumps similar to Multistack ARA
Peak Heating Load + Backup System	(3) 150 Boiler HP Biodiesel Boilers	(3) 150 Boiler HP Biodiesel Boilers	(3) 150 Boiler HP Biodiesel Boilers	(4) 4,000 MBH Natural Gas Condensing Boilers	(4) 4,000 MBH Natural Gas Condensing Boilers	(4) 4,000 Natural Gas Condensing Boilers
Peak Cooling Load + Backup System	(4) 950 Ton Centrifugal Chillers with Cooling Towers	(4) 900 Ton Centrifugal Chillers with Cooling Towers	(4) 900 Ton Centrifugal Chillers with Cooling Towers	(4) 800 Ton Centrifugal Chillers with Cooling Towers	(4) 800 Ton Centrifugal Chillers with Cooling Towers	(4) 750 Ton Centrifugal Chillers with Cooling Towers
Hot water and Chilled Water Distribution	Chilled water and hot water supply and return through buildings and direct buried as required.					
Emergency Generators + Backup System	Emergency generators for life-safety and heating system. The cooling plant is not on optional standby.					
Fuel Storage	36-48 hours of backup fuel storage in the plant.					

Best Option Geothermal Borefield

The potential geothermal borefield site is parking lots and green space immediately surrounding the North Plant. The target percent of peak heating load is 15% to 30% of the peak heating load to maximize utilization of the geothermal borefield. For resiliency, the closed-loop vertical borefields will be piped in groups or 'circuits', with each circuit having supply and return piping directly to the building. The satellite images below show the approximate site area required for the 'Light and 'Heavy' geothermal options. The "Light" geothermal option would require the parking lot to the south of Pinanski Hall. The 'Heavy' geothermal option would require the parking lot to the south of Pinanski Hall, the parking lot to the north of Pinanski Hall and green space to the east of Olney Hall. The parking lots would need to be re-paved and the green-space would need to be landscaped.

Best Option A1 and A2 geothermal borefield



Best Option B1 and B2 geothermal borefield

Good Option

The table below shows the main north plant equipment required if all buildings pursue “GOOD” energy conservation measures. Options with “A” include a large geothermal field, “B” includes a medium size geothermal field and “C” includes no geothermal. Options with “1” include biodiesel boilers and options with “2” include natural gas condensing boilers.

	GOOD A1 Heavy Geo + Biodiesel	GOOD B1 Light Geo + Air-source + Biodiesel	GOOD C1 Air-source + Biodiesel	GOOD A2 Heavy Geo + Air-source + Gas	GOOD B2 Light Geo + Air-source + Gas	GOOD C2 Air-source + Gas
Heat Recovery Chillers	(22) 50 Ton modular heat recovery chillers with VFDs and ground connection	(12) 50 Ton modular heat recovery chillers with VFDs and ground connection	None	(22) 50 Ton modular heat recovery chillers with VFDs and ground connection	(12) 50 Ton modular heat recovery chillers with VFDs and ground connection	None
Geothermal Borefield	Closed Loop Vertical Borefield 350 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 175 Boreholes at 500 ft depth	None	Closed Loop Vertical Borefield 350 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 175 Boreholes at 500 ft depth	None
Air-to-Water Heat Pumps	None	(29) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(57) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(57) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(86) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(114) 30 Ton Air-to-Water heat pumps similar to Multistack ARA
Peak Heating Load + Backup System	(3) 350 Boiler HP Biodiesel Boilers	(3) 350 Boiler HP Biodiesel Boilers	(3) 350 Boiler HP Biodiesel Boilers	(6) 6,000 MBH Natural Gas Condensing Boilers	(6) 6,000 MBH Natural Gas Condensing Boilers	(6) 6,000 Natural Gas Condensing Boilers
Peak Cooling Load + Backup System	(4) 950 Ton Centrifugal Chillers with Cooling Towers	(4) 900 Ton Centrifugal Chillers with Cooling Towers	(4) 800 Ton Centrifugal Chillers with Cooling Towers	(3) 800 Ton Centrifugal Chillers with Cooling Towers	(3) 750 Ton Centrifugal Chillers with Cooling Towers	(3) 650 Ton Centrifugal Chillers with Cooling Towers
Hot water and Chilled Water Distribution	Chilled water and hot water supply and return through buildings and direct buried as required.					
Emergency Generators + Backup System	Emergency generators for life-safety and heating system. The cooling plant is not on optional standby.					
Fuel Storage	36-48 hours of backup fuel storage in the plant.					

Good Option Geothermal Borefield

The potential geothermal borefield site is parking lots and green space immediately surrounding the North Plant. The target percent of peak heating load is 15% to 30% of the peak heating load to maximize utilization of the geothermal borefield. For resiliency, the closed-loop vertical borefields will be piped in groups or 'circuits', with each circuit having supply and return piping directly to the building. The satellite images below show the approximate site area required for the 'Light and 'Heavy' geothermal options. The "Light" option would require the parking lot to the south of Pinanski Hall, the parking lot to the north of Pinanski Hall and green space to the east of Olney Hall. The parking lots would need to be re-paved and the green-space would need to be landscaped. The 'Heavy' geothermal option would require that in addition to demolishing Pinanski Hall. Geothermal boreholes underneath buildings is possible before construction, but does take away valuable real estate which could be slated for new buildings. Maintaining space and future options is a paramount in an urban environment.

Good Option A1 and A2 geothermal borefield

Good Option B1 and B2 geothermal borefield

Business As Usual (For Reference Only)

The table below shows the main north plant equipment required if all buildings replace in kind and pursue no energy conservation measures. Options with "A" include a large geothermal field, "B" includes a medium size geothermal field and "C" includes no geothermal. Options with "1" include biodiesel boilers and options with "2" include natural gas condensing boilers.

	BAU A1 Heavy Geo + Biodiesel	BAU B1 Light Geo + Air-source + Biodiesel	BAU C1 Air-source + Biodiesel	BAU A2 Heavy Geo + Air-source + Gas	BAU B2 Light Geo + Air-source + Gas	BAU C2 Air-source + Gas
Heat Recovery Chillers	(44) 50 Ton modular heat recovery chillers with VFDs and ground connection	(22) 50 Ton modular heat recovery chillers with VFDs and ground connection	None	(44) 50 Ton modular heat recovery chillers with VFDs and ground connection	(22) 50 Ton modular heat recovery chillers with VFDs and ground connection	None
Geothermal Borefield	Closed Loop Vertical Borefield 700 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 350 Boreholes at 500 ft depth	None	Closed Loop Vertical Borefield 700 Boreholes at 500 ft depth	Closed Loop Vertical Borefield 350 Boreholes at 500 ft depth	None
Air-to-Water Heat Pumps	None	(58) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(116) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(116) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(175) 30 Ton Air-to-Water heat pumps similar to Multistack ARA	(233) 30 Ton Air-to-Water heat pumps similar to Multistack ARA
Peak Heating Load + Backup System	(3) 700 Boiler HP Biodiesel Boilers	(3) 700 Boiler HP Biodiesel Boilers	(3) 700 Boiler HP Biodiesel Boilers	(12) 6,000 MBH Natural Gas Condensing Boilers	(12) 6,000 MBH Natural Gas Condensing Boilers	(12) 6,000 Natural Gas Condensing Boilers
Peak Cooling Load + Backup System	(4) 1,050 Ton water-cooled Centrifugal Chillers with Cooling Towers	(4) 950 Ton water-cooled Centrifugal Chillers with Cooling Towers	(4) 950 Ton water-cooled Centrifugal Chillers with Cooling Towers	(3) 500 Ton water-cooled Centrifugal Chillers with Cooling Towers	(2) 450 Ton air-cooled chillers	(1) 350 Ton air-cooled chiller
Hot water and Chilled Water Distribution	Chilled water and hot water supply and return through buildings and direct buried as required.					
Emergency Generators + Backup System	Emergency generators for life-safety and heating system. The cooling plant is not on optional standby.					
Fuel Storage	36-48 hours of backup fuel storage in the plant.					

Business As Usual Geothermal Borefield

The potential geothermal borefield site is parking lots and green space immediately surrounding the North Plant. The target percent of peak heating load is 15% to 30% of the peak heating load to maximize utilization of the geothermal borefield. For resiliency, the closed-loop vertical borefields will be piped in groups or 'circuits', with each circuit having supply and return piping directly to the building. The satellite images below show the approximate site area required for the 'Light and 'Heavy' geothermal options. The "Light" option would require the parking lot to the south of Pinanski Hall, the parking lot to the north of Pinanski Hall, the green space to the east of Olney Hall and demolishing Pinanski Hall. The 'Heavy' geothermal option would require that in addition to demolishing the Olney Hall and take away valuable real estate which could be slated for new buildings. Geothermal boreholes underneath buildings is possible before construction, but does take away valuable real estate which could be slated for new buildings. Maintaining space and future options is a paramount in an urban environment.

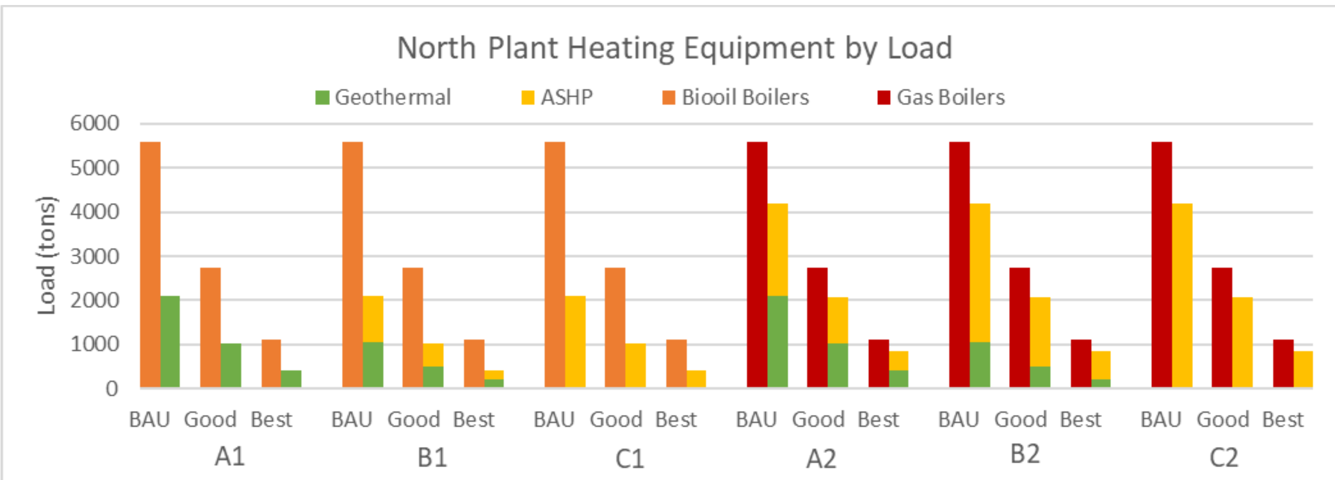
Business As Usual Option A1 and A2 geothermal borefield

Business As Usual Option B1 and B2 geothermal borefield

Heating loads by Equipment

The primary heating equipment for the new North Campus plant will consist of ground-source heat pumps, air-source heat pumps, biodiesel boilers and gas boilers. The sizing of the geothermal is based on 30% of the peak heating load for the heavy geothermal options, 15% for the light geothermal options. For biodiesel options, the air-source heat pumps are sized based on having at least 30% heat pump capacity (either ground-source or air-source), while the gas options are sized to have at least 80% of the peak heating load to meet the energy goals of the campus. Biodiesel and gas boilers are sized for resiliency for 80% of the design capacity. The options with biodiesel are carbon neutral while the gas boilers options are >95% carbon neutral.

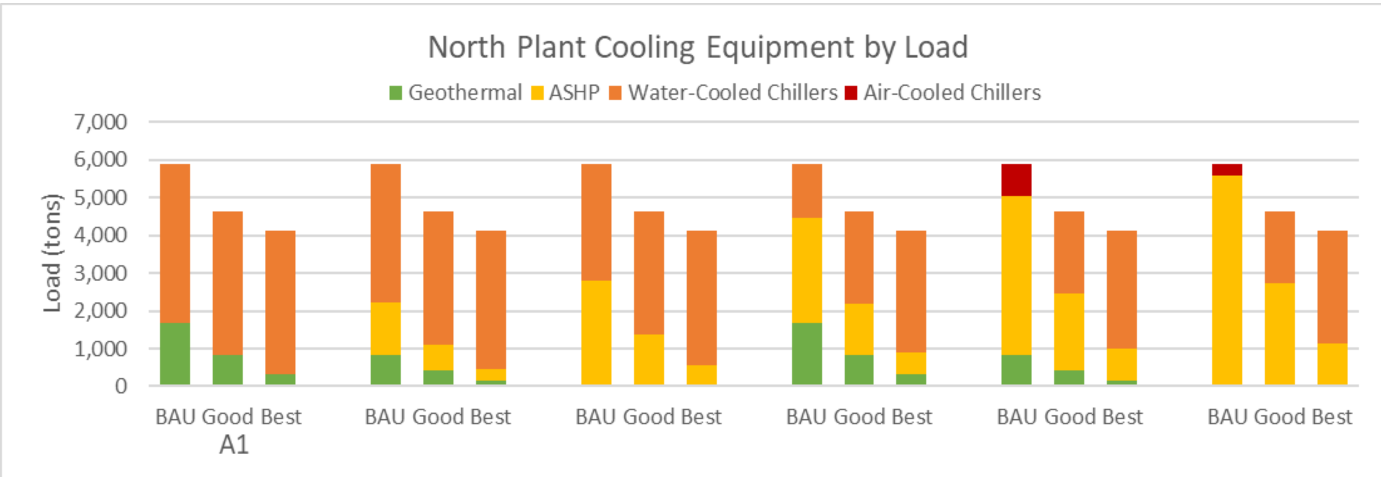
The chart below shows the 18 North Plant options and the associated ground-source heat pump, air-source heat pump, biodiesel boiler and gas boiler capacities.



Cooling loads by Equipment

The primary cooling equipment for the new North Campus plant will consist of ground-source heat pumps, air-source heat pumps, air-cooled chillers and water-cooled chillers with cooling towers. The sizing of ground-source heat pumps and air-source heat pumps are based on the heating design loads. The sizing of the air-cooled chiller and water-cooled chiller plant options are based on the remaining load for the option. Air-cooled was used when the remaining cooling load was less than 1,000 tons.

The chart below shows the 18 North Plant options and the associated ground-source heat pump, air-source heat pump, air-cooled chiller and water-cooled chiller capacities.



North Campus Life-Cycle Cost Analysis

A life-cycle cost analysis (LCCA) provides an estimate of the total net present cost of ownership including construction costs, maintenance costs, equipment replacement costs and energy costs over a given study period. The analysis assumes construction would start in 2025 and include costs through 2050.

The discount rate, escalation rates, equipment life, and study length are shown in the table below.

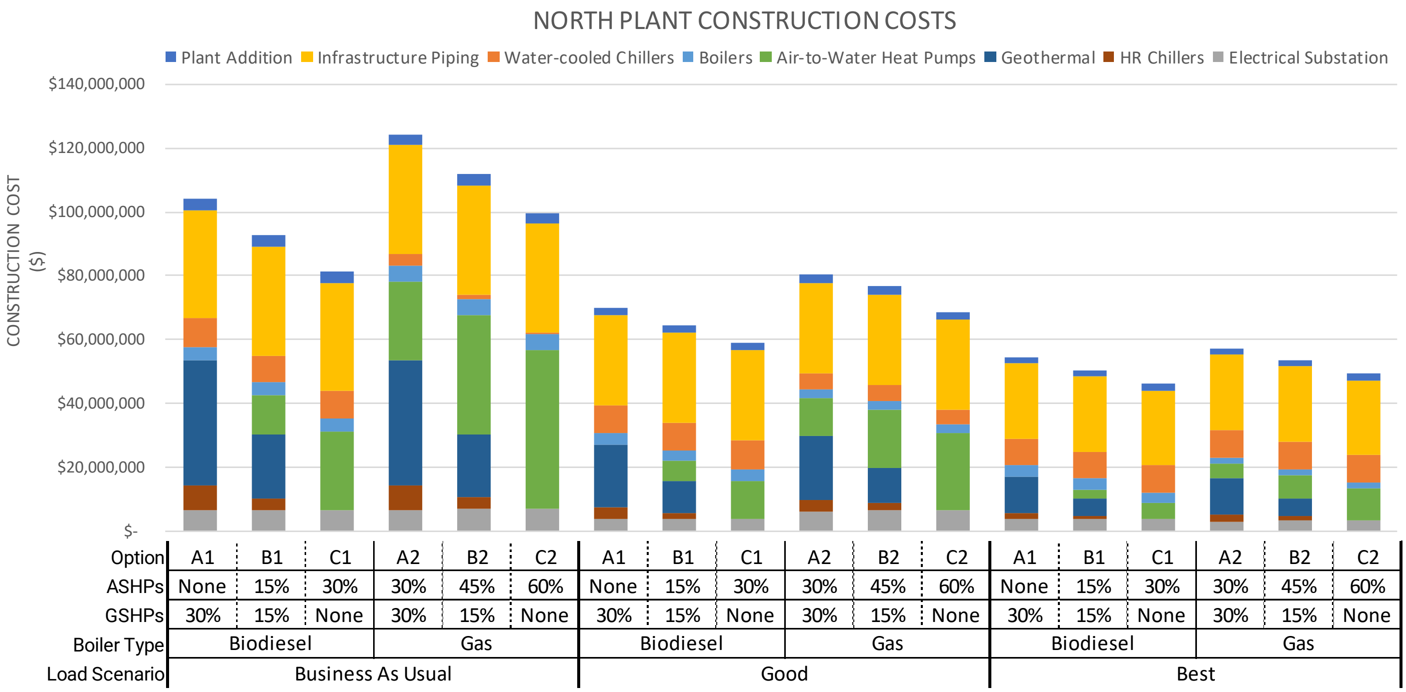
INPUT	VALUE
Discount Rate	5%
Maintenance Escalation Rate	3%
Utility Escalation Rate	3%
Escalation Rate of Future Costs	3%
Equipment Life	Pumps and heat pumps: 15 years Boilers and chillers: 25 years
Study Length	25 years

The utility rates used in the analysis have been provided by UMass Lowell. The electricity rate is 0.132 $/kWh, the gas rate is 9.36 $/MMBtu and the biodiesel rate is 3.50 $/gallon. The maintenance costs include the costs associated with equipment as well as costs to staff the plant.

Construction Costs

The plant construction costs have been estimated based on costs in today's dollars to have a clear relative comparison of construction costs between the options, regardless of when plant equipment is installed. The options include an addition located to the northeast of the existing boiler plant to house the cooling plant equipment including centrifugal chillers, heat recovery chillers, pumps, etc with the cooling towers and some of the air-source heat pumps on the roof. The remainder of the air-source heat pumps will be located on the roof of the adjacent building.

The chart below shows the costs for the central plant for all options and all load scenarios. Each option shows the load scenario (Business as Usual, Good and Best), the boiler type (biodiesel and gas), and the percent of peak heating capacity is ground-source and air-source heat pumps.

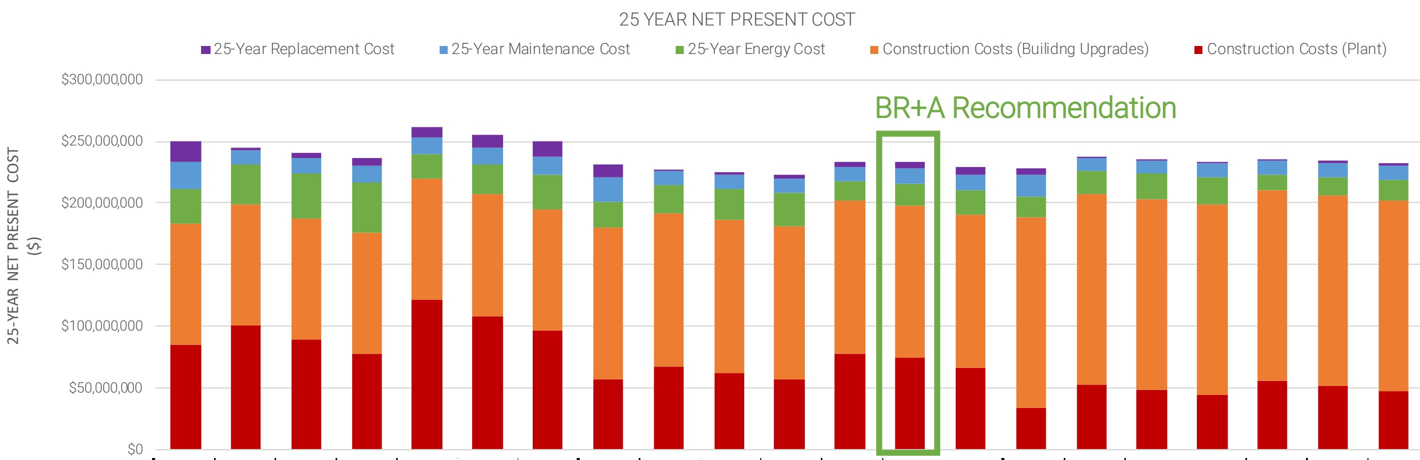


A few things stand out.

1. Reducing peak load at the buildings reduces the construction cost of the north campus plant because it reduces the amount of mechanical equipment required to heat and cool the buildings.
2. Increasing the air-source heat pumps to eliminate boiler use results in an increase in construction cost. The construction cost per btu of heat at design day is much higher for an air-source heat pump than a biodiesel boiler.
3. The cost of geothermal is relatively low when comparing to air-source heat pumps operating at low outdoor air conditions. Geothermal exchanges heat with the ground and therefore does not operate at a reduced capacity at low ambient. It is possible in the future for air-to-water heat pumps to maintain nominal capacity and hot water supply temperatures at low ambient, but currently most manufacturers do not.

Life-cycle Cost Analysis Results

The chart below shows the life-cycle cost for all options and all load scenarios compared to the building stand-alone (SA). Each option shows the load scenario (Business as Usual, Good and Best), the boiler type (biodiesel and gas), and the percent of peak heating capacity is ground-source and air-source heat pumps. Note that to meet the alternative energy goals, the gas boiler options are required to have more air-source heat pumps, with the gas boilers for only when the outdoor air temperature is below the 99% winter design temperature and emergency operation.



Load Scenario	Business As Usual						
Option	SA	A1	B1	C1	A2	B2	C2
ASHPs	100%	None	15%	30%	30%	45%	60%
GSHPs	n/a	30%	15%	None	30%	15%	None
Boiler Type	n/a	Biodiesel			Gas		

Load Scenario	Good						
Option	SA	A1	B1	C1	A2	B2	C2
ASHPs	100%	None	15%	30%	30%	45%	60%
GSHPs	n/a	30%	15%	None	30%	15%	None
Boiler Type	n/a	Biodiesel			Gas		

Load Scenario	Best						
Option	SA	A1	B1	C1	A2	B2	C2
ASHPs	100%	None	15%	30%	30%	45%	60%
GSHPs	n/a	30%	15%	None	30%	15%	None
Boiler Type	n/a	Biodiesel			Gas		

Recommendation

BR+A recommends the north campus select a central plant to centralize maintenance and provide more reliability. The "Good B2 – Light Geo + Air-source + Gas Boilers" offers the best balance of load reductions, energy efficiency and future flexibility. The "Good B2 – Light Geo + Air-source + Biodiesel Boilers" option offers similar benefits, with the one caveat being the use of biodiesel boilers for a portion of the heating load. Using the "Good" load scenario accounts for some buildings being designed to meet the "best scenario", some only able to achieve "Good" and some remaining as "Business as Usual". This is to account for unforeseen circumstances as the building upgrades are pursued.

The plant equipment installs a high efficiency geothermal closed-loop geothermal heat exchanger below the two parking lots to the north of the plant. Ground-source heat pumps are more efficient, have a longer expected life and are more reliable than air-source heat pumps. Since the site cannot accommodate the full heating load with geothermal, air-source heat pumps are used for a portion of the peak heating load. The option allows the plant to continue to use the gas steam boilers until the hot water and chilled water distribution is in place and the steam boilers can be taken offline. At that time, a final decision regarding gas vs biodiesel boilers can be made. Biodiesel may be more common and cost effective in the future and therefore use biodiesel in place of heat pumps may be more desirable to achieve the carbon neutral goals by 2050.

South Campus Energy Efficiency Results

Project profiles were developed for each building on the South Campus pilot building are developed in order to evaluate and quantify energy, emissions, and heating/cooling load impacts. Measures were identified by using the ASHRAE Level I Audit procedure. Two scenarios - "Good" and "Best" – were detailed in order to outline the range of opportunities compared to a Default/Business-As-Usual ("BAU") Case. The BAU case was defined as the 2019 energy use profiles adjusted for key factor including expanded lab operations, added cooling, and centralized ventilation. Energy end use breakdowns were estimated based building core end use given the lack of campus submetering. Current and future 2050 carbon emissions were quantified using values from the "30-year Forecast Preliminary Report." Heating and cooling loads were quantified in order to enable evaluation of central vs. decentralized scenarios. Air-side energy recovery and envelope are the key strategies outlined to reduce heating and cooling loads.

Compared to the Default/Business-As-Usual ("BAU") Case, the South Campus, "Good" case is expected to achieve a 47% energy reduction and 35% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast), the emissions reduction is expected to be closer to 70%. The South Campus, "Best" case is expected to achieve a 53% energy reduction and 43% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast"), the emissions reduction is expected to be closer to 74%.

The reductions outlined above are expected to greatly exceed the EUI and emissions requirements of Executive Order No. 594. The remaining emissions can be offset with renewables sources.

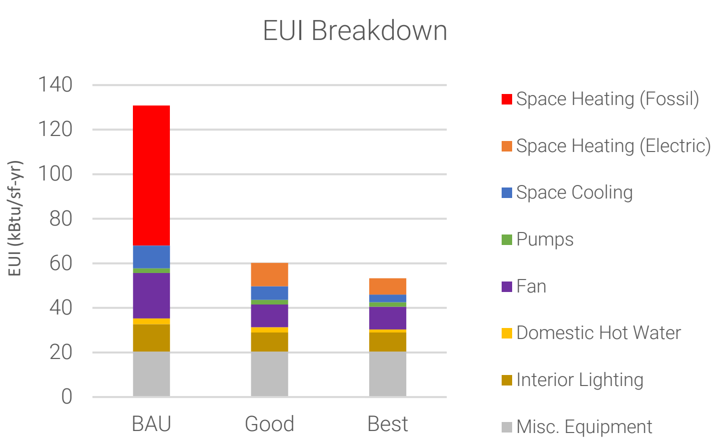
Based on decisions made by UML regarding the North Campus, the Team will evaluate the viability of centralized heating/cooling systems on the South Campus.

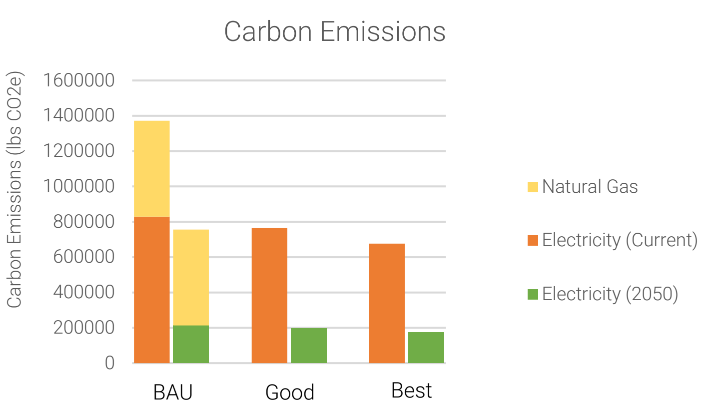
Durgin Hall

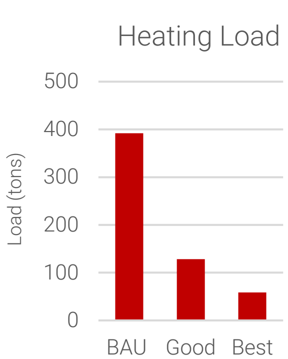
Campus	South Campus
Core End Use	Office/Classroom
Square Footage	70865
Last Major Renovation	2019

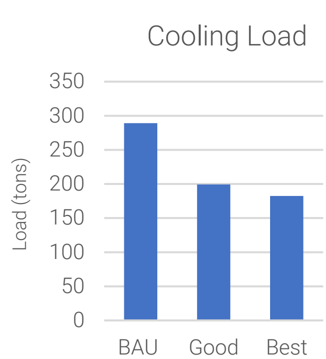
Building Summary

Durgin Hall is an office/classroom building with performance space on the South Campus. It has a Building Score of 67. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of envelope upgrades, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5c - Air-side Systems - Constant to variable volume
ECM 5e - Air-side Systems - Airflow setbacks
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

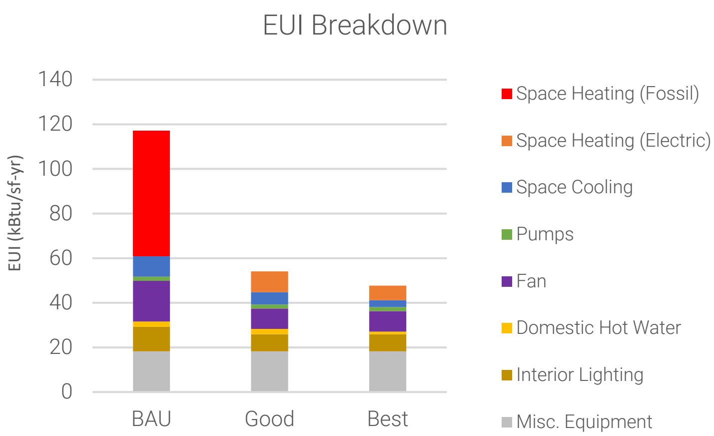
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

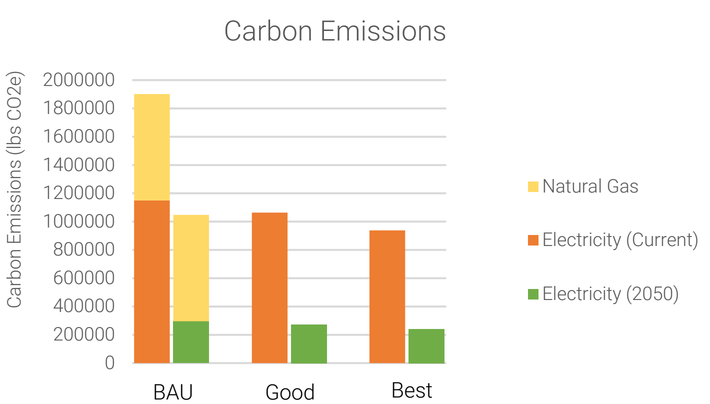
O'Leary Library

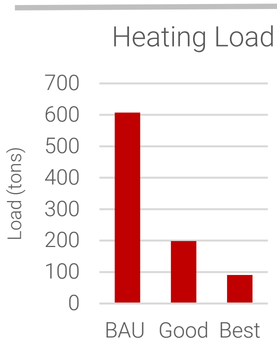
Campus	South Campus
Core End Use	Office/Classroom
Square Footage	109788
Last Major Renovation	2019

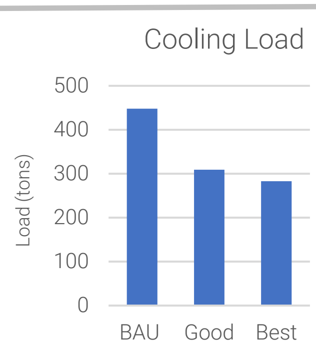
Building Summary

O'Leary Library building is an office/classroom building on the South Campus. It has a Building Score of 68. This makes it a higher priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 5e - Air-side Systems - Airflow setbacks
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

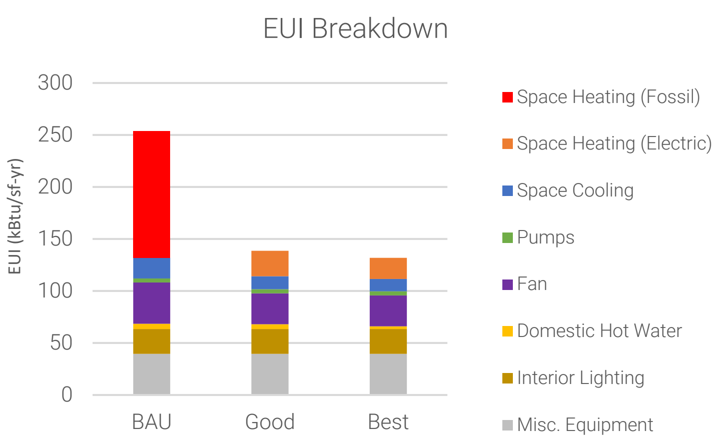
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

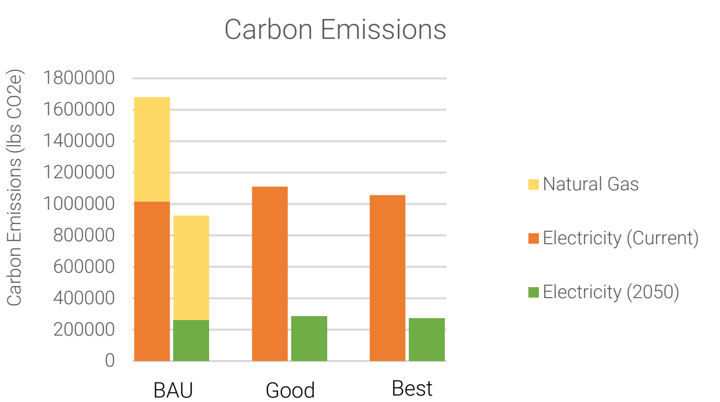
McGauvran Center

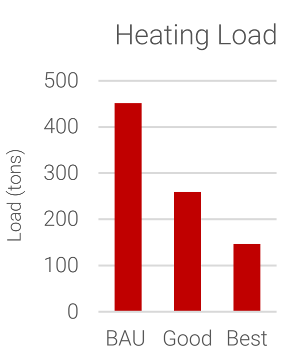
Campus	South Campus
Core End Use	Lab
Square Footage	44756
Last Major Renovation	2015

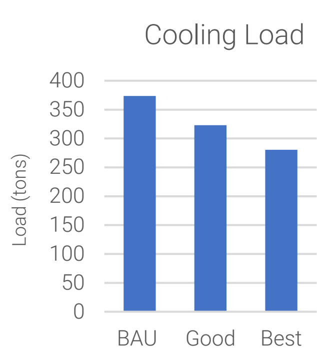
Building Summary

McGauvran Center is an office/classroom building with dining on the South Campus. It has a Building Score of 62. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, and energy efficient heating and cooling systems. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Air-cooled Chiller
High-quality envelope; new insulation and new windows and doors

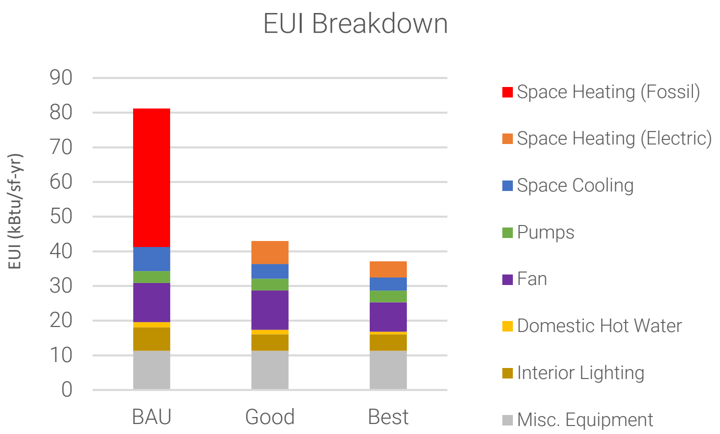
Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

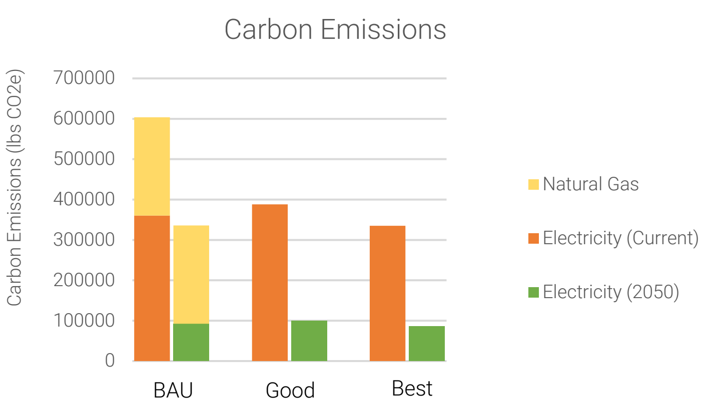
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

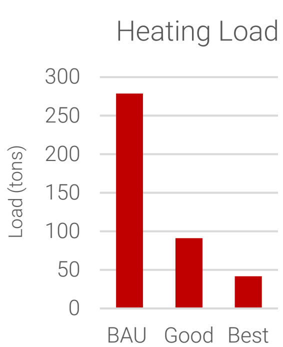
Mahoney Hall

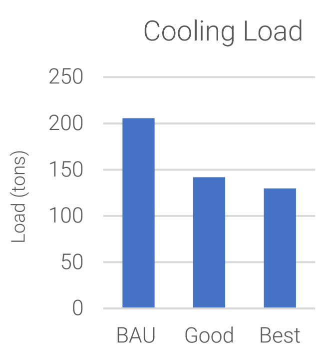
Campus	South Campus
Core End Use	Office/Classroom
Square Footage	50394
Last Major Renovation	1960

Building Summary
Mahoney Hall is an office/classroom building on the South Campus. It has a Building Score of 60. This makes it a high priority for energy efficiency improvements particularly given direct steam systems. The business as usual case assume added central ventilation and cooling. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Direct Steam
Window AC
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10a - Controls - DDC
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

Dugan Hall

Campus	South Campus
Core End Use	Office/Classroom
Square Footage	52643
Last Major Renovation	1962

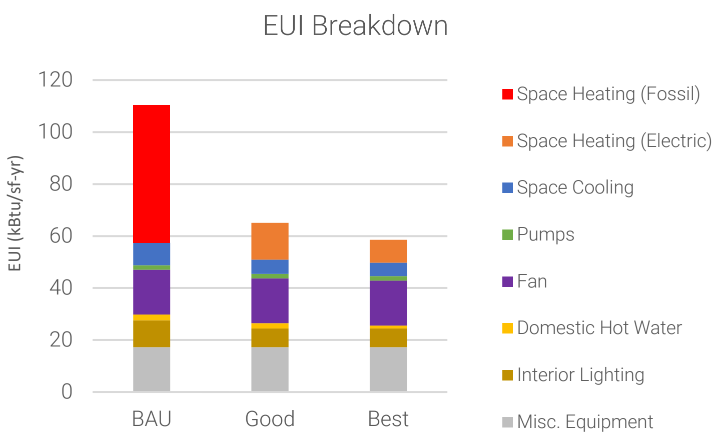
Building Summary

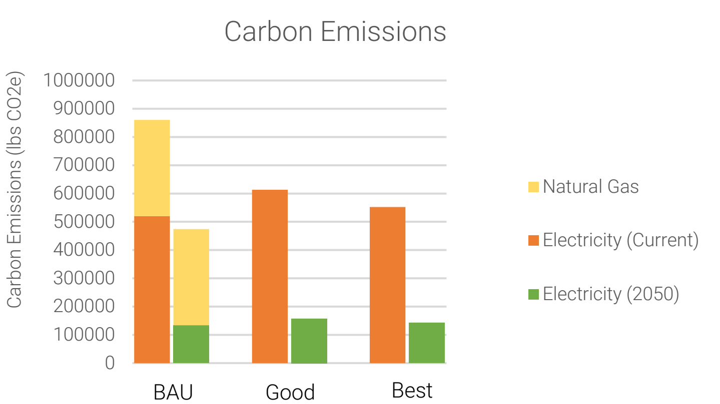
Dugan Hall is an office/classroom building on the South Campus. It has a Building Score of 56. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of envelope upgrades, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

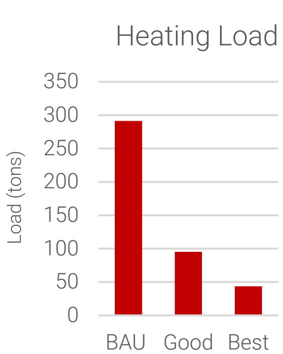
Current
Steam-to-HHW
DX Cooling
Candidate for envelope improvements

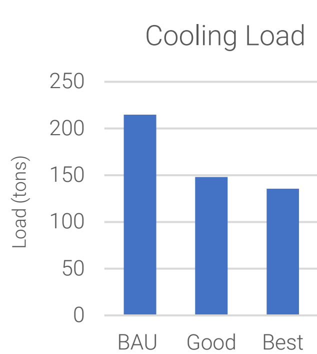
Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater









Concordia Hall

Campus	South Campus
Core End Use	Residential
Square Footage	41380
Last Major Renovation	1966

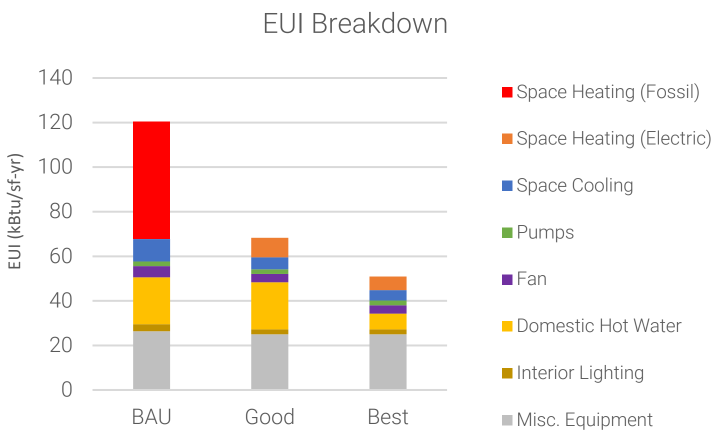
Building Summary

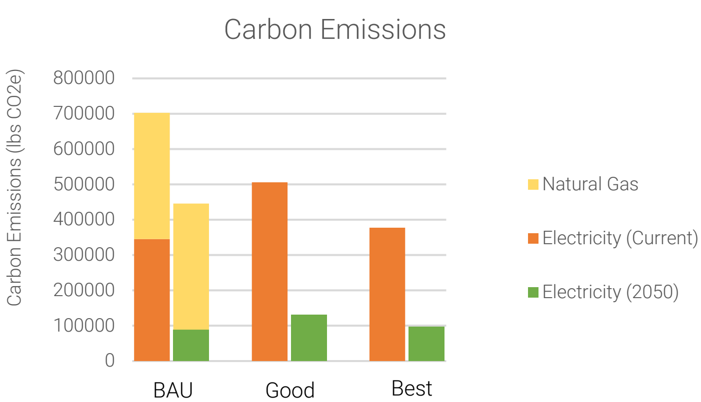
Concordia Hall is residential building on the South Campus. It has a Building Score of 72. This makes it a higher priority for energy efficiency improvements particularly given direct steam systems. The business as usual case assumes ventilation and cooling will be added. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.

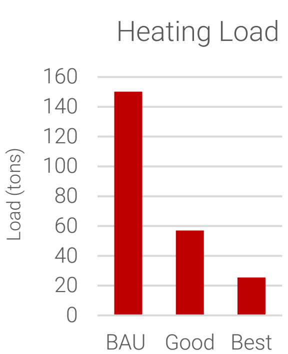
Current
Steam-to-HHW
No cooling
Candidate for envelope improvements

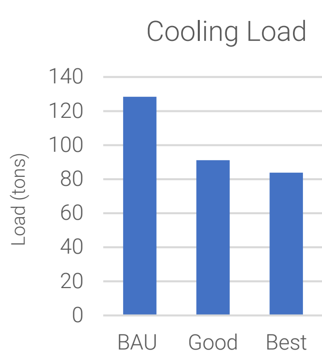
Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7a - Water-side Systems - Standalone VRF
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9e - Plumbing - ASHP Water Heater with Storage







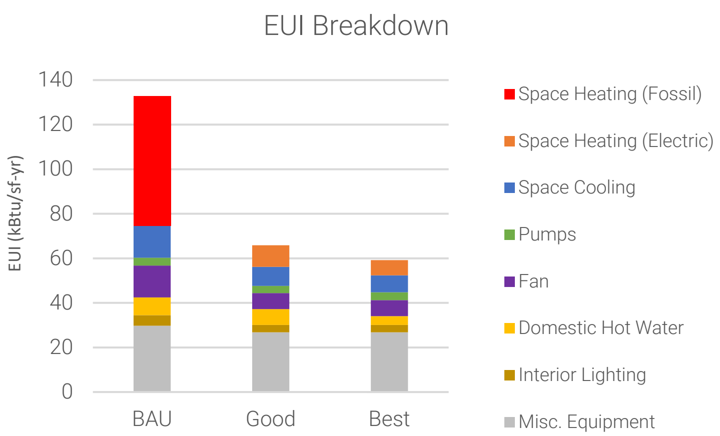


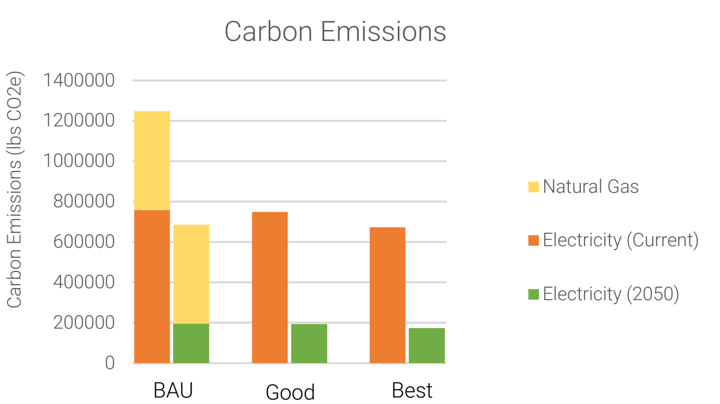
Weed Hall

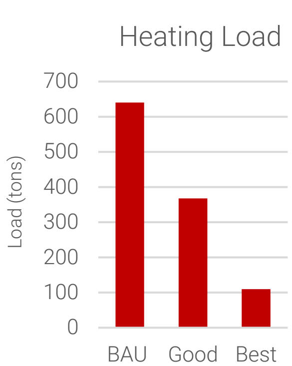
Campus	South Campus
Core End Use	Lab
Square Footage	63469
Last Major Renovation	1966

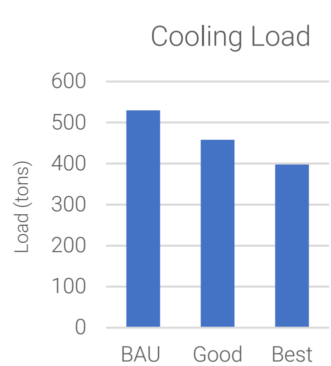
Building Summary

Weed Hall is an lab building on the South Campus. It has a Building Score of 59. This makes it a higher priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
Steam-to-HHW
Water-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5b - Air-side Systems - Decoupled systems
ECM 5d - Air-side Systems - Constant to variable volume
ECM 9c - Plumbing - Electric Water Heater
ECM 6c - Air-side Energy Recovery - 50% (Runaround Coil)
ECM 7c - Water-side Systems - Pump VFDs
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11b - Process Loads - Filtered Fume Hoods
ECM 11c - Process Loads - Low Flow Fume Hoods
ECM 11d - Process Loads - Fume Hood Vacancy Sensors
ECM 11f - Process Loads - Energy Star Office Equipment

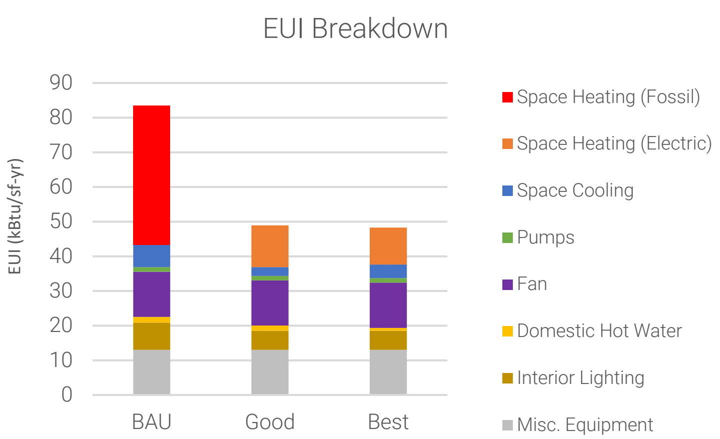
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 5f - Air-side Systems - Aircuity, particle counters
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)
ECM 9b - Plumbing - Instantaneous Water Heater

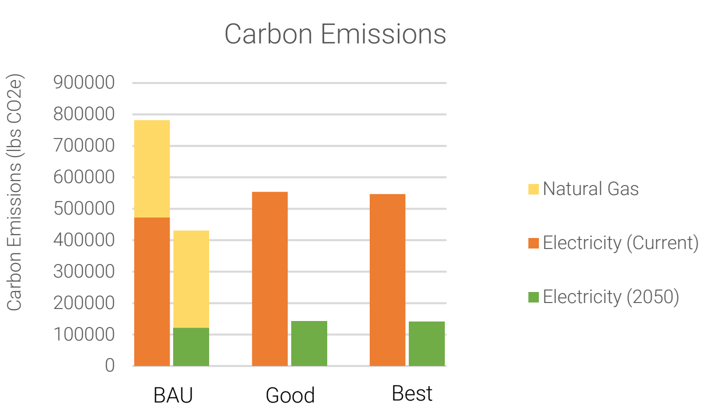
Health & Social Sciences Building

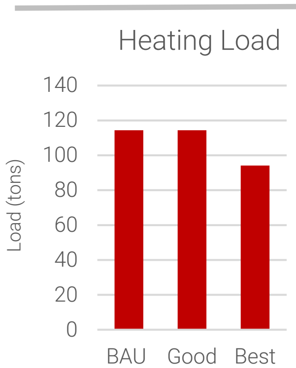
Campus	South Campus
Core End Use	Office/Classroom
Square Footage	63237
Last Major Renovation	2013

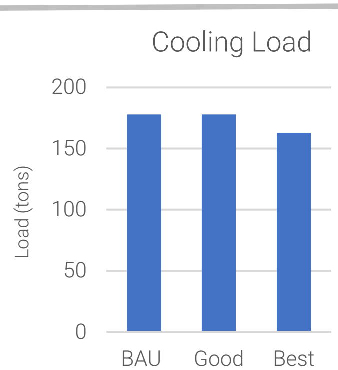
Building Summary

The Health & Social Sciences Building is an office/classroom building with some dry labs on the South Campus. It has a Building Score of 46. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy efficient heating and cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
Steam-to-HHW
Water-cooled Chiller
High-quality envelope; new insulation and new windows and doors

Good
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5e - Air-side Systems - Airflow setbacks
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

150 Wilder - Desmarais House

Campus	South Campus (satellite)
Core End Use	Office
Square Footage	5317
Last Major Renovation	1905

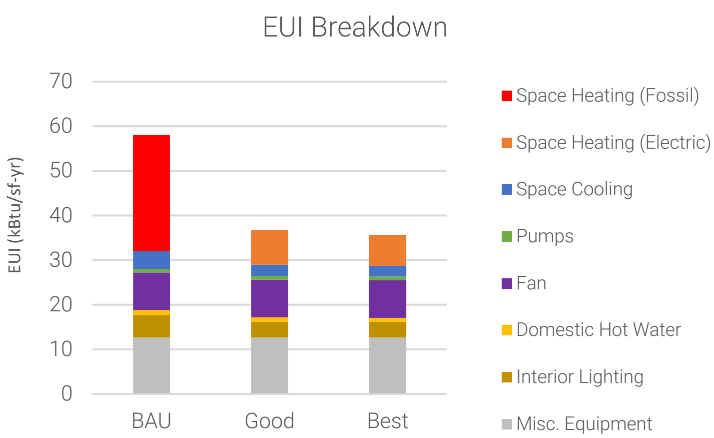
Building Summary

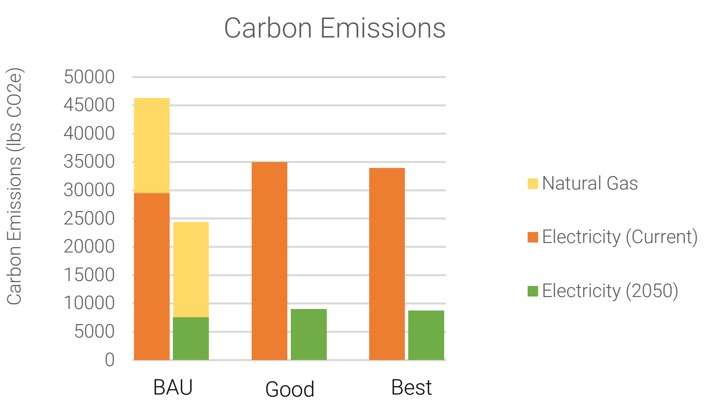
Desmarais House is a small office building on the South Campus. It has a Building Score of 33. This makes it a lower priority as it relates to energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Improved envelope reduce heating and cooling loads.

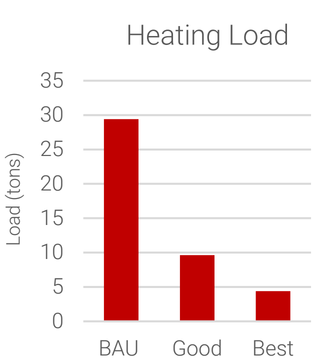
Current
Steam Boiler (local)
No Cooling
Candidate for envelope improvements

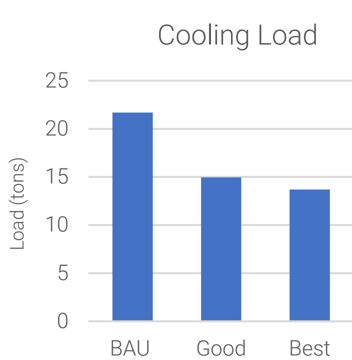
Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-paned
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10a - Controls - DDC
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 7a - Water-side Systems - Standalone VRF
ECM 9b - Plumbing - Instantaneous Water Heater







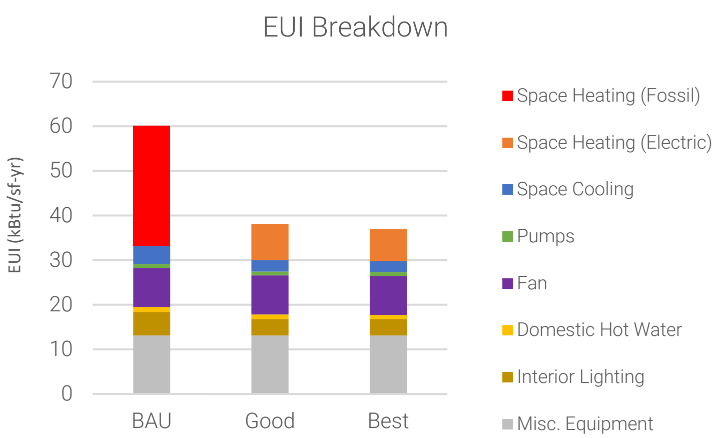


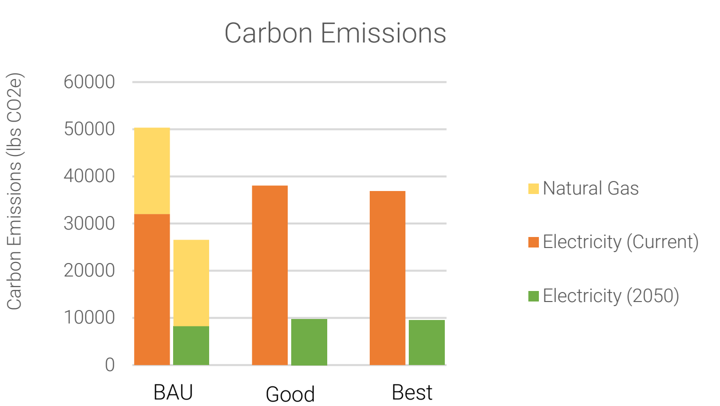
820 Broadway

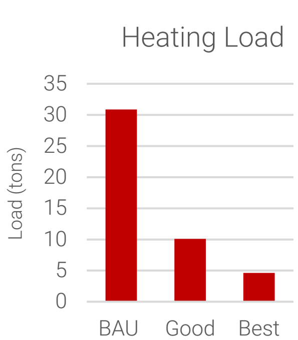
Campus	South Campus (satellite)
Core End Use	Office
Square Footage	5583
Last Major Renovation	1890

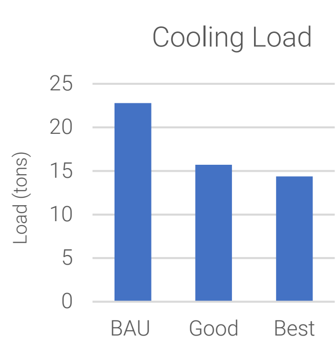
Building Summary

820 Broadway is a small office building on the South Campus. It has a Building Score of 33. This makes it a lower priority as it relates to energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Improved envelope reduce heating and cooling loads.









Current
Steam Boiler (local)
No Cooling
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-paned
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10a - Controls - DDC
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 7a - Water-side Systems - Standalone VRF
ECM 9b - Plumbing - Instantaneous Water Heater

Coburn Hall

Campus	South Campus
Core End Use	Office/Classroom
Square Footage	67889
Last Major Renovation	2020

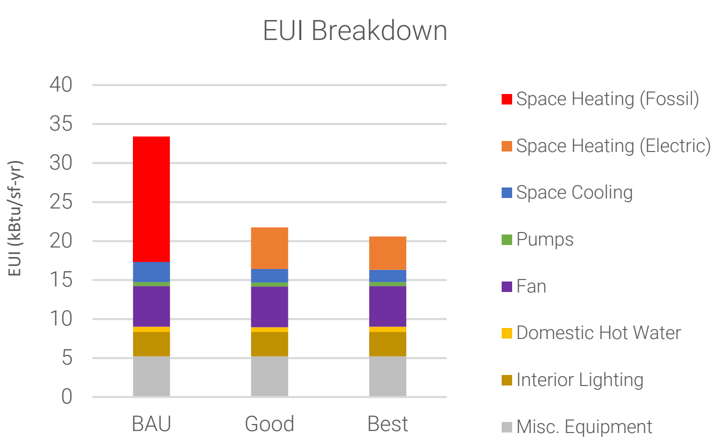
Building Summary

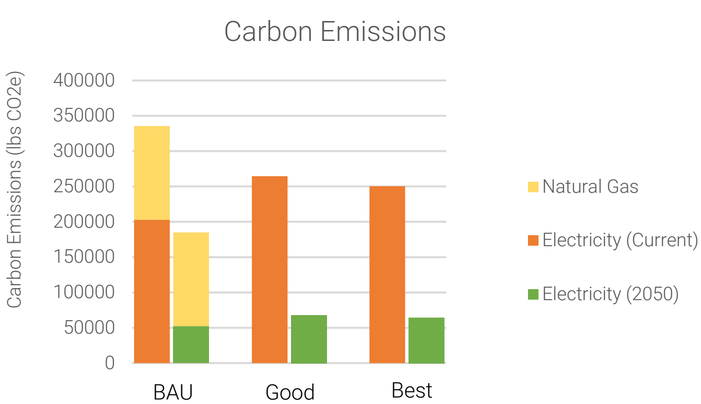
Coburn Hall is an office/classroom building on the South Campus. It has a Building Score of 18. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. Future carbon reduction is in result to electrified heating strategy. Minor envelope upgrades reduce heating and cooling loads.

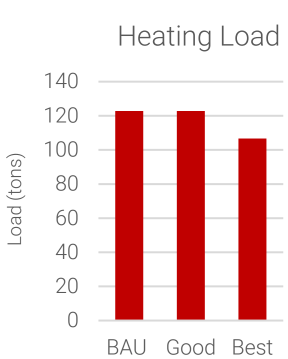
Current
Steam-to-HHW
Air-cooled Chiller
High-quality envelope; new insulation and new windows and doors

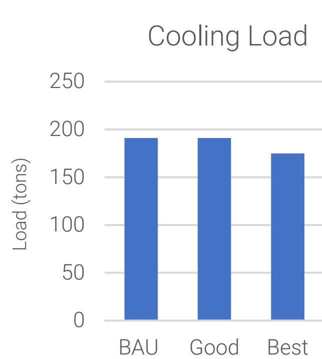
Good
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9a - Plumbing - Low Flow Fixtures
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater







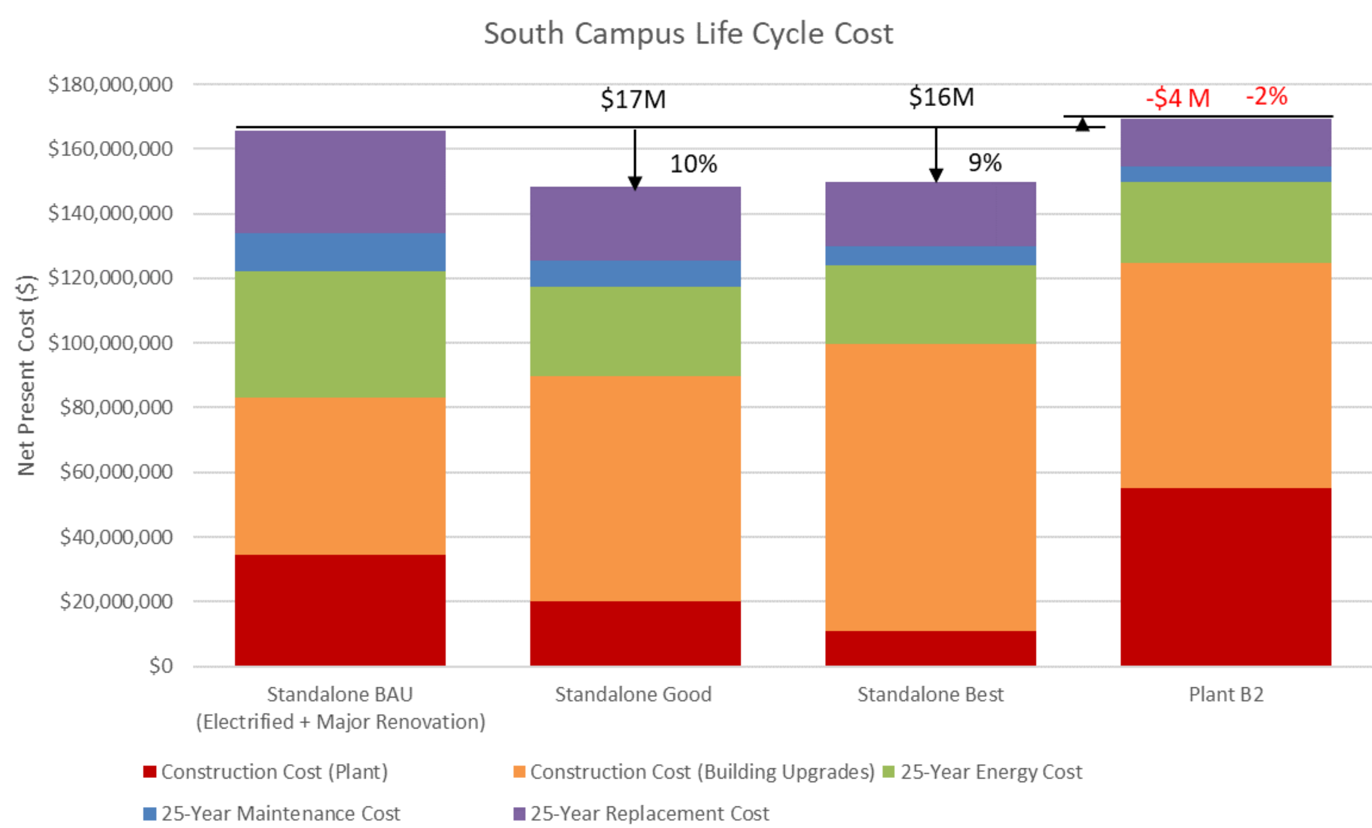


South Campus Plant Alternatives

The South Campus is currently served by three steam boilers that were replaced in 2015. The options for meeting the alternative energy requirements for the south campus buildings is to pursue stand-alone electrified heating and cooling plants or to install and expand the south campus central plant. These electrification options can be bundled with building upgrades under the "Good" or "Best" energy conservation bundles. These options are summarized below:

1. Stand-alone heating and cooling plants and code minimum building upgrades
2. Stand-alone with "Good" ECM package building upgrades
3. Stand-alone heating and cooling with "Best" ECM package building upgrades
4. Central Utility Plant using the North Campus "Good B2 – Light Geo + Air-source + Gas Boilers" Option for the south campus

The central plant options were vetted in the north central plant analysis and determined that the "Good B2 – Light Geo + Air-source + Gas Boilers" option was the best plant option. For the reasons described in the "Alternative Energy Measures Descriptions" of this report and the north plant analysis, converting to biodiesel is not be the best option from an emissions and operating cost perspective at this time. The chart below shows the 25-year life-cycle cost analysis for the South Campus Options for electrification.



Recommendation

BR+A recommends decentralizing the heating and cooling equipment for the south campus (Stand-alone Good in the chart). The reason for this is because it provides the best balance between construction cost and operating cost, resulting in the lowest life-cycle cost. Implementing a central hybrid ground-source / air-source system based on the analysis of from the north campus analysis would also not be life-cycle cost effective. There are a number of factors that results in a negative life-cycle cost compared to building stand-alone heating and cooling including:

1. The design heating load is lower than the north campus for the “Good” and “Best” options.
2. The piping distribution is higher due to a more spread out.
3. The building types are primarily residence halls and education buildings, which have low heating and cooling loads when the envelope and mechanical systems are improved.

The analysis shows that doing some building upgrades during major renovations should be performed to reduce heating and cooling loads and thus reducing heating and cooling equipment cost. It is expected that some buildings may be renovated to the “Best” bundle, some will be renovated to the “Good” scenario and some will remain as existing, making the “Good” scenario the best representative option that incorporates unforeseen factors.

East Campus Energy Efficiency Results

Project profiles were developed for each building on the East Campus pilot building are developed in order to evaluate and quantify energy, emissions, and heating/cooling load impacts. Measures were identified by using the ASHRAE Level I Audit procedure. Two scenarios - "Good" and "Best" – were detailed in order to outline the range of opportunities compared to a Default/Business-As-Usual ("BAU") Case. The BAU case was defined as the 2019 energy use profiles adjusted for key factor including expanded lab operations, added cooling, and centralized ventilation. Energy end use breakdowns were estimated based building core end use given the lack of campus submetering. Current and future 2050 carbon emissions were quantified using values from the "30-year Forecast Preliminary Report." Heating and cooling loads were quantified in order to enable evaluation of central vs. decentralized scenarios. Air-side energy recovery and envelope are the key strategies outlined to reduce heating and cooling loads.

The East Campus, "Good" case is expected to achieve a 41% energy reduction and 26% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast), the emissions reduction is expected to be closer to 68%. The East Campus, "Best" case is expected to achieve a 54% energy reduction and 43% emissions reduction. Based on future emissions rate (as detailed in the "30-Year Forecast"), the emissions reduction is expected to be closer to 75%. The remaining emissions can be offset with renewables sources.

The reductions outlined above are expected to greatly exceed the EUI and emissions requirements of Executive Order No. 594. The Investment Phase will detail how these projects can be structured in order to meet these requirement timelines.

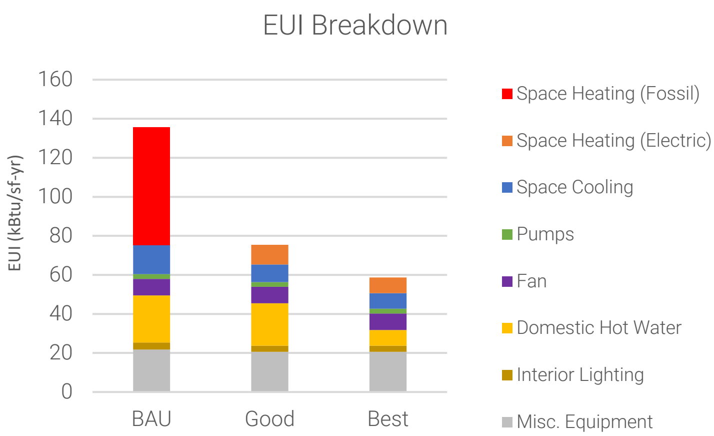
The East Campus is not expected to be an appropriate site for centralized heating/cooling systems given the lack of space type and load diversity; limited space in the urban environment; and relative locations of buildings to one another.

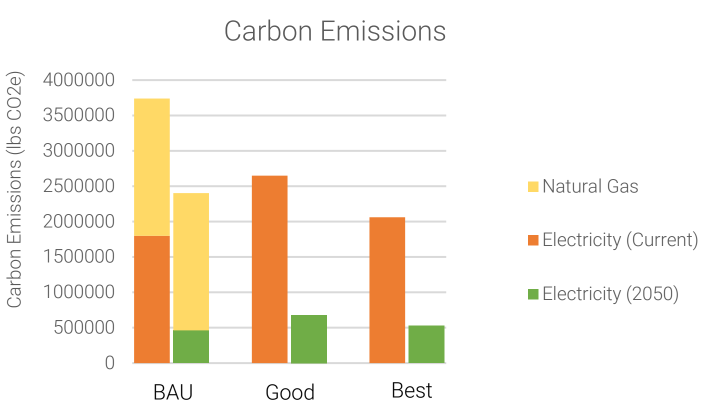
Fox Hall

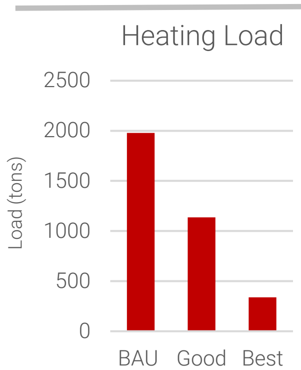
Campus	East Campus
Core End Use	Lab
Square Footage	196192
Last Major Renovation	2019

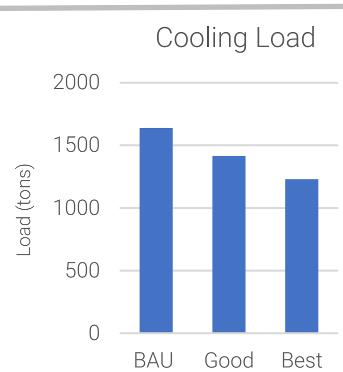
Building Summary

Fox Hall is a residential building with dining on the East Campus. It has a Building Score of 59. This makes it a high priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, high efficiency heating/cooling systems, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Air-cooled Chiller
Candidate for envelope improvements

Good
ECM 1a - Wall Insulation - R-10 continuous insulation
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8b - Lighting - Daylight Sensors
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11g - Process Loads - Energy Star Kitchen All-Electric Energy Star

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9e - Plumbing - ASHP Water Heater with Storage

River Hawk Village

Campus	East Campus
Core End Use	Residential
Square Footage	197841
Last Major Renovation	2017

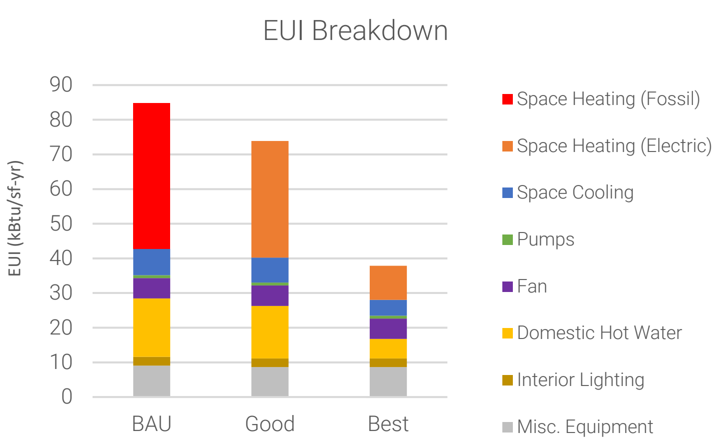
Building Summary

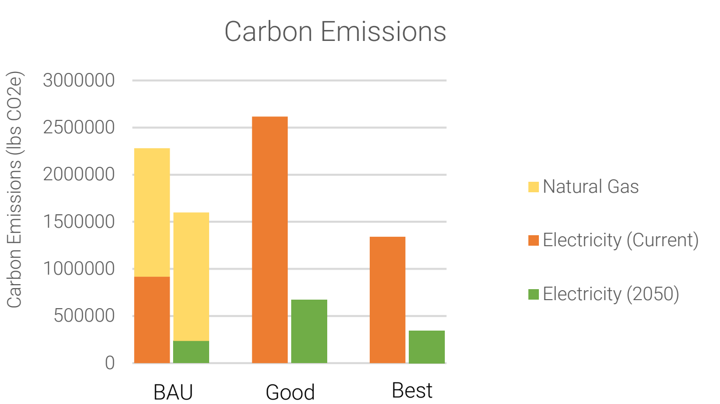
Riverhawk Village is a residential building on the East Campus. It has a Building Score of 56. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy recovery. Future carbon reduction is in result to electrified heating strategy. Energy recovery upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

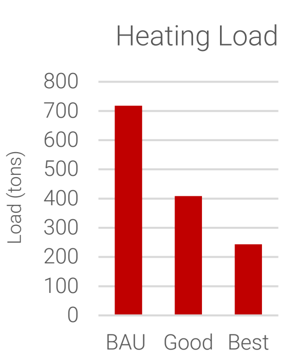
Current
HHW Boiler
WSHP
High-quality; new insulation and new windows and doors

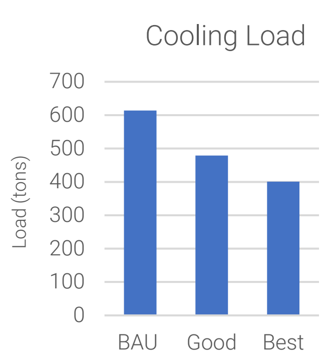
Good
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9e - Plumbing - ASHP Water Heater with Storage









Leitch Hall

Campus	East Campus
Core End Use	Residential
Square Footage	52768
Last Major Renovation	2014

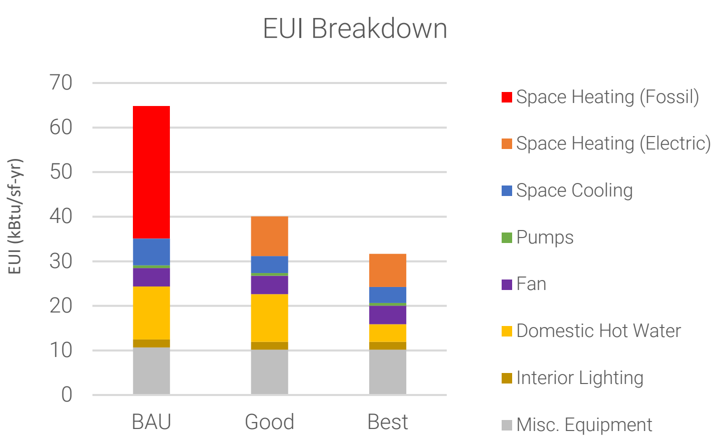
Building Summary

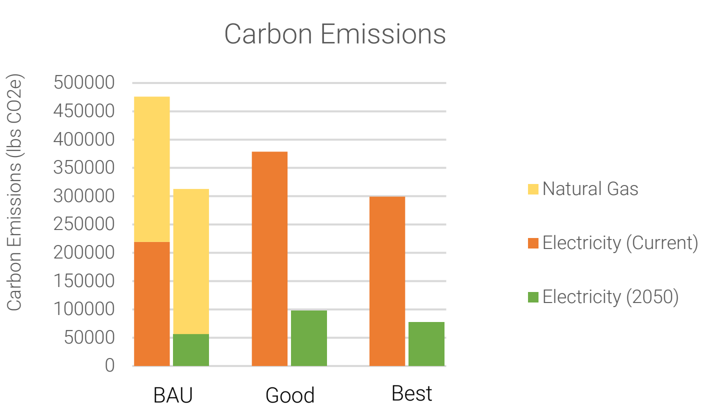
Leitch Hall is a residential building on the East Campus. It has a Building Score of 52. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

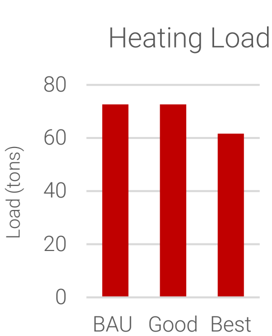
Current
HHW Boiler
DX Cooling
Acceptable envelope; original components

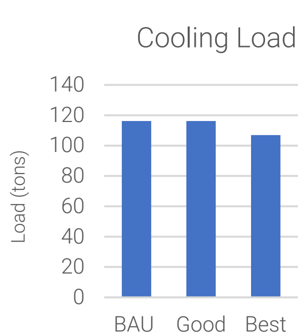
Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 7a - Water-side Systems - Standalone VRF
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9e - Plumbing - ASHP Water Heater with Storage





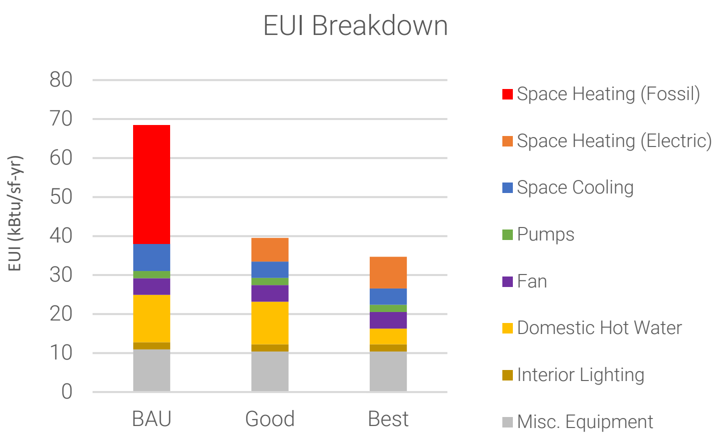


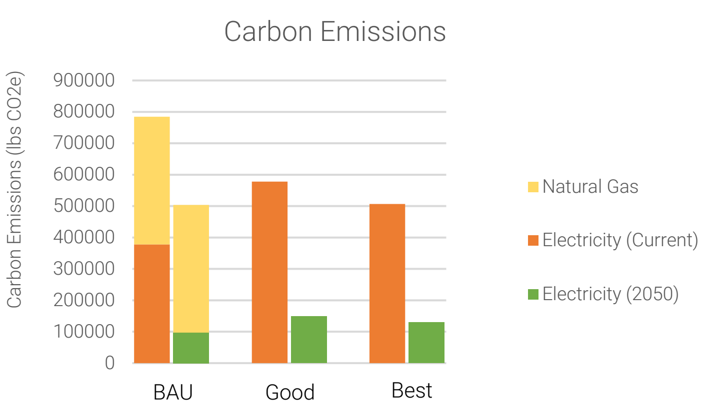


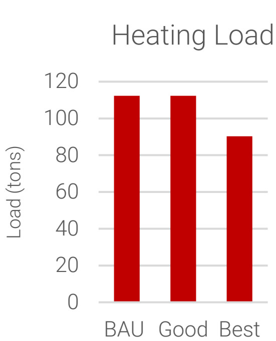
Donahue Hall

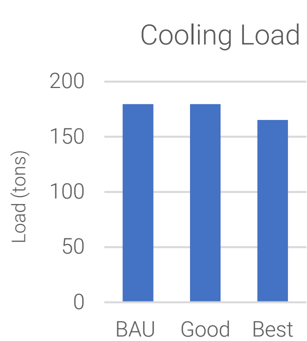
Campus	East Campus
Core End Use	Residential
Square Footage	81593
Last Major Renovation	2019

Building Summary
Donahue Hall is a residential building on the East Campus. It has a Building Score of 51. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.









Current
HHW Boiler
Water-cooled Chiller
Acceptable envelope; original components

Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7a - Water-side Systems - Standalone VRF
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change

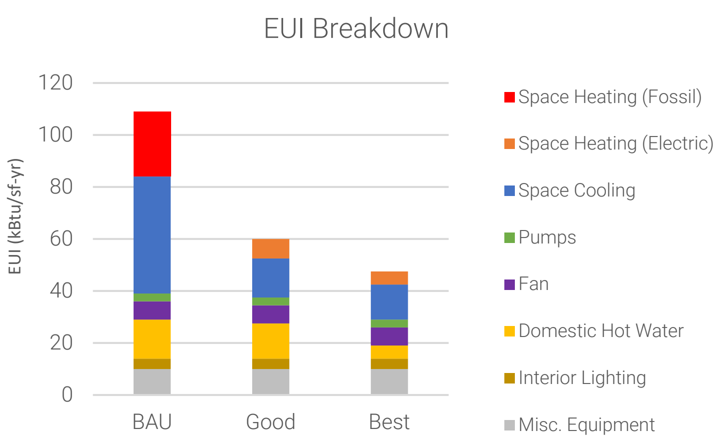
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9e - Plumbing - ASHP Water Heater with Storage

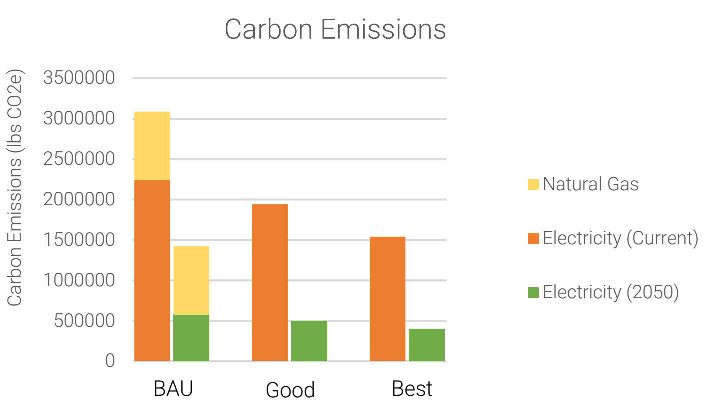
Tsongas Center at UMass Lowell

Campus	East Campus (satellite)
Core End Use	Other
Square Footage	181230
Last Major Renovation	2019

Building Summary

Tsongas Center is an ice rink with dining on the East Campus. It has a Building Score of 50. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.





Current
Steam Boiler (local)
Air-cooled Chiller
Acceptable envelope; original components

Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone WSHP
ECM 8b - Lighting - Daylight Sensors
ECM 10b - Controls - Retro-commissioning
ECM 11g - Process Loads - Energy Star Kitchen All-Electric Energy Star

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9e - Plumbing - ASHP Water Heater with Storage

UMass Lowell Inn & Conference Center

Campus	East Campus (satellite)
Core End Use	Residential
Square Footage	163946
Last Major Renovation	2019

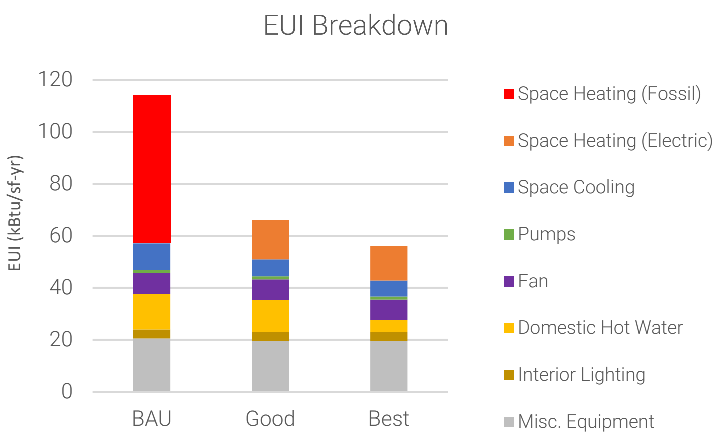
Building Summary

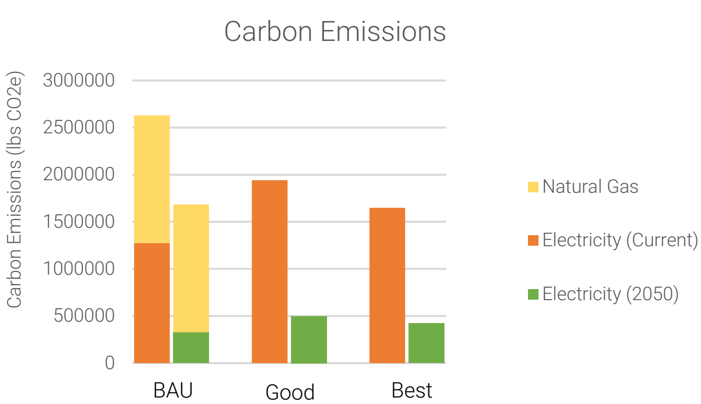
UMass Lowell Inn & Conference Center is a residential building on the East Campus. It has a Building Score of 49. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of air-side energy efficiency and high efficiency heating/cooling systems. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

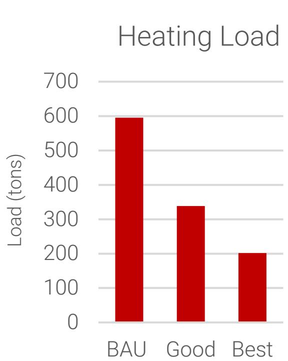
Current
Gas-Fired/Electric Heat
DX Cooling
Acceptable envelope; original components

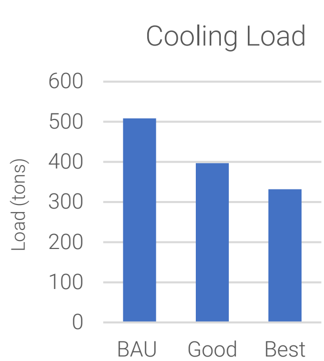
Good
ECM 7a - Water-side Systems - Standalone VRF
ECM 8b - Lighting - Daylight Sensors
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11g - Process Loads - Energy Star Kitchen All-Electric Energy Star

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 7b - Water-side Systems - Standalone AWHP









Campus Recreation Center

Campus	East Campus
Core End Use	Fitness
Square Footage	62185
Last Major Renovation	2019

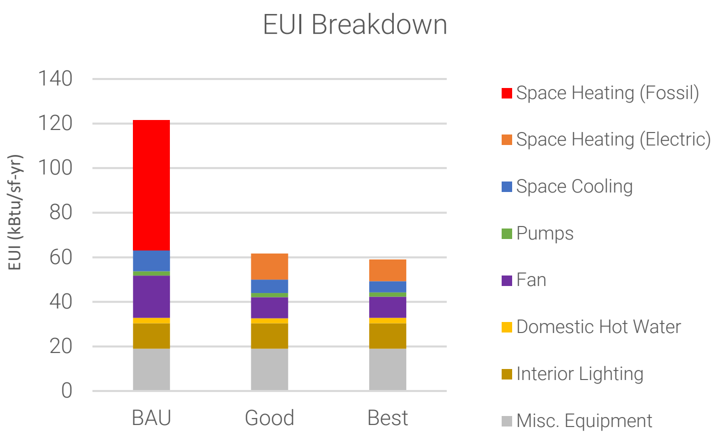
Building Summary

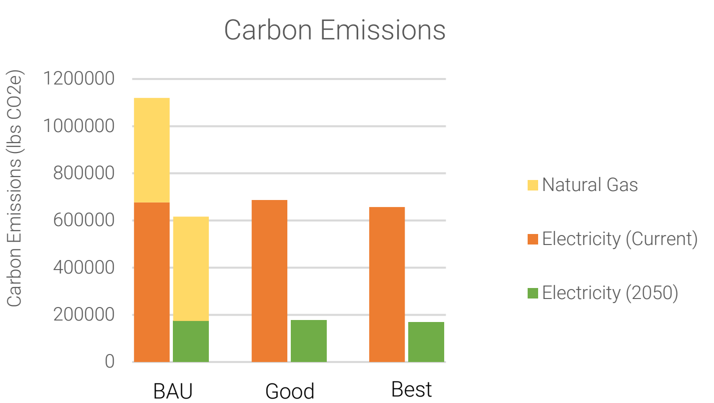
Campus recreation center is a fitness building on the East Campus. It has a Building Score of 47. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of air-side energy recovery, high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

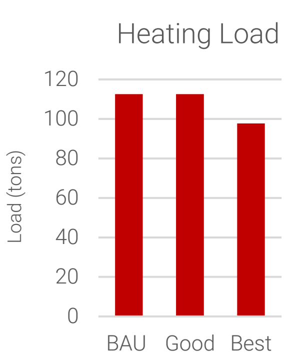
Current
HHW Boiler
Water-cooled Chiller
High-quality envelope; new insulation and new windows and doors

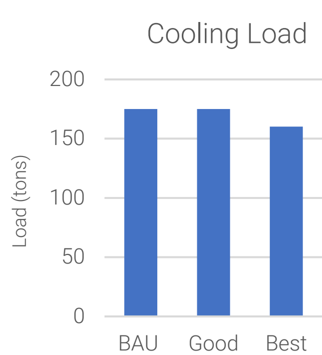
Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9e - Plumbing - ASHP Water Heater with Storage









Bourgeois Hall

Campus	East Campus
Core End Use	Residential
Square Footage	52979
Last Major Renovation	2014

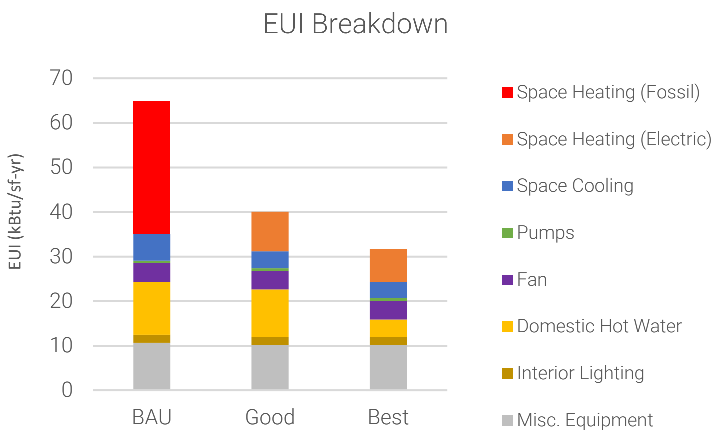
Building Summary

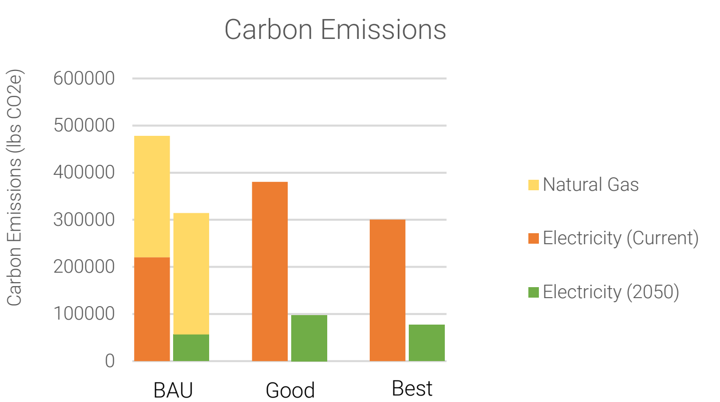
Bourgeois Hall is a residential building on the East Campus. It has a Building Score of 44. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.

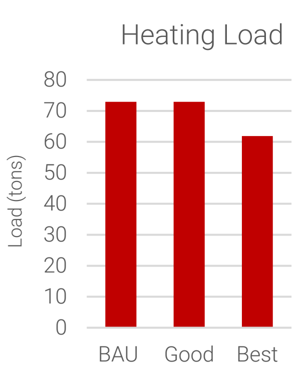
Current
HHW Boiler
DX Cooling
Acceptable envelope; original components

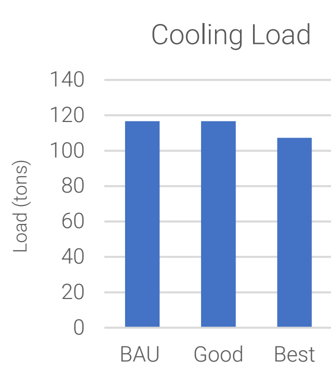
Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 7a - Water-side Systems - Standalone VRF
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9e - Plumbing - ASHP Water Heater with Storage







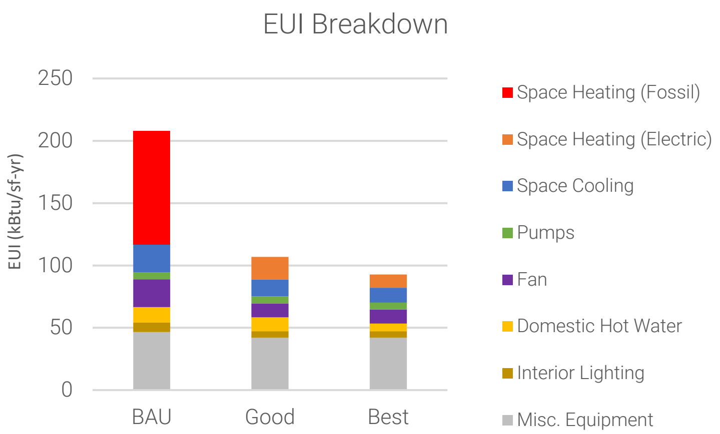


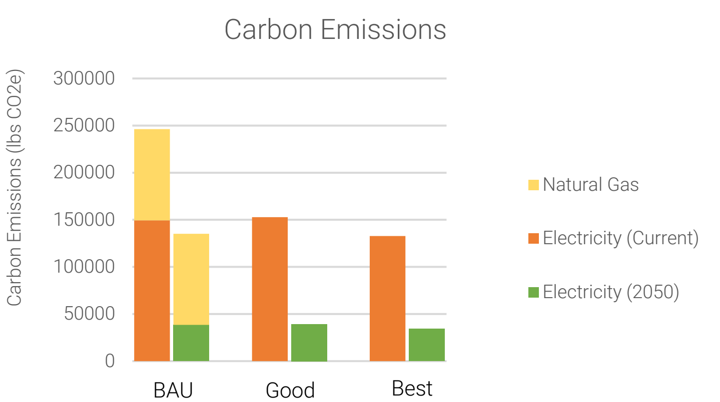
Ames Textile

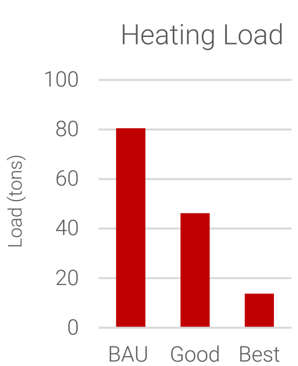
Campus	East Campus
Core End Use	Lab
Square Footage	7985
Last Major Renovation	2006

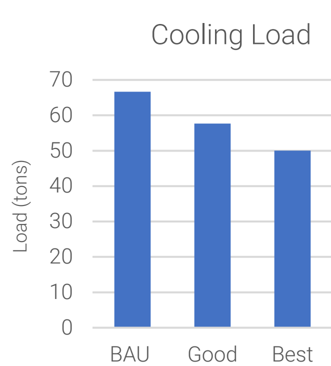
Building Summary

Ames Textile is small lab building on the East Campus. It has a Building Score of 41. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, and lighting controls. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
DX Cooling
Acceptable envelope; original components

Good
ECM 2a - Roof Insulation - R-30 continuous insulation
ECM 3a - Glazing U-value/SHGC - Double-pane
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5b - Air-side Systems - Decoupled systems
ECM 5d - Air-side Systems - Constant to variable volume
ECM 6c - Air-side Energy Recovery - 50% (Runaround Coil)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 7c - Water-side Systems - Pump VFDs
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9b - Plumbing - Instantaneous Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change
ECM 11f - Process Loads - Energy Star Office Equipment

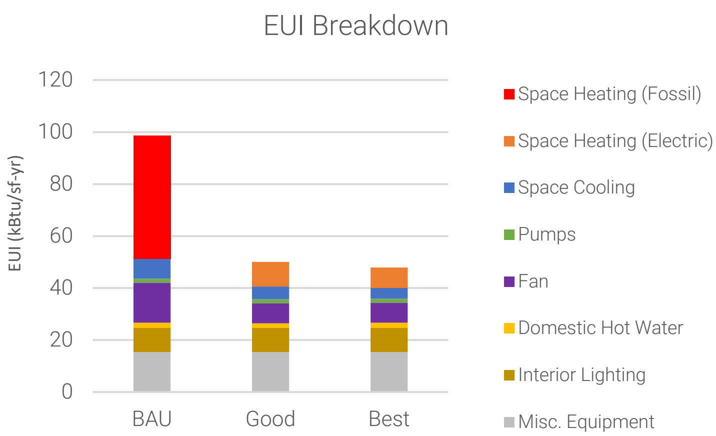
Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 5f - Air-side Systems - Aircuity, particle counters
ECM 6d - Air-side Energy Recovery - 70% (Konvekta/HP)

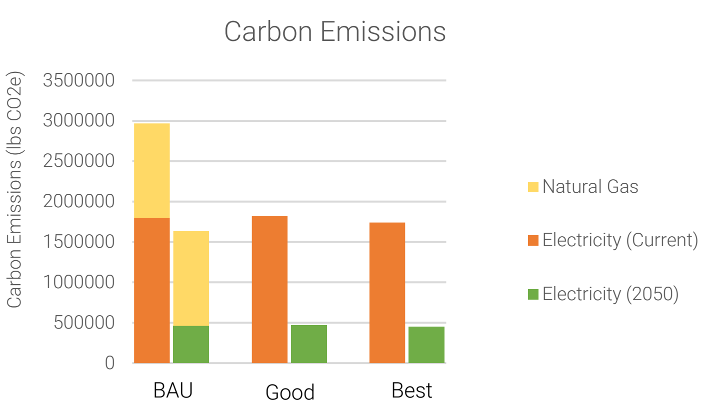
University Crossing

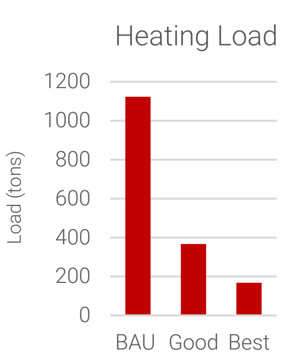
Campus	East Campus
Core End Use	Office/Classroom
Square Footage	202969
Last Major Renovation	2014

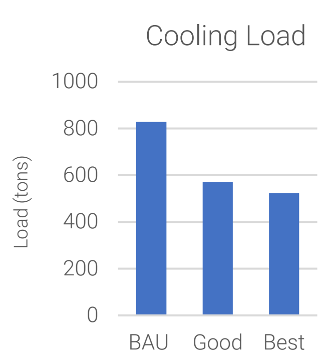
Building Summary

University Crossing is an office/classroom building with dining on the East Campus. It has a Building Score of 43. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. A current carbon increase would be a result of minor energy efficiency upgrades and electrified heating strategy. Minor envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper system operation.









Current
HHW Boiler
Water-cooled Chiller
High-quality envelope; new insulation and new windows and doors

Good
ECM 1a - Wall Insulation - R-10 continuous insulation*
ECM 3a - Glazing U-value/SHGC - Double-pane*
ECM 4a - Infiltration - 0.25 cfm/sf
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8b - Lighting - Daylight Sensors
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater

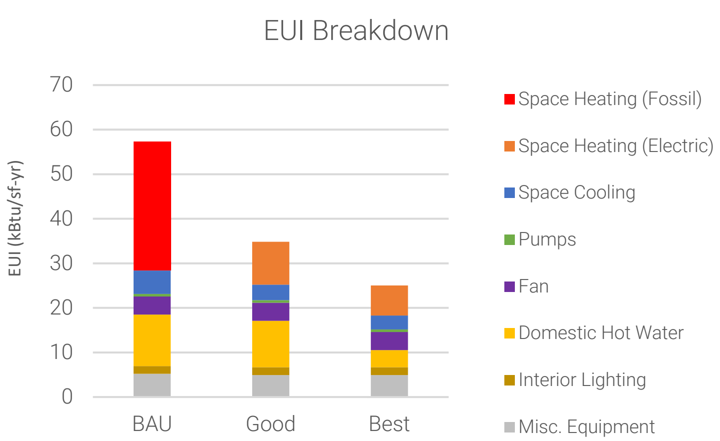
*Only applies to Salem Street

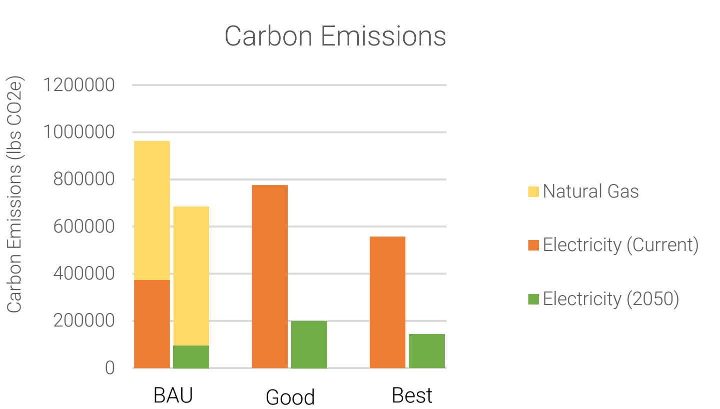
University Suites Residence Hall

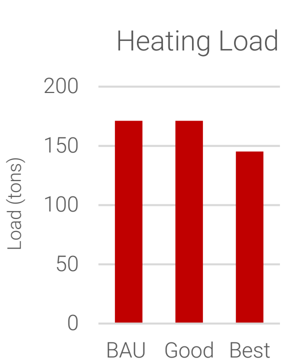
Campus	East Campus
Core End Use	Residential
Square Footage	124323
Last Major Renovation	2013

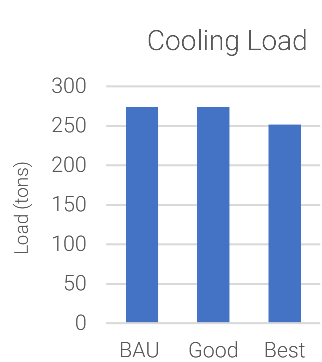
Building Summary

University Suites Residence Hall is a residential building on the East Campus. It has a Building Score of 39. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of high efficiency heating/cooling system. Future carbon reduction is in result to electrified heating strategy. Energy recovery upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Water-cooled Chiller
High-quality envelope; new insulation and new windows and doors

Good
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9d - Plumbing - Electric Water Heater with Storage
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11a - Process Loads - Behavior Change

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9e - Plumbing - ASHP Water Heater with Storage

Charles Hoff Alumni Scholarship Center

Campus	East Campus
Core End Use	Office
Square Footage	5815
Last Major Renovation	2014

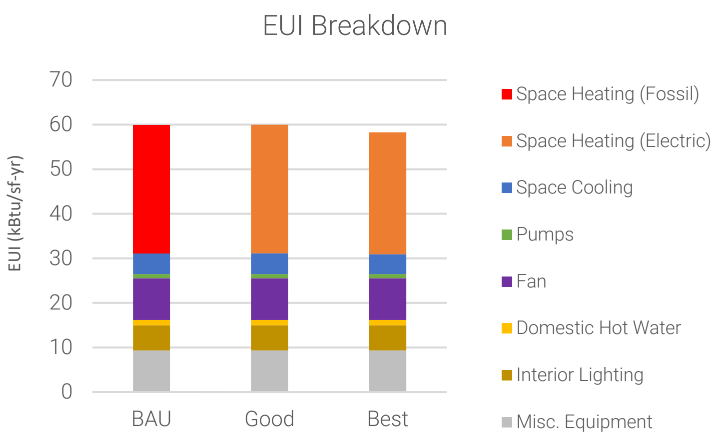
Building Summary

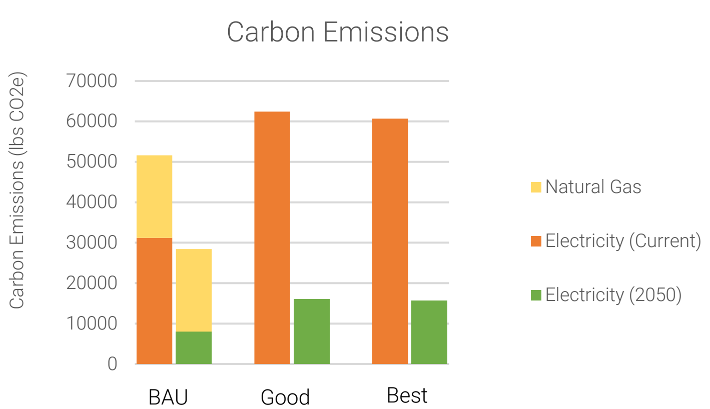
Charles Hoff Alumni Scholarship is an office building on the East Campus. It has a Building Score of 34. This makes it a medium priority for energy efficiency improvements. The EUI reduction in the Best case is a result of envelope upgrades. A current carbon increase would be a result of minor energy efficiency upgrades and electrified heating strategy. Natural ventilation is expected to be maintained.

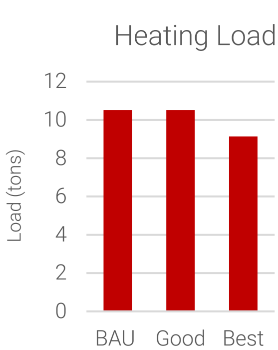
Current
Furnace
DX Cooling
High-quality envelope; new insulation and new windows and doors

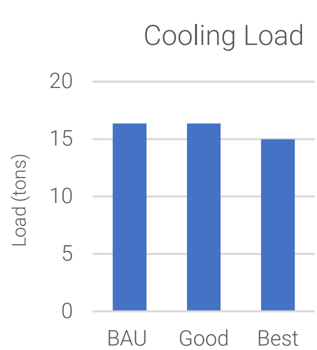
Good
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 9b - Plumbing - Instantaneous Water Heater







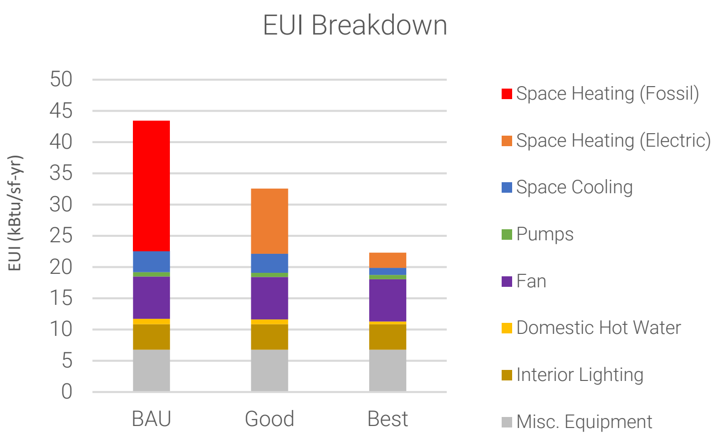


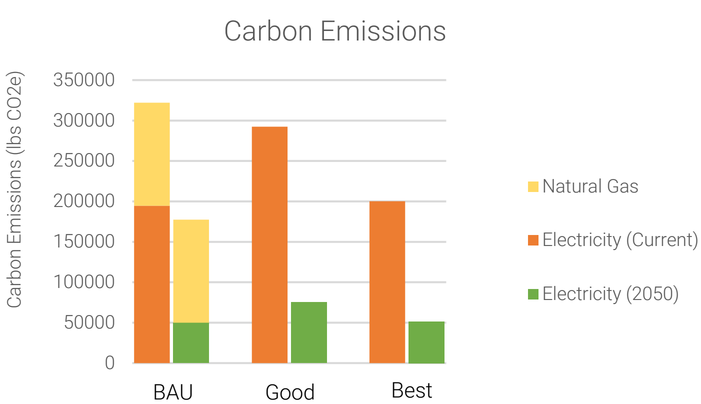
Graduate and Professional Studies Center

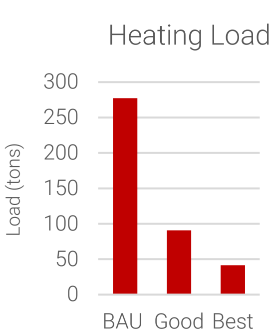
Campus	East Campus
Core End Use	Office/Classroom
Square Footage	50119
Last Major Renovation	2009

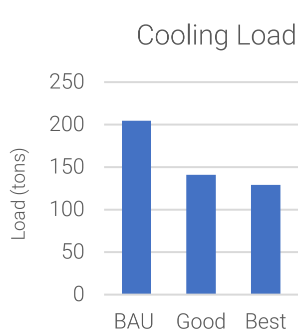
Building Summary

The Graduate and Professional Studies building is an office/classroom building on the East Campus. It has a Building Score of 34. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of improved envelope, energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads. Retro-commissioning can be a useful tool to ensure proper operation of recently renovated systems.









Current
HHW Boiler
Air-cooled Chiller
Candidate for envelope improvements

Good
ECM 5a - Air-side Systems - Decoupled systems
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 7b - Water-side Systems - Standalone AWHP
ECM 9a - Plumbing - Low Flow Fixtures
ECM 9c - Plumbing - Electric Water Heater
ECM 10b - Controls - Retro-commissioning
ECM 10c - Controls - DDC Sequence Upgrades
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)

Wannalancit Business Center

Campus	East Campus
Core End Use	Office/Classroom
Square Footage	122721
Last Major Renovation	2019

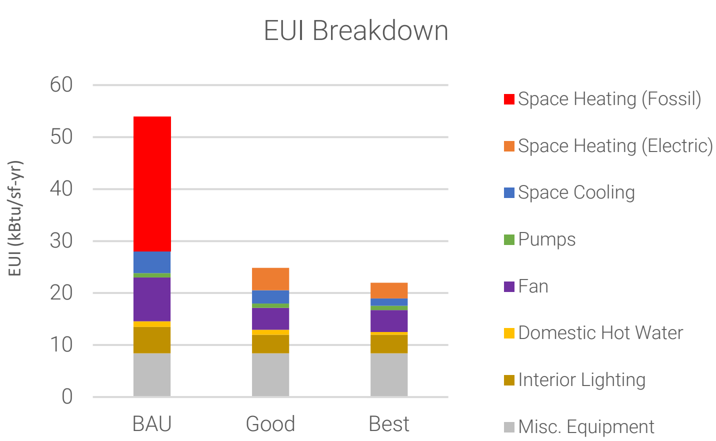
Building Summary

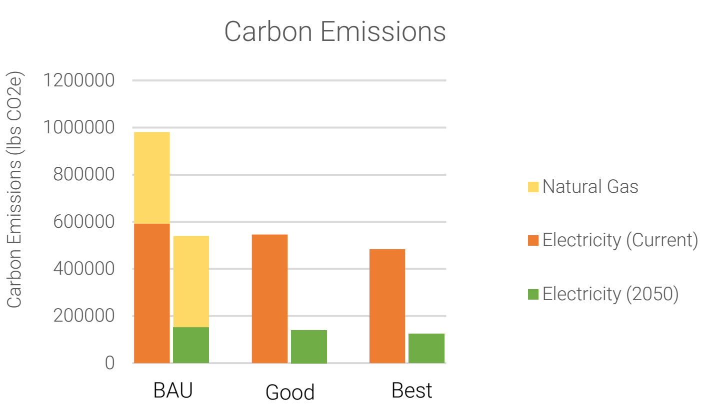
Wannalancit Business Center is an office building with some wet labs on the East Campus. It has a Building Score of 30. This makes it a lower priority for energy efficiency improvements. The EUI reduction in the Good and Best cases are a result of energy recovery, decoupled heating/cooling and ventilation systems, lighting, lighting controls, domestic hot water heater, and low flow fixtures. Future carbon reduction is in result to electrified heating strategy. Air-side energy recovery and envelope upgrades reduce heating and cooling loads.

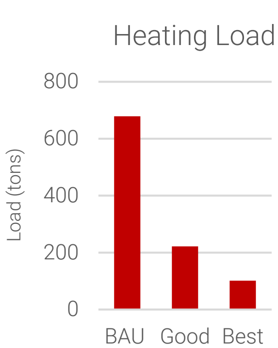
Current
HHW Boiler
DX Cooling
Acceptable envelope; original components

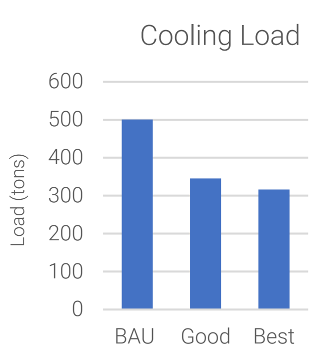
Good
ECM 6a - Air-side Energy Recovery - 70% (Single Wheel)
ECM 9c - Plumbing - Electric Water Heater
ECM 5a - Air-side Systems - Decoupled systems
ECM 7b - Water-side Systems - Standalone AWHP
ECM 8a - Lighting - LED Conversion
ECM 8b - Lighting - Occupancy Sensors
ECM 8b - Lighting - Daylight Sensors
ECM 9a - Plumbing - Low Flow Fixtures
ECM 11f - Process Loads - Energy Star Office Equipment

Best
ECM 1b - Wall Insulation - R-30 continuous insulation
ECM 2b - Roof Insulation - R-50 continuous insulation
ECM 3b - Glazing U-value/SHGC - Triple-pane
ECM 4b - Infiltration - 0.1 cfm/sf @ 75 Pa
ECM 6b - Air-side Energy Recovery - 90% (Heat Regen)
ECM 9b - Plumbing - Instantaneous Water Heater







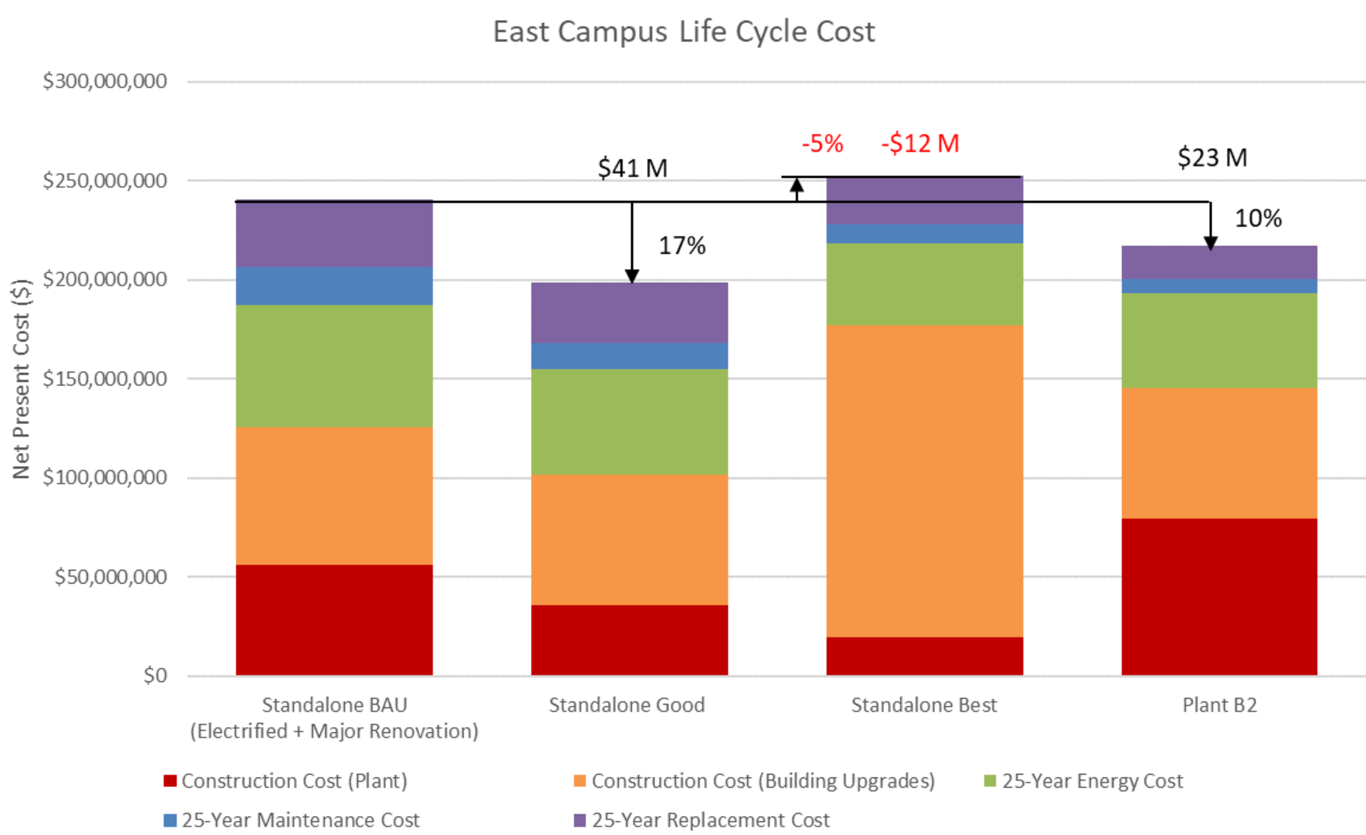


East Campus Plant Alternatives

The East Campus is currently served by three steam boilers that were replaced in 2015. The options for meeting the alternative energy requirements for the east campus buildings is to pursue stand-alone electrified heating and cooling plants or to install and expand the east campus central plant. These electrification options can be bundled with building upgrades under the "Good" or "Best" energy conservation bundles. These options are summarized below:

1. Stand-alone heating and cooling plants and code minimum building upgrades
2. Stand-alone with "Good" ECM package building upgrades
3. Stand-alone heating and cooling with "Best" ECM package building upgrades
4. Central Utility Plant using the North Campus "Good B2 – Light Geo + Air-source + Gas Boilers" Option for the east campus

The central plant options were vetted in the north central plant analysis and determined that the "Good B2 – Light Geo + Air-source + Gas Boilers" option was the best plant option. For the reasons described in the "Alternative Energy Measures Descriptions" of this report and the north plant analysis, converting to biodiesel is not be the best option from an emissions and operating cost perspective at this time. The chart below shows the 25-year life-cycle cost analysis for the East Campus Options for electrification.



Recommendation

BR+A recommends decentralizing the heating and cooling equipment for the east campus (Stand-alone Good in the chart). The reason for this is because it provides the best balance between construction cost and operating cost, resulting in the lowest life-cycle cost. Implementing a central hybrid ground-source / air-source system based on the analysis of from the north campus analysis would also not be life-cycle cost effective. There are a number of factors that results in a negative life-cycle cost compared to building stand-alone heating and cooling including:

4. The design heating load is lower than the north campus for the “Good” and “Best” options.
5. The piping distribution is higher due to a more spread out.
6. The building types are primarily residence halls and education buildings, which have low heating and cooling loads when the envelope and mechanical systems are improved.

The analysis shows that doing some building upgrades during major renovations should be performed to reduce heating and cooling loads and thus reducing heating and cooling equipment cost. It is expected that some buildings may be renovated to the “Best” bundle, some will be renovated to the “Good” scenario and some will remain as existing, making the “Good” scenario the best representative option that incorporates unforeseen factors.

On-site Renewable Solar Analysis

Overview

The project team was tasked by UML to conduct a solar photovoltaic (PV) assessment of various campus sites ("the sites") as part of the Alternatives Analysis. Sites are listed in

South Campus	
150 Wilder - Desmarais House	South Maintenance Facility
820 Broadway	South Power Plant
Allen House	Weed Hall
Coburn Hall	Riverview Suites Lot
Concordia Hall	Broadway/ Riverview Lot
Dugan Hall	Upper Mahoney Lot
Durgin Hall	Lower Mahoney Lot
Health & Social Sciences Building	South Parking Garage
Mahoney Hall	Solomont Way Lot
McGauvran Center	Coburn Lot
O'Leary Library	Wilder Faculty/ Staff/ Visitor Lot
Sheehy Hall	Durgin Lot

East Campus	
Ames Textile	Pawtucket Visitor. Metered Lot
Bourgeois Hall	Fr. Morrissette Blvd
Campus Recreation Center	Merrimack Lot
Charles Hoff Alumni Scholarship Center	Merrimack Street Lot
Donahue Hall	Fox Lot
Fox Hall	East Parking Garage
Graduate and Professional Studies Center	Campus Rec Lot
Leitch Hall	Wannalancit East Courtyard
River Hawk Village	Tremont Lot
Tsongas Center at UMass Lowell	Ames Lot
University Crossing	Lawrence Drive Lot
University Suites Residence Hall	Perkins Lot
Wannalancit Business Center	Tsongas Lot B
110 Canal	Canal Lot
Salem Street/ Admissions Lot	Lower Locks Garage
Fletcher Lot	Hall St. Garage

below:

North Campus	
Ball Hall	Pulichino Tong Business Center
Costello Athletic Center	Saab Emerging Technologies & Innovation Center
Cumnock Hall	Southwick Hall
Dandeneau Hall	UMass Lowell Bellegarde Boathouse
Falmouth Hall	Standish Visitor/ Metered Lot
Kitson Hall	Pinanski/ Costello Lot
Lydon Library	Olsen Lot
North Power Plant	North Parking Garage
Olney Hall	Riverside Lot B
Olsen Hall	Riverside Lot A
Perry Hall	Cumnock Lot
Pinanski Hall	Cross River Center Lot

South Campus	
150 Wilder - Desmarais House	South Maintenance Facility
820 Broadway	South Power Plant
Allen House	Weed Hall
Coburn Hall	Riverview Suites Lot

Concordia Hall	Broadway/ Riverview Lot
Dugan Hall	Upper Mahoney Lot
Durgin Hall	Lower Mahoney Lot
Health & Social Sciences Building	South Parking Garage
Mahoney Hall	Solomont Way Lot
McGauvran Center	Coburn Lot
O'Leary Library	Wilder Faculty/ Staff/ Visitor Lot
Sheehy Hall	Durgin Lot

East Campus	
Ames Textile	Pawtucket Visitor. Metered Lot
Bourgeois Hall	Fr. Morrissette Blvd
Campus Recreation Center	Merrimack Lot
Charles Hoff Alumni Scholarship Center	Merrimack Street Lot
Donahue Hall	Fox Lot
Fox Hall	East Parking Garage
Graduate and Professional Studies Center	Campus Rec Lot
Leitch Hall	Wannalancit East Courtyard
River Hawk Village	Tremont Lot
Tsongas Center at UMass Lowell	Ames Lot
University Crossing	Lawrence Drive Lot
University Suites Residence Hall	Perkins Lot
Wannalancit Business Center	Tsongas Lot B
110 Canal	Canal Lot
Salem Street/ Admissions Lot	Lower Locks Garage
Fletcher Lot	Hall St. Garage

After achieving load reduction through energy conservation measures and campus system electrification, UML is interested in offsetting electricity purchased from the utility with clean renewable energy. This intent aligns with Executive Order No. 569 which calls on government to "expand upon existing strategies for the Commonwealth to lead by example in making new, additional reductions in greenhouse gas emissions," and specifically supports the following objectives:

- Increase the amount of renewable and clean energy on the grid by increasing onsite renewable energy generation, the procurement of renewable energy supply, and continued development of clean energy resources; and
- Expand the deployment and use of energy storage and other strategies to minimize peak demand.

The objective of this solar assessment was to determine the most successful options for installing campus-wide distribution solar PV by determining the most viable sites. Options considered include the different types of solar PV systems including ballasted roof mount, mechanically attached roof mount, and parking canopy structures. In addition, the assessment evaluates opportunities for integrating Battey Energy Storage Systems (BESS) into renewable energy projects to increase utility bill savings.

The assessment first investigates the site-specific viability based on building and parking dimensions and constraints, shading considerations, typical mounting structures and products, and minimum array size. Local weather data and system size are used to model solar electricity generation. PV production models, BESS operation characteristics, and industry-standard project costs are utilized to estimate the financial impact of integrating solar and storage into the project sites.

This solar assessment report covers the relevant utility programs, incentives, installation options, financing options, and feasibility evaluation. The feasibility evaluation consists of the following:

- An evaluation to determine suitability of rooftop solar and shade canopies on parking lot locations;
- PV system modeling to determine electricity output from sites;
- An investigation of utility rate programs and incentives that benefit a solar PV and BESS interconnection;
- Financing options to fund the solar PV and BESS projects including incentives;
- A deep dive on design and financial analysis for three pilot sites: Ball Hall, Olney Hall, and Sheehy Hall;
- A financial analysis of battery storage integration into two pilot sites: Ball Hall and Tsongas Center; and
- Technical appendices for backup documentation.

Programs and Initiatives

Utility, state, and federal incentives can support the adoption and deployment of solar PV projects by lowering the cost or facilitating the integration with the utility grid. Programs and incentives are as follows:

Net Metering

Customers of regulated utility companies in Massachusetts, such as National Grid, are permitted to generate electricity to offset electrical usage. Energy generated onsite from assets such as wind generators or solar photovoltaic systems are connected to a bi-directional meter to measure the net energy used. When energy is purchased from the utility company, the net meter spins forward and when more electricity is generated than needed, energy is exported to the grid and the net meter spins backwards.

Solar or wind net metering systems on public facilities are restricted to 10 MW or less per G.L. c. 164, §138. When electricity is exported to the grid, net metering credits (NMC) are created and assigned to the generating entity. "Banked" credits can offset charges associated with the delivery, supply, and customer portions of the generating entity's electric bill. NMC's can offset up to 100% of the utility bill and appear as dollars on the electric bill, not as kWh. Net metering credits are not always assigned on a 1:1 ratio to kilowatt-hours (kWh's) exported due to non-bypassable customer fees and charges collected by the utility. The NMC calculation is based on the type and size of generating facility. Credits do not expire and rollover to the next billing cycle and can be assigned to other accounts within Independent System Operator New England (ISO).

Solar Massachusetts Renewable Target (SMART) Tariff

Massachusetts SMART Tariff for those considering installing a Behind-the-Meter System (Tariff Generation Unit under the SMART Program.) The Solar Massachusetts Renewable Target (SMART) Program is the newest program established to support the development of solar in Massachusetts. The DOER regulation in 225 CMR 20.00 sets the regulatory framework for the program. The tariff-based incentive is paid directly by the utility company to the system owner, following the approval of the application by the Solar Program Administrator. The SMART Program is a 1,600 MW declining block incentive program. Eligible projects must be interconnected by one of three investor-owned utility (IOU) companies in Massachusetts: Eversource, National Grid, and Unitil. Each utility has established blocks that decline in incentive rates between each block. SMART incentive applications for PV systems greater than 500 kW-DC must be co-located with an Energy Storage System to qualify. Incentive payments are remitted to the system owner/ applicant, and in the case of third-party ownership, some portion of the incentive payment should be passed through to the buyer (UML) in the form of a reduced PPA rate.

Solar Massachusetts Renewable Target (SMART) – Energy Storage System Incentive

This performance-based incentive is determined on the ratio of total energy storage system max power discharge to total PV DC power rating, the full discharge duration, and the production of the system. There is a minimum efficiency requirement stating that the energy storage system paired with the solar photovoltaic generation unit must have at least a 65% round trip efficiency under normal operation. There are also operational requirements, such as the energy storage system must discharge at least 52 complete cycle equivalents per year and must remain functional and operational for the PV generation unit to continue to be eligible for the energy storage adder. Additionally, the nominal useful energy capacity of the energy storage system paired with the PV system must be at least two hours and incentivized for no more than six hours. The nominal rated power capacity of the storage system paired with a PV generation unit must be at least 25 per cent and shall be incentivized for no more than 100% of the rated capacity, as measured in direct current, of the PV generation unit. Incentive payments are remitted to the system owner/ applicant, and in the case of third-party ownership, some portion of the incentive payment should be passed through to the buyer (UML) in the form of a reduced PPA rate.

Solar Renewable Energy Certificate (SREC)

SRECs represent the renewable and/or environmental attributes associated with electricity that is produced by solar generators. One credit is created for each MWh of solar electricity generated. Massachusetts Renewable Portfolio Standard (RPS) mandates that distribution companies buy specified quantities of SRECs each year.

Federal Investment Tax Credit (ITC)

Businesses that install PV and Battery Energy Storage Systems (BESS) are eligible to receive an (ITC) investment tax credit, which can be used to directly offset federal tax liability on a dollar-for-dollar basis. If the tax credit exceeds the tax liability the credit can be rolled into future tax periods for 20 years. Commercial projects that commence construction through the end of 2022 are eligible to receive a 26% tax credit of the total PV system cost. The ITC steps down thereafter: 2023 projects qualify for a 22% ITC, 2024 and later projects qualify for a 10% ITC. While this incentive is not available to the tax-exempt entities such as UML, it is anticipated that systems owned by a third-party will pass through a portion of the savings in the form of a reduced PPA rate.

Federal Modified Accelerated Cost-Recovery System (MACRS)

Under the federal MACRS, businesses may recover investments in PV and ESS property through depreciation deductions. MACRS establishes a lifespan for various types of property over which the property may be depreciated. For PV and energy storage systems, the taxable basis of the equipment must be reduced by 50% of any federal tax credits associated with the system. While this incentive is not available to the tax-exempt entities such as UML, it is anticipated that systems owned by a third-party will pass through a portion of the savings leveraged by MACRS in the form of a reduced PPA rate.

Modeling Approach

The project team collected site data from UML then applied typical design criteria and justifiable assumptions to establish viable locations for PV development and model representative system production. While all sites were screened by the project team and viable sites Modeled, only the three pilot project locations were elaborated in detail herein.

Data Sources

Site data was collected from a combination of UML-provided databases, satellite imagery, and site visit observations. Hatch Data was utilized for utility 15-minute interval data in kilowatt-hours (kWh's) for the pilot sites to build electricity usage profiles. Aerial/satellite imagery from Google Earth was utilized as an input for the PV system modeling tool (described below) and for shade/obstacle recognition. UML resources such as the web-based Campus Map and data from Sightlines reports were used for additional site detail and identification of parking lots.

Tools

Helioscope

The industry-leading tool, Helioscope, was used to develop site-specific PV production models and estimate site energy offset. Helioscope incorporates equipment specifications and efficiencies, array orientation(s) and tilt(s), user-identified obstacle shading, and local weather and temperature data to provide energy generation models.

Energy Toolbase

Another powerful solar PV modeling software, Energy Toolbase, was used to calculate important financial metrics for the pilot sites. The financial model was used to calculate a series of annual cash flows for the life expectancy of the equipment and incorporated two financing scenarios: direct purchase and power purchase agreement (PPA). The software was used to develop and model cashflows for net metering credits, operations and maintenance, and applicable incentives. Energy Toolbase reported the following metrics:

- Electricity costs with and without the PV system ($)
- Electricity savings and annual cashflows ($)
- Simple payback (years)

- PPA costs and cashflows ($/kWh)
- Net present value (NPV in 2021$)
- Internal rate of return (IRR in percent)
- Leveled cost of energy (LCOE in $/W)

Equipment Assumptions

The table below presents PV and BESS equipment assumptions used for conceptual system design and production modeling.

Variable	Assumption Value	Warranty	Justification
Module type	LG Electronics, 410N2W-A5 (410W)	25 yr	Typical Tier 1 solar module
Inverter type (carport canopy)	Solectria, PVI-36TL, PVI-60TL	15 yr	Typical 36kW, 60kW grid-tied string inverters for carports
Inverter type (roof mount)	SolarEdge, SE 17.3KUS, SE33.3KUS, SE66.6KUS, SE100KUS	15 yr	Typical 33kW, 66kW, 100kW string inverter with rapid shut-down
PV optimizer (roof mount)	SolarEdge, P850	25 yr	Compatible 850W DC power optimizer (2 inputs) for use with SolarEdge Inverters
BESS	Chint, CPS-ESS 30/65-US, 60/130-US, 120/260-US 240/520-US	10 yr	UL9540 turnkey 2-hour BESS (inverter, EMS, climate control, enclosure), LG Chem Li-Ion batteries. 65-520kWh.

Design Criteria

The table below presents the design guidance and justification for PV siting on the campus. While these criteria are typical of design best practices, exception may be taken in appropriate circumstances. For example, while ballasted roof mount racking is the design preference, there may be opportunities for monolithic tilt, mechanically attached rooftop arrays. Individual designs will note any exceptions taken.

Description	Design Guidance	Justification
Roof coverage	Minimum of 10% of roof area left undeveloped and available for other uses	Energy conservation measures such as new HVAC equipment may require roof space in the future
Roof mount racking	Ballasted non-penetrating racking where possible	Contingent on AHJ guidance and building exposure per ASCE 7-10. Reduces roof penetrations and impacts to roof warranties. Existing campus PV precedent.
Roof mount inverter location	Inverters to be mounted on roof unless otherwise noted	Reduction of DC wiring and service accessibility
Roof mount tilt & orientation	10° tilt with interspaced rows, oriented south, +/- 20°	Typical of low-profile roof mount systems to maximize use of available rooftop while minimizing interrow spacing/shading
Roof setbacks	Minimum 5' setback from roof edge/parapet and from major rooftop equipment	Typical of commercial rooftop installations to allow safe access
Carport clear height	10' clear height unless intended for heavy vehicle parking	Standard clear height for public parking lots, excludes fire lanes and heavy vehicle parking

Carport tilt and orientation	7° tilt south, east, or west	Typical of canopy parking structures
Carport structure	Double bay Tee structure or long span structure where possible	Reduces steel $/Watt and maximizes Watts/SF
Carport lighting	Light standards in canopy area to be removed and under canopy lighting installed	Typical of carport canopy systems
Carport inverter location	Inverters to be mounted on canopy columns	Typical of carport canopy systems
Parking garage canopy	Post and beam structure with pitched arrays. Assumes structure can support added dead weight	Maximizes beam spans for vehicular movement. Structural review of garage beyond scope of assessment
DC/AC inverter loading ratio	Up to 1.25	Typical load ratio to maximize economy of inverter capacity without limiting instantaneous output. Systems with arrays in multiple orientations may have higher load ratio
BESS location	Exterior ground mount	Typical BESS installation requirements
BESS operating model	Charge from solar and/or grid	Most flexible operating model, determined by the greatest savings
BESS sizing	Nominal power rating of at least 25% of the nominal PV system size (kW-DC)	For compliance with SMART Energy Storage System incentive
BESS hour rating	BESS kWh/ BESS kW ≥ 2	For compliance with SMART Energy Storage System incentive

Financial Models

Financial models were used to show lifecycle PV project economics using different financing vehicles such as direct purchase and power purchase agreement (PPA).

Direct Purchase (Build, Own, Operate, Maintain)

The university procures a contractor to design, build, and commission the solar PV project. UML is responsible for paying all upfront costs associated with the site including permitting, due diligence, drainage/hydrology assessments, geotechnical surveys, economic modeling, system design & engineering, procurement, construction, and commissioning. Once commissioned, UML purchases an O&M package so that the contractor can maintain the system and guarantee uptime. Equipment replacement beyond the warranty period is in addition to the O&M package and the cost is borne by the university. Electricity generated by the system is consumed by the facility and any excess electricity is sent to the utility grid as part of the NMC program. In this scenario UML retains all REC's generated by the PV system but be ineligible to receive the ITC as there is no tax liability to apply the credit.

Power Purchase Agreement

The university allows a solar project developer (seller) to build, own, and operate the solar PV project on site and signs a power purchase agreement to purchase all or part of the electricity generated by the system. A PPA is a contractual agreement whereby the project owner agrees to sell electricity to the university at a fixed price per kilowatt-hour over an extended contract term (typically 20 – 25 years). PPA's can include annual rate escalations where the price per kWh increases by a predetermined percentage every year. Because the project developer is responsible for delivering a predetermined quantity of energy annually, O&M is included in the base PPA rate paid by UML. Shortfalls in annual production resulting in higher utility payments are compensated by the developer. Inversely, the university is liable for purchasing energy produced by the equipment, therefore system size and energy appetite are critical in managing risk. UML: does not own any REC's or the ITC under this scenario, but the system owner/financier leverages the ITC for tax equity and reduces the PPA rate that the university pays.

This option provides several financial advantages to public agencies including no upfront cost and passthrough of tax incentives that would otherwise not be available under other procurement methods. The disadvantage of a PPA is that the university would not own the environmental attributes of the green energy and therefore solar deployed through a PPA would not help UML achieve net zero targets.

Assumptions

The assumptions and the justification for each feasibility input are listed in the table below. Cost breakdown for rooftop PV was based on the National Renewable Energy Laboratory's Q1 2020 report, *U.S Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*. Figure 1 provides a project cost breakdown in \$/Watt-DC drawn from national PV project data.

Variable	Assumption Value	Justification
PV degradation (%/year)	0.50%	Typical solar PV system degradation
Utility escalation (%/year)	3.00%	Historic
PPA rate – roof mount (\$/kWh)	\$0.12	Conservative PPA rate for systems over 100 kW-DC (ranges \$0.10-0.15/watt)
PPA rate – shade structure (\$/kWh)	\$0.14	Conservative PPA rate for systems over 100 kW-DC (ranges \$0.11-0.17/watt)
PPA rate – BESS adder (\$/kWh PV)	\$0.04 - \$0.12	Contingent on SMART incentive value and BESS rating
PPA escalation rate (%/year)	1.0%	Conservative PPA escalation rate. Current PPA's often have 0% escalation clause.
Roof mount cost (\$/Watt)	\$2.15 - \$2.75	*US Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020* (NREL). Increased 15% for MA educational institution.
Shade Structure (\$/Watt)	\$3.50 - \$4.00	Typical for systems over 100 kW
BESS cost (\$/kWh)	\$708 - \$1,000	*US Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020* (NREL).
Operation and Maintenance (\$/Watt)	\$0.02	Typical industry cost for O&M agreement
Operation & Maintenance Annual Escalation (%/year)	2%	Typical industry O&M escalator
Equipment Replacement (\$/Watt)	\$0.12	Inverter replacement after year 15
Nominal Discount Rate including inflation and real discount rate (%)	5%	Typical for public institution

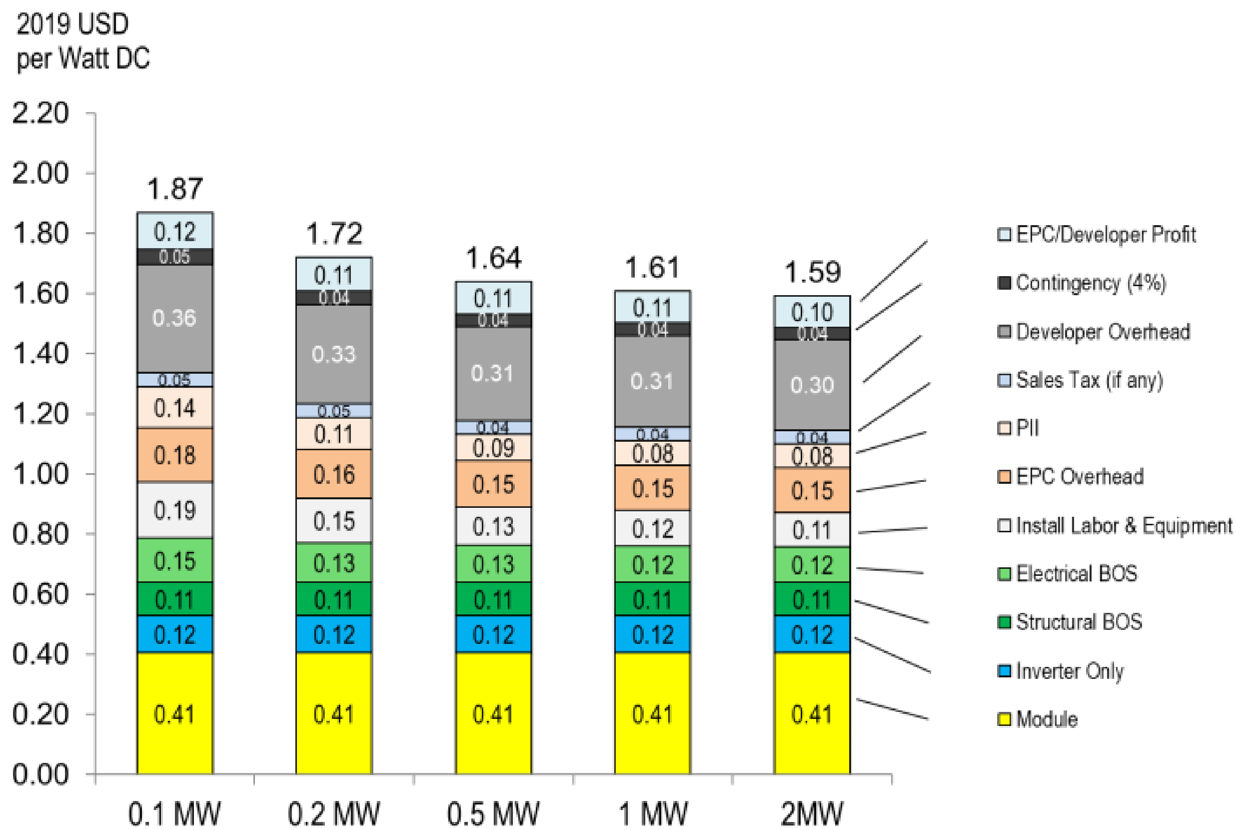


Figure 1 - NREL 2020 U.S. Benchmark: Commercial Rooftop PV System Costs (2019 USD/W-DC)

Minimum System Size

While solar PV systems can be designed to any size, soft costs for design and engineering, permitting, mobilization, and project management make up a greater percentage of total cost for small projects thus reducing cost effectiveness. Conversely, larger systems achieve economies of scale that often translate into better pricing and higher quality/more competitive bidders. While it is understood that the intent of campus-wide PV development is not exclusively financial in nature, the project team recognizes that efficient use of capital is critical to achieving aggressive clean energy targets. As such, sites were prioritized to maximize solar production and favorable economics. To leverage economies of scale, installations less than 100 kW-DC should generally be avoided.

RESULTS

Electrical Utility Information

Utility rate and tariff option depends on the electric utility provider, use type of facility, customer election, service size, and peak demand. It is often required and/or advantageous to change rate option after deploying PV and BESS. Mandatory rate change and opportunities for rate optimization were evaluated to determine the most favorable combination of solar, storage, and utility power. The table below presents site utility information and data reviewed.

#	Bldg. Name	Utility Tariff	Elec. Consumption (MWh/yr)	15-min
1	Ball Hall	G3	906	✓
2	Olney Hall	G3	4,167	✓
3	Sheehy Hall	G3	334	✓[1]

Pilot Project Solar Production Models

Pilot sites were modeled using Helioscope to show representative PV designs and simulate resulting electricity generation for each. Summary results are shown in the table below with detailed designs in subsequent sections.

#	Site	PV System Type	System Size (kW-DC)	Year-1 Total Site Load (MWh)	Year-1 Solar Gen. (MWh)	Energy Offset
1	Ball Hall	Ballasted Roof Mount	111.9	906.2	151.5	17%
2	Olney Hall	Monolithic Tilt Roof Mount	110.7	4,167.2	141.5	3%
3	Sheehy Hall	Ballasted Roof Mount	59.9	334.0	80.9	24%

[1] Sheehy interval data was not available, energy data from Concordia used for energy profile and scaled up for larger building size

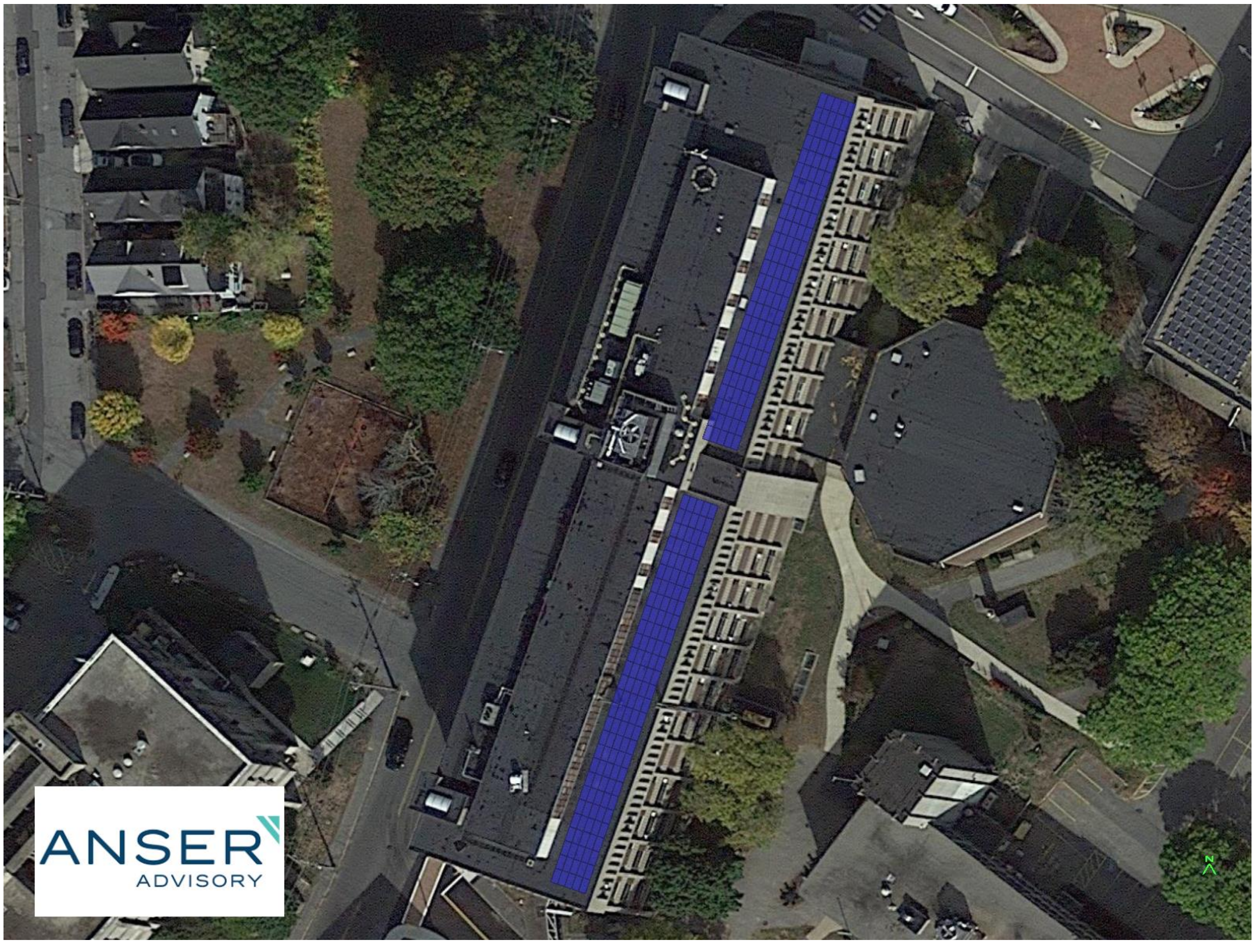
Ball Hall

Ball Hall has a 24,700 SF rooftop with roof mounted HVAC equipment scattered throughout. Future building upgrades may require additional HVAC space provisions which informed a PV layout that creates an available space contingency. Modules are oriented due south to limit the interrow spacing required to keep module edges from shading back rows.

Variable	Value	Description
DC Nameplate	111.9 kW-DC	(273) LG 410 modules
AC Nameplate	100.0 kW	1.12 DC/AC load ratio
Cash Price	$240,585	$2.15/W-DC installed
20-yr PPA Price	$0.12/kWh	Base rate for year 1 plus 1% annual escalator years 2-20
Weather Dataset	TMY, 10km grid	(42.65, -71.32), NREL (prospector)
System Losses	11.9%	Shading, reflection, soiling, irradiance, temperature, module mismatch, optimizer efficiency, wiring, clipping, inverter efficiency, AC losses
kWh/kW	1,354	Annual energy generated per 1 kW of solar installed (site-specific)
Azimuth	180°	
Tilt	10°	
Racking	Ballasted	Non-penetrating module racking w/ integrated grounding

Olney Hall

Olney Hall has a 35,500 SF rooftop with mechanical room located in the center creating two roof levels. Limited roof area for solar equipment informed a fixed tilt array design on the east side of the building. The 10° array tilt will keep the high edge only 3' above the low edge reducing the impact of wind loading and resulting structural requirements.

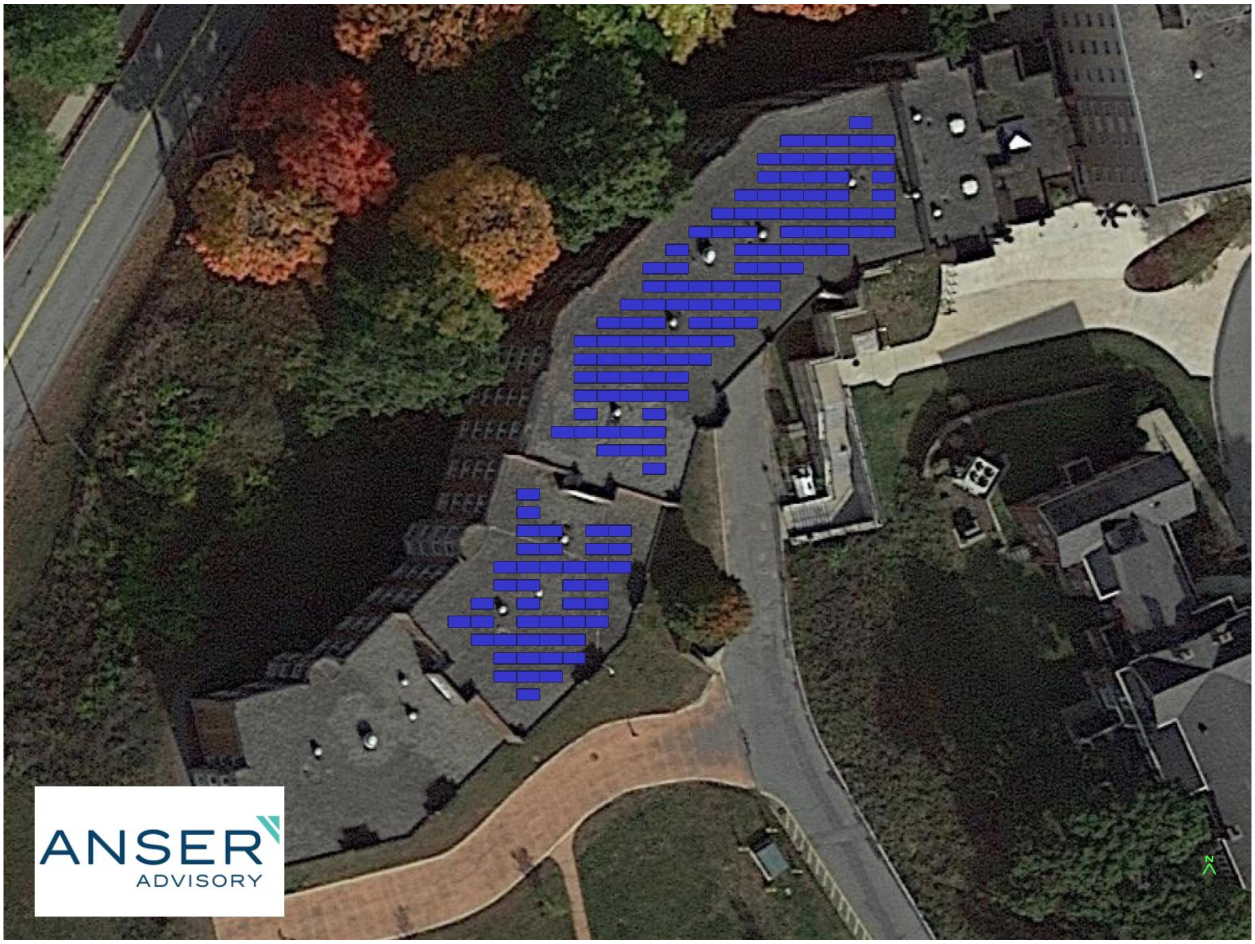


Olney Hall PV Layout

Variable	Value	Description
DC Nameplate	110.7 kW-DC	(270) LG 410W modules
AC Nameplate	100.0 kW	1.11 DC/AC load ratio
Cash Price	$238,005	$2.15/W-DC installed
20-yr PPA Price	$0.13/kWh	Base rate for year 1 plus 1% annual escalator years 2-20
Weather Dataset	TMY, 10km grid	(42.65, -71.35), NREL (prospector)
System Losses	12.0%	Shading, reflection, soiling, irradiance, temperature, module mismatch, optimizer efficiency, wiring, clipping, inverter efficiency, AC losses
kWh/kW	1,279	Annual energy generated per 1 kW of solar installed (site-specific)
Azimuth	109°	
Tilt	10°	
Racking	Monolithic fixed tilt	Penetrating mechanical connection to roof structure

Sheehy Hall

Sheehy Hall has a 15,750 SF roof with several vents and but no existing HVAC equipment. The unique shaped roof is segmented reducing the available area for PV. The southern-most roof was left undeveloped creating a contingency for future HVAC equipment. While a larger system could be sited by shifting the orientation east of south, the net gain is relatively small (~6kW) and further diluted by a lower kWh/kWp factor.



Sheehy Hall PV Layout

Variable	Value	Description
DC Nameplate	59.9 kW-DC	(146) LG 410W modules
AC Nameplate	66.6 kW	0.9 DC/AC load ratio
Cash Price	$163,594	$2.90/W-DC installed
20-yr PPA Price	$0.18/kWh	Base rate for year 1 plus 1% annual escalator years 2-20
Weather Dataset	TMY, 10km grid	(42.65, -71.35), NREL (prospector)
System Losses	12.2%	Shading, reflection, soiling, irradiance, temperature, module mismatch, optimizer efficiency, wiring, clipping, inverter efficiency, AC losses
kWh/kW	1,351	Annual energy generated per 1 kW of solar installed (site-specific)
Azimuth	180°	
Tilt	10°	
Racking	Ballasted	Non-penetrating module racking w/ integrated grounding

Aggregate PV System Sizing and Production Details

A total of 80 sites were included in the Alternatives Analysis for PV feasibility inclusive of campus buildings and parking lots (surface and garage structures). Of these sites, 29 were excluded from further analysis due to limiting factors such as insufficient usable area, shading from buildings and trees, proximity to permanent structures, and presence of existing PV. The remaining 51 sites were modeled with PV systems using assumptions and design criteria as listed in this section. Appendix M provides a breakdown of each site of the 80 sites reviewed during in this report as well as an explanation for exclusion, if ruled out.

Individual PV system designs range from 30 kW-DC to 2,680 kW-DC and are categorized into systems greater than (>) 100 kW-DC and systems less than (<) 100 kW-DC. The intent of this categorization is to focus PV development efforts on larger sites that can leverage more favorable economies of scale. Smaller sites were left within the analysis to show the full PV development potential of the campus.

The table below provides a summary of the quantity of sites evaluated, nameplate PV system size in kW-DC, and resulting PV production in MWh's per year. Note that the 18 sites modeled with PV system sizes under 100 kW make up only 7% of the total annual electricity generation while the 33 sites larger than 100 kW compose the other 93%.

Description	Excluded	PV Size < 100 kW	PV Size > 100 kW	TOTALS
Sites	29	18	33	**80**
Total Size (kW-DC)	-	936	13,460	**14,397**
Total Production (MWh/yr)	-	1,235	17,464	**18,700**

The table below shows a summary breakdown of PV system sizes over 100 kW by UML campus and mounting structure (roof mounted to building or carport canopy structure). 85% of the total PV system capacity and annual production shown below is proposed at parking sites, this capacity represents 84% of the total annual production for systems over 100 kW-DC. The balance system capacity and annual production is attributable to rooftop PV on existing buildings. **PV systems located at parking sites represent a crucial segment for UML to maximize onsite renewable energy generation.**

Campus / Type	Sites	PV Size > 100 kW-DC	Total Production (MWh/yr)
East	**18**	**5,235**	**6,693**
Building	7	1,453	1,915
Parking	11	3,781	4,778
North	**9**	**5,132**	**6,797**
Building	3	323	428
Parking	6	4,809	6,370
South	**6**	**3,094**	**3,974**
Building	2	306	409
Parking	4	2,788	3,565
Grand Total	**33**	**13,460**	**17,464**

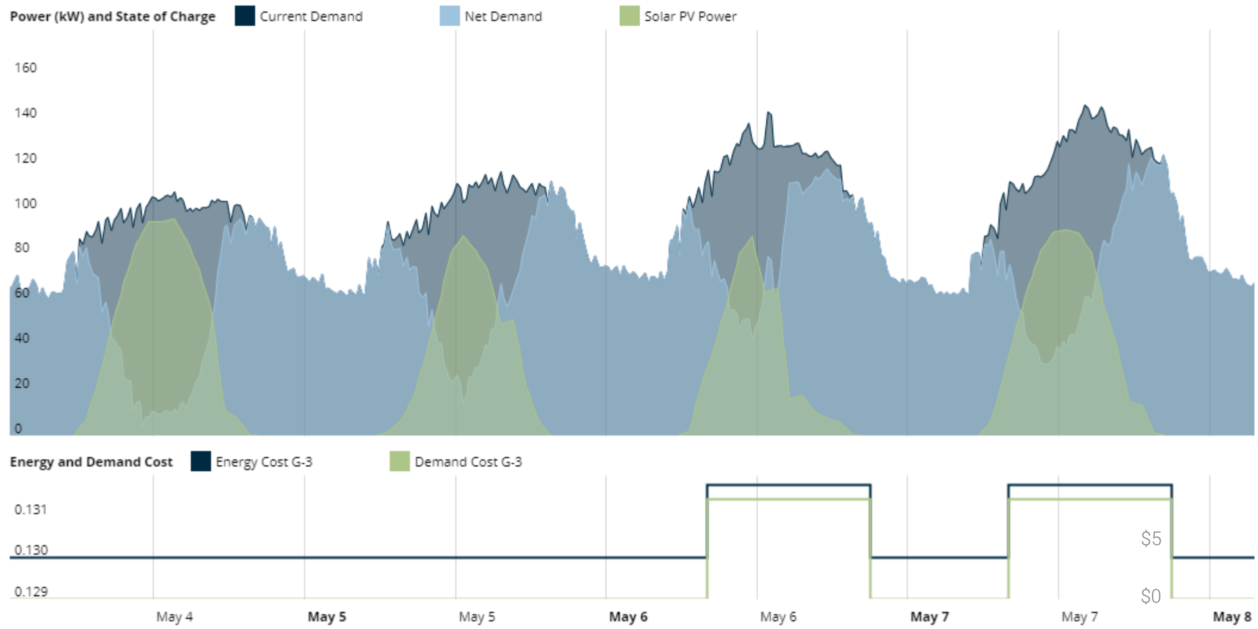
The table below shows a summary breakdown of PV system sizes under 100 kW by UML campus and mounting structure (roof mounted to building or carport canopy structure). No PV systems under 100 kW in size were modeled for parking locations. This is primarily due to the fact that small parking lots tend to be irregular sizes and be located close to buildings and trees. Developing small rooftop PV systems is not the most effective way of achieving UML energy and climate targets as can be seen by the comparatively low electricity generation potential of the 18 sites with systems under 100 kW. That said, some small sites are approaching 100 kW in size or may have other drivers for PV integration such as visibility, research, etc.

Campus / Type	Sites	PV Size < 100 kW-DC	Total Production (MWh/yr)
East	**1**	**41**	**54**
Building	1	41	54
Parking	0	0	0
North	**11**	**632**	**846**
Building	11	632	846
Parking	0	0	0
South	**6**	**263**	**336**
Building	6	263	336
Parking	0	0	0
Grand Total	**18**	**936**	**1,235**

PV Generation Profile

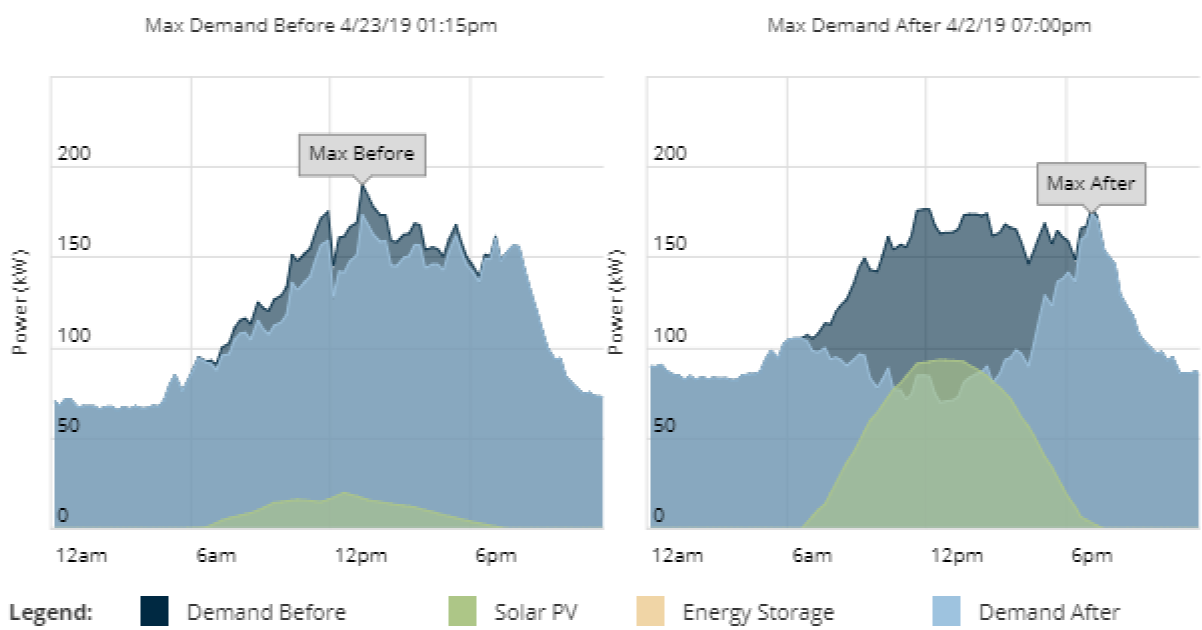
Grid-tied PV systems generate electricity when the sun is shining, and offset electricity purchased from the utility or provided by other onsite sources such as cogeneration systems. PV production models are critical in understanding when and how much electricity is available so that an economic value can be assigned to the generation.

The graph below depicts a simulation of PV production at Ball Hall from Sat. May 4th – Tue. May 7th. The dark gray color represents the site's electricity use profile and is based on the site's 2019 15-minute interval utility data. The green color represents solar PV electricity supplied to the building from the 112 kW system modeled above and based on historic weather datasets. The resulting light blue color represents the net demand required from National Grid. The blue and green lines below the demand profile are representative of National Grid peak periods for demand charges and energy charges. Since the utility tariff does not impose time of use (TOU) periods on weekends, there is no change in utility rates on May 4th and 5th. During weekdays the TOU on-peak periods line up with the generation hours for PV, providing an opportunity to generate electricity while rates are the highest.



Sample Energy Profile (Ball Hall)

The graphs below are demand simulations for the month of April before and after PV integration. The graph on the left shows the before PV, non-concurrent (NC) peak occurs on April 23rd at 1:15PM. This date depicts low solar production which is likely attributable to inclement weather. However, even during this "rainy day" scenario, the site demand is reduced slightly from 191 kW to 174 kW which shifts the April NC peak demand event to April 2nd at 7:00PM when solar has gone offline for the day. As seen above this peak demand shift can have utility bill implications and offer bill savings in addition to the electricity savings in kilowatt-hours.



Sample Demand Profile (Ball Hall)

Pilot Project PV System Financial Models

Financial models were built for the three pilot sites to show PV project economics for both direct purchase and power purchase agreement financing mechanisms.

Per Section 0, PV projects connected behind the meter may qualify for the SMART incentive program. The SMART program offers substantial financial benefit to qualifying systems over a 20-year term but is temporal in the sense that entry to the program will eventually be capped once funds are depleted. While it is appropriate to assume that PV projects developed in the next few years could qualify for one of the incentive blocks, this assumption becomes more uncertain the further out a project start moves from the current date. As such, the SMART program should not be relied upon for PV system cost reduction except for projects with an eminent development date. For illustrative purposes, project costs are shown below with and without the SMART program incentive.

The table below shows project financials for the pilot sites including the SMART incentive. Incentive is based on the compensation rate for National Grid's Capacity Block 10 (systems 25-250 kW-AC). All three pilot sites are able to recover initial investment under 9 years and have positive net present values at the end of the project lifecycle.

System Size (kW-DC)	PV System Cost ($)	25-year O&M ($)	SMART PV Incentive ($)	25-year Utility Bill Savings ($)	25-year Net Benefit (2019$)	25-year Net Present Value ($)	Simple Payback (yrs)	IRR (%)
Ball Hall	$ (240,585)	$ (85,135)	$ 274,484	$ 847,174	$ 795,938	$ 329,683	6.5	15.6%
Olney Hall	$ (238,005)	$ (84,199)	$ 256,357	$ 824,779	$ 758,931	$ 309,705	6.7	15.1%
Sheehy Hall	$ (173,594)	$ (45,530)	$ 146,472	$ 426,862	$ 354,210	$ 173,594	9.0	10.7%

The table below shows the same PV projects without the SMART incentive as is illustrated by lower NPV's and roughly 3-4 more years to achieve simple payback. While Ball and Olney Halls still look promising from an economic perspective, the smaller Sheehy Hall is less so, with an NPV of just $26,108 at 25 years.

System Size (kW-DC)	PV System Cost ($)	25-year O&M ($)	SMART Incentive ($)	25-year Utility Bill Savings ($)	25-year Net Benefit (2019$)	25-year Net Present Value ($)	Simple Payback (yrs)	IRR (%)
Ball Hall	$ (240,585)	$ (85,135)	$ -	$ 847,174	$ 521,454	$ 158,512	9.9	10.0%
Olney Hall	$ (238,005)	$ (84,199)	$ -	$ 824,778	$ 502,573	$ 149,848	10.1	9.8%
Sheehy Hall	$ (173,594)	$ (45,530)	$ -	$ 426,862	$ 207,738	$ 26,108	13.5	6.3%

The table below shows the pilot site PV project economics when financed with a 20-year PPA and 1% annual rate escalation. PPA rates are variable from site to site, they are based on the installation cost, system maintenance, tax credits, asset depreciation, and financing risk. It is uncommon to see PPA's for smaller systems such as Sheehy Hall and as such, it is difficult to estimate the rate for this system. There are often economies for bundling several projects into a PPA portfolio and this can be a mechanism to incorporate smaller systems. Additionally, project economics may be further improved by leveraging a 25-year PPA with a reduced PPA rate. The financials shown below are attractive for Ball and Olney Halls but not for Sheehy as the NPV is essentially neutral at project end of life.

Site	PPA Rate	20-year PPA Payments	20-year Utility Bill Savings	20-year Net Benefit (2019$)	20-year Net Present Value
Ball Hall	$ 0.12	$ (398,430)	$ 625,322	$ 226,892	$ 127,298
Olney Hall	$ 0.13	$ (403,128)	$ 608,791	$ 205,663	$ 114,584
Sheehy Hall	$ 0.18	$ (318,919)	$ 335,180	$ 16,261	$ 3,572

Aggregate PV System Cost

The table below shows approximate project costs per campus and installation type. Project costs were based on system size, type (roof mount or canopy carport), and assumptions identified in Section 0. The blended cost across the portfolio is $3.42/Watt installed.

Campus / Type	Sites <100 kW	Sites 100 - 500 kW	Sites 500 - 1,000 kW	Sites >1,000 kW	Cost (2021$)
East	**1**	**16**	**2**	**0**	**$ 17,943,574**
Building	1	6	1	0	$ 3,116,874
Parking	0	10	1	0	$ 14,826,700
North	**11**	**6**	**1**	**2**	**$ 19,870,615**
Building	11	3	0	0	$ 2,748,665
Parking	0	3	1	2	$ 17,121,950
South	**6**	**4**	**1**	**1**	**$ 11,423,025**
Building	6	2	0	0	$ 1,512,875
Parking	0	2	1	1	$ 9,910,150
Grand Total	**18**	**26**	**4**	**3**	**$ 49,237,214**

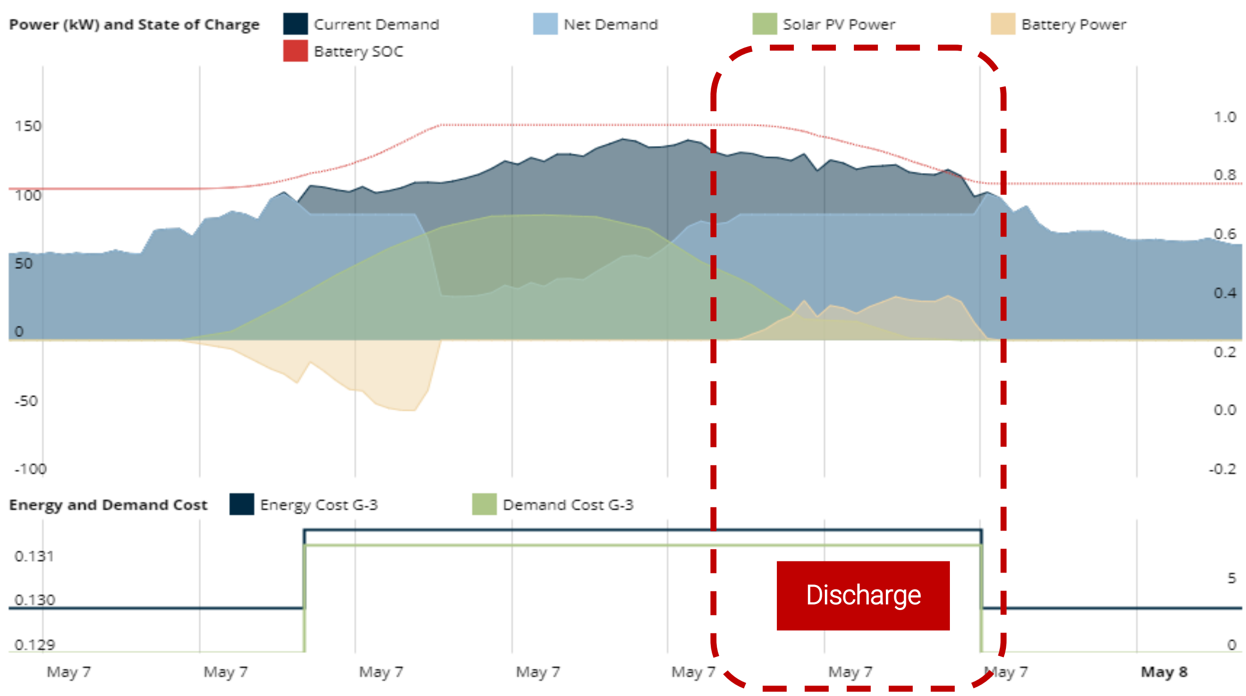
Battery Energy Storage Systems

Solar generation coupled with battery storage is becoming a viable option in the renewable energy industry. Energy storage systems are more than a battery, a typical BESS includes a battery bank, power inverter (DC/AC), energy management system software (EMS), monitoring equipment, and a climate-controlled enclosure. Ratings of BESS are typically listed in kW and kWh where kW is the maximum instantaneous power output in kilowatts and kWh is the total energy storage capacity of the battery. The quotient of kW/kWh is the hours of operation at full power. For example, a 60kW/120kWh BESS is a 2-hour battery while a 30kW/30kWh BESS is a 1-hour battery. In reality the operation of battery energy storage systems is more nuanced, but these nominal values provide standardization for discussion purposes.

ESS have two primary use cases: electrical bill savings and facility energy resiliency.

Electric Bill Savings

On-site energy storage provides an opportunity to strategically reduce energy and demand charges when utility rates are highest then recharge when rates are lower or when solar energy is readily available. While batteries do not produce their own energy, they enable an on-site PV system to maximize the value of solar energy based on the utility rate characteristics, season, weather, and facility power requirements. The figure below demonstrates how a BESS recharges (peach color) from solar (green color) during the morning and discharges to the facility when energy and demand rates are highest and solar is insufficient to cover the building's need. Demand and energy charges are shown as lines below the x-axis with price units on the y-axis. By deploying the battery during the on-peak period, the net demand is reduced by 44 kW. A BESS operating in this manner over the course of months and years can realize utility bill saving and offset the equipment and software investment.



While energy storage systems have the capability to charge from the grid when energy is cheap and discharge to the facility when energy is expensive (energy arbitrage). Energy arbitrage is only effective where there is a large delta between on-peak and off-peak energy rates. In some cases BESS can augment customer savings by participating in ISO-New England's demand response program. Battery storage has the capability to provide more advanced ancillary services to the energy market such as frequency regulation, however the financial analysis of BESS market participation is beyond the scope of this assessment.

Facility Energy Resiliency

BESS installed with the appropriate software and transfer switches have the capability of providing emergency backup power. Resiliency is generally of great interest to public institutions. While there can be clear economic benefits associated with power reliability (e.g. research output and business operation), these benefits are not associated with utility rates and thus cannot be modeled within a typical utility savings financial assessment. BESS designed for resiliency are more complicated and expensive than those designed for utility bill savings by about 20% and typically are slower to recover their investment, if at all. **While BESS resiliency may help harden UML buildings to the impacts of intermittent power disruptions, they are unlikely to supplant a liquid fuel generator and as such would have limited impact on long term energy and climate targets.**

Pilot Project BESS Models

In depth battery storage modeling was completed for two representative facilities: Ball Hall and Tsongas Center. Ball Hall was selected from the three pilot sites as a typical small/medium PV system candidate while Tsongas Center was selected due to the PV system size being greater than 500 kW. Per SMART incentive program requirements, any PV incentive application submitted for a system larger than 500 kW-DC must include energy storage. Appendix N contains a list of UML sites where storage is required based on modeled PV system sizes as well as relevant design guidance.

For greatest system efficiency and economy, it is ideal to have batteries located close to both the PV system and the site where electricity is consumed. This can be more complicated when utilizing large carport canopy systems that are distant from buildings. In this case it may be necessary to utilize step up transformers to limit costs or selectively site BESS upstream closer to the utility meter.

BESS must be located outside on grade due to ventilation and fire requirements. Siting of BESS can be a challenge at dense locations where undeveloped/ available space is limited. Battery storage systems range in physical dimension from the size of a typical closet (5'W x 3'D x 7'H) to container-sized enclosures such as the Tesla Megapack that come in scalable packages (24'W x 6'D x 8'H). The BESS modeled for Ball and Tsongas require approximately 27 sqft with an additional 35 sqft of unimpeded access space. As BESS increase in size, siting considerations play an increasingly important constraint on project viability.

UML has two primary utility meters which complicates estimating the value of BESS on a site-by-site basis for the buildings and properties that are bulk metered. Since BESS provides value through peak power demand reduction, shaving demand spikes at one building may not reduce the aggregate peaks as seen by the utility through the meter. For the purposes of this assessment each building submeter was evaluated as if it were a utility meter, however, in practice, savings may differ.

The table below shows PV and BESS system details for the two pilot sites. With each site could accommodate a larger battery bank, the configuration below was found to best leverage the SMART incentive.

#	Site	PV System Type	System Size (kW-DC)	BESS Rating[2] (kW/kWH)	Year-1 Total Site Load (MWh)	Year-1 Solar Gen. (MWh)	Energy Offset
1	Ball Hall	Ballasted Roof Mount	111.9	37/74	906.2	151.5	17%
2	Tsongas Center	Mech. Attached on Roof	502.7	150/300	2,939.8	678.9	19%

[2] Approximate BESS rating. Actual size varies by product specification, product offerings change frequently.

Pilot Project PV+BESS Financial Models

The financial viability of battery energy storage systems are still variable and PV+BESS projects frequently have lower net cost savings than PV only projects. To promote battery storage, the Commonwealth uses incentives such as the SMART battery storage program to improve the cost effectiveness of systems. In practice, UML or the potential third-party system owner will align the BESS design with SMART program requirements to best leverage the incentive and maximize project savings. Over time, the economics of BESS will improve as battery prices decrease and as utilities continue to impose rate changes in response to renewable energy grid penetration.

Both sites reviewed achieve positive NPV's at the end of the project lifecycle both for cash and PPA arrangements and can be seen in the tables below. While the economic outlook of PV+BESS is positive, PV only scenarios still outperform PV+BESS in lifecycle NPV. This is not uncommon across the industry right now and is related to the O&M costs, battery replacement costs at year 15, and BESS product cost.

System Size (kW-DC)	PV+BESS System Cost ($)	25-year O&M ($)	SMART Incentive ($)	25-year Utility Bill Savings ($)	25-year Net Benefit (2019$)	25-year Net Present Value ($)	Simple Payback (yrs)	IRR (%)
Ball Hall	$ (381,848)	$ (113,798)	$ 383,168	$ 884,171	$ 771,693	$ 263,008	8.6	11.0%
Tsongas Center	$ (1,233,729)	$ (530,873)	$ 1,040,163	$ 3,861,836	$ 3,137,397	$ 1,172,537	7.7	12.8%

Site	PPA Rate	20-year PPA Payments	20-year Utility Bill Savings	20-year Net Benefit (2019$)	20-year Net Present Value
Ball Hall	$ 0.18	$ (597,645)	$ 653,211	$ 55,566	$ 21,865
Tsongas Center	$ 0.17	$ (2,528,889)	$ 2,853,174	$ 324,286	$ 145,619

Assessing Alternative Strategies

The recommendations contained within this report are based on today's available technology. Technology change is accelerating. Therefore, it is paramount to establish a process for evaluating alternative strategies in order to take advantage of future, more efficient technologies and alternative energies that would align or accelerate UML's path to carbon neutrality. This vetting process is intended to align with Executive Order No. 594 goal to consider opportunities to use innovative technologies that can effectively address challenges not solved by business-as-usual practices.

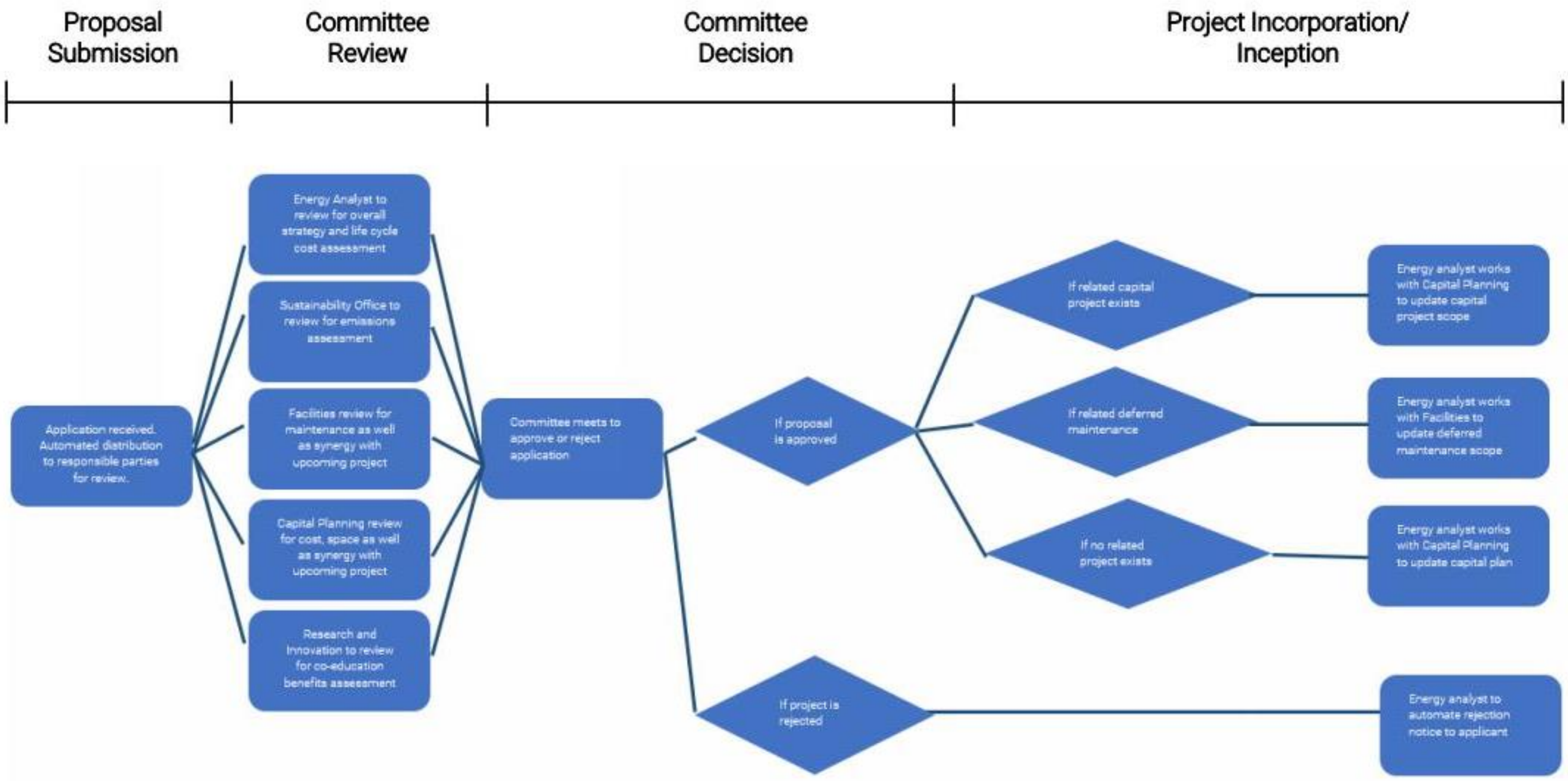
A proposed process could be similar to a Green Revolving Loan Fund or could be an extension of the Sustainability Engagement & Enrichment Development (S.E.E.D.) Fund. Proposals for energy efficiency, electrification, renewable deployment, and alternative energy are submitted by students, faculty, and staff to a committee representing key University entities (i.e. capital planning, facilities, energy management, sustainability, business development, and research innovation). The funds for projects can be extended as grants or loans. Loans can be repaid with the savings from implemented projects. The current AEMP Steering Committee could be extended to serve as this committee. Proposals could also be accepted from the greater Lowell community as an extension of the Lowell Green Community Partnership.

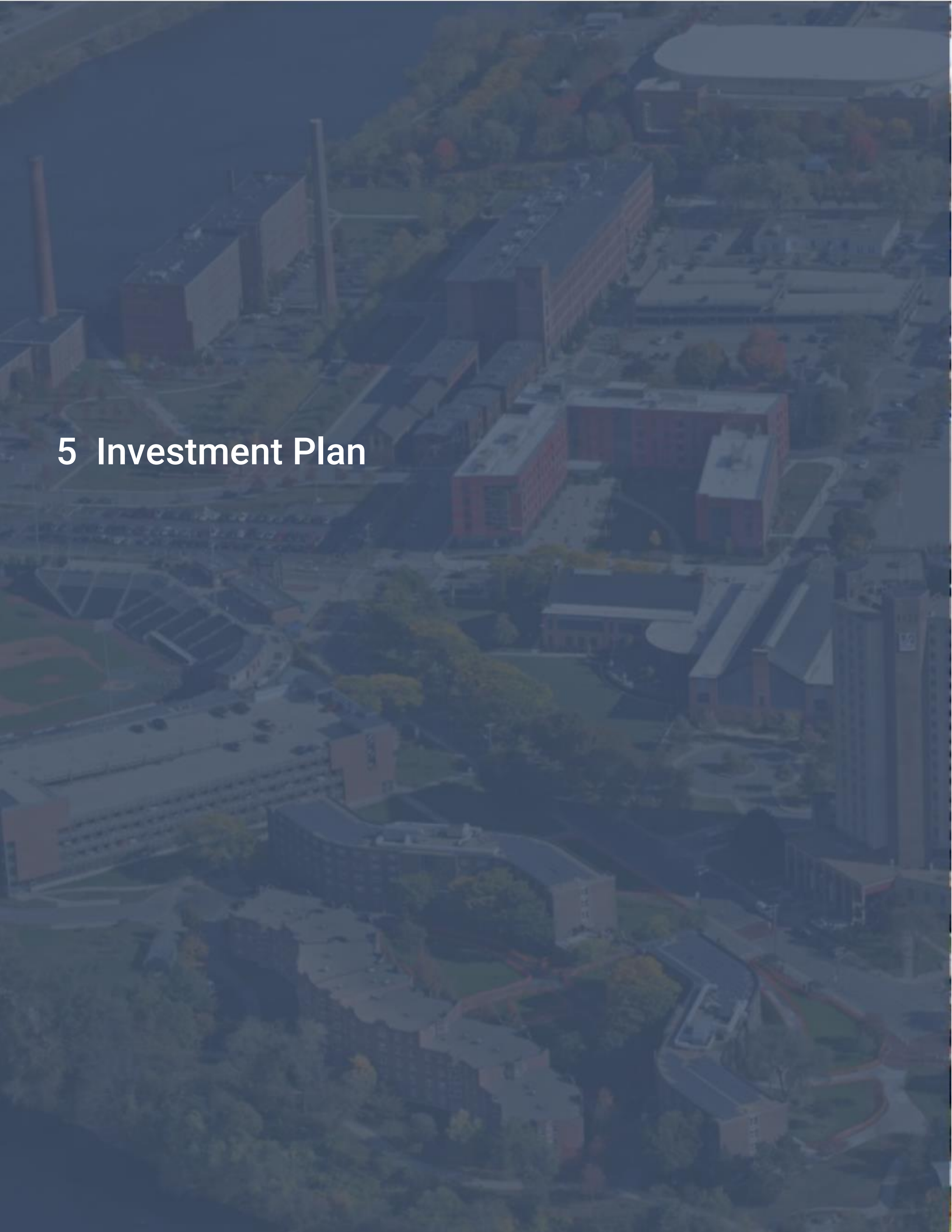
The recommendations within this Alternative Energy Master Plan (AEMP) and their associated performance targets can provide the baseline by which proposals are compared. Key performance indicators for comparison are: energy, emissions, and load reduction. In addition, other benefits should be considered when vetting proposals: life cycle cost, maintenance, reliability, resiliency, space allocation, educational co-benefits, and student engagement (i.e. behavioral change). The proposal form developed should prompt the applicant on each of these topics to enable an objective review.

It's expected that many of the AEMP recommendations, particularly deep energy retrofits, will be incorporated as part of capital projects. Therefore, it is recommended that a green building standard be established prescribing energy and emissions performance targets for new buildings and major renovations as well as prescriptive strategies for smaller scope projects. This will give design teams the flexibility to investigate alternative strategies while aligning with the overall carbon neutral vision. Education of project managers is important to ensure that design teams are proposing designs aligned with the requirements.

At the start of this process, it is recommended that project prioritization is aligned with the overall AEMP methodology: building energy efficiency/load reduction, plant electrification, renewable energy. Initial projects should target energy efficiency in the form of low temperature hot water and decoupled heating/cooling and ventilation systems, and/or target the top 1/3 of Building Scores (buildings with a score of 60 and above). As these types of projects are completed, project scope can be extended to incorporate electrification, renewable energy, and the top 2/3 of Building Scores (buildings with a score of 40 and above).

ALTERNATIVE STRATEGY ASSESSMENT





5 Investment Plan

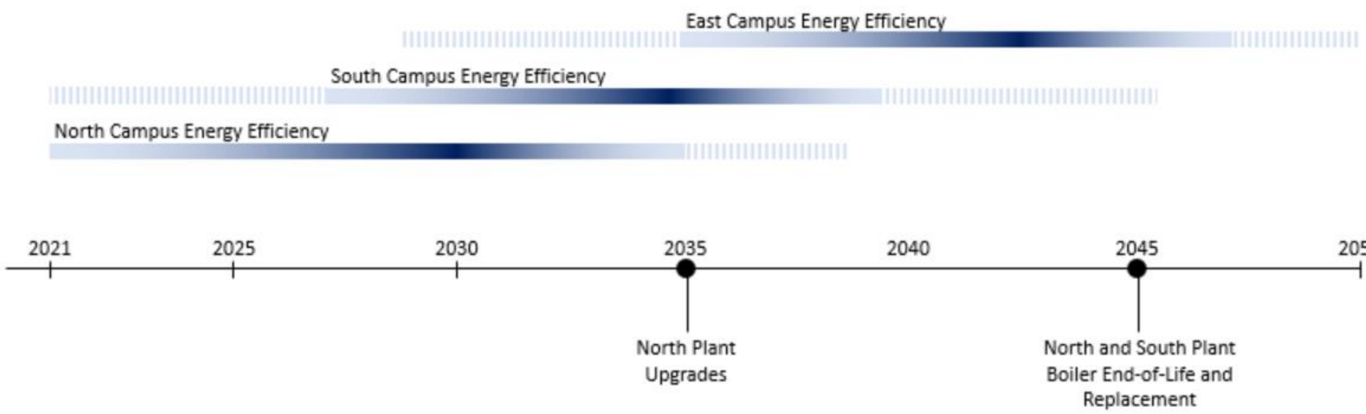
Investment Plan

The goal of the investment plan is to provide UML with actionable, cost-effective energy efficiency and alternative energy projects in order to approach the University's carbon neutral goal by 2050 and the emission and EUI requirements as outlined in Executive Order 594. Building score was used to strategically determine the degree to which building energy efficiency and alternative energy projects are recommended: Business-as-usual (BAU), Good, or Best upgrades. Upgrades on the North Campus are prioritized first, followed by the South Campus, and followed by those on the East Campus in order to sufficiently reduce load before the implementation of a central plant on the North Campus and to maximize the useful life of central plant assets on the North and South campuses. Conformance with the investment plan would result in the following key achievements:

1. Carbon neutrality by 2050 with implementation of this plan and an offset purchase equivalent to approximately 3,300 MTCDE
2. Reduce onsite building fossil fuel emissions by 98% by 2050 meeting all required EO594 targets (compared to 2004 baseline)
3. Reduce EUI by 64% by 2050 meeting all current EO594 targets (compared to 2004 baseline)
4. The Selected Scenario is estimated to be a $986 million first cost premium as compared to the BAU (Central Steam + Deferred Maintenance).
5. There is a negative return on investment when comparing the Selected Scenario to the BAU (Central Steam + Deferred Maintenance)

Implementation Timeline

The timing of energy efficiency and alternative energy projects were prioritized based on building score, Building score was further used to determine whether a building is recommended for business-as-usual (BAU), Good, or Best upgrades. The timeline below shows the relative timing of energy efficiency and alternative energy projects on each campus as well as critical central plant milestones.



Energy efficiency projects for buildings on the North Campus were prioritized in order to reduce loads ahead of new central plant upgrades. North Campus building energy efficiency projects are recommended to be implemented between the present and 2035. Construction for new heating hot water and chilled water piping infrastructure would take place during this time. 2035 would be targeted for when a new plant and vertical closed loop geothermal boreholes would be built adjacent to the current heating plant location. This new building would house the heat recovery chillers, supplemental chillers, and cooling towers. Air-to-water heat pumps would be located on the roof of the new building as well as the current plant, Falmouth Annex, and ground-mounted (if necessary). The steam plant would be upgraded with a central steam-to-hot water heat exchanger to meet peak load. This allows for UML to maximize the useful life of the two (2) boilers installed in 2015. Furthermore, the capacity of the existing boilers provided redundancy and resiliency in alignment with Executive Order 594. 2045 is the estimated horizon when these boilers would be up for replacement. This affords UML the flexibility to evaluate future fuel type trends whether that's natural gas, biofuel, or another fuel type that may provide efficiency, emissions, availability, and/or resiliency benefits compared to its natural gas and biofuel counterparts.

The South Campus building energy efficiency and alternative energy projects would be prioritized next ahead of retiring the South Plant central plant assets while maximizing their useful life. As proven most cost effective as detailed of the Default-Alternative Analysis, buildings on the South Campus would consist of standalone heat pump heating/cooling plants (individual systems for each building). Projects would generally be targeted between 2035 and 2045. 2045 is the estimated horizon when the boilers would be up for replacement. Therefore, 2045-2050 should be targeted to complete all South Campus projects such that the plant can be retired at that time. Projects on the East Campus would take final priority – generally taking place between 2040-2050 – as completion of these projects do not need to happen before the end of life of central plant assets. As proven most cost effective as part of the Default-Alternative Analysis, buildings on the East Campus would also consist of standalone heat pump heating/cooling plants. The table on the following page details recommended levels of upgrades and timeline for each building defining the Selected Scenario.

2020-2025

North campus infrastructure piping upgrades including:

- Low temperature hot water and chilled water distribution

Best upgrades for the following buildings:

- Ball Hall (North Campus)
- Costello Athletic Center (North Campus)
- Olney Hall (North Campus)

Good upgrades for the following buildings:

- Olsen Hall (North Campus)

2025-2030

North campus infrastructure piping upgrades including:

- Low temperature hot water and chilled water distribution

Good upgrades for the following buildings:

- Falmouth Hall (North Campus)
- Kitson Hall (North Campus)
- Southwick Hall (North Campus)
- Cumnock Hall (North Campus)
- Lydon Library (North Campus)

2030-2035

North Plant expansion

- Construction of expanded central plant building
- Geothermal boreholes, air-to-water heat pumps, heat recovery chillers, supplemental chillers, and cooling towers (existing boilers to remain)

Good upgrades for the following buildings:

- Dandeneau Hall (North Campus)

Business-as-usual/deferred maintenance only for the following buildings:

- Perry Hall (North Campus)
- Pinanski Hall (North Campus)
- Pulichino Tong Business Center (North Campus)
- Saab Emerging Technologies & Innovation Center (North Campus)

2035-2040

Best upgrades for the following buildings:

- Concordia Hall (South Campus)
- Mahoney Hall (South Campus)
- Sheehy Hall (South Campus)
- Tsongas Center at UMass Lowell (East Campus)
- Weed Hall (South Campus)

Heat pump upgrades for the following buildings:

- Donahue Hall (East Campus)
- River Hawk Village (East Campus)
- University Crossing (East Campus)

2040-2045

North Plant boiler replacement
Decommission South Plant
Good upgrades for the following buildings:

- Dugan Hall (South Campus)
- Durgin Hall (South Campus)
- Health & Social Sciences Building (South Campus)
- McGauvran Center (South Campus)
- O'Leary Library (South Campus)

Heat pump upgrades for the following buildings:

- Bourgeois Hall (East Campus)
- Campus Recreation Center (East Campus)
- Coburn Hall (South Campus)
- Leitch Hall (East Campus)
- University Suites Residence Hall (East Campus)

2045-2050

Good upgrades for the following buildings:

- Ames Textile (East Campus)
- Fox Hall (East Campus)
- Graduate and Professional Studies Center (East Campus)
- UMass Lowell Inn & Conference Center (East Campus)
- Wannalancit Business Center (East Campus)

Heat pump upgrades for the following buildings:

- 150 Wilder - Desmarais House (East Campus)
- 820 Broadway (East Campus)
- Allen House (South Campus)
- Charles Hoff Alumni Scholarship Center (East Campus)
- UMass Lowell Bellegarde Boathouse (North Campus)

Financial Investment

Three scenarios were developed in order to show the relative cost of the Selected Scenario: BAU (Central Steam + Deferred Maintenance), BAU (Electric + Major Renovation), and the Selected Scenario. All scenarios account for upgrades on all three of the campuses, as summarized below:

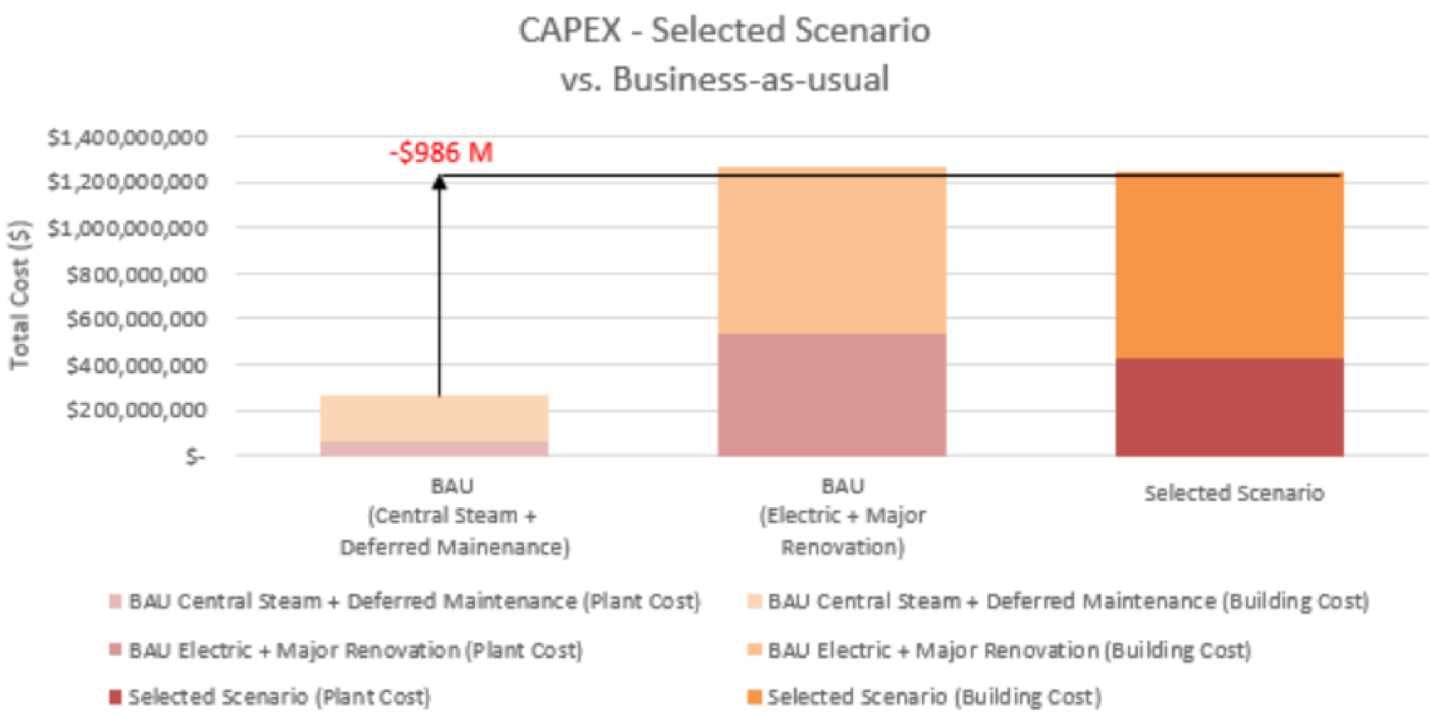
1. The BAU (Central Steam + Deferred Maintenance) option assumes that UML would perform the deferred maintenance defined in the Sightlines deferred maintenance backlog and maintain its central steam plant and infrastructure on the North and South Campuses and existing standalone system heating and cooling plant types at existing standalone buildings.
2. The BAU (Electric + Major Renovation) assumes a hypothetical case in which UML would electrify heating systems at individual buildings as part of a decentralized approach with limited amount of building upgrades as would be required as part of a major renovations and system replacements to rely on low-temperature hot water for heating.
3. The Selected Scenario proposes to make optimal building upgrades as part of major renovations to reduce loads and energy consumption and provide electric heat pump heating systems at central and standalone buildings.

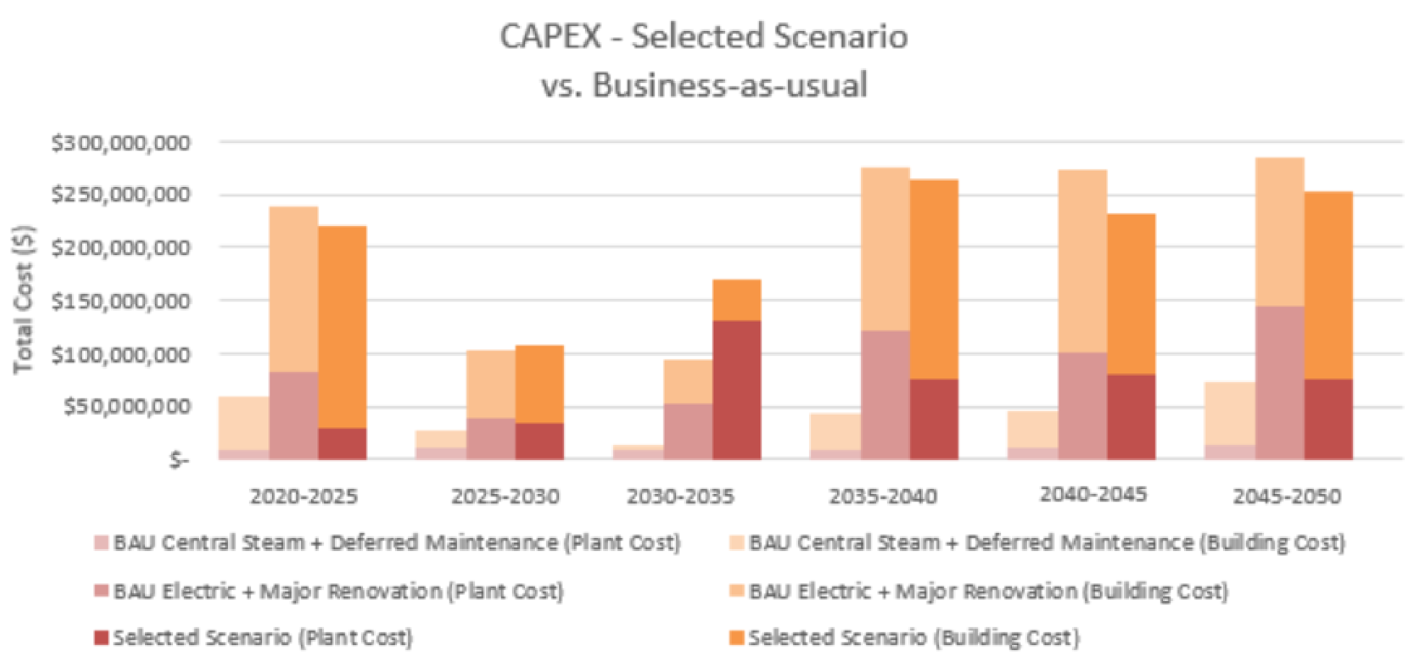
The BAU (Central Steam + Deferred Maintenance) scenario would not meet UML's 2050 carbon neutral goal nor the requirements of Executive Order 594. This scenario assumes UML would maintain its central steam plant and infrastructure on the North and South Campuses. Costs were aggregated from the available Sightlines assessment. Plant costs include boiler replacement, piping infrastructure upgrades, and heat exchanger replacements. Plant costs also include decentralized plant equipment replacements at individual buildings (i.e. boiler, chiller). Building upgrades only include deferred maintenance most relevant to: envelope and MEP energy upgrades. It is assumed that these costs are inclusive of all costs including material, labor, and soft costs.

BAU (Electric + Major Renovation) would meet UML's 2050 carbon neutral goal. This scenario assumes electrification using heat pumps with minimal energy efficiency upgrades as part of a major building renovation. This baseline is intended to further demonstrate energy efficiency is key to cost effective carbon neutral solutions.

The graphs on the following page show the total capital costs cost over a 25 year period leading up to 2050 with a breakdown of the costs into 5-year periods when the projects are recommended to occur. Plant costs are in various shades of red. Each shade represents a different scenario. Building costs are shown in various shades of orange. Each shade represents a different scenario. The BAU (Electric + Major Renovation) and Selected Scenario only account for related envelope and MEP energy upgrades. Costs account for mark-ups and escalation (see Appendix R for assumptions). All other unrelated costs are excluded (i.e. FF&E, architectural finishes, structural). Key takeaways are as follows:

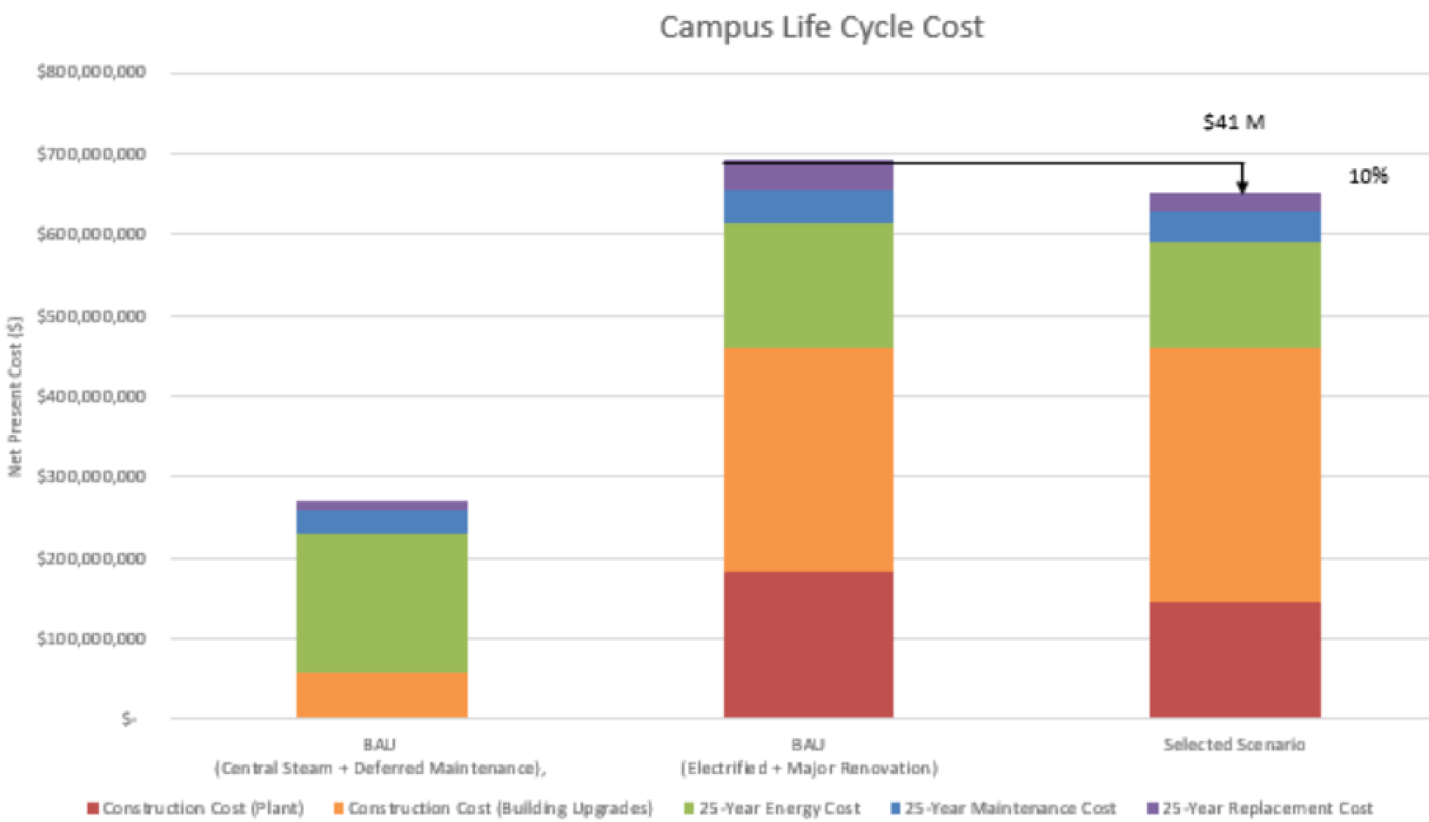
1. The Selected Scenario is estimated to be a $986 million first cost premium as compared to the BAU (Central Steam + Deferred Maintenance).
2. The initial investment in energy efficiency in the Selected Scenario results in reduced plant size and cost which overall results in a $21 million lower first cost than BAU (Electric + Major Renovation).


CAPEX - Selected Scenario
vs. Business-as-usual
-$986 M
Total Cost ($)
$1,400,000,000
$1,200,000,000
$1,000,000,000
$800,000,000
$600,000,000
$400,000,000
$200,000,000
$-
BAU (Central Steam + Deferred Mainenance)
BAU (Electric + Major Renovation)
Selected Scenario
BAU Central Steam + Deferred Maintenance (Plant Cost)
BAU Central Steam + Deferred Maintenance (Building Cost)
BAU Electric + Major Renovation (Plant Cost)
BAU Electric + Major Renovation (Building Cost)
Selected Scenario (Plant Cost)
Selected Scenario (Building Cost)


CAPEX - Selected Scenario
vs. Business-as-usual
Total Cost ($)
$300,000,000
$250,000,000
$200,000,000
$150,000,000
$100,000,000
$50,000,000
$-
2020-2025
2025-2030
2030-2035
2035-2040
2040-2045
2045-2050
BAU Central Steam + Deferred Maintenance (Plant Cost)
BAU Central Steam + Deferred Maintenance (Building Cost)
BAU Electric + Major Renovation (Plant Cost)
BAU Electric + Major Renovation (Building Cost)
Selected Scenario (Plant Cost)
Selected Scenario (Building Cost)

The graph below shows the net present cost for each scenario over a 25-year life cycle. Note that net present cost is shown as opposed to total cost (as shown on the previous page). The 25-year costs for energy, maintenance and replacement are incorporated in addition to the plant and building upgrade costs. The energy costs decrease (green bar) as more building upgrades are incorporated (indicated by the increase in size to the orange bar). Maintenance costs and replacement costs are driven by less equipment in scenarios with central plants. Key takeaways are as follows:

1. The Selected Scenario is estimated to be a $41 million (10%) net present cost reduction as compared to the BAU (Electric + Major Renovation) scenario.



Improved Resiliency

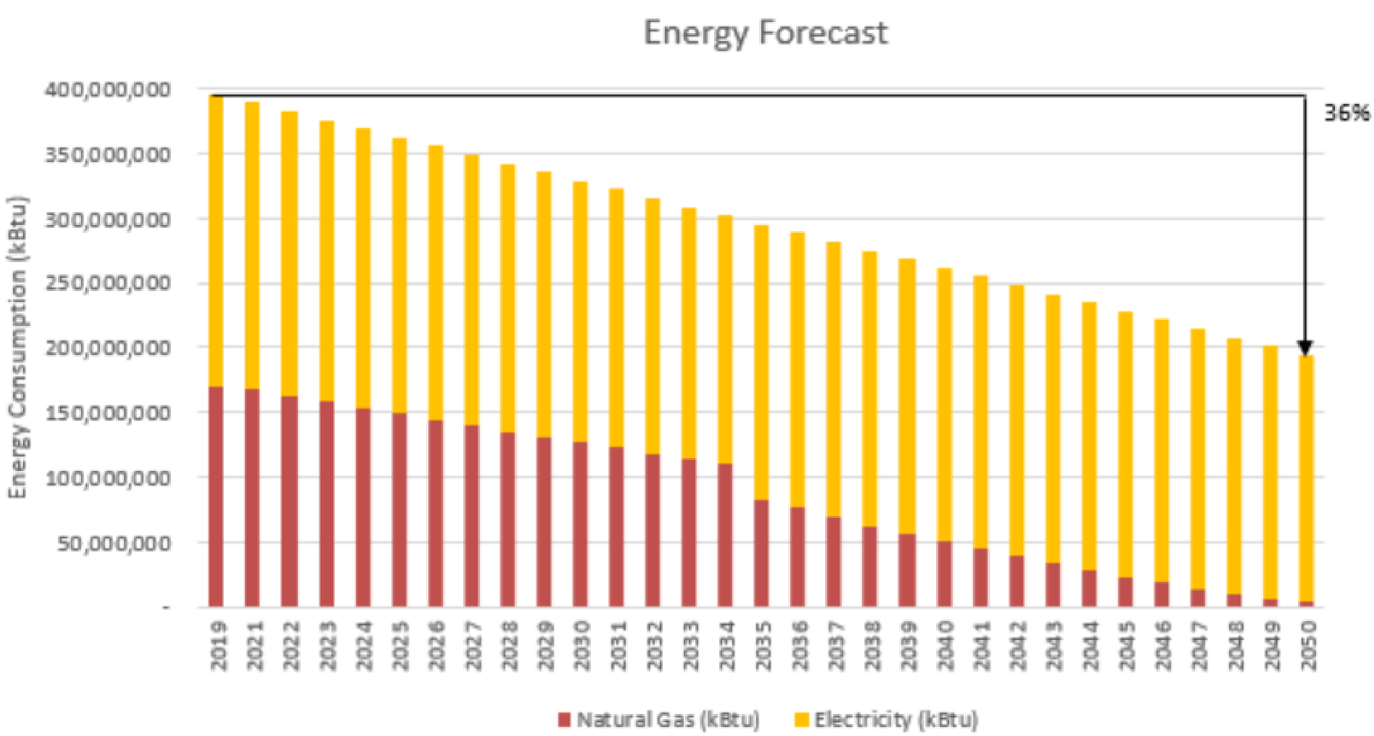
Executive Order 594 requires facility and energy resilience and to adhere to all applicable resiliency requirements, including, but not limited to, Executive Order 569 and the Massachusetts State Hazard Mitigation and Climate Adaptation Plan to improve the capacity of critical infrastructure and energy systems to withstand growing weather-related impacts associated with climate change. This plan incorporates improved levels of resiliency for the campus. The recommended North Campus Central Plant incorporates multiple fuel sources for heating: electric (heat recovery chillers and air-to-water heat pumps), natural gas, and fuel oil (dual fuel boilers). Backup generators are recommended to be provided to maintain heating via the boilers and pump operation for 36 hours as requested by UML. UML should review critical operation in buildings designated for standalone heating/cooling systems to determine if emergency power upgrades are required beyond those currently in place.

Energy, Emissions, EUI Results

The Selected Scenario results in significant reductions in energy and emissions. This creates a pathway towards carbon neutrality by 2050 and achievement of Executive Order 594 target requirements for building emissions and EUI. Note that this section references Executive Order 484. Executive Order 594 replaced Executive Order 484 during the course of this study in April 2021. Both sets of energy and emissions requirements are shown as benchmarks in order to showcase UML's previous progress as well as potential, future progress.

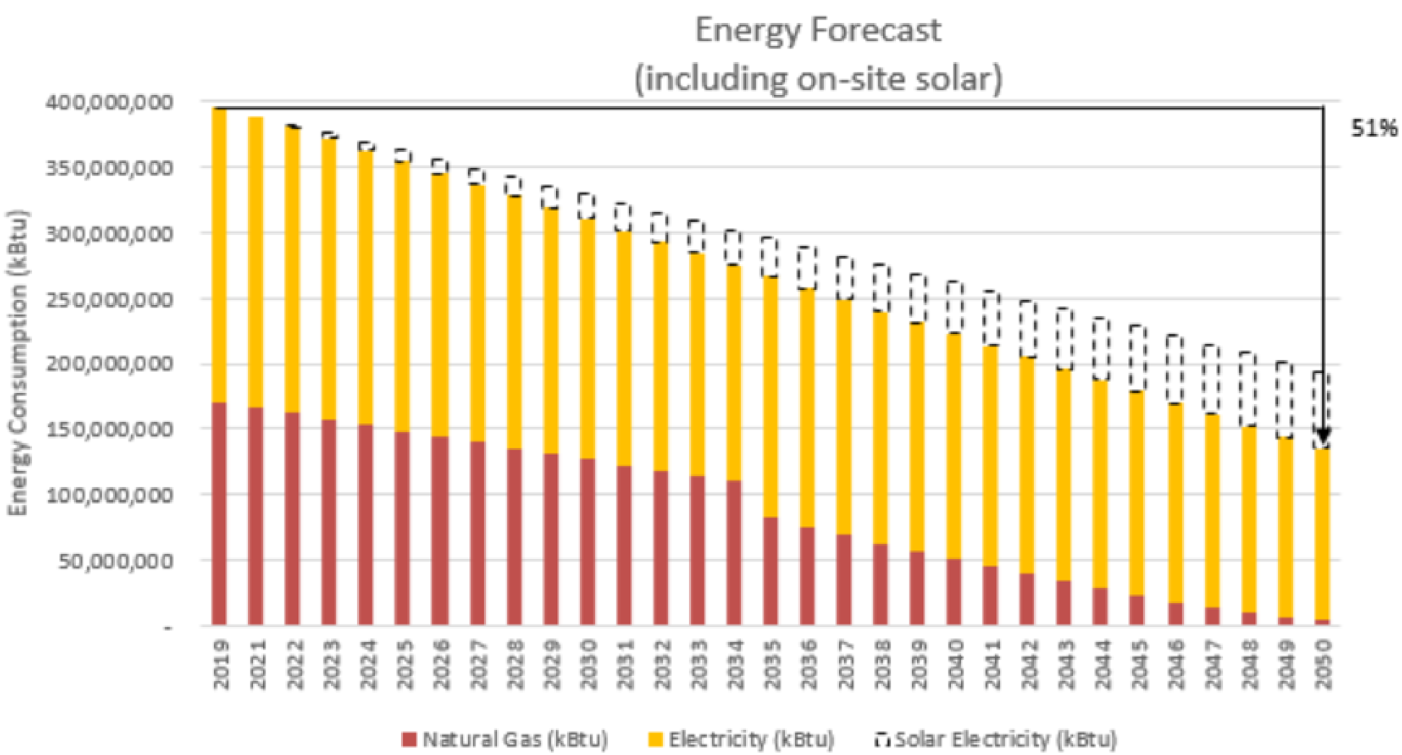
The graph below shows the energy reduction of implementing the Selected Scenario compared to present day energy consumption. Present day energy consumption is used as the baseline as opposed to 2004 given that there are no related Executive Order requirements for energy consumption. Natural gas consumption is reduced as a result of energy efficiency and electrification of heating systems. In 2035, the natural gas consumption is expected to reduce at a greater rate, which is a result of the North Campus plant upgrades coming online. Electricity consumption reduces as a slower rate as some energy efficiency improvements are offset by electrification. Key takeaways are as follows:

1. The Selected Scenario is estimated to reduce energy consumption 36% compared to energy consumption in 2019.



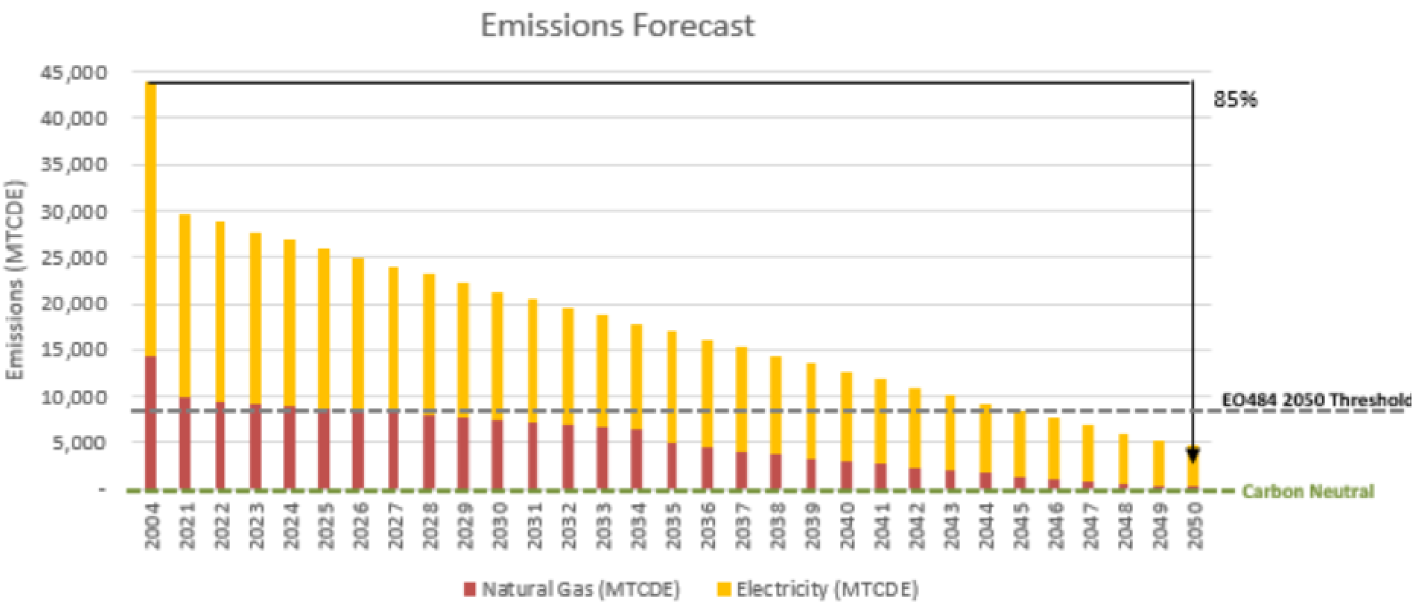
The graph below shows the further energy reduction as a result of deploying all onsite solar PV as identified in the Default-Alternative section. It is not reasonable to assume that UML would deploy onsite solar PV in all locations identified, but this analysis provides a book end for the maximize reduction achievable from onsite renewables. Key takeaways are as follows:

1. The Selected Scenario is estimated to reduce energy consumption 51% compared to energy consumption in 2019.



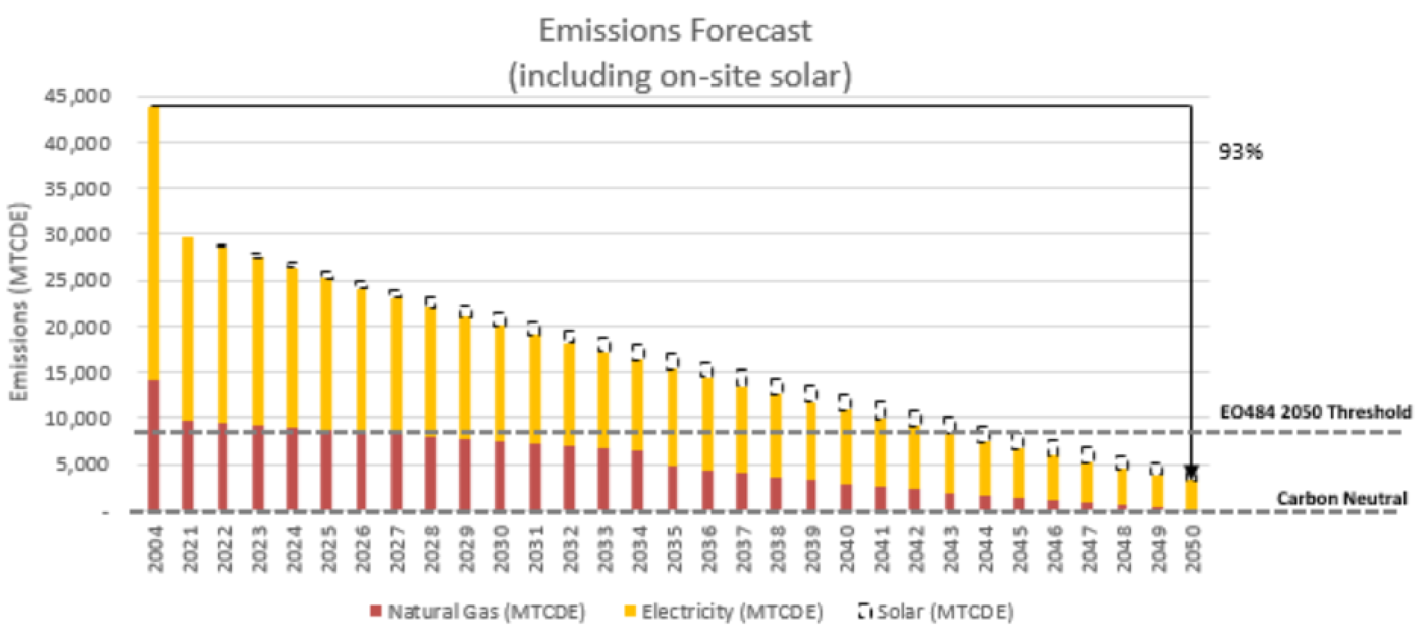
Reduction in natural gas consumption as a result of electrification and reduction in overall energy consumption as result of energy efficiency drives down emissions. Previous to the adoption of Executive Order 594, Executive Order 484 required an 80% emissions reduction compared to a 2004 baseline. The graph below shows the reduction of emissions over time. Key takeaways are as follows:

1. The Selected Scenario is estimated to reduce building emissions 85% compared to emissions in 2004. About half of this reduction is the result of grid emission reductions.
2. Achievement of carbon neutrality by 2050 would require a carbon offset purchase equivalent to approximately 3,300 MTCDE



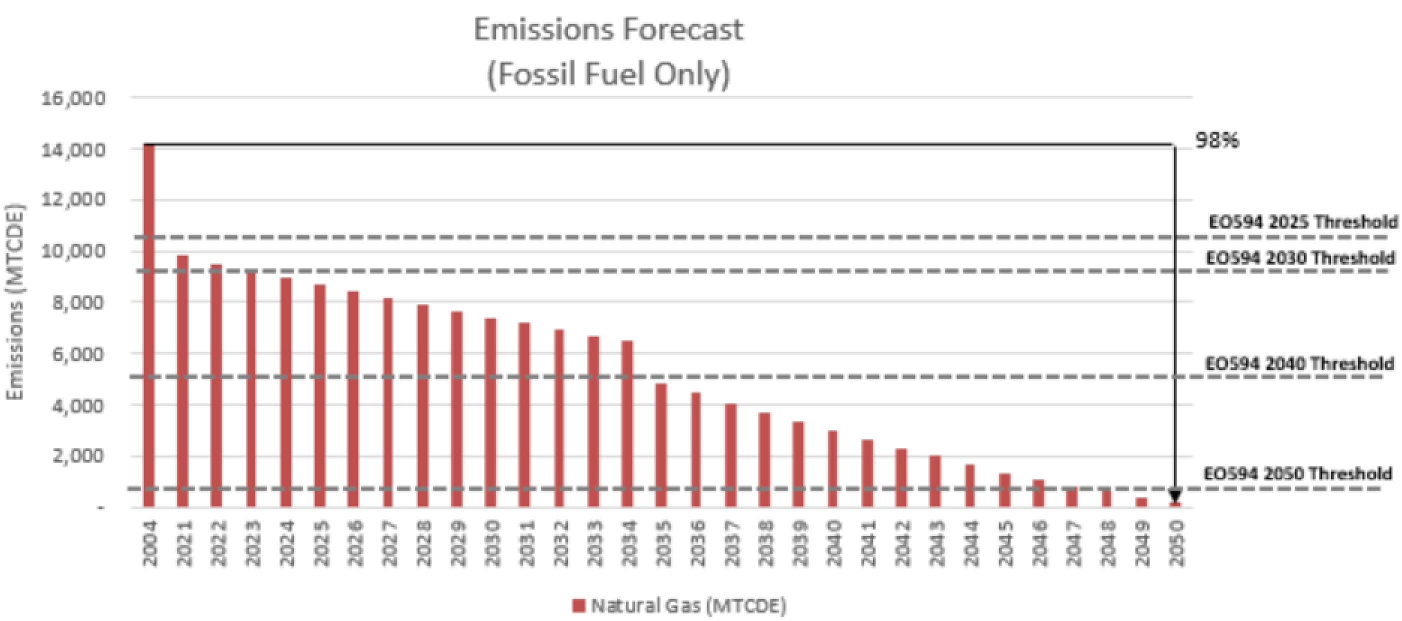
Generation and retirement of renewable energy credits (RECs) from onsite renewables is another means to reduce emissions. At this time, RECs are owned by the utility as part of the SMART incentive program. The financial incentive from SMART is critical in the cost effectiveness of solar PV projects. If the SMART program were to change such that UML could retain and retire the RECs, then the RECs could result in further emission reduction. However, it is expected that UML would sell the RECs given the economic benefit. Therefore, the graph below is intended to serve as a reference only. The graph shows the reduction of emissions over time as a result of onsite solar PV deployment. Key takeaways are as follows:

1. The Selected Scenario is estimated to reduce building emissions 93% compared to emissions in 2004. About half of this reduction is the result of grid emission reductions.
2. Achievement of carbon neutrality by 2050 would require a carbon offset purchase equivalent to approximately 1,900 MTCDE



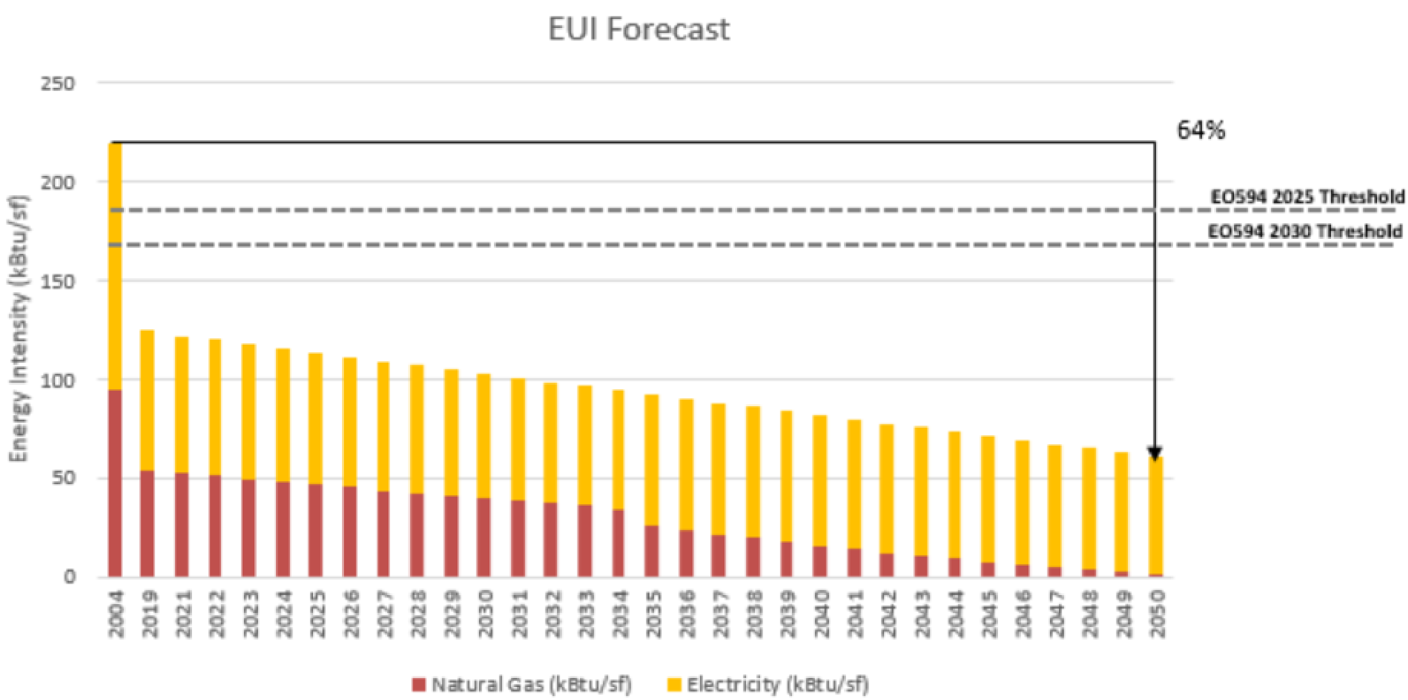
Executive Order 594 (EO594) requires reducing emissions associated with the burning of on-site fossil fuels at buildings and in vehicles by 20% in 2025, 35% in 2030, 60% in 2040 and 95% in 2050 (as compared to a 2004 baseline). UML has already met the 2025 and 2030 thresholds based on data compiled by Competitive Energy Solutions. The scope of this alternative energy master plan was building emissions only. Therefore, the 2004 baseline as indicated on the following page was developed by assuming the 30% reduction in total emissions between 2004 and 2019. The graph shows the reduction in onsite fossil fuel emissions as a result of implementing the Selected Scenario. Key takeaways are as follows:

1. The Selected Scenario is estimated to reduce onsite fossil fuel emissions 98% compared to a 2004 baseline.
2. UML could meet both the EO594 2040 and 2050 targets by fully implementing the plant and building upgrades as part of the Selected Scenario.



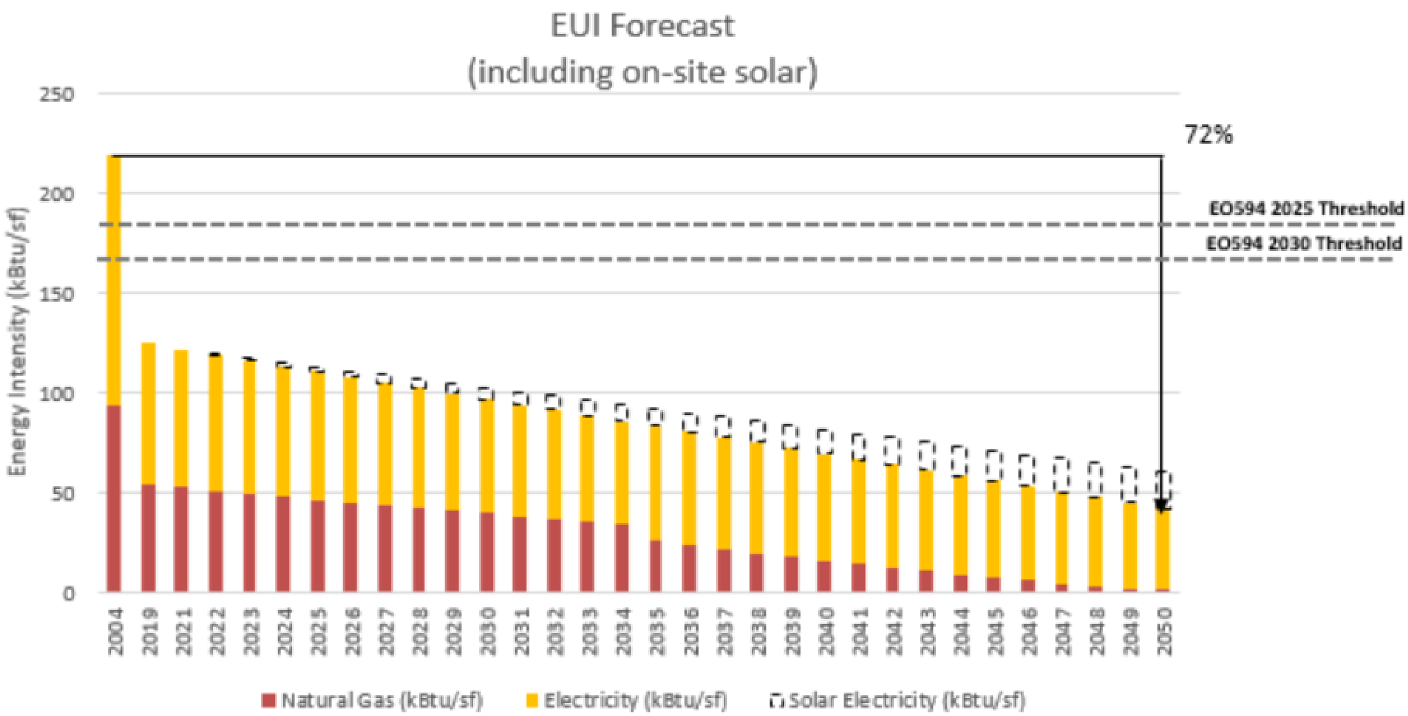
Executive Order 594 (EO594) requires reducing energy use intensity (EUI) from a 2004 baseline by 20% in 2025 and 25% in 2030. UML has already met these thresholds based on data compiled by Competitive Energy Solutions. The scope of this alternative energy master plan was for buildings as indicated as part of the Metering and Data Management Report. Therefore, the 2004 baseline as indicated below was developed by assuming the 43% reduction in EUI between 2004 and 2019. The graph shows the reduction in EUI as a result of implementing the Selected Scenario. The EO594 2040 and 2050 targets are not defined at this time but energy efficiency upgrades as part of the Selected Scenario will certainly contribute to achieving future targets. Key takeaways are as follows:

1. The Selected Scenario is estimated to be emissions 64% compared to EUI of buildings covered under this study in 2004 referenced as part of EO594.



The graph below is intended to serve as a reference for the impact of onsite solar PV deployment if RECs were to be retired. Key takeaways are as follows

1. The Selected Scenario is estimated to be emissions 72% compared to EUI of buildings covered under this study in 2004 referenced as part of EO594.



Summary

The investment plan for the Selected Scenario provides UML with actionable, cost-effective energy efficiency and alternative energy projects in order to approach the University's carbon neutral goal by 2050 as well as meet the emission and EUI requirements as outlined in Executive Order 594. The Selected Scenario is estimated to be a $986 million first cost premium as compared to the BAU (Central Steam + Deferred Maintenance). There is a negative return on investment when comparing the Selected Scenario to the BAU (Central Steam + Deferred Maintenance). A carbon offset purchase equivalent to an estimated 3,300 MTCDE would be required in order to achieve carbon neutrality by 2050. Changes to the Clean Energy Standard (CES) requiring procurement from clean energy sources beyond 80% could reduce this required purchase. Funding of the investment plan is contingent on external funding. Therefore, collaboration with DOER and other DCAMM agencies to agree on a path forward towards a common goal is paramount. UML is uniquely positioned to implement this plan given available operations, teaching, and research resources as well as interagency collaboration.