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CAMPUS ENERGY MASTER PLAN
UMASS DARTMOUTH

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CAMPUS ENERGY MASTER PLAN
UMASS DARTMOUTH

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1. EXECUTIVE SUMMARY

Campus Goal

University of Massachusetts at Dartmouth (UMassD) has publicly committed to achieving carbon neutrality by 2050 with the goal of accelerating that goal to 2030 if possible. Ramboll has worked with UMassD along with the Massachusetts Division of Capital Asset Management and Maintenance, the Massachusetts Department of Energy Resources, and Competitive Energy Services to develop this Energy Master Plan to achieve those goals.

Campus Overview

The University of Massachusetts Dartmouth (UMassD) is a state college located in North Dartmouth, Massachusetts. UMassD serves nearly 9,000 students who pursue majors in 50 baccalaureate and 40 graduate programs, including 12 at the doctoral level. Founded in 1895, the Dartmouth campus has been a thriving component of the University of Massachusetts system since 1991, with over 50,000 alumni/ae.

The University's resident population capacity of nearly 4,000 represents approximately 50% of the undergraduate student body, with commuter students accounting for the balance. In addition to the student population, the UMassD employees approximately 1,453 personnel that commute to work daily.

Energy Master Planning Approach

Ramboll utilized the following approach to generate this EMP.

1. Utilize historical data to understand how, where, and when energy is used on campus
2. Review where sub-meters are currently installed and recommend new locations which will allow UMassD to better understand how, where, and when energy is used on campus
3. Benchmark the campus buildings to understand how they compare on their energy use (on a per square foot basis) against peers of similar use and geography
4. Understand the campus modernization plans in order to project future energy demands
5. Consider a wide range of technologies which could be used at the campus and filter that list down to the viable technologies that have the ability to contribute to carbon neutrality at the least economic cost and do not impose excessive risk
6. Consider a wide range of possible solutions and then screen them using both qualitative and quantitative considerations in order to select a preferred solution
7. Introduce an implementation plan for the selected scenario which will include process schematics, an implementation schedule, spatial arrangements, and an AACE Class 4 cost estimate
8. Summarize the findings of this process in a comprehensive energy master plan report which can be used to guide UMassD to achieve carbon neutrality

The following sections will summarize the findings of the energy master plan.

Data Analysis

The campus provided two years of utility and submetered data to aid in the understanding of how and when various forms of energy is required on campus. The campus also communicated its intentions to modernize over the next 20 years so that the future energy demands could be estimated.

Table 1-1 shows the total electricity and natural gas use and cost for the main campus for 2019 from utility bills. The resulting GHG emissions are shown in Table 1-2.

Table 1-3 shows the baseline (2019) and 2030 estimated building level end use loads (not input fuel) for electricity, heating (space heating and domestic water heating) and chilled water. Peak hourly rates are also included. Note that these totals exclude some minor buildings and site lighting loads.

Table 1-1. 2019 Utility Supply Cost Summary Table

Commodity	2019 Annual Use	Peak Demand	Unit Cost	Annual Cost
Electricity (Purchased)	15,362,480 kWh	4,523 kW	0.140 $/kWh	2,148,670 $/yr
Natural Gas	3,265,989 Therms	NA	0.690 $/Therm	2,253,532 $/yr
Total	NA	NA	NA	4,402,202 $/yr

Table 1-2. 2019 Utility Supply GHG Summary Table

Commodity	2019 Annual Use	Emission Factor	GHG Production
Electricity	15,362 MWh	528 $lbCO_2e/MWh$	3,679 Metric Tons
Natural Gas	3,265,989 Therms	11.7010 $lbCO_2e/Therm$	17,334 Metric Tons
Total	NA	NA	21,013 Metric Tons

Table 1-3. Building Load Summary Table

Utility	2019 Annual Load	2019 Peak Demand	2030 Annual Load	2030 Peak Demand
Electricity	27,272,694 kWh	4,815 kW	26,983,820 kWh	4,910 kW
Heating	136,749 MMBtu	46.1 MMBtu/h	131,674 MMBtu	44.2 MMBtu/h
Chilled Water	69,160 MMBtu	43.7 MMBtu/h	70,783 MMBtu	44.8 MMBtu/h

Current Campus Infrastructure

UMassD currently operates a central heating plant with some buildings that are not connected to the steam distribution system. The campus does not have a centralized chilled water district, but utilizes a mixture of steam absorption chillers, water cooled chillers, and air-cooled chillers that are located throughout the campus.

Table 1-4. Current Central Heating Plant Generating Assets

	Input	Output	Efficiency %	Pressure psig	Notes
Central Utility Plant					
Steam Boilers #1	8,375 MBH	6700 MBH	80%	150	1
Steam Boiler #2 & #3	41,440 MBH ea.	26,000 lb/hr ea.	66%	250	2
Gas Turbine	23,760 MBH	1,627 kW			3
Heat Recovery Steam Generator	228 °F Feedwater	23,700 lb/hr	61% (w/ duct	100	
Duct Burner	18,980 MBH	15,420 MBH	81%		
Athletic Center Heating Plant					
Two Cleaver Brooks Boilers	10206 MBH	8369 MBH	82%	15	4

1. Cleaver Brooks; CB-428-200; Manufactured 1965
2. The Bigelow Company; KS-21-250; Manufactured 1965
3. Manufactured 2012
4. Cleaver Brooks; Manufactured 1998

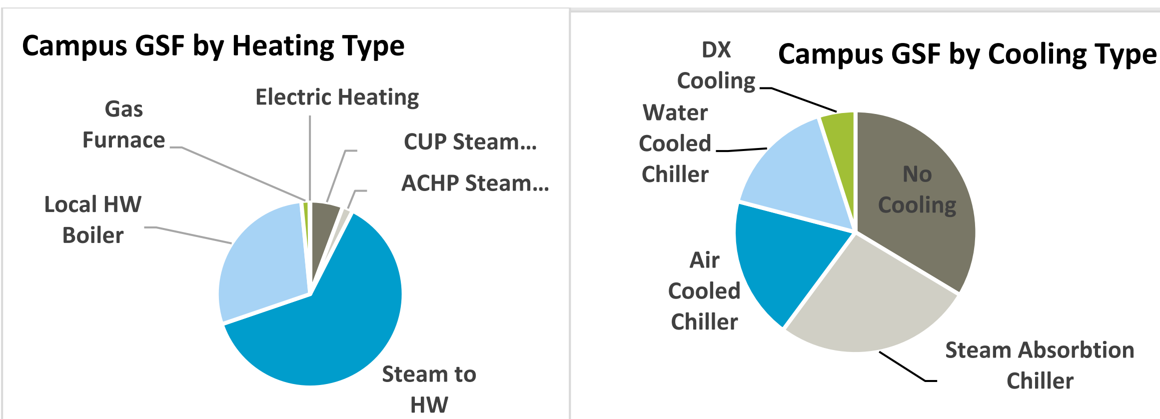


Figure 1-1. Campus Heating and Cooling by Source

Selection of Preferred Solution

Ramboll undertook a step-wise and methodical approach to assessing viable technologies, developing scenarios, screening the scenarios, and then selecting a preferred scenario. After the preferred scenario was selected the project team further developed the scenario into execution phases, sized assets, developed a process flow diagram, spatial layouts, and electrical 1-line schematics which supported the development of an execution schedule and cost estimate for the project.

Submetering

The campus has already made significant progress implementing a campus submeter program. There are currently 27 working power meters and 13 steam meters on campus measuring building electric and steam demand, some of which meter multiple buildings.

The project considered adding building level submeters for the following services; electricity, natural gas, steam, condensate, chilled water, potable water, domestic hot water, and in some cases, an electrical submeter that would be installed specifically to monitor an electric chiller. By adding these meters UMassD would have the ability to better understand energy use and monitor for equipment failures so that they can be addressed quickly. Table 1-5 presents the existing number of submeters as well as the number of recommended new submeters.

Table 1-5. Recommended and Existing Meters

Official Building Name	Existing Meters							
	ELECT	NG	STM	COND	CHW	PTBLE WTR	DHW	ELECT - CLG
Existing Meters	**26**	**2**	**13**	**0**	**0**	**0**	**0**	**0**
Recommended Meters	**3**	**5**	**4**	**18**	**19**	**28**	**28**	**7**
Total	**29**	**7**	**17**	**18**	**19**	**28**	**28**	**7**

The project also divided the recommended meters according to two priority levels to aid in the implementation and provided a cost estimate based on recently completed projects at similar institutions. Table 1-6 presents a summary of the priority levels and estimated costs.

Table 1-6. Total Meter Estimated Cost

Meter	QTY		Total Cost
Priority Meters	65		$2,270,547
Second Priority Meters	47		$1,449,493
Total	**112**		**$3,720,041**

The submetering program is recommended to be implemented on the existing buildings as soon as possible. By installing submeters now, the campus will be able to gather data which will aid in the design and implementation of the selected scenario to achieve carbon neutrality. The recommended submeters are recommended for the existing building mechanical systems and the selected solution cost estimate includes an estimate for submeters for the proposed mechanical systems.

Benchmarking

The key performance indicator (KPI) of annual energy use intensity (*e.g.* kBtu/SF was calculated in order to compare then energy use intensity to the 2012 Commercial Buildings Energy Consumption Survey (CBECS) data sets, which is considered the industry standard benchmark. By benchmarking the campus, the project could identify how efficiently the campus utilizes energy and estimate the opportunity for future energy savings. Table 1-7 shows the results of the benchmarking and identifies that the buildings consume approximately 20% more energy than the average of similar buildings in a similar geography.

Table 1-7. Overall Campus EUI Comparison

	Total EUI (kBtu/SF)
2004 Baseline[1]	**164.2**
2012 EO484 Goal (20% reduction)	**131.4**
2020 EO484 Goal (35% reduction)	**106.7**
2020 Performance (Campus Weather Normalized)	**159.9**
CBECS Weighted Campus Benchmark	**127.5**

[1] As provided by CES on 11/6/2020 via e-mail. 1,849105 SF; 303,574,849 kBtu.

The benchmarking shows that there are opportunities for energy conservation at the campus. Since the CBECS benchmark value is an average of existing buildings, there is the opportunity to lower the EUI well below CBECS values. The campus EUI is largely impacted by the brutalist architectural which is common on campus. UMassD's central campus is comprised mostly of buildings designed by Paul Rudolph (in brutalist architecture) they present a number of challenges to energy efficiency. It is recommended that the insulation level be improved on the existing buildings in order to improve the campus EUI.

Modernization Plans

Several documents were reviewed and interviews were performed to understand what modifications or improvements were planned for the campus over the next 10-20 years. The project team reviewed the 2017 Campus Master Plan as well as the Sightlines presentation entitled "The University of Massachusetts – Dartmouth FY17 ROPA Final Presentation". The campus master plan identified some substantial demolitions, new construction, and additions on campus and the Sightlines data which recommended 24 buildings for gut renovations, four buildings for systematic renovations.

While both plans identified a large amount of differed maintenance, interviews with the campus staff identified that there is ongoing planning for the following projects over the next 10 years which is the shortest goal for carbon neutrality:

Renovation of MacLean Campus Center (including a 2,380 GSF addition)

- Construction of Balsam Hall dorm
- Construction of Spruce Hall dorm
- Completion of The Grove dining hall
- Demolition of Elmwood Hall
- Demolition of Maple Ridge Hall
- Demolition of Chestnut Hall
- Demolition of Roberts Hall

The future energy demand curves for electricity, heating and cooling were all adjusted to account for the planned renovations. The current campus modernization plans will not be enough to achieve the EX 484 35% energy reduction on an EUI basis.

Technology Screening

The team completed a brainstorming session to identify the technologies which could contribute to carbon neutrality. The technologies identified were based on industry experience and technology availability. At the initial stage, no filtering was applied with respect to cost, technical feasibility, other screening criteria.

Ramboll then filtered the list down to the viable technologies and screened out the technologies that were cost prohibitive, did not contribute to UMassD's goals, or that had not matured and were seen as too risky. The following technologies were considered as viable and were carried forward into the development of scenarios:

Energy conversion and supply units

- Gas boiler
- Biooil engines
- Biomass heat-only boiler (wood chips)
- Biooil boiler
- Electric boiler
- HP (air-to-water) - large scale
- HP (air-to-water) - small scale
- GSHP closed loop, horizontal, individual
- GSHP closed loop, vertical
- Photovoltaics
- Wind turbine
- Large Solar Thermal
- Conventional electric chiller
- Heat-recovery electric chiller

Thermal storage technologies

- TTES (Tank Thermal Energy Storage)
- ATES (Aquifer Thermal Energy Storage)
- PTES (Pit Thermal Energy Storage)
- BTES (Borehole Thermal Energy Storage)

Scenario Development and Screening

The team developed 12 possible future scenarios to be considered for evaluation. These scenarios were combinations of the technologies screened during the previous step and included heat pump technologies (air source and ground source), bio fuels, biomass, solar, as well as several energy storage options including tank thermal energy storage, pit energy thermal storage, borehole thermal energy storage and aquifer thermal energy storage. The team considered the business as usual scenario as the basis of comparison of future scenarios and it was also included as the 13th scenario.

The scenarios were filtered down to five scenarios using qualitative and light quantitative measures. These five scenarios underwent a detailed technology and economic modeling process which enabled a direct comparison of the scenarios. The criteria for comparison included the cost (represented as a net present value) and emissions (represented as metric tons of CO_2).

Each of the five scenarios utilized a central approach for hot water and chilled distribution systems. The distribution system modeling was completed in Termis where the hydraulic model would determine the distribution system requirements. The five scenarios also underwent energy modeling utilizing EnergyPro which estimated the performance of various components and how they would perform in order to meet the campus' energy demands while minimizing the cost and GHG values.

Table 1-8 provides a description of the five scenarios which were selected for detailed analysis. Figure 1-2 provides the key performance metrics of the scenarios which resulted from the energy and economic modeling. It is noted that an additional variation on scenario 4C was also modeled in order to better understand the optimal sizing of the equipment.

Table 1-8. Filtered Solutions

Scenario	Description
0	Continued production of heating and cooling, but including campus extension with new buildings and potential building renovations
3A	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, BTES
3B	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, PTES
4B	HRC/GSHP (cooling and heating), biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, PTES
4C	HRC/GSHP (cooling and heating), air-source HP, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, PTES

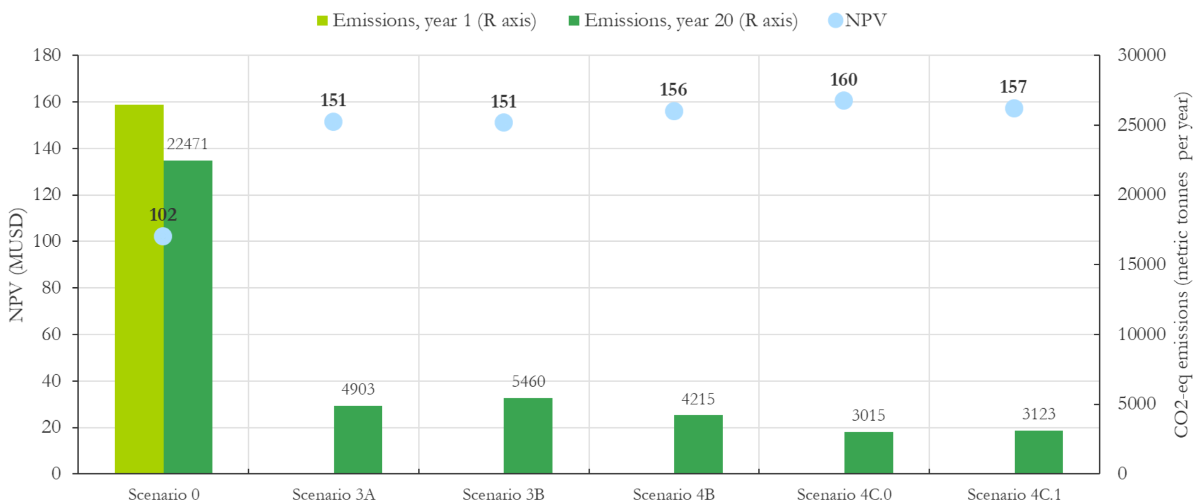


Figure 1-2. CO_2-eq Emissions and Net Present Value for the Filtered Scenarios

The results from the EnergyPRO simulations and the economic analysis were discussed with UMassD, identifying pros and cons of each scenarios, cost and environmental performance, risks and resiliency issues. Based on these discussions, the selected scenario was developed based on the following items that were learned from the simulations:

- Borehole thermal energy storage is preferred over pit thermal energy storage as a seasonal thermal energy storage. This was a result of the direct comparison between scenario 3A and 3B which only differed by the seasonal storage technology.
- In order to fully reduce the CO_2 emissions associated to heat production without utilizing offsets the natural gas boilers and biomass boilers were replaced by bio-diesel boilers. Each scenario during the modeling utilized the boilers for the peak production and none of the options achieved the full 100% carbon reduction.
- It was preferable to operate air source heat pumps as air cooled chillers as well instead of having dedicated air-cooled chillers in addition to the air source heat pumps. This was concluded based on the operating hours of the equipment and a detailed discussion with a heat pump expert.

The selected scenario consists of the following attributes:

<u>Energy Sources</u>
- Renewable Electricity – 2.5MW Solar PV Canopies
- Renewable Bio-diesel
- Natural Gas (for resiliency only)

<u>Thermal Generation</u>
- Heat Recovery Chillers
- Ground Source Heat Pumps
- Air Sourced Heat Pumps
- Dual fired (Bio-Diesel and Natural Gas) Boilers
- Air-cooled Chillers

<u>Thermal storage</u>
- Tank Thermal Energy Storage
- Borehole Thermal Energy Storage

<u>Distribution System</u>
- Low Temperature Hot Water Distribution System
- Chilled Water Distribution System

<u>Emergency Power</u>
- Backup biodiesel generators

Implementation Plan
Having selected the preferred solution the project shifted to developing an implementation plan which would support an AACE Class 4 cost estimate for the selected scenario. The first step in the implementation plan was to develop the phasing plan. The following provides an overview of the phasing plan.

- **Phase 1 – Enabling and Centralization** – This phase introduces the low temperature hot water and chilled water districts along with the first phase of heat pumps, an energy transfer station, and two tank thermal energy storage (TTES) systems. During this phase, some of the existing generating assets will continue to be utilized on natural gas.
- **Phase 2 – Earnest Shift from Fossil Fuels to Electrification** – This phase introduces the full build out of heat pumps along with the seasonal storage of bore hole thermal energy storage (BTES). This phase will retire the steam distribution network and utilize heat pumps as the primary energy source. Limited combustion fossil fuels will be utilized.
- **Phase 3 – Alternate Fuel Sourcing for Full Carbon Neutrality** – This phase will achieve 100% carbon neutrality through procurement of carbon neutral fuels which could include, electricity, renewable natural gas or biooil, as well as carbon offsets if needed for economic optimization.

After developing the phasing plan, additional supporting schematics were generated. These included, a process flow schematic, spatial layouts, and a detailed construction schedule. These documents can be found in Section 9.6 of the report.

Implementation Schedule

Two implementation schedules were developed for the project; a base schedule and an accelerated schedule. The base schedule assumed traditional procurement, design, and construction techniques would be used. It also included a five-year funding period prior to the start of Phase 1 and the retirement of the natural gas turbine in 2035 when the unit will be free from the debt payments.

The base schedule identified that the construction activities could be completed as soon as 2037 using the constraints identified. This schedule meets the Executive Order 484 requirements of 80% reduction by 2050, achieves UMassD's pledge to the American College & University Presidential Climate Commitment with carbon neutrality by 2050, and achieves the campus public pledge for carbon neutrality by 2040. This schedule does not allow for the campus to achieve carbon neutrality by 2030 so an accelerated version of the schedule was developed to understand if carbon neutrality could be possible.

The accelerated schedule accelerated the funding period of Phase 1 to three years (instead of five) and disregarded the debt payments for the gas turbine which are repaid with the savings that the gas turbine offers. The accelerated schedule shows that it is possible to complete the selected scenario and achieve carbon neutrality in the fall of 2030 given the durations presented.

	Base Schedule		**Accelerated Schedule**	
	Start Date	**Completion Date**	**Start Date**	**Completion Date**
Funding for Phase 1	1/1/2021	8/7/2025	1/1/2021	10/5/2023
Phase 1	8/8/2025	10/29/2030	10/6/2023	12/26/2028
Phase 2	10/25/2030	10/10/3035	8/8/2025	2/14/2030
Phase 3	10/11/2035	5/20/2037	4/13/2029	11/21/2030

For the purposes of cost estimating and energy projections, the analysis considers that the base schedule is used with the use of renewable fuels beginning in 2040.

Cost Estimate

The project developed a detailed cost estimate for the selected solution assuming the base schedule. The schedule was developed to an AACE Class 4 Level Standard using the Timberline software and is included as Appendix E. Ramboll used the AACE Class 4 estimating methodology as the minimum standard and improved the estimate by using semi-detailed unit costs, detailed unit costs with forced detailed take-offs and equipment quotes. Ramboll used the schematics included in Section 9.6 as primary inputs for the basis of the estimate which is included as Appendix C. The basis of the estimate identifies the unit take offs, other schematics, and also identifies assumptions that enabled the development of the project schedule.

Table 1-9 presents the estimated construction costs for the selected solution by phase and area of work. The cost estimates are presented with the backend markups integrated in the cost estimate values. It can be seen that a full cost estimate of approximately $153 million dollars is expected as part of the implementation.

Table 1-9. Selected Solution Cost Estimate by Phase

Initiative	**Phase 1**	**Phase 2**	**Phase 3**	**TOTAL**
Year	(2025 – 2030)	(2030 – 2035)	(2035 – 2040)	-
Central Heating Plant Upgrades and Demolition/Replacement	$ 1,570,434	$ 2,397,815	$ -	$ 3,968,249
Distribution Network	$ 11,814,290	$ -	$ -	$ 11,814,290
NetZero Energy Plant	$ 28,695,089	$ 21,089,750	$ 808,510	$ 50,593,349
Geothermal Borings and BTES	$ -	$ 45,307,995	$ -	$ 45,307,995
Thermal Tank Energy Storage Installation	$ 4,179,089	$ -	$ -	$ 4,179,089
Building Upgrades and Conversions	$ 12,495,526	$ -	$ -	$ 12,495,526
Emergency Backup Generation	$ 3,690,090	$ -	$ -	$ 3,690,090
Solar PV Car Canopies	$ -	$ -	$ 21,009,882	$ 21,009,882
Total	**$ 62,444,518**	**$ 68,795,558**	**$ 21,818,392**	**$153,058,468**

GHG Estimates

The GHG emissions in metric tons of CO_2 for the phased approach of the selected solution is presented in Figure 1-3. The realized and projected CO_2 emissions are shown in comparison to the EX 484 mandates.

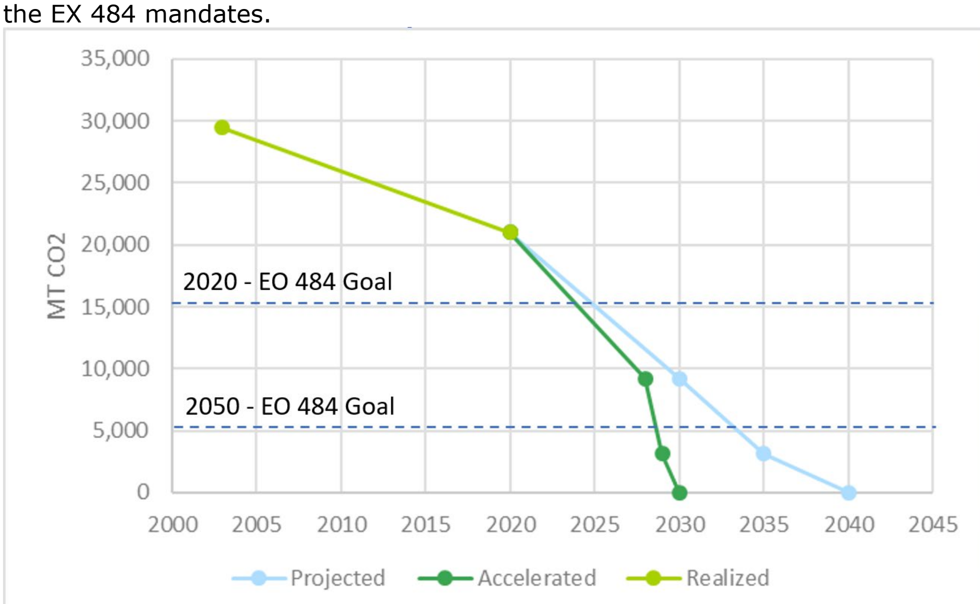


Figure 1-3. GHG Emission Estimate for Selected Solution vs EO 484 Mandates

Recommendations

This report has identified a pathway to carbon neutrality for UMassD, but there are certain guiding principles that should guide UMassD through subsequent analysis which will eventually lead to achieving carbon neutrality.

1. **Energy Conservation -** This study found that significant energy savings may be possible, and that the campuses current modernization plan may leave room for additional energy conservation improvements to be obtained. Any energy conservation efforts will reduce the cost to implement the selected solution and should be prioritized such that the energy savings can be obtained and observed (via data) prior to the engineering of the carbon neutral solution.
2. **Renewable Energy Generation -** This study identified that renewable energy (both solar photovoltaic and on-shore wind) warrant further investigation. This plan includes 2.5MW of solar PV car canopies but obtaining quotes will enable UMassD to select the most cost effective technology.
3. **Implementation of the Selected Solution and Continuous Refinement -** This study found a pathway to carbon neutrality for the main campus of UMassD. We recognize that the energy market is constantly changing and technologies that are not considered viable today could be considered a best practice within a short period of time. It is recommended that UMassD use this study as a path forward and begin to plan the implementation of it, but also recognize the improvements that could be made upon it as technologies progress in the future.

2. CAMPUS OVERVIEW

The University of Massachusetts Dartmouth (UMassD) is a state college located in North Dartmouth, Massachusetts. UMassD serves nearly 9,000 students who pursue majors in 50 baccalaureate and 40 graduate programs, including 12 at the doctoral level. Founded in 1895, the Dartmouth campus has been a thriving component of the University of Massachusetts system since 1991, with over 50,000 alumni/ae.

The University's resident population capacity of nearly 4,000 represents approximately 50% of the undergraduate student body, with commuter students accounting for the balance. In addition to the student population, the UMassD employees approximately 1,453 personnel that commute to work daily.

The main campus, situated on 710 acres, is augmented by a new state-of-the-art marine research facility in New Bedford, the Commonwealth's only public law school, and a robust offering of highly ranked on-line programs. UMass Dartmouth is part of the five-campus UMass System that is governed by a President and a 22-member Board of Trustees.

UMass Dartmouth has embarked on a new era of vision, action, and success under the leadership of its new Chancellor, Robert Johnson Ph.D., who began his tenure on July 1, 2017. As the university approaches its 125th anniversary in 2020, the community will be embarking on a strategic planning process together to create an aspirational shared vision for the university.[2]

Figure 2-1 provides the campus map for reference throughout the project. The main campus buildings were designed by modernist architect Paul Rudolph beginning in the early 1960s to distinguish the campus from the outside world and provide a social utopian environment. Rudolph made both the exterior and interior of each building of rough concrete, an essential element of the style known as Brutalism, and he endowed buildings with large windows[3]. These architectural features give the campus a distinct identity, but unfortunately do not contribute to energy efficient buildings. Many of the campus buildings are registered with the Massachusetts Historical commission and modifications to the buildings may be limited by that registration.

This project focused on the main campus, though some consideration was given to the SMAST campus. The main campus is the dominant energy user of the UMassD footprint.

The SMAST campus did receive a cursory review for energy sources and the campus provides two unique opportunities for energy sources. Firstly, the campus is sited adjacent to the New Bedford Wastewater Treatment Plant. The wastewater itself can serve as a heat source for heat pumps and the temperature of it remains relatively stable throughout the year. Secondly, it is located on a peninsula which extends into Buzzards Bay. The campus owns a sea water intake system which provides sea water for marine wildlife. The seawater can also be used as a heat source for heat pumps. Both of these opportunities should be considered for any decarbonization effort at the SMAST campus in the future.

[2] Much of the campus overview was provided in the RFP for this project by UMassD

[3] https://en.wikipedia.org/wiki/University_of_Massachusetts_Dartmouth

Map Key

A Liberal Arts (Group I)
B Main Auditorium (Group V)
C MacLean Campus Center
- UMass Pass Office
- Campus Store

D Resident Dining Hall
E Residence Halls
F Foster Administration Building
- Bursar and Registrar
- Financial Aid
- Universiy Enrollment Center

G Power Plant and Campus Police
H Visual and Performing Arts Building (Group VI)
I Tripp Athletic Center
J Library
K Lecture Halls
L Science and Engineering Building (Group II)
M Textile Building (Group III)
N Violette Building (Group IV)
O Tower (Campanile)
P Amphitheater
Q Entrance Booth
R Auditorium Annex
S Charlton College of Business
T Dion Science/Engineering and Nursing Building
U Cedar Dell Village

EMERGENCY CALL BOXES #

1	Lot 1 walkway	9	Lot 7 walkway
2	Lot 17 walkway	10	Auditorium patio
3	Library road	11	Lot 4 walkway
4	Library main entrance	12	Dorm lot 2
5	Cedar Dell walkway	13	Courtyard dorms
6	Cedar Dell West	14	Group 1
7	Cedar Dell South	15	Dorm road
8	Lot 9 walkway	16	Fitness center

Figure 2-1. UMassD Campus Map

3. CAMPUS ENERGY AND EMISSION GOALS

3.1 Current Goals

As a public entity, UMassD is mandated by Executive Order 484 to reduce greenhouse gas emissions "GHG" 40% by 2020, obtain 30% of electricity from renewable sources by 2020, reduce overall energy consumption (on a per square foot basis) 35% by 2020, and reduce GHG 80% by 2050. The baseline for the GHG values was 29,459 Metric Tons of CO_2 in 2003.

UMassD has committed to achieving carbon neutrality by 2050 as a signatory of the American College & University Presidential Climate Commitment (ACUPCC), has publicly expressed the goal of carbon neutrality by 2040 and has interest in accelerating their transition to carbon neutrality by 2030 if possible. In order to achieve these goals, UMassD contracted with Ramboll to achieve the following goals as part of this project:

1. Evaluate UMassD's existing energy metering, data management systems, and data governance practices to establish accurate energy usage and demand baselines and to effectively analyze onsite electricity and steam production, building-level performance, and campus-level energy performance on an ongoing basis
2. Forecast the main campus' hourly and annual energy demands between 2020 and 2040
3. Identify energy sources and/or energy savings opportunities that can meet the campus' growth over the next 20 years in a reliable, cost effective, and sustainable manner
4. Identify energy sources and energy savings opportunities that can enable UMassD 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. Specify the physical infrastructure, operating systems, and costs for UMassD to implement the recommended energy strategy to meet the campus' reliability, cost, and sustainability objectives over the next 20 years.

UMassD baselined their GHG emissions in 2004 with an annual CO_2 emission of 25,622 Metric Tons.[4]

Baseline GHG Emissions	**25,622 Metric Tons**

3.2 Progress to Date

UMassD has made some progress since their greenhouse gas baseline was established in 2003. At one point, a decrease of 16% was achieved and the campus is currently estimated at a 6% reduction versus the 2002 baseline. For the purposes of this project, carbon neutrality is defined as scope 1 and scope 2 emissions and is normalized to gross square feet (GSF) of campus space. Primary scope 1 emissions include central combustion sources, but do not include use of fertilizers, campus vehicle fuel consumption, or use of refrigerants.

The progress made to date has been achieved through the cogeneration unit and implementation of energy conservation measures.

[4] Value provided via e-mail on 11/3/2020.

4. CAMPUS MASTER PLANING

Ramboll worked with UMassD in order to project what modifications will be made to the campus in the coming years in order to project the future utility loads of the campus. There were two documents that were used to guide the future campus arrangement; the UMass Dartmouth Campus Master Plan which is included as Appendix A, and the Sightlines presentation entitled "The University of Massachusetts – Dartmouth FY17 ROPA Final Presentation"; included as Appendix B.

Figure 4-1 is an excerpt from the Campus Master Plan which shows the existing buildings at the time the report was generated.

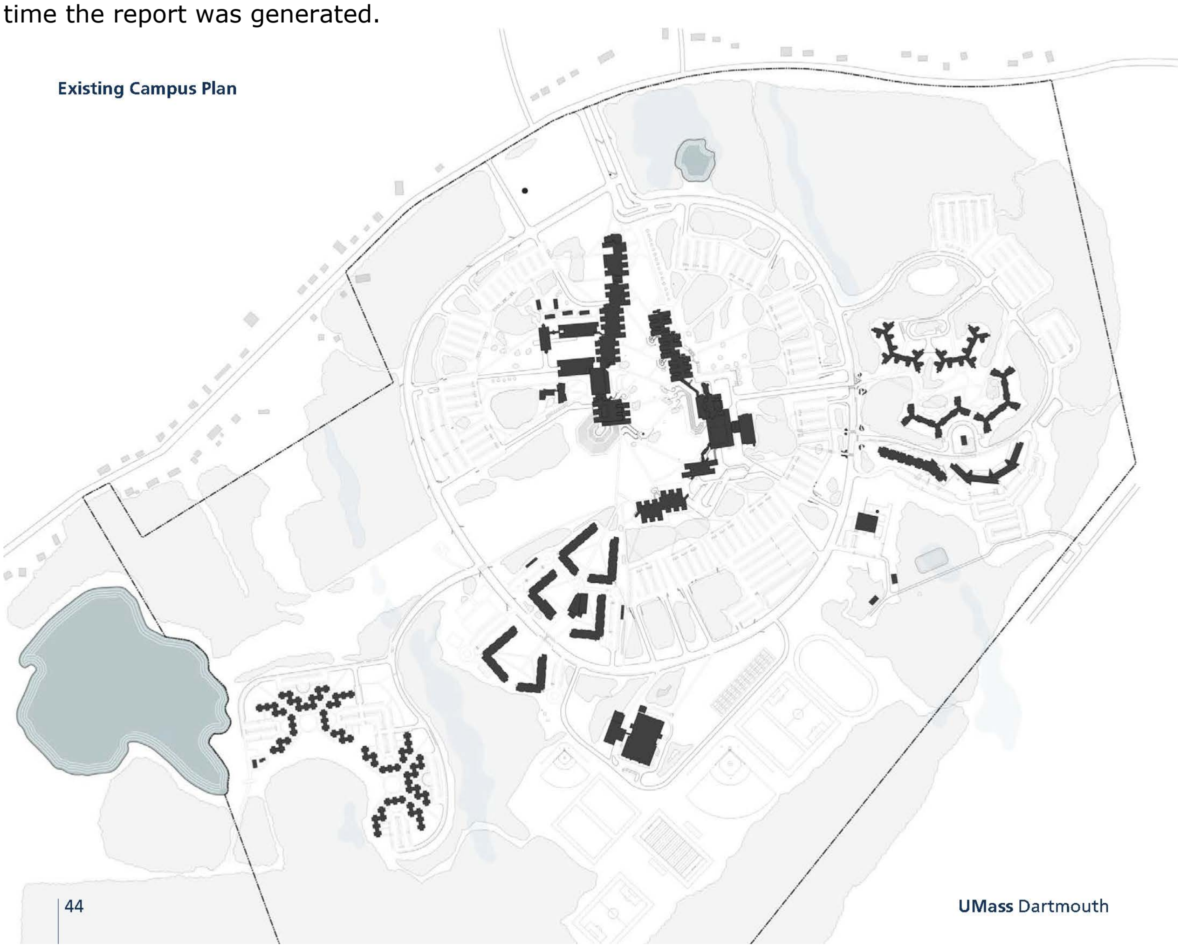


Figure 4-1. Existing Campus Plan from Campus Master Plan 2017

Figure 4-2 is an excerpt from the Sightlines presentation which identifies the net asset value of each building utilizing a four-category approach of building that are recommended for one of the following four categories:

- **Capital Upkeep –** These buildings are in good condition and are not expected to have any upgrades in the near future.
- **Repair and Maintain –** These buildings are in good condition and mechanical and electrical equipment will be repaired if a failure occurs or in accordance with maintenance schedules.

- **Systematic Renovations –** These buildings have reached a point where upgrades should occur on a system basis, but the building will continue to be utilized as it is currently configured.
- **Transitional/Gut Renovation –** These buildings are in need of modernization and were recommended to go through substantial renovations. These renovations are expected to be brought up to modern energy code requirements as part of those renovations or the building will be demolished and not renovated.

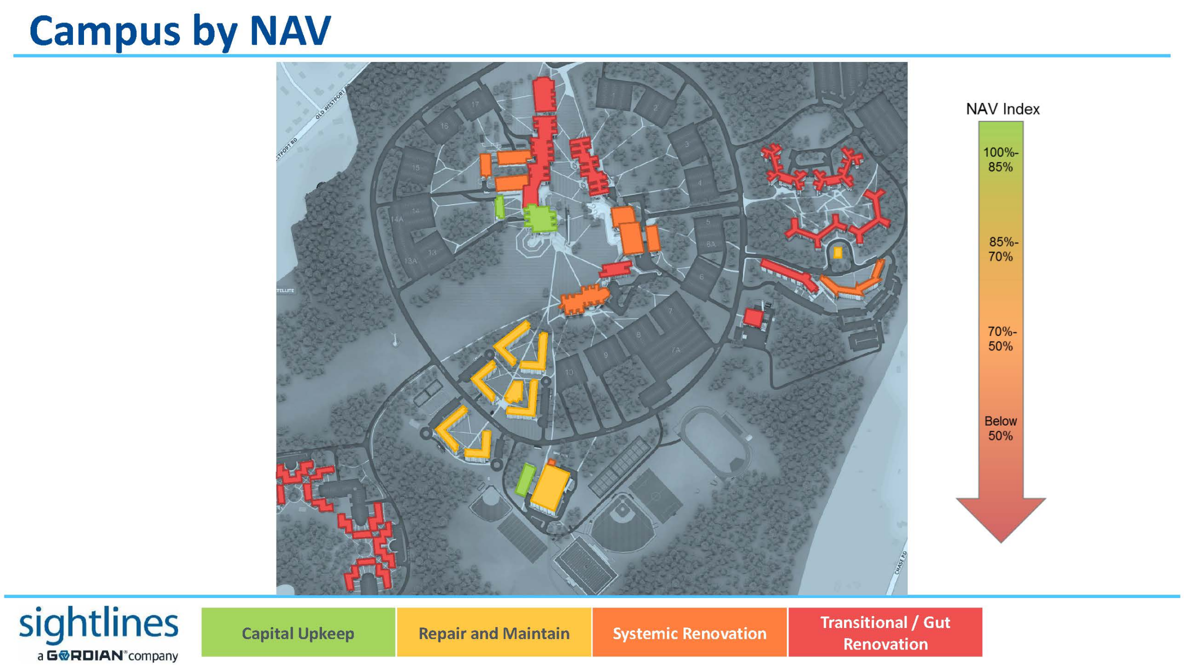


Figure 4-2. Net Asset Value by Building from Sightlines

Figure 4-3 is an excerpt from the Campus Master Plan which identifies the proposed campus plan. This future condition identified in the Campus Master Plan is aspirational in nature and the campus has not secured funding for these modernizations. Ramboll worked with UMassD to project when building modifications will occur and Table 4-1 presents the planned renovations, demolitions, and construction that were agreed upon for the basis of this evaluation.

Figure 4-3. Proposed Campus Plan from Campus Master Plan 2017.[5]

Table 4-1. Campus Modernization Table

Official Building Name	Gross Sqft	Sightlines Evaluation Net Asset Value (NAV)	Proposed Plans	Proposed Year of Demolition	Future Proposed Renovation Year
Liberal Arts	111,617	Transitional/Gut Reno.	Renovation	NA	2030+
Auditorium Annex	4,652	Transitional/Gut Reno.	None	NA	NA
Main Auditorium	54,588	Systematic Reno.	None	NA	NA
MacLean Campus Center	66,700	Systematic Reno.	Renovation of MacLean & Banquet Hall	NA	2027

[5] The red cloud on Figure 4-3 identifies that modifications are planned since the publication of this plan. The complex shown is no longer planned as a P3 project is currently being completed to install a dormitory in that location.

Official Building Name	Gross Sqft	Sightlines Evaluation Net Asset Value (NAV)	Proposed Plans	Proposed Year of Demolition	Future Proposed Renovation Year
Residents' Dining Hall	23,317	Systematic Reno.	None	NA	NA
Foster Administration	66,840	Transitional/Gut Reno.	Renovation	NA	2030+
Center for Visual and Performing Arts	100,655	Systematic Reno.	Renovation	NA	2030+
Claire T. Carney Library	130,379	Capital Upkeep	None	NA	NA
Science and Engineering Lecture Halls	22,582	Transitional/Gut Reno.	None	NA	NA
Textile	46,811	Systematic Reno.	None	NA	NA
Science and Engineering	174,376	Transitional/Gut Reno.	Renovation	NA	2030+
Violette Research	48,497	Systematic Reno.	None	NA	NA
Dion Science and Engineering	84,575	Transitional/Gut Reno.	Renovation	NA	2030+
Charlton College of Business	19,434	Capital Upkeep	None	NA	NA
Research Building	22,000	Repair and Maintain	None	NA	NA
Elmwood Hall	98,235	Transitional/Gut Reno.	Demolition	2022	NA
Maple Ridge Hall	98,235	Transitional/Gut Reno.	Demolition	2022	NA
Chestnut Hall	94,266	Transitional/Gut Reno.	Demolition	2022	NA
Roberts Hall	85,138	Transitional/Gut Reno.	Demolition	2022	NA
Pine Dale Hall	104,794	Repair and Maintain	Improvements	NA	2030+
Oak Glen Hall	101,700	Transitional/Gut Reno.	Improvements	NA	2030+
Chase Road Center	6,367	Repair and Maintain	None	NA	NA
Public Safety/Steam Plant	15,592	Transitional/Gut Reno.	None	NA	NA
Willow Hall	76,240	Repair and Maintain	None	NA	NA
Hickory Hall	76,212	Repair and Maintain	None	NA	NA
Evergreen Hall	71,616	Repair and Maintain	None	NA	NA
Birch Hall	75,584	Repair and Maintain	None	NA	NA
Aspen Hall	61,940	Repair and Maintain	None	NA	NA
Ivy Hall	79,840	Repair and Maintain	None	NA	NA

Official Building Name	Gross Sqft	Sightlines Evaluation Net Asset Value (NAV)	Proposed Plans	Proposed Year of Demolition	Future Proposed Renovation Year
Woodland Commons	10,979	Repair and Maintain	None	NA	NA
Tripp Athletic Center	83,346	Repair and Maintain	Renovation	NA	2030+
Fitness Center	24,910	Capital Upkeep	None	NA	NA
Athletic Center Heating Plant	1,687	Systematic Reno.	None	NA	NA
Cedar Dell Village South 7	11,820	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 6	9,184	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 5	14,590	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 4	33,223	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 3	14,590	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 2	9,184	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village South 1	14,590	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 14	11,820	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 13	9,184	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 12	14,590	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 11	33,223	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 10	14,590	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 9	9,184	Transitional/Gut Reno.	Demolition	2037	NA
Cedar Dell Village West 8	11,820	Transitional/Gut Reno.	Demolition	2037	NA

The planned modifications to the campus are particularly important when we project the future energy demand of the campus. As Table 4-1 shows, the MacLean Campus Center is the only renovation that will occur within the timeframe of the future scenario; several buildings are also slated for demolition before 2030. See Section 6.9 for the future energy demand estimates.

5. CAMPUS ENERGY INFRASTRUCTURE

Ramboll performed a site visit to visit and survey the existing energy infrastructure that UMassD utilizes to meet the heating and cooling demands of the campus. The following is a summary of the existing infrastructure at the time of the visit.

5.1 Central Heating Plant

5.1.1 Summary

Table 5-1 provides a summary of the steam generating assets within the UMassD central campus. An overview of each piece of equipment is provided along with manufacturer and model number if applicable.

Table 5-1. Steam Generating Assets Summary Table

	Input	Output	Efficiency %	Pressure psig	Notes
Central Utility Plant					
Steam Boilers #1	8,375 MBH	6700 MBH	80%	150	1
Steam Boiler #2 & #3	41,440 MBH ea.	26,000 lb/hr ea.	66%	250	2
Gas Turbine	23,760 MBH	1,627 kW			3
Heat Recovery Steam Generator	228 °F Feedwater	23,700 lb/hr	61% (w/ duct	100	
Duct Burner	18,980 MBH	15,420 MBH	81%		
Athletic Center Heating Plant					
Two Cleaver Brooks Boilers	10206 MBH	8369 MBH	82%	15	4

1. Cleaver Brooks; CB-428-200; Manufactured 1965
2. The Bigelow Company; KS-21-250; Manufactured 1965
3. Manufactured 2012
4. Cleaver Brooks; Manufactured 1998

5.1.2 Boilers

UMassD has three natural gas fired boilers within their steam plant. Boiler #1 is a firetube boiler which is sized as a summer boiler and the other two boilers are of equal size and are commonly utilized throughout the winter heating months. Figure 5-1 presents a photo of Boiler #1 which is located within the central plant. UMassD also has two fire tube boilers that are located within the heating plant for the athletic center.

Figure 5-1. Boiler #1 "Pony Boiler"

5.1.3 Gas Turbine

UMassD operates a Kawasaki 1.6 MW natural gas turbine along with its heat recovery steam generator (HRSG). The gas turbine was commissioned in 2015 with a 20-year financing term and estimated to have a 20-30 year run time. UMassD has had some maintenance issues with the turbine and the blades were replaced twice due to mechanical issues.

A condenser is available for the gas turbine to dump steam if required to maximize electrical generation. The condenser is not able to condense 100% of the steam capacity of the gas turbine and if steam loads are low then the gas turbine may be required to be shut down in order to meet state emission requirements. The condenser allows the turbine to be used to a greater extent than it otherwise would be able to; however, there are periods in the summer where it is not available.

The gas turbine is fed by a natural gas compressor station that compresses the natural gas for injection. The HRSG utilizes selective catalytic reducer and a CO catalyst to reduce air pollutants and ammonia is available to support this operation.

Figure 5-2. Natural Gas Turbine


Figure 5-3. Natural Gas Compressor

Figure 5-4. Steam Condenser

5.1.4 Campus Steam Distribution System

UMassD has operated a steam distribution system since the central steam plant was installed. The steam distribution system consists of both direct buried and steam tunnel piping. Steam was once distributed to many of the buildings on campus; however, in recent years, some buildings were disconnected from the steam system in favor of less expensive decentralized heating systems.

The campus replaced much of the steam piping approximately 5-6 years ago after condensate recovery rates decreased to approximately 20%. After completion of the project, condensate recovery rates were estimated near 90%.

Figure 5-5. Steam Tunnel Which Serves Roberts, Elmwood, Chestnut, Maple, Oak Glen, and Pinedale

5.2 Liquid Fuel Storage

The central plant used to operate as a duel fuel plant with natural gas as the primary fuel and fuel oil as a liquid secondary fuel. The existing fuel oil tanks developed a lead between the primary and secondary containment which lead to the campus no longer using fuel oil as a backup fuel.

Figure 5-6. Abandoned Fuel Oil Tanks

5.3 Battery Storage System

UMassD has a battery electrical storage system which was manufactured by Tesla. The battery system is part of a demonstration project which is hosted by UMassD. A third party operates the battery system, identifies when to charge or deplete the storage, and splits the cost savings with the campus. The battery storage system was not considered as part of the campus system since the system is part of a demonstration project and since UMassD does not control the unit.

Figure 5-7. Tesla Battery Storage System

5.4 Wind Turbine

When this project began a wind turbine was located on the main campus. The turbine has been purchased second hand and operational issues lead to the eventual removal of the wind turbine which was removed during the summer of 2020.

5.5 Solar PV Generation

UMassD has approximately four solar photovoltaic arrays that are located on the roof of the buildings. The arrays are relatively small in comparison to the electrical demand of the campus. The electrical generation of the units were included in the energy analysis for this project.

A 5-MW solar parking canopy project was considered for the campus as part of previous emission reduction efforts and the project was inhibited because the upstream interconnection costs were estimated at approximately $1M due to the significant solar distributed generation along the south shore of Eversources territory.

Figure 5-8. Solar PV System Controller

5.6 Chilled Water Systems

Approximately 14 buildings on campus have air conditioning systems. There are nine buildings that utilize steam absorption chilling, five buildings that utilize water cooled chillers, six buildings that use air cooled chillers, and six buildings that utilize direct expansion cooling. The steam absorption chillers that are distributed throughout campus serve as the primary steam load during the summer months which enables the gas turbine steam to be utilized.

Figure 5-9. Sample Building Level Chiller

5.7 Metering

The field visit conducted on January 9, 2020 identified steam and electric submeters. The electrical meters appeared to be two variations with one variation supporting the solar PV arrays and the other metering building level electrical consumption.

Figure 5-10. Sample Building Steam Meter

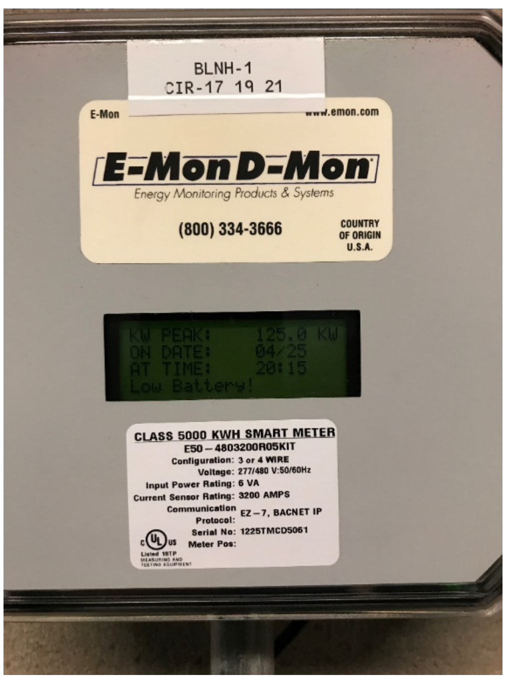


Figure 5-11. Sample Building Electrical Meter

Figure 5-12. Sample Building Electrical Meter

5.8 Electrical Service Capacity

Several of the alternative options that were considered rely on a transitioning from a fossil fuel-based energy source to an electrification solution that relies heavily upon heat pumps. Since these solutions will likely increase the demand of the campus, it is important to identify the capacity of the primary electrical service feeder that is provided from Eversource.

Ramboll reviewed the UMassD campus 1-line electrical drawings to estimate the maximum service capacity of the main feeders for the campus. Figure 5-13 is a portion of drawing E-3 “Primary Switchgear One Line Diagram” which identifies the two primary service connections from Eversource that power the main UMassD electrical meter.

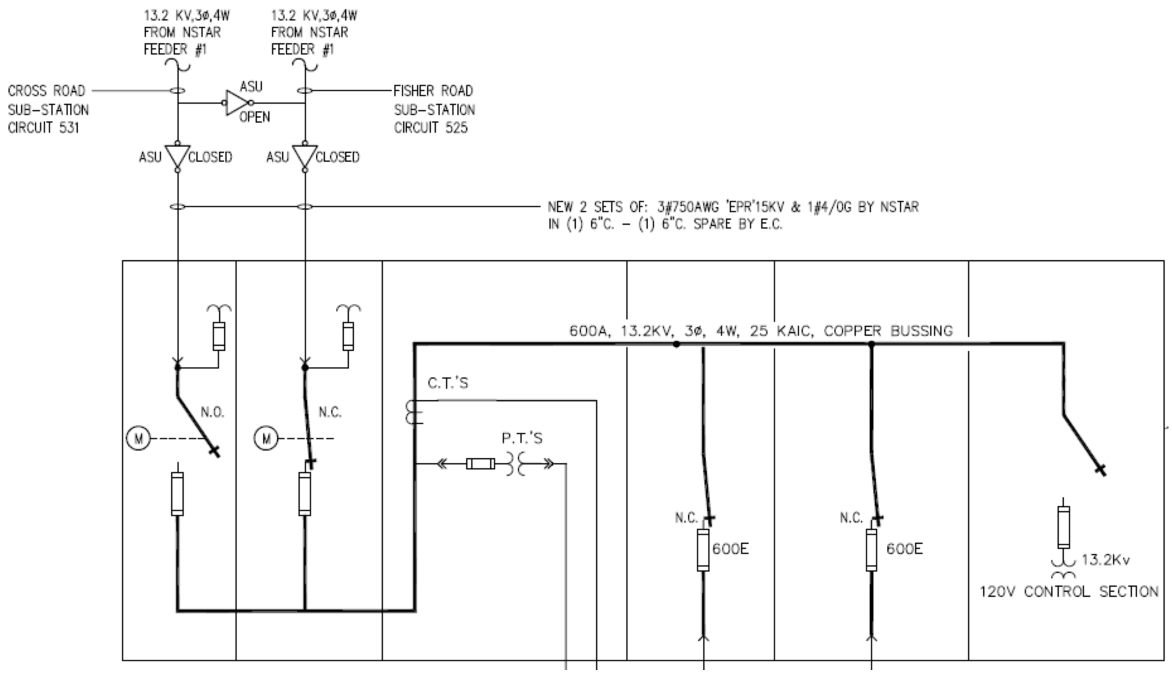


Figure 5-13. Extract from Drawing E-3 Primary Switchgear One Line Diagram

It can be seen that there are two 13.2 kV feeders from NSTAR; NSTAR was the previous name of the electrical utility company which eventually became Eversource. One feeder is fed from circuit 531 on the Cross Road substation and the other is from circuit 525 of the Fisher Road substation. There is also a tie breaker which interconnects the feeders.

The campus has two main disconnects (one for each feeder) and the typical operation is to have one disconnect switch open and the other closed with the tie breaker open so that only one electrical feeder is active. Within the campus system there is a single 600A 13.2kV buss which services two 600 Amp breakers that connect to the "block house" which serves at the major campus electrical distribution hub.

Based on this electrical drawing it appears that the main campus service is capable of 11.5 MW of electrical service, assuming a power factor of .85. The campus electrical consumption peak for 2019 was 4.8 MW and in 2018 was 5.7 MW; these values account for any electrical production behind the meter which could have reduced the connected load from the grid. As a result, there is approximately 5.8 MW of additional capacity available to serve additional loads in terms of campus main electrical infrastructure. It should also be noted that depending on where the equipment is located on the campus, there could be downstream electrical infrastructure limitations at the building transformer and distribution feeder level.

The electrical capacity estimate is based on the electrical components that are depicted on the campus electrical 1-line drawings. While some seasonal capacity limitations or improvements may occur, these estimates should serve as minimum values for both summer and winter conditions.

6. PRELIMINARY ENERGY ANALYSIS

6.1 Introduction to PEA

Ramboll developed this preliminary energy analysis with the goals of characterizing how, where, and when UMassD produces and consumes energy and estimating future energy demands and consumption. The campus energy use was disaggregated to the extent possible and attributed to the system or building that utilized it. The submetering data enables the disaggregation down to the building level and then building performance was benchmarked using the CBECS database.

The campus modernization plan was used to estimate future energy demands at the building level so that an hourly energy demand curve could be estimated and used as the demand profile in the scenario energy modeling utilizing EnergyPRO. This section provides an overview of the energy analysis that was completed.

6.2 Energy Supply Database

The following sections describe how energy is supplied and used within UMassD.

6.2.1 Building Information

Table 6-1 lists each of the buildings on campus, the size of each building and which buildings are currently heated and cooled.

Table 6-1. Building Information

Campus Building	Size GSF	Building Number #	Heated	Cooled
Liberal Arts	111,617	1	•	
Auditorium Annex	4,652	3	•	•
Main Auditorium	54,588	4	•	•
MacLean Campus Center	66,700	5	•	•
Residents' Dining Hall	23,317	6	•	•
Foster Administration	66,840	7	•	•
Center for Visual and Performing Arts	100,655	8	•	•
Claire T. Carney Library	130,379	10	•	•
Science and Engineering Lecture Halls	22,582	11	•	•
Textile	46,811	12	•	•
Science and Engineering	174,376	13	•	•
Violette Research	48,497	14	•	•
Dion Science and Engineering	84,575	15	•	•
Charlton College of Business	19,434	23	•	•
Research Building	22,000	24	•	•
Elmwood Hall	98,235	30	•	
Maple Ridge Hall	98,235	31	•	
Chestnut Hall	94,266	32	•	
Roberts Hall	85,138	33	•	

Campus Building	Size GSF	Building Number \#	Heated	Cooled
Pine Dale Hall	104,794	35	•	•
Oak Glen Hall	101,700	36	•	•
Willow Hall	76,240	41	•	•
Hickory Hall	76,212	42	•	•
Evergreen Hall	71,616	43	•	•
Birch Hall	75,584	44	•	•
Aspen Hall	61,940	45	•	•
Ivy Hall	79,840	46	•	•
Woodland Commons	10,979	47	•	•
Tripp Athletic Center	85,033	50	•	
Fitness Center	24,910	51	•	•
Cedar Dell Village South 7	11,820	70	•	
Cedar Dell Village South 6	9,184	71	•	
Cedar Dell Village South 5	14,590	72	•	
Cedar Dell Village South 4	33,223	73	•	
Cedar Dell Village South 3	14,590	74	•	
Cedar Dell Village South 2	9,184	75	•	
Cedar Dell Village South 1	14,590	76	•	
Cedar Dell Village West 14	11,820	77	•	
Cedar Dell Village West 13	9,184	78	•	
Cedar Dell Village West 12	14,590	79	•	
Cedar Dell Village West 11	33,223	80	•	
Cedar Dell Village West 10	14,590	81	•	
Cedar Dell Village West 9	9,184	82	•	
Cedar Dell Village West 8	11,820	83	•	
TOTAL	**2,333,337**		**44**	**24**

6.2.2 Building Heating Supply

Table 6-2 describes the various heating sources for the campus buildings. Most of the academic buildings are served by the campus central utility plant (CUP) steam boilers with a steam to hot water heat exchanger at the buildings. Only a few buildings on campus use steam directly in air handling unit heating coils. Several of the residence halls and apartments are heated by local hot water boilers. A small percentage of the campus buildings are heated by gas fired rooftop units. Tripp Athletic Center uses steam directly from the Athletic Center Heating Plant (ACHP).

Table 6-2. Heating Supply by Building

Campus Building	STM from CUP	STM to HW Conv.	STM from ACHP	Local HW Boiler	Gas Furnace	Electric Coils
Liberal Arts	•	•				
Auditorium Annex	•	•				

Campus Building	STM from CUP	STM to HW Conv.	STM from ACHP	Local HW Boiler	Gas Furnace	Electric Coils
Main Auditorium	•	•				
MacLean Campus Center	•	•				
Residents' Dining Hall	•	•				
Foster Administration	•	•				
Center for Visual and Performing Arts	•	•				
Claire T. Carney Library	•	•				
Science and Engineering Lecture Halls	•	•				
Textile	•	•				
Science and Engineering	•	•				
Violette Research	•	•				
Dion Science and Engineering	•	•				
Charlton College of Business				•	•	
Research Building	•	•				
Elmwood Hall	•	•				
Maple Ridge Hall	•	•				
Chestnut Hall	•	•				
Roberts Hall	•	•				
Pine Dale Hall	•	•				
Oak Glen Hall	•	•				
Willow Hall				•		
Hickory Hall				•		
Evergreen Hall				•		
Birch Hall				•		
Aspen Hall				•		
Ivy Hall				•		
Woodland Commons					•	•
Tripp Athletic Center			•			
Fitness Center					•	
Cedar Dell Village South 7				•		
Cedar Dell Village South 6				•		
Cedar Dell Village South 5				•		
Cedar Dell Village South 4				•		
Cedar Dell Village South 3				•		
Cedar Dell Village South 2				•		
Cedar Dell Village South 1				•		
Cedar Dell Village West 14				•		
Cedar Dell Village West 13				•		
Cedar Dell Village West 12				•		
Cedar Dell Village West 11				•		

Campus Building	STM from CUP	STM to HW Conv.	STM from ACHP	Local HW Boiler	Gas Furnace	Electric Coils
Cedar Dell Village West 10				•		
Cedar Dell Village West 9				•		
Cedar Dell Village West 8				•		
TOTAL	**20**	**20**	**1**	**21**	**3**	**1**

Figure 6-1 is a breakdown of the campus heating sources as percentages of the campus total gross square footage. Claire T. Carney Library, Main Auditorium/Annex, Violette Research, and Research have a few air handling units with steam heating coils. Tripp Athletic Center is 100% heated by steam from the Athletic Center Heating Plant.

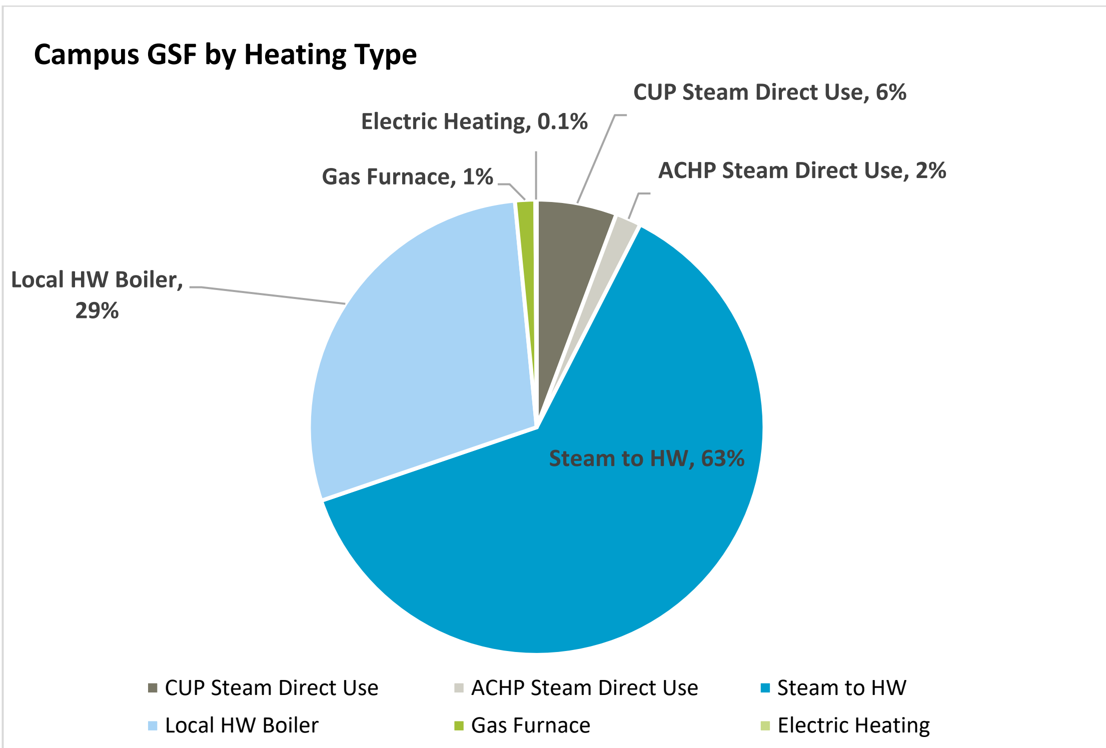


Figure 6-1. Percent of Campus GSF by Heating Type

6.2.3 Building Cooling Supply

Table 6-3 describes the various cooling sources across campus. Most academic buildings on campus are cooled by either the steam absorption chillers or by water-cooled chillers. Most of the residence halls are cooled by air-cooled chillers or are not cooled. Some of the chillers on campus serve multiple buildings. Additionally, some building spaces are cooled by direct-expansion (DX) cooling via rooftop units and split system air-conditioning units.

Table 6-3. Cooling Supply by Building

Campus Building	Steam Absorb. Chiller	Water-Cooled Chiller	Air-Cooled Chiller	DX Cooling
Liberal Arts				
Auditorium Annex	•			

Campus Building	Steam Absorb. Chiller	Water-Cooled Chiller	Air-Cooled Chiller	DX Cooling
Main Auditorium	•			
MacLean Campus Center	•			
Residents' Dining Hall	•			
Foster Administration		•		
Center for Visual and Performing Arts	•			
Claire T. Carney Library	•			
Science and Engineering Lecture Halls		•*		
Textile	•			•
Science and Engineering		•*		
Violette Research		•*		
Dion Science and Engineering		•		•
Charlton College of Business				•
Research Building				•
Elmwood Hall				
Maple Ridge Hall				
Chestnut Hall				
Roberts Hall				
Pine Dale Hall	•*			
Oak Glen Hall	•*			
Willow Hall			•*	
Hickory Hall			•*	
Evergreen Hall			•*	
Birch Hall			•*	
Aspen Hall			•*	
Ivy Hall			•*	
Woodland Commons				•
Tripp Athletic Center				
Fitness Center				•
Cedar Dell Village South 7				
Cedar Dell Village South 6				
Cedar Dell Village South 5				
Cedar Dell Village South 4				
Cedar Dell Village South 3				
Cedar Dell Village South 2				
Cedar Dell Village South 1				
Cedar Dell Village West 14				
Cedar Dell Village West 13				
Cedar Dell Village West 12				
Cedar Dell Village West 11				

Campus Building	Steam Absorb. Chiller	Water-Cooled Chiller	Air-Cooled Chiller	DX Cooling
Cedar Dell Village West 10				
Cedar Dell Village West 9				
Cedar Dell Village West 8				
TOTAL	**7**	**2**	**0**	**6**
●* Buildings that share a chiller				

Figure 6-2 is a breakdown of the campus cooling sources as percentages of the campus total gross square footage. For buildings that are cooled by both chillers and DX equipment, it was assumed that most of the building gross square footage is cooled by the chiller and less than thirty percent (30%) of the building gross square footage is cooled by DX equipment. Percentage estimates by technology were reviewed with campus staff.

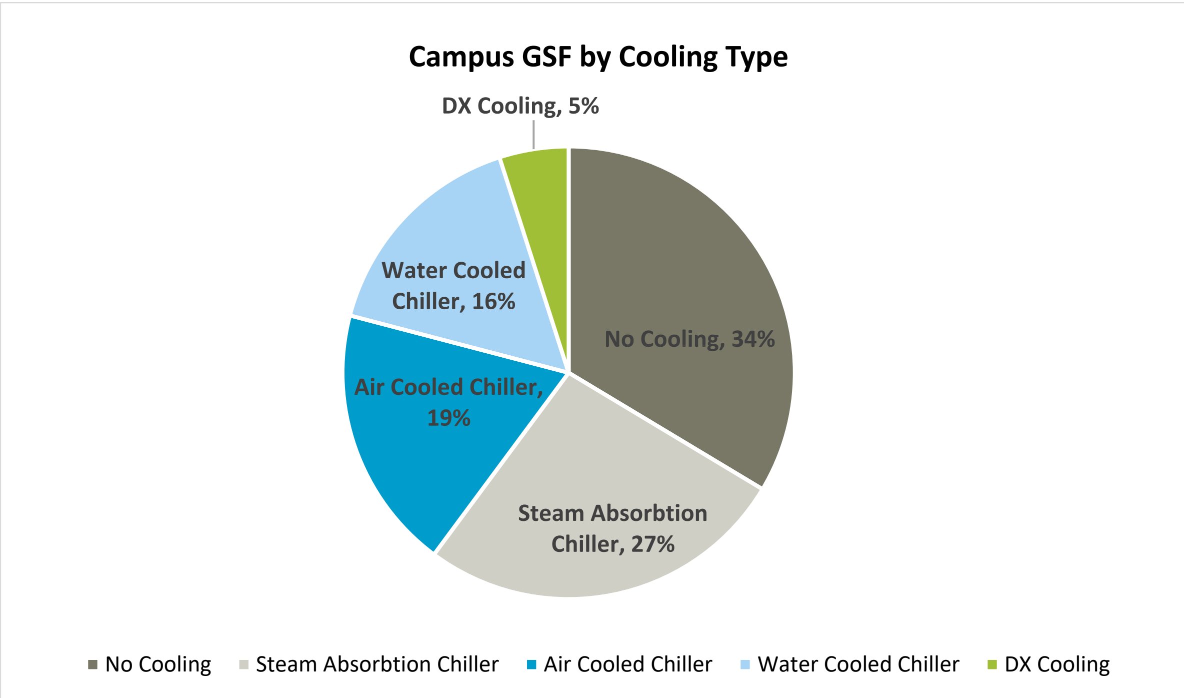


Figure 6-2. Percent of Campus GSF by Cooling Type

6.2.4 Campus Energy Plants

The campus has two energy plants, the Central Utility Plant (CUP) and the Athletic Center Heating Plant (ACHP).

The CUP houses the campus' a combined heat and power (CHP) system for generating electricity and steam. A gas turbine runs 24/7 to generate the electricity using natural gas. Heat is recovered from the gas turbine exhaust and is used by the heat recovery steam generator (HRSG) to generate steam for heating and/or cooling. The heat recovery steam generator is the primary source for steam heating from the CUP. A duct burner on the gas turbine's exhaust can provide additional heating to increase the steam output from the HRSG.

Three steam boilers are also located in the CUP and used for steam generation for heating and/or cooling. Typically plant operators will only need to run one of the steam boilers on top of the HRSG during the heating season, but on a very cold day a second steam boiler is required.

The Athletic Center Heating Plant also houses steam boilers that serve the Athletic Center Heating Plant and Tripp Athletic Center. The Athletic Center Heating Plant was installed for two reasons. First, the steam line that previously served the complex needed to be replaced and the capital cost to install the heating plant was less than the cost to replace the steam line. Second, the dedicated steam plant enables the Athletic Center to have continuous steam even when the central plant requires a shutdown. Table 6-4 describes each equipment's capacity and efficiency.

Table 6-4. Energy Plant Equipment

	Input	Output	Efficiency %	Pressure psig	Notes
Central Utility Plant					
Steam Boilers #1	8,375 MBH	6,700 MBH	80%	150	Cleaver Brooks; CB-428-200; Mfd. 1965
Steam Boiler #2 & #3	41,440 MBH ea.	26,000 lb/hr ea.	66%	250	The Bigelow Company; Mfd. 1965
Gas Turbine	23,760 MBH	1,627 kW			
Heat Recovery Steam Generator	228°F Feedwater	23,700 lb/hr	61% (w/ duct burner)	100	Mfd. 2012
Duct Burner	18,980 MBH	15,420 MBH	81%		
Athletic Center Heating Plant					
Steam Boilers (2)	10,206 MBH	8,369 MBH	82%	15	Cleaver Brooks; Mfd. 1998

6.2.5 Building HVAC Equipment

Table 6-5 describes the major heating equipment at the campus buildings.

Table 6-5. Building Major Heating Equipment

Campus Building	Quantity	Boiler/Water Heater Type	Heating Input Energy MBH	Efficiency[6]	Equipment Age	Notes
Charlton College of Business						
Gas Fired HW Boilers	2	Non-condensing	1,010 ea.	75%	2004	
Willow Hall						
Gas Fired HW Boilers	5	Non-condensing	1,950 ea.	75%	2005	Serves Willow and Evergreen Halls
Birch Hall						
Gas Fired HW Boilers	5	Non-condensing	1,950 ea.	75%	2005	Serves Birch and Hickory Halls
Ivy Hall						
Gas Fired HW Boilers	5	Non-condensing	1,950 ea.	75%	2005	Serves Ivy and Aspen Halls
Cedar Dell Village South 7						

[6] Efficiency estimated as a seasonal average annual efficiency based on boiler type and equipment age.

Campus Building	Quantity	Boiler/Water Heater Type	Heating Input Energy MBH	Efficiency [6]	Equipment Age	Notes
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village South 6						
Gas Fired HW Boiler	1	Non-condensing	315	75%	2007	
Cedar Dell Village South 5						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village South 4						
Gas Fired HW Boiler	1	Non-condensing	1,404	75%	2007	
Cedar Dell Village South 3						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village South 2						
Gas Fired HW Boiler	1	Non-condensing	315	75%	2007	
Cedar Dell Village South 1						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village West 14						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village West 13						
Gas Fired HW Boiler	1	Non-condensing	315	75%	2007	
Cedar Dell Village West 12						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village West 11						
Gas Fired HW Boiler	1	Non-condensing	1,404	75%	2007	
Cedar Dell Village West 10						
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	
Cedar Dell Village West 9						
Gas Fired HW Boiler	1	Non-condensing	315	75%	2007	
Cedar Dell Village West 8						

Campus Building	Quantity	Boiler/Water Heater Type	Heating Input Energy MBH	Efficiency [6]	Equipment Age	Notes
Gas Fired HW Boiler	1	Non-condensing	491	75%	2007	

Table 6-6 describes the major cooling equipment at the campus buildings.

Table 6-6. Building Major Cooling Equipment

Campus Building	Quantity	Chiller Type	Cooling Energy Tons	Efficiency [7] COP	Equipment Age	Notes
Main Auditorium/Annex						
Chiller	1	Steam Absorption	120	0.6	2010	
MacLean Campus Center						
Chiller	1	Steam Absorption	235	0.6	2007	
Residents' Dining Hall						
Chiller	1	Steam Absorption	155	0.6	1999	
Foster Administration						
Chiller	1	Water Cooled		4	2000	
Center for Visual and Performing Arts						
Chiller	1	Steam Absorption	446	0.6		
Claire T. Carney Library						
Chiller	1	Steam Absorption	518	0.6	2018	
Textile						
Chiller	1	Steam Absorption	155	0.6	2007	
Science and Engineering						
Chiller (being replaced)	1	Carrier Water Cooled	600	4	1993	Serves Science and Engineering, Science and Engineering Lecture Halls, and Violette Research
Dion Science and Engineering						
Chiller (being replaced)	1	McQuay Water Cooled	200	4	1986	
Pine Dale						

[7] Efficiency estimated as a seasonal average annual efficiency based on the chiller type and equipment age. Steam absorption chillers are single effect.

Campus Building	Quantity	Chiller Type	Cooling Energy Tons	Efficiency[7] COP	Equipment Age	Notes
Chiller	1	Steam Absorption	446	0.6	2002	Serves Pine Dale and Oak Glen Hall
Willow Hall						
Chiller	1	Air Cooled	300	2.9	2016	Serves Willow and Evergreen Halls
Birch Hall						
Chiller	1	Air Cooled	300	2.9	2017	Serves Birch and Hickory Halls
Ivy Hall						
Chiller	1	Air Cooled	300	2.9	2017	Serves Ivy and Aspen Halls

6.2.6 Utility Prices

UMassD's electricity is delivered by Eversource Energy and supplied by Constellation Energy. The campus has one main electric account for the campus and 8 smaller electric accounts for buildings off site.

Natural gas is delivered by Eversource Energy and supplied by Direct Energy. The campus has two major natural gas accounts, one for the cogeneration system and one for the CUP boilers. There are also several smaller gas accounts for the buildings not served by the CUP, such as residential buildings and the athletic buildings.

Table 6-7 shows the 24-month average utility prices for the campus from January 2018 to December 2019. The electricity prices below are from the utility bills provided by the campus for the main electric account. The natural gas prices below are from the utility bills provided by the campus for the cogeneration system. The annual water bill for the campus is representative from November 2019 through October 2020.

Table 6-7. Utility Prices

	Supply	Delivery	Demand	Total
Electricity	0.091 $/kWh	0.030 $/kWh	8.98 $/kW	0.140 $/kWh
Natural Gas	0.505 $/Therm	0.195 $/Therm	-	0.700 $/Therm
Water Chemical Treatment				470,803 $/year

6.2.7 CO_2 Emissions

The CO_2 emission factors from natural gas and electricity are shown in Table 6-8 as provided by UMassD/CES.

Table 6-8. Emission Factors

	Emission
CO_2 Emission from Natural Gas[8]	11.7010 lbCO₂e/Therm
CO_2 Emission from Electricity[9]	528 lbCO₂e/MWh

Table 6-9. 2019 Utility Supply GHG Summary Table

Commodity	2019 Annual Use	Emission Factor	GHG Production
Electricity	15,362 MWh	528 $lbCO_2e$/MWh	3,679 Metric Tons
Natural Gas	3,265,989 Therms	11.7010 $lbCO_2e$/Therm	17,334 Metric Tons
Total	NA	NA	21,013 Metric Tons

6.2.8 Heating Values

The heating value for natural gas is stated in Table 6-10 (Source: Ramboll).

Table 6-10. Heating Values

	Emission
Natural Gas	100,000 Btu/Therm

6.3 Campus Current Energy Performance

A Preliminary Energy-Use Analysis (PEA) was developed for the entire campus. Key performance indicators (KPIs), such as Annual Energy Use Intensity (*e.g.* kBtu/SF, kWh/SF), Energy Cost Intensity ($/SF), and peak demand intensity (W/SF), were calculated. Monthly energy use and demand were charted and analyzed. Building energy performance, as measured by Site and Source Energy Use Intensities (EUI, expressed as kBtu/SF), was compared to the 2012 Commercial Buildings Energy Consumption Survey (CBECS) data sets, which are industry standard benchmarks.

For the campus level PEA, the raw utility bill data was used. The comparison CBECS benchmark is college/university. For the building level PEA results, it is important to estimate the total inputs to each building so that the building performance can be evaluated. It also provides a means of estimating potential efficiency improvements. At the building level, peer buildings from CBECS were chosen from the same climate zone and included building types: college/university education, laboratory, recreation, dormitory, and restaurant/cafeteria.

For the building level PEA estimates, the total electricity used by the buildings was calculated using data provided for electricity generated by the CHP and by the solar PV systems. The battery system impact was also included, but it has minimal impact. The natural gas consumed in order to generate the electricity was deducted for the building level PEA; not all of the CHP gas input, only the portion attributed to the electric output.

[8] Based on excel spreadsheet provided by CES (CES_Dartmouth_Attachment 4_LBE Metrics_20200106.xlsx).
[9] Based on excel spreadsheet provided by CES (CES_UMD_Grid Emissions Forecast_20200408 (Ramboll).xlsx).

The EUI by input fuel for buildings with separate utility meters or campus submeters was calculated from the meter data. The EUI for the buildings not individually metered was estimated by apportioning the campus electric and natural gas meter usage to each individual building based on the closest CBECS peer building type; for some buildings a combination of types.

Daily steam data from the boilers and the CHP system was made available for analysis. For all steam generated at the CUP, it was estimated that 75% of the steam produced served the end uses and the remaining 25% represents system distribution losses.[10]. For the buildings which receive domestic hot water (DHW) heating from the CUP, the annual load was estimated based on typical consumption for peer buildings in the CBECS database. The hourly load shape for dorm buildings is based on monitored data from a peer dorm building; the DHW load shape for the other campus buildings was taken from COMNET, a building modeling guideline.

Figure 6-3 shows the daily steam use data with the DHW load subtracted versus daily average outside air temperature. The data show good correlation for heating. The cooling correlation is more scattered but shows the expected trend. For the baseline profiles of end uses served by CUP steam, the 2019 monitored steam data was used directly. For days with missing data, the correlation models were applied. During the cooling period there is a significant reheat load required as a result of the air handling systems in use (*e.g.*, constant volume reheat and variable air volume). The cooling period steam use required for reheat was estimated at 20%; this results in a cooling equivalent full load hours of 832 hours, which is in alignment with typical university buildings. Hourly cooling and heating load profiles were derived from the daily cooling and heating loads based on the outside air temperature profile for each day.

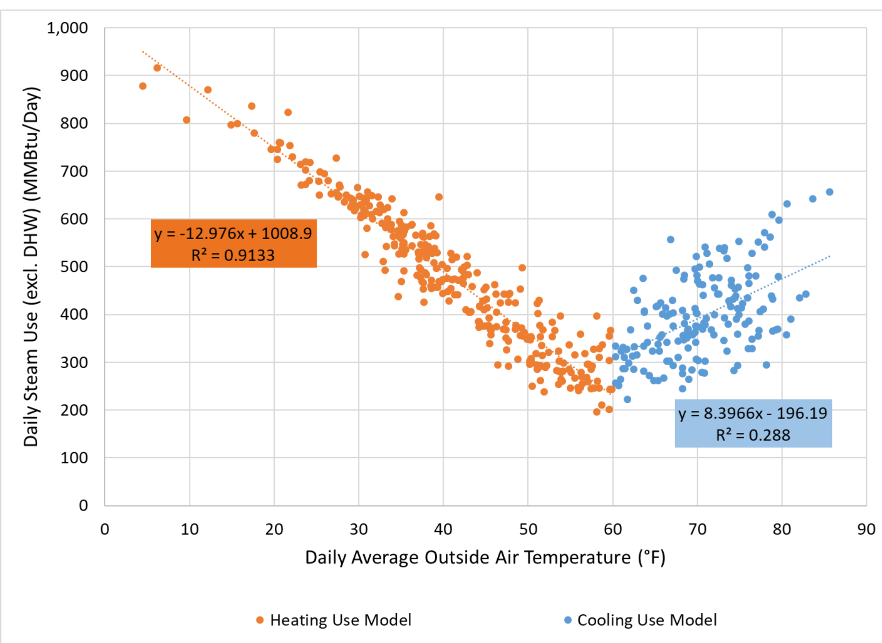


Figure 6-3. Daily Steam Use Model

[10] There is no data available to calculate the distribution losses. Ramboll has seen losses on the order of 25% for similar campuses. UMassD agreed to use 25% as a reasonable assumption.

The PEA includes estimates of annual energy use for each major end-use including lighting, space heating, space cooling, fans, pumps, plug loads, domestic water heating, process equipment, cooking, and refrigeration. The end-use energy consumption is not measured; it is disaggregated from the building total consumption based on end-use percentages from the CBECS database for similar building types. Including these end-use estimates provides the opportunity to identify major end uses, as well as to estimate the impact of potential savings estimates.

Regression models were developed from the utility data for normalization of weather-dependent consumption from the two observed years to typical year weather conditions. This compensates for any atypical weather that may have occurred and predicts typical year heating and cooling energy.

Table 6-11 shows the total electricity and natural gas use and cost for the main campus for 2019. The resulting GHG emissions are shown in Table 6-12.

Table 6-11. 2019 Utility Supply Cost Summary Table

Commodity	2019 Annual Use	Peak Demand	Unit Cost	Annual Cost
Electricity	15,362,480 kWh	4,523 kW	0.140 $/kWh	2,148,670 $/yr
Natural Gas	3,265,989 Therms	NA	0.690 $/Therm	2,253,532 $/yr
Total	NA	NA	NA	4,402,202 $/yr

Table 6-12. 2019 Utility Supply GHG Summary Table

Commodity	2019 Annual Use	Emission Factor	GHG Production
Electricity	15,362 MWh	528 lbCO2e/MWh	3,679 Metric Tons
Natural Gas	3,265,989 Therms	11.7010 lbCO2e/Therm	17,334 Metric Tons
Total	NA	NA	21,013 Metric Tons

Table 6-13 presents the overall campus EUI compared to the CBECS weighted benchmark for the campus.

Table 6-13. Overall Campus EUI Comparison

	Total EUI (kBtu/SF)
2004 Baseline [11]	**164.2**
2012 EO484 Goal (20% reduction)	**131.4**
2020 EO484 Goal (35% reduction)	**106.7**
2020 Performance (Campus Weather Normalized)	**159.9**
CBECS Weighted Campus Benchmark	**127.5**

[11] As provided by CES on 11/6/2020 via e-mail. 1,849,105 SF; 303,574,849 kBtu.

6.4 Building Level Current Energy Performance (Benchmarking)

Table 6-14 presents the results of the PEA and benchmarking analysis for individual campus buildings.

Table 6-14. Building Energy Consumption Comparison to CBECS Peer Benchmark

Energy Use Analysis and Benchmarking Profile — **Building Summary EUI**

UMass at Dartmouth, 285 Old Westport Rd, North Dartmouth, MA, 02747

Building	Gross Area (SF)	Weather Normalized EUI: Electricity (kBtu/SF)	Weather Normalized EUI: Natural Gas (kBtu/SF)	Weather Normalized EUI: Total (kBtu/SF)	CBECS Building Type	Weighted CBECS Comparison (kBtu/SF)	Notes
Liberal Arts	111,617	46.8	93.9	140.7	100% College/university	124.0	2, 3
Main Auditorium & Annex	59,240	24.4	149.5	174.0	100% College/university	129.3	1, 3
MacLean Campus Center	66,700	61.8	149.3	211.1	100% College/university	129.3	1, 3
Residents' Dining Hall	23,317	84.7	221.3	306.0	50% College/university 50% Restaurant/cafeteria	214.2	1, 3
Foster Administration	66,840	25.2	93.9	119.1	100% College/university	129.3	1, 3
Center for Visual and Performing Arts	100,655	34.1	149.3	183.3	100% College/university	129.3	1, 3
Claire T. Carney Library	130,379	36.3	149.7	186.0	100% College/university	129.3	2, 3
Science and Engineering Lecture Halls	22,582	52.0	93.9	145.9	100% College/university	129.3	2, 3
Textile	46,811	78.3	168.8	247.0	80% College/university 20% Laboratory	149.4	1, 3
Science and Engineering	174,376	73.7	102.1	175.7	70% College/university 30% Laboratory	159.4	1, 3
Violette Research	48,497	66.9	121.6	188.6	100% Laboratory	229.6	1, 3
Dion Science and Engineering	84,575	73.7	102.1	175.7	70% College/university 30% Laboratory	159.4	1, 3
Charlton College of Business	19,434	52.0	101.6	153.6	100% College/university	129.3	1, 3
Research Building	22,000	184.8	121.6	306.5	100% Laboratory	229.6	1, 3
Elmwood Hall	98,235	18.8	52.4	71.2	100% Dormitory	73.5	1, 3
Maple Ridge Hall	98,235	16.8	52.4	69.2	100% Dormitory	73.5	1, 3
Chestnut Hall	94,266	8.3	52.4	60.7	100% Dormitory	73.5	1, 3
Roberts Hall	85,138	10.4	52.4	62.9	100% Dormitory	73.5	1, 3
Pine Dale Hall	104,794	37.8	70.4	108.2	100% Dormitory	75.3	1, 3
Oak Glen Hall	101,700	37.8	70.4	108.2	100% Dormitory	75.3	1, 3
Willow Hall	76,240	37.9	47.1	85.0	100% Dormitory	75.3	1, 3
Hickory Hall	76,212	39.0	47.1	86.1	100% Dormitory	75.3	1, 3
Evergreen Hall	71,616	39.0	47.1	86.1	100% Dormitory	75.3	1, 3
Birch Hall	75,584	47.0	47.1	94.1	100% Dormitory	75.3	1, 3
Aspen Hall	61,940	20.4	47.1	67.5	100% Dormitory	75.3	1, 3
Ivy Hall	79,840	39.0	47.1	86.1	100% Dormitory	75.3	1, 3
Woodland Commons	10,979	71.5	74.8	146.3	100% College/university	129.3	1, 3
Tripp Athletic Center	85,033	22.6	82.9	105.5	100% Recreation	66.1	2, 3
Fitness Center	24,910	29.4	57.3	86.7	100% Recreation	73.0	1, 3
Cedar Dell Village South	107,181	16.6	47.1	63.7	100% Dormitory	73.5	1,3
Cedar Dell Village West	104,411	37.3	47.1	84.4	100% Dormitory	73.5	1, 3

Notes:

1. Building electricity from main campus meter. Electric EUI calculated based on building submeter data.

2. Building electricity from main campus meter, but no building submeter. Remaining main campus data apportioned by buildings CBECS estimates to calculate Electric EUI.
3. Building natural gas from main campus meter. Natural gas main campus meter data apportioned based on buildings CBECS estimates.
4. EUI by input fuel is bold underlined if that end use is submetered at the building level.

Figure 6-4 shows the estimated annual energy use for each building by input fuel. The red line shows the estimated energy use for the relevant benchmark to each building.

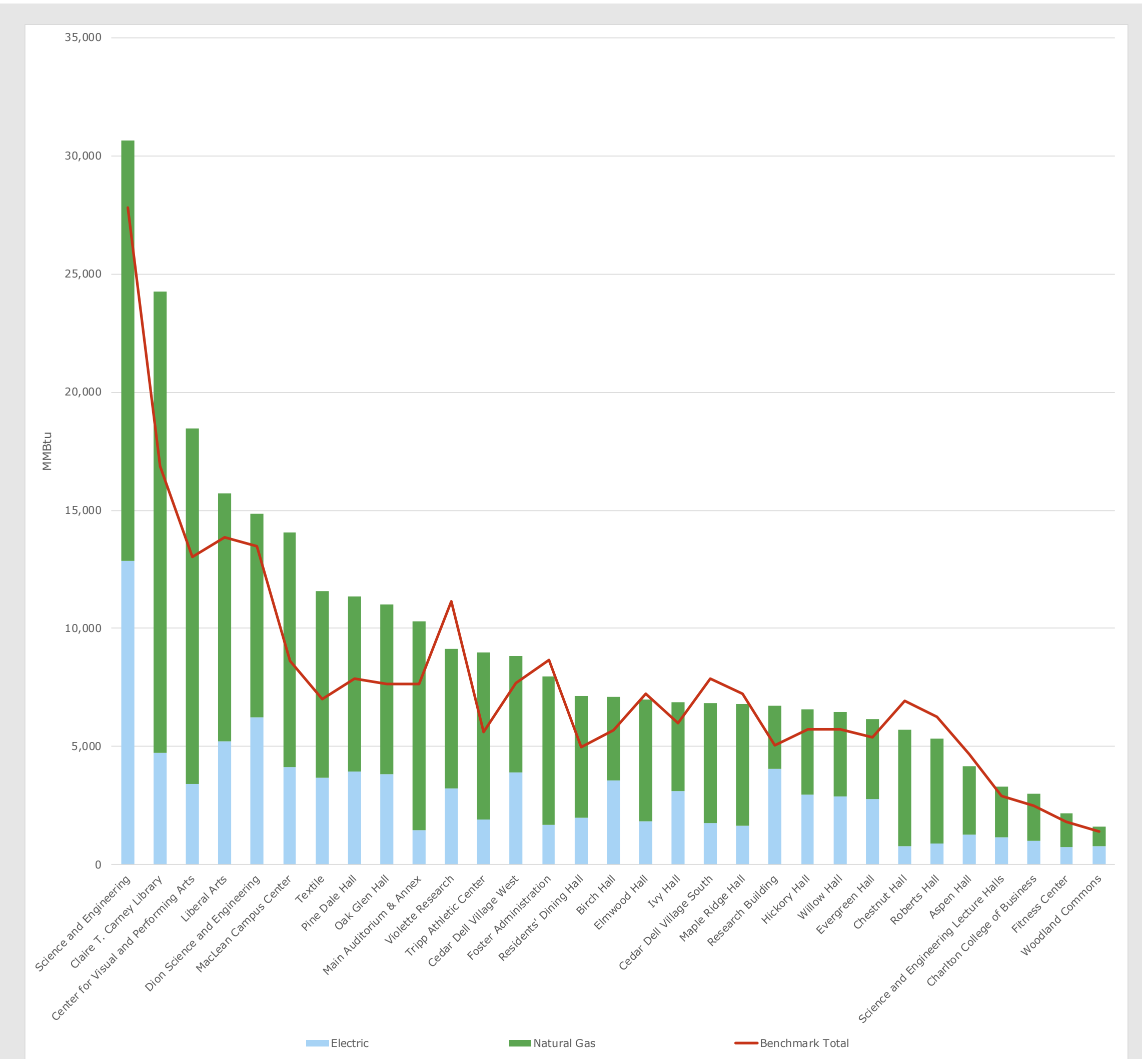


Figure 6-4. Building Level Energy Use by Fuel, Including Benchmark Comparison

Figure 6-5 shows the EUI for each building in a stacked bar by component input fuel. The total EUI for the corresponding benchmark building is shown by the red line.

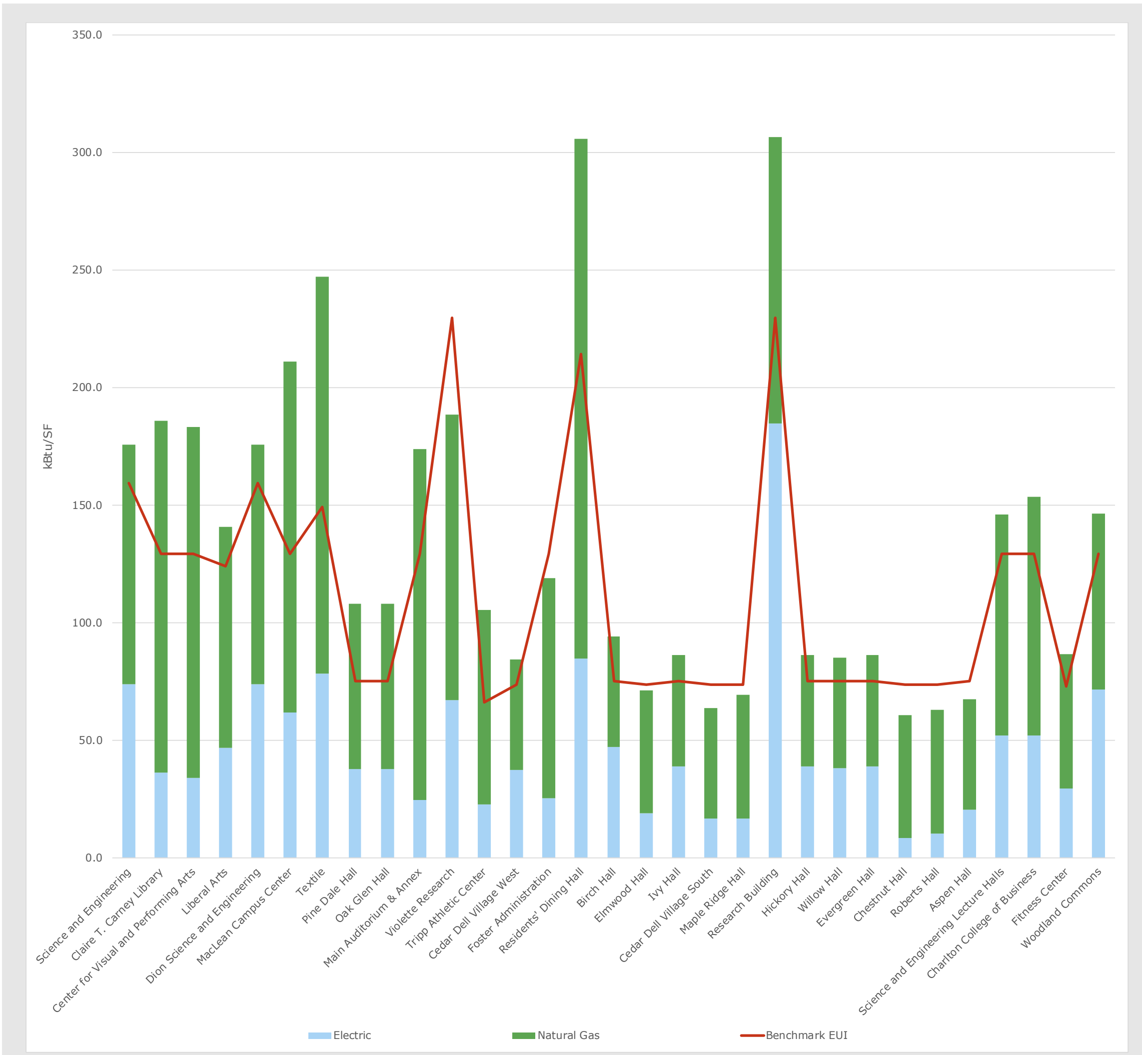


Figure 6-5. Building EUI by Fuel, Including Benchmark Comparison

6.5 Energy Retrofit Potential

The benchmark comparisons show room for potential savings for many campus buildings. The only building with major renovations planned before 2030 is the MacLean Campus Center. The energy reduction for major renovations of this building is estimated at 30%[12]; bringing it close to the benchmark median.

[12] An energy performance goal has not been established for this project. UMassD agreed that a 30% reduction is reasonable.

6.6 Campus Energy Demand

6.6.1 Campus Electric Demand

The electric demand profiles for the campus are based on hourly metered data from both the main campus electric account and the cogeneration system for the period of January 2018 through December 2019. Figure 6-6 and Figure 6-7, respectively, show the campus electric hourly demand profiles and electric load duration curves for 2018 and 2019.

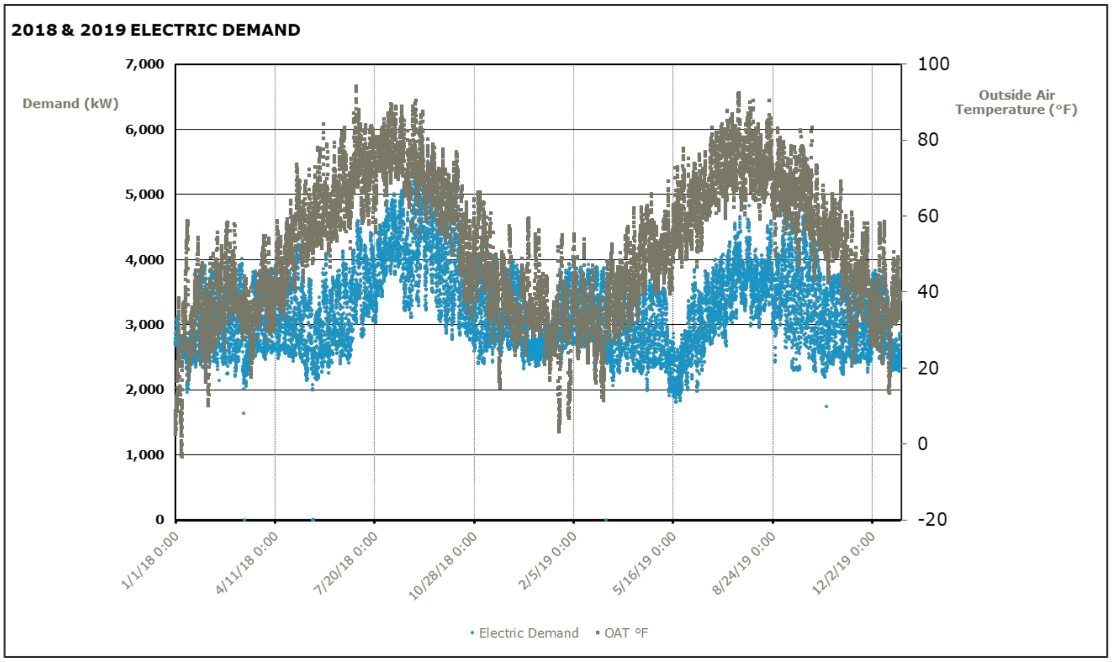


Figure 6-6. 2018 & 2019 Electric Demand

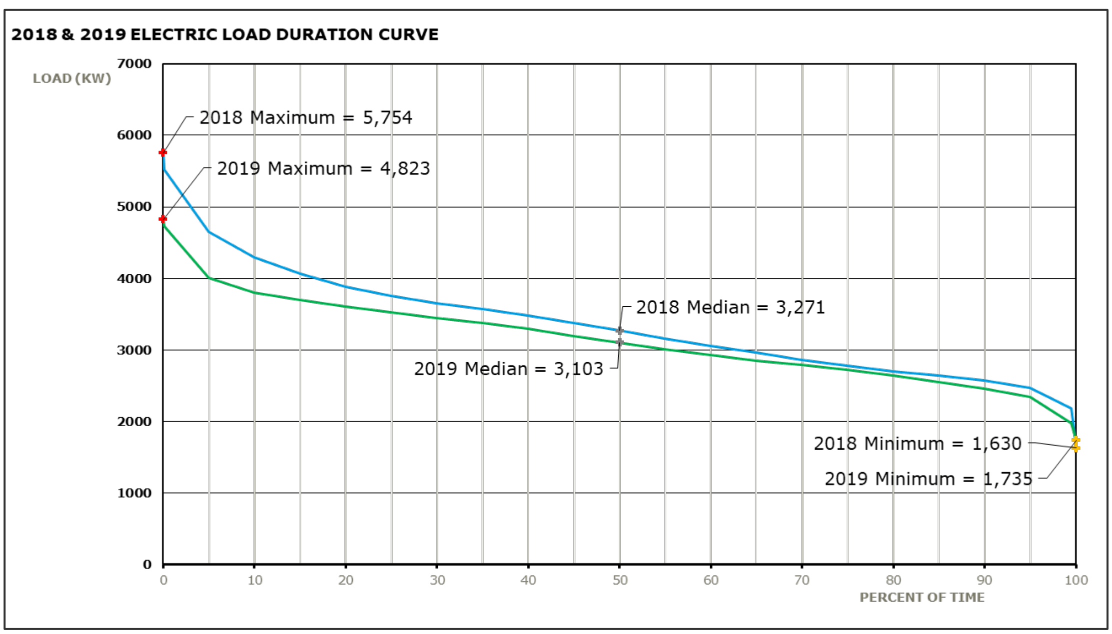


Figure 6-7. 2018 & 2019 Electric Load Duration Curve

6.7 Current Energy Supply

The current energy supply is based on the steam data provided by the campus. Note the supply data represents the input energy; not the energy required for the end user. The space heating, service water heating, and space cooling supply represent only those loads served by the CUP.

6.7.1 Total Steam Supply Profile

The total steam supply profile is estimated based on the steam data from the CUP for the period of January 2018 through December 2019. The total steam supply profile represents the steam supplied by the CUP steam boilers and heat recovery steam generator. Figure 6-8 represents the total steam supply profile, which includes steam used for space heating, service water heating, and space cooling. Figure 6-9 represents the steam supply duration curves for 2018 and 2019.

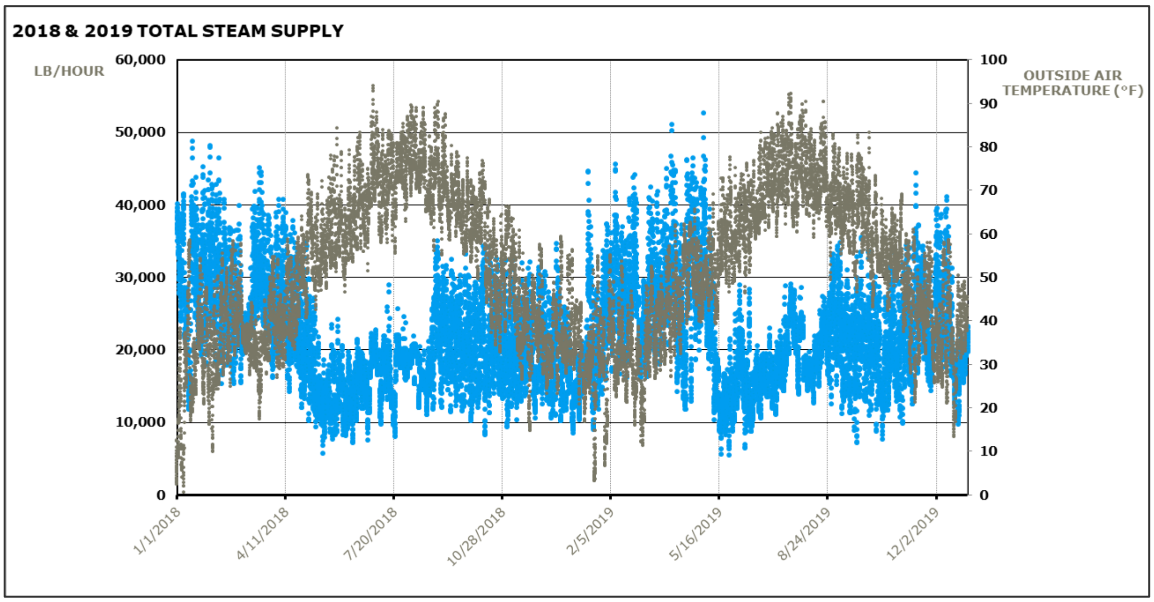


Figure 6-8. 2018 & 2019 Total Steam Supply

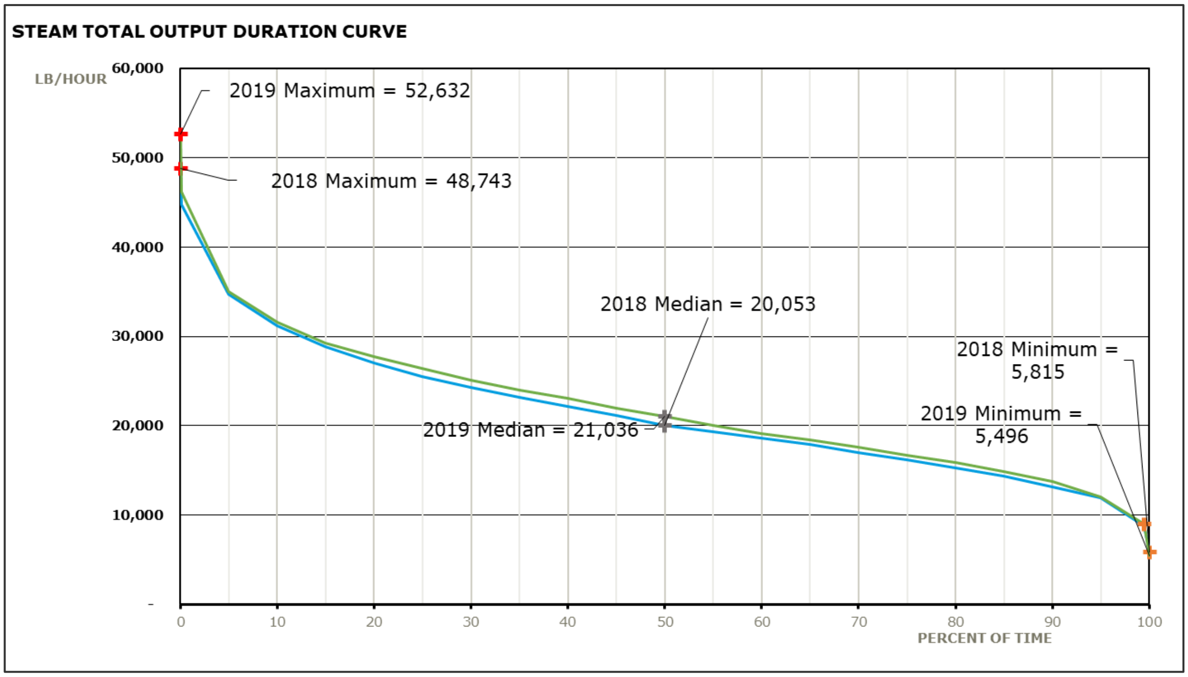


Figure 6-9. 2018 & 2019 Steam Output Duration Curve

6.7.1.1 Steam Heat Supply Profile

The heat supply profile is based on a portion of the steam data from the CUP for the period of January 2018 through December 2019. Figure 6-10 represents the steam heating supply profile, which includes steam used for space heating and domestic hot water. Figure 6-11 represents the steam heating supply duration curves for 2018 and 2019.

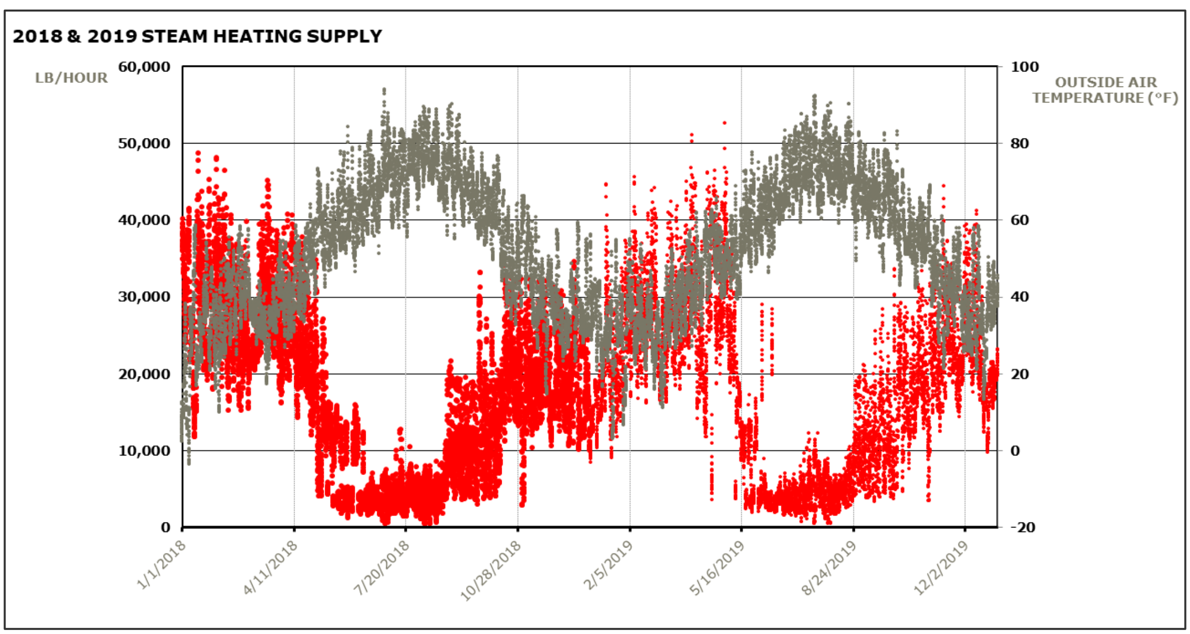


Figure 6-10. 2018 & 2019 Steam Heating Supply

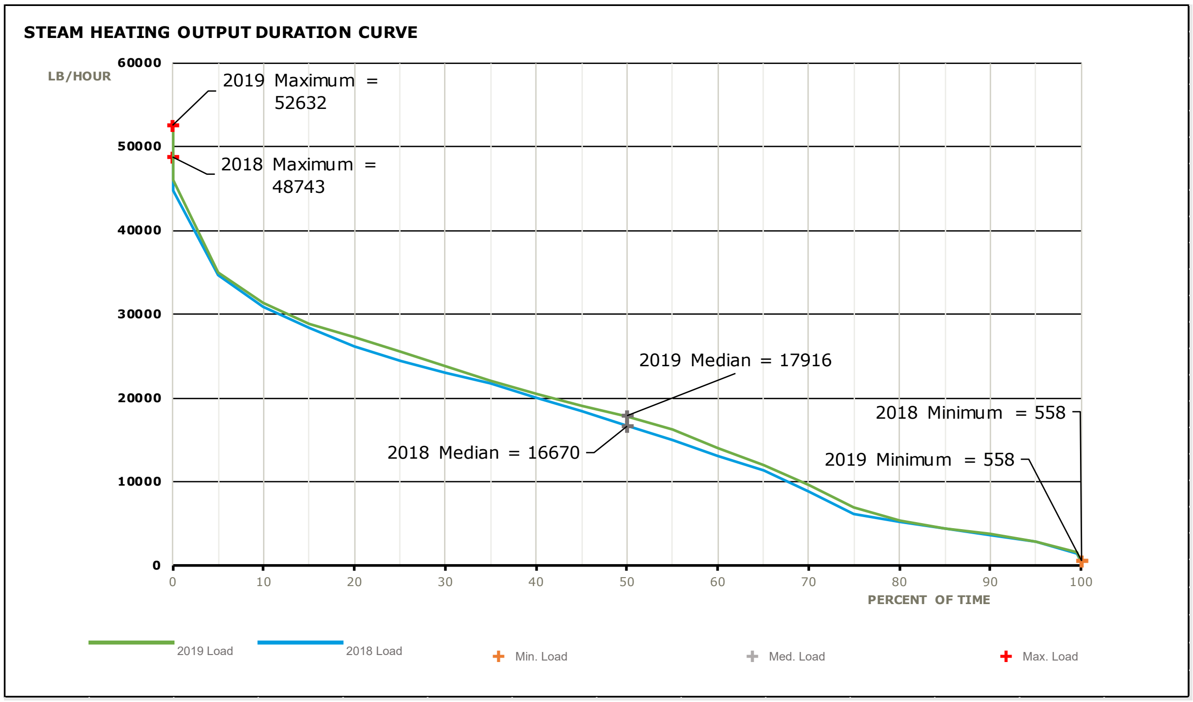


Figure 6-11. 2018 & 2019 Steam Heating Supply Duration Curve

6.7.2 Cooling Supply Profile

The cooling supply profile is based on a portion of the steam data from the CUP for the period of January 2018 through December 2019. The cooling supply profile represents the steam supplied to the steam absorption chillers. Figure 6-12 represents the steam cooling supply profile. Figure 6-13 represents the steam cooling supply duration curves for 2018 and 2019.

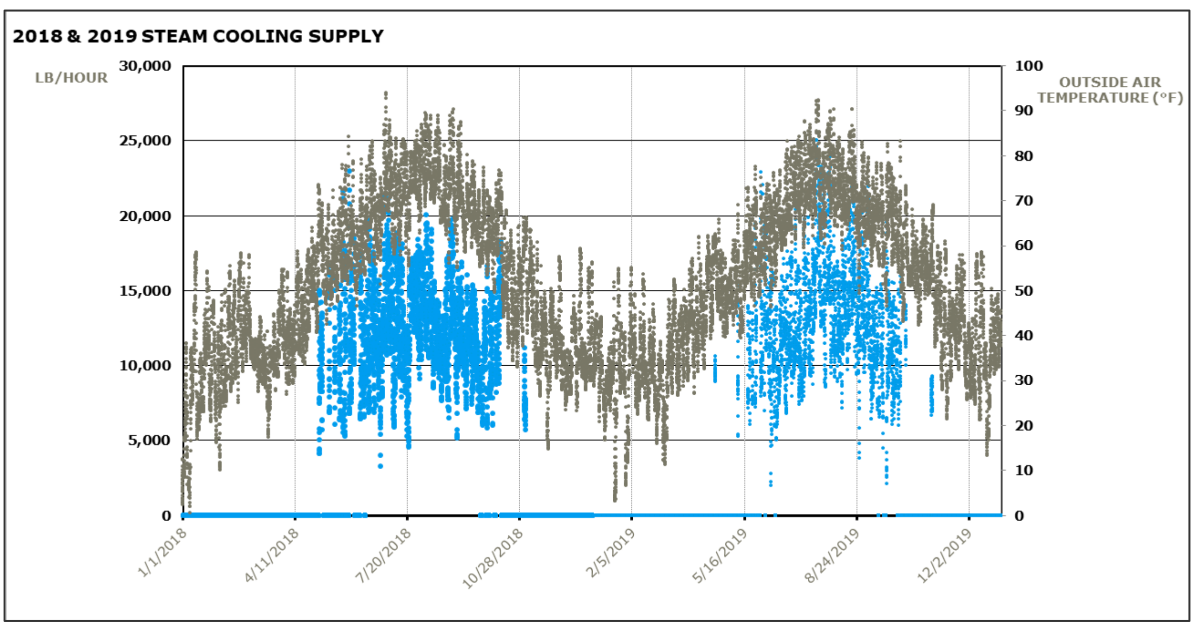


Figure 6-12. 2018 & 2019 Steam Cooling Supply

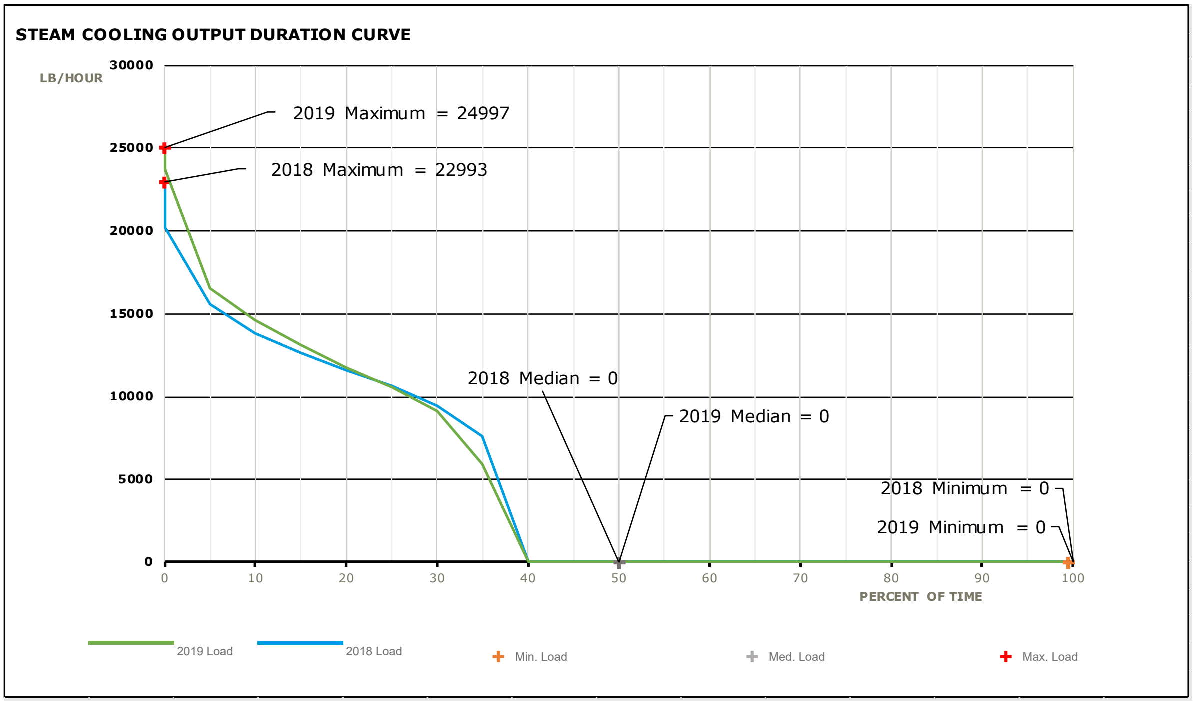


Figure 6-13. 2018 & 2019 Steam Cooling Supply Duration Curve

6.8 Building Energy Demand

Section 6.6 described the methodology of estimating building level energy use as well as end-use estimates. These estimates are on the input fuel side, just as they are in CBECS and as would be reflected in utility bills. For electrical loads, the input fuel (electricity) is essentially equal to the demand or load. For heating and cooling applications we consider the conversion efficiency.

When considering options to serve building heating and cooling demands with other potential technologies, the input energy should be determined based on what thermal demands are required for the building. The heating demands are developed based on the heating input fuel and considering conversion efficiency of the existing technology; similarly, cooling demands are based on the cooling input fuel.

Table 6-15 contains the estimated annual baseline heating, cooling, and electric demand for each building. Note the demand data represents the energy required for the end user; not the input energy, which considers equipment conversion efficiency and on-site distribution losses. Also the building electricity includes that required for local electric cooling equipment.

Figure 6-14 and Figure 6-15 show the baseline hourly profiles and load duration curves developed for total net heat and cooling demands, respectively. Note that the analysis does show peak cooling loads of the same order as peak heating loads. The driving force behind this is the underlying steam data, which is used for most of the heating and cooling. Recalling Figure 6-3, the peak steam use for cooling is close to that for heating. Also, the cooling load served by that steam is higher than the input energy given an estimated COP of 0.6 for the steam absorption chillers.

Figure 6-16 shows the baseline hourly total electric demand profile and the load duration curve; this represents the electricity consumed by the buildings, not just what is imported from the grid.

Table 6-15. Energy Demand by Building

Building	Size (GSF)	Annual Net Heat (MWh)	Annual Net Heat (MMBtu)	Annual Net Cooling (MWh)	Annual Net Cooling (MMBtu)	Annual Net Electricity (MWh)
Liberal Arts	111,617	2,814	9,601	0	0	1,523
Main Auditorium & Annex	59,240	1,498	5,110	1,767	6,028	424
MacLean Campus Center	66,700	1,682	5,738	1,989	6,787	1,201
Residents' Dining Hall	23,317	626	2,135	778	2,653	575
Foster Administration	66,840	1,685	5,750	151	515	494
Center for Visual and Performing Arts	100,655	2,538	8,658	3,002	10,242	1,002
Claire T. Carney Library	130,379	3,302	11,266	3,888	13,267	1,381
Science and Engineering Lecture Halls	22,582	569	1,942	105	357	342
Textile	46,811	1,265	4,317	1,750	5,971	1,073
Science and Engineering	174,376	4,872	16,622	1,534	5,235	3,745
Violette Research	48,497	1,672	5,704	488	1,665	951
Dion Science and Engineering	84,575	2,363	8,062	809	2,761	1,816
Charlton College of Business	19,434	421	1,436	117	401	295
Research Building	22,000	758	2,587	795	2,714	1,191
Elmwood Hall	98,235	1,066	3,638	0	0	535
Maple Ridge Hall	98,235	1,066	3,638	0	0	478
Chestnut Hall	94,266	1,023	3,491	0	0	227
Roberts Hall	85,138	924	3,153	0	0	260
Pine Dale Hall	104,794	1,137	3,881	1,015	3,462	1,155
Oak Glen Hall	101,700	1,104	3,766	985	3,360	1,121
Willow Hall	76,240	659	2,249	145	494	840
Hickory Hall	76,212	659	2,248	149	510	867
Evergreen Hall	71,616	619	2,113	140	479	814
Birch Hall	75,584	654	2,230	178	609	1,034
Aspen Hall	61,940	536	1,827	63	216	367
Ivy Hall	79,840	690	2,356	157	534	908
Woodland Commons	10,979	220	750	66	226	229
Tripp Athletic Center	85,033	1,518	5,180	0	0	561
Fitness Center	24,910	311	1,060	197	672	213
Cedar Dell Village South	107,181	927	3,162	0	0	516
Cedar Dell Village West	104,411	903	3,080	0	0	1,136
Total	2,333,337	40,079	136,749	20,270	69,160	27,273

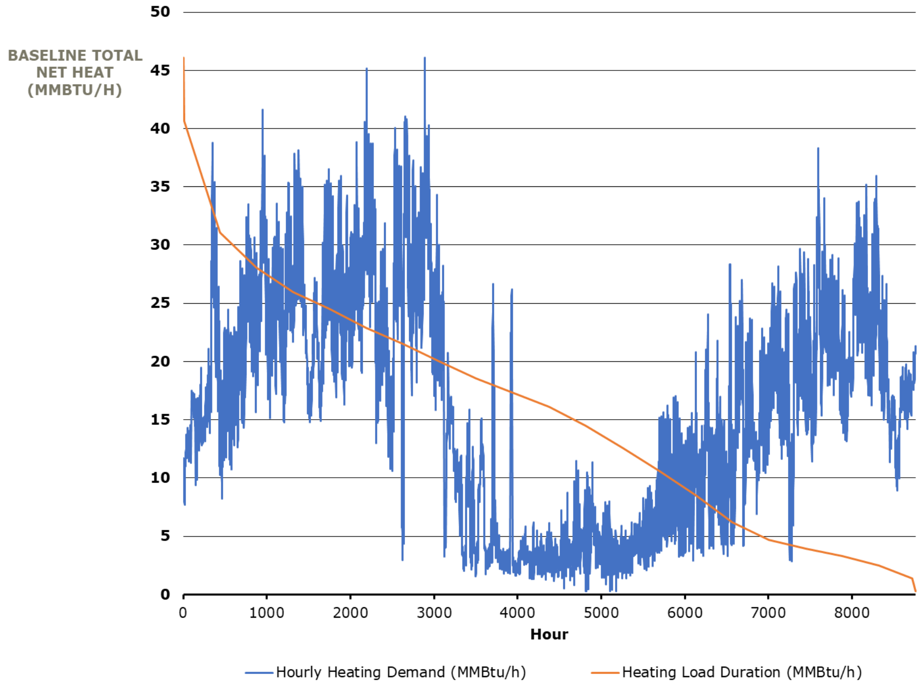


Figure 6-14. Baseline Total Annual Net Heat Profile

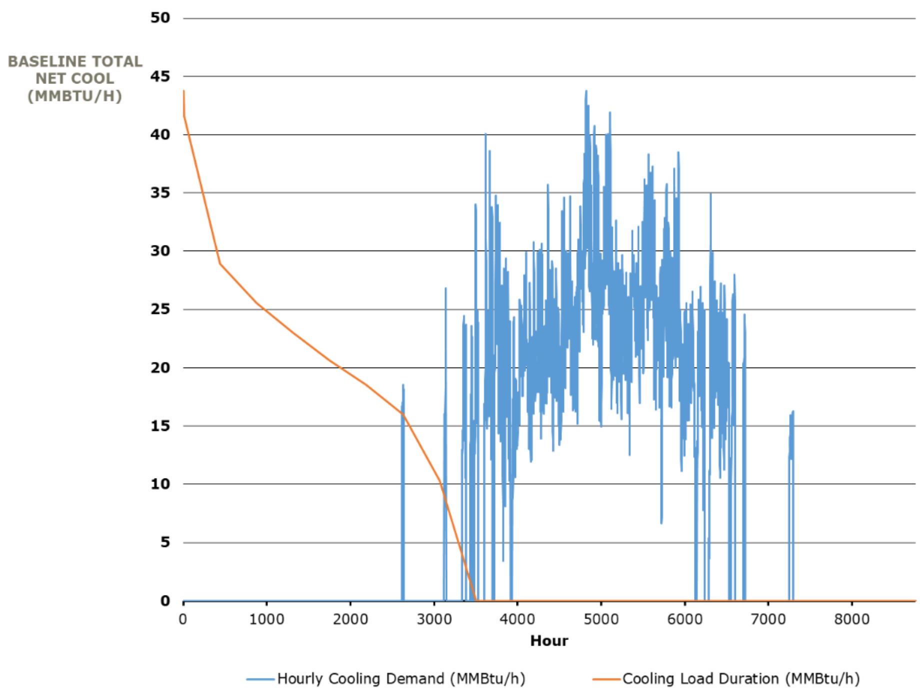


Figure 6-15. Baseline Total Annual Net Cooling Profile

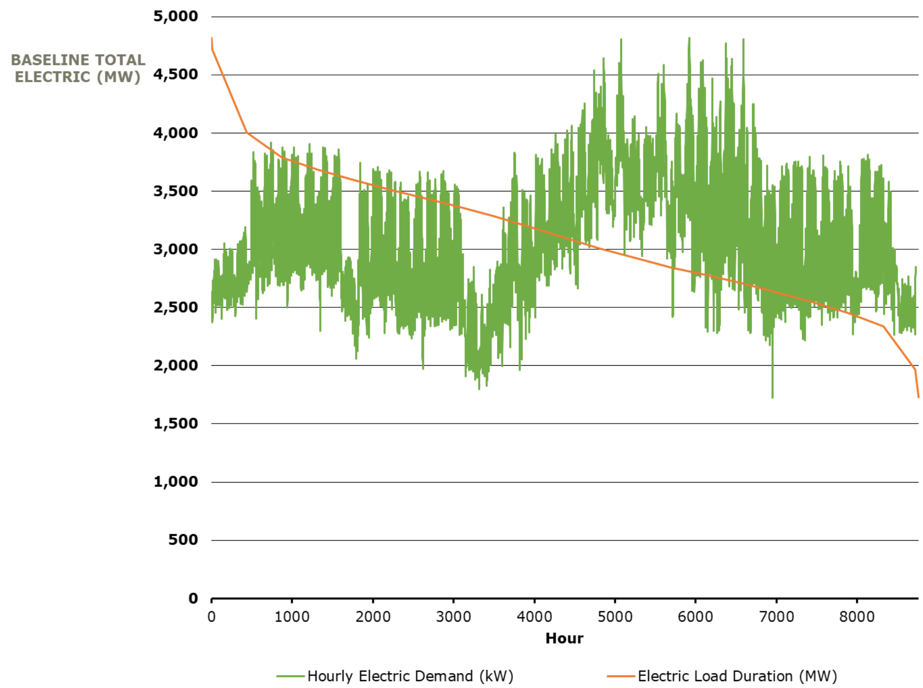


Figure 6-16. Baseline Total Building Annual Electric Demand Profile

6.9 Brutalist Architectural Challenges

Paul Rudolph's Brutalist architectural style includes minimalist construction techniques that showcase the bare building materials and prioritizes structural elements over decorative design. The style commonly makes use of exposed concrete or brick, angular geometric shapes and a predominantly monochrome color palette.[13] UMassD's central campus is comprised mostly of buildings designed by Paul Rudolph and some of the features that present energy conservation challenges are:

- The exterior finish of the buildings are fluted concrete
- The interior of the buildings are concrete
- The buildings were constructed with monolithic concrete pours which bridge the interior and exterior of the build without a thermal break or insulation
- Structural elements (such as concrete beams) extend from the exterior of the building into the interior of the space and serve as a bridge to heat loss
- The windows are constructed with a single pane of glass
- There are many cantilevered sections of the buildings which provide additional surfaces where heat can escape

Given the challenges of the Butalist architecture, the campus has assessed possible ways to improve the energy performance of the buildings and implemented some projects. The campus has successfully incorporated window replacements and installed exterior curtain walls to limit the campus heat loss. Some additional recommendations to improve the energy performance include:

[13] https://en.wikipedia.org/wiki/Brutalist_architecture

- Continued replacements of single pane windows with higher performance double pane windows
- Further insulation improvements in a series of approaches
    - Increased roof insulation may be the least impactful to the architectural nature of the buildings
    - Exterior insulation could be applied under cantilevered sections of the buildings
    - Exterior insulation could be applied which could mimic the original exterior finish of the buildings
    - Interior insulation panels on both the exterior walls as well as structural elements which do not have a thermal break
- Continued use of exterior curtain walls
- Interior insulated partitions could act as a thermal barrier to the interior of the building

Because many of these approaches are very intrusive, they are recommended as part of a larger rehabilitation to the buildings.

6.10 Future Energy Demand

The 2030 demand profiles have been adjusted to reflect: the renovation of MacLean Campus Center (including a 2,380 GSF addition); addition of Balsam Hall dorm, Spruce Hall dorm, and The Grove dining hall; and demolition of Elmwood Hall, Maple Ridge Hall, Chestnut Hall and Roberts Hall. The MacLean renovation is expected to reduce space heating, space cooling and electricity use by 30%. Energy projections for the new dorms are based on a 30% reduction in space heating, space cooling and electricity use as compared to similar existing dorms at UMassD. The Grove energy use is based on the Resident's Dining Hall but with 30% lower EUI.

Table 6-16 contains the estimated annual baseline heating, cooling, and electric demand for each building.

Figure 6-17 and Figure 6-18 show the future hourly profiles and load duration curves developed for total net heat and cooling demands, respectively. Figure 6-19 shows the future hourly total electric demand profile and the load duration curve; this represents the electricity consumed by the buildings, not just what is imported from the grid, and does not include central plant electricity. Note that compared to the baseline electric demand curve, the future curve considers reductions in building loads due to the replacement of some electric cooling equipment with central chilled water as well as future renovations and new buildings.

Table 6-16. Future Energy Demand by Building

Building	Size (GSF)	Annual Net Heat (MWh)	Annual Net Heat (MMBtu)	Annual Net Cooling (MWh)	Annual Net Cooling (MMBtu)	Annual Net Electricity (MWh)
Liberal Arts	111,617	2,814	9,601	0	0	1,523
Main Auditorium & Annex	59,240	1,498	5,110	1,767	6,028	424
MacLean Campus Center	66,700	1,688	5,759	1,989	6,787	1,201
Residents' Dining Hall	23,317	626	2,135	778	2,653	575
Foster Administration	66,840	1,685	5,750	151	515	456
Center for Visual and Performing Arts	100,655	2,538	8,658	3,002	10,242	1,002
Claire T. Carney Library	130,379	3,302	11,266	3,888	13,267	1,381
Science and Engineering Lecture Halls	22,582	569	1,942	105	357	316
Textile	46,811	1,265	4,317	1,750	5,971	1,073
Science and Engineering	174,376	4,872	16,622	1,534	5,235	3,361
Violette Research	48,497	1,672	5,704	488	1,665	829
Dion Science and Engineering	84,575	2,363	8,062	809	2,761	1,614
Charlton College of Business	19,434	421	1,436	88	300	265
Research Building	22,000	758	2,587	596	2,035	992
Elmwood Hall		0	0	0	0	
Maple Ridge Hall		0	0	0	0	
Chestnut Hall		0	0	0	0	
Roberts Hall		0	0	0	0	
Pine Dale Hall	104,794	1,137	3,881	1,015	3,462	1,155
Oak Glen Hall	101,700	1,104	3,766	985	3,360	1,121
Willow Hall	76,240	659	2,249	105	358	803
Hickory Hall	76,212	659	2,248	108	370	829
Evergreen Hall	71,616	619	2,113	102	347	779
Birch Hall	75,584	654	2,230	129	441	989
Aspen Hall	61,940	536	1,827	46	157	351
Ivy Hall	79,840	690	2,356	114	387	869
Woodland Commons	10,979	220	750	50	170	212
Tripp Athletic Center	85,033	1,518	5,180	0	0	561
Fitness Center	24,910	311	1,060	148	504	164
Cedar Dell Village South	107,181	927	3,162	0	0	516
Cedar Dell Village West	104,411	903	3,080	0	0	1,136
Balsam Hall	132,500	1,002	3,418	173	589	1,001
Spruce Hall	132,500	1,002	3,418	173	589	1,001
The Grove	28,000	582	1,987	654	2,230	483
Total	2,250,463	38,591	131,674	20,745	70,783	26,984

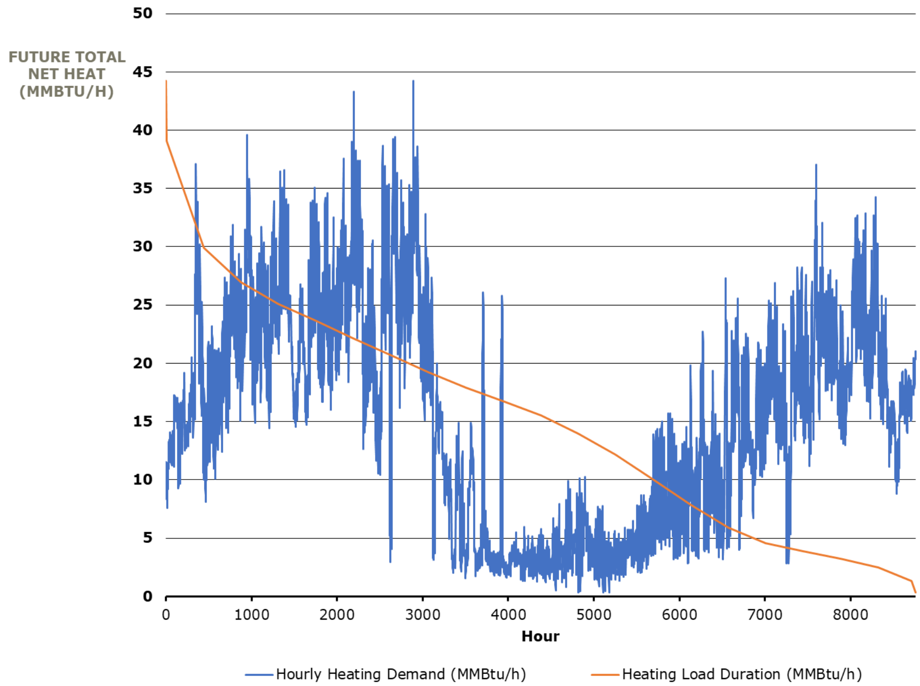


Figure 6-17. Future Total Annual Net Heat Profile

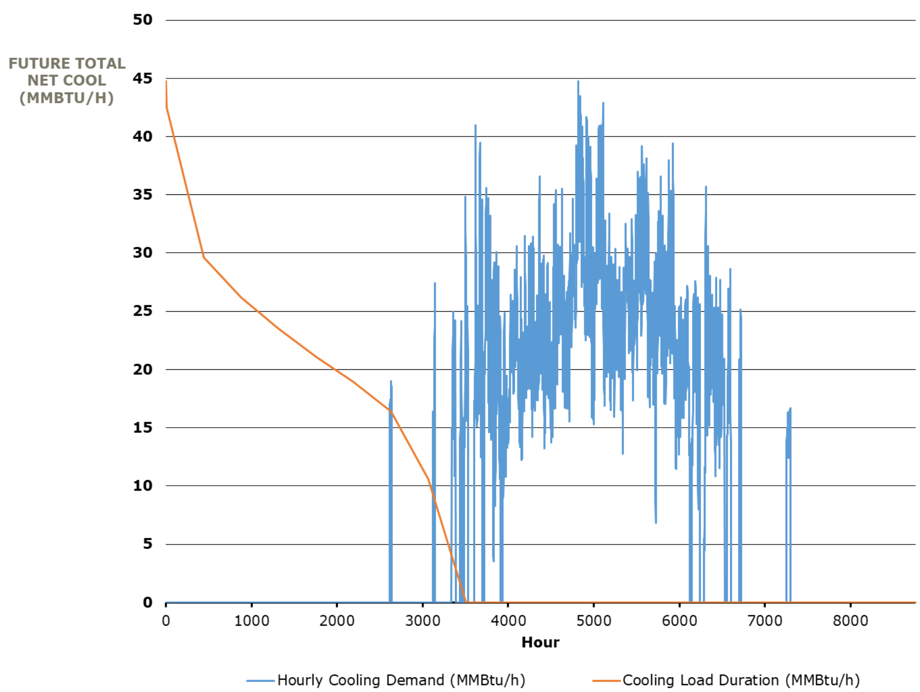


Figure 6-18. Future Total Annual Net Cooling Profile

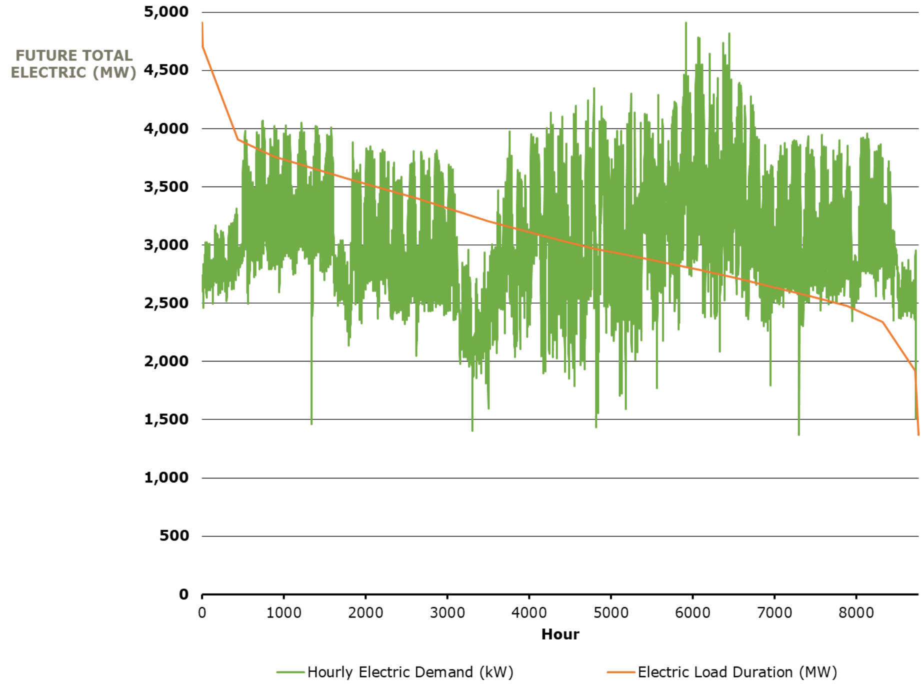


Figure 6-19. Future Total Building Annual Electric Demand Profile

7. CAMPUS SUBMETER PROGRAM AND RECOMMENDATIONS

7.1 Existing Submeters

The campus has already made significant progress implementing a campus submeter program. There are currently 27 working power meters and 13 steam meters on campus measuring building electric and steam demand, some of which meter multiple buildings. Electric and steam use are monitored either through the campus building automation system (BAS) or a Siemens electric monitoring system. Meter data captured by these systems will be used in a preliminary energy-use analysis (PEA).

The campus is looking to expand its submetering program to include additional utility meters. Table 7-1 shows the existing meters on campus.

Table 7-1. Existing Meters

Official Building Name	Existing Meters						
	ELECT	NG	STM	COND	CHW	PTBLE WTR	DHW
Liberal Arts	E		E				
Main Auditorium & Auditorium Annex	E		E*				
MacLean Campus Center	E		E				
Residents' Dining Hall	E		E				
Foster Administration	E		E				
Center for Visual and Performing Arts	E		E				
Claire T. Carney Library	E		E				
Science and Engineering Lecture Halls	E						
Textile	E		E				
Science and Engineering	E		E				
Violette Research	E		E				
Dion Science and Engineering	E		E				
Charlton College of Business							
Research Building	E		E				
Elmwood Hall	E						
Maple Ridge Hall	E						
Chestnut Hall	E						
Roberts Hall	E						
Pine Dale Hall	E*		E*				
Oak Glen Hall	E*		E*				
Chase Road Center		E					
Public Safety/Steam Plant							
Willow Hall	E						
Hickory Hall	E						
Evergreen Hall	E						
Birch Hall	E						
Aspen Hall	E						
Ivy Hall	E						
Woodland Commons	E						
Tripp Athletic Center	E	E					

Official Building Name	Existing Meters						
	ELECT	NG	STM	COND	CHW	PTBLE WTR	DHW
Fitness Center	E						
Athletic Center Heating Plant							
Cedar Dell Village South 7	E*						
Cedar Dell Village South 6	E*						
Cedar Dell Village South 5	E*						
Cedar Dell Village South 4	E*						
Cedar Dell Village South 3	E*						
Cedar Dell Village South 2	E*						
Cedar Dell Village South 1	E*						
Cedar Dell Village West 14	E*						
Cedar Dell Village West 13	E*						
Cedar Dell Village West 12	E*						
Cedar Dell Village West 11	E*						
Cedar Dell Village West 10	E*						
Cedar Dell Village West 9	E*						
Cedar Dell Village West 8	E*						
Spruce							
Balsam							
The Grove							
Total Number of Existing Meters	**26**	**2**	**13**	**0**	**0**	**0**	**0**
Total Number of Buildings with Existing Meters	**42**	**2**	**14**	**0**	**0**	**0**	**0**
E - Existing Meter							
E*- Building shares a meter							

7.2 Recommended Submetering Criteria

7.2.1 Electric Meters

Electric submetering is relatively inexpensive and should be installed for most buildings on campus. Air-conditioned buildings or buildings with significant lighting and equipment loads should take priority. Buildings that are less than 10,000 ft^2 and have minimal contribution to the total campus energy consumption, such as storage spaces or garages, are not recommended for building submetering. If it is financially permittable, an additional electric submeter may be installed to monitor building cooling equipment such as chillers or rooftop units for buildings with large cooling loads.

7.2.2 Natural Gas Meters

The campus has 19 natural gas accounts for the main campus buildings. One main gas account is used for most of the campus buildings. The remaining gas accounts are for buildings off campus or are for buildings not centrally located on main campus, such as the Tripp Athletic Center or potentially the residence halls. However, it could not be determined which buildings are associated with each natural gas account.

It is first recommended to determine which natural gas accounts are associated with which building. It is then recommended that the remaining buildings not associated with an individual natural gas account and are heated by individual gas fired hot water boilers or large gas furnaces are metered.

7.2.3 Steam and Condensate Meters

For buildings served by the campus steam distribution network, it is recommended that both steam and condensate meters be installed. This recommendation includes buildings that already have a steam meter in place. Using both meters will provide the highest accuracy for measuring heating energy consumption at each building. In addition to measuring heating energy usage, condensate meters will determine the percent of condensate recovered and identify areas where the campus may be having problems recovering condensate. Ultrasonic condensate meters can be installed without cutting into the piping and are relatively inexpensive.

If installing both steam and condensate meters is not a financially viable option and there is no known difference between incoming steam and condensate return quantity, then it is recommended the campus meter condensate return flow as a proxy for steam. This is due to accuracy concerns of steam meters. Additionally, challenges are typically presented when sizing and selecting steam meters due to differences in summer and winter demands. However, to be consistent with the current metering practice, it is recommended that both steam and condensate meters be installed.

7.2.4 Chilled Water Meters

The larger campus academic buildings are cooled with chilled water. It is recommended that each of these buildings have a Btu meter to measure building cooling energy. Each Btu meter includes a flow meter and two temperature sensors. Btu meters are relatively inexpensive and easily integrated through the campus BAS system.

7.2.5 Potable Water Meters

The campus should also consider installing potable water meters as part of its submetering program. The priority buildings for installing potable water meters are residence halls, dining halls, athletic facilities and potentially laboratory buildings. These buildings typically have a higher domestic water usage due to their greater regular occupancy and usage of locker or dorm room showers, dishwashers, laundry machines, sinks and lavatories.

7.3 Recommended Meters to be Installed

Table 7-2 shows the recommended meters to install for each building on campus as well as buildings with electric and steam usage already metered. Note some of the existing meters on campus monitor multiple buildings. These recommendations are for the current energy systems and the recommendation would be to install the meters right away to have a greater understanding of the energy use at the campus so that the data is available prior to the planning and design of the campuses transition to a carbon neutral energy system.

Energy meters will be incorporated as part of the campus transition to a net zero energy system and the costs for those meters will be included in the cost estimate for the selected solution.

Table 7-2. Recommended and Existing Meters

Official Building Name	Existing Meters							
	ELECT	NG	STM	COND	CHW	PTBLE WTR	DHW	ELECT – CLG*
Liberal Arts	E		E	R2		R2	R2	
Main Auditorium & Auditorium Annex	E		E	R2	R1	R2	R2	
MacLean Campus Center	E		E	R2	R1	R2	R2	
Residents' Dining Hall	E		E	R2	R1	R1	R1	
Foster Administration	E		E	R2	R1	R2	R2	
Center for Visual and Performing Arts	E		E	R2	R1	R2	R2	
Claire T. Carney Library	E		E	R2	R1	R2	R2	
Science and Engineering Lecture Halls	E		R2	R1	R1	R2	R2	
Textile	E		E	R2	R1	R2	R2	R2
Science and Engineering	E		E	R2	R1	R1	R1	
Violette Research	E		E	R2	R1	R1	R1	
Dion Science and Engineering	E		E	R2	R1	R1	R1	R2
Charlton College of Business	R1	R1				R2	R2	R2
Research Building	E		E	R2		R1	R1	R2
Elmwood Hall	E							
Maple Ridge Hall	E							
Chestnut Hall	E							
Roberts Hall	E							
Pine Dale Hall	E		E	R1	R1	R1	R1	
Oak Glen Hall	E		E	R1	R1	R1	R1	
Chase Road Center		E				R1	R1	
Public Safety/Steam Plant	R1		R2	R1		R2	R2	R2
Willow Hall	E	R1			R1	R1	R1	
Hickory Hall	E				R1	R1	R1	
Evergreen Hall	E				R1	R1	R1	
Birch Hall	E	R1			R1	R1	R1	
Aspen Hall	E				R1	R1	R1	
Ivy Hall	E	R1			R1	R1	R1	
Woodland Commons	E					R2	R2	R2
Tripp Athletic Center	E	E	R2	R1		R1	R1	
Fitness Center	E	R1				R1	R1	R2
Athletic Center Heating Plant	R1		R2	R1		R2	R2	
Cedar Dell Village South 7	E							
Cedar Dell Village South 6	E							
Cedar Dell Village South 5	E							
Cedar Dell Village South 4	E							
Cedar Dell Village South 3	E							
Cedar Dell Village South 2	E							
Cedar Dell Village South 1	E							
Cedar Dell Village West 14	E							
Cedar Dell Village West 13	E							
Cedar Dell Village West 12	E							
Cedar Dell Village West 11	E							
Cedar Dell Village West 10	E							
Cedar Dell Village West 9	E							

Official Building Name	Existing Meters							
	ELECT	NG	STM	COND	CHW	PTBLE WTR	DHW	ELECT – CLG*
Cedar Dell Village West 8	E							
Spruce								
Balsam								
The Grove								
Total Number of New Meters	**3**	**5**	**4**	**18**	**19**	**28**	**28**	**7**
Total Number of Existing and New Meters	**29**	**7**	**17**	**18**	**19**	**28**	**28**	**7**

E - Existing meter

R1 - Priority meters to install

R2 - Second priority meters to install

*** Identifies an electrical sub meter that is dedicated to an electric chiller so that the cooling demand and load profile can be better understood**

A comprehensive energy dashboard interface is also recommended as part of the submetering upgrade. Having the ability to quickly and easily see and analyze the data is critically important as the data alone is not valuable without the ability to interpret it. A particular platform is not recommended, but an open protocol and non-proprietary system does have the added benefit of being customized. It is understood that the Commonwealth Energy Intelligence System (CEI) may be available to UMassD and it should also be considered.

7.3.1 Estimated Meter Cost

Table 7-3 below shows the estimated cost for the recommended priority meters listed in Table 7-2.

Table 7-3. Priority Meter Estimated Cost

Meter	QTY	Material	Labor	GC	Contingency	Unit Cost	Total Cost
Electric	3	$3,365	$1,422	$1,175	$718	$6,680	$20,041
Natural Gas	5	$9,639	$7,788	$4,279	$2,614	$24,319	$121,596
Steam	0	$26,600	$12,134	$9,510	$5,810	$54,054	$0
Condensate	6	$10,356	$10,287	$5,068	$3,096	$28,808	$172,850
Chilled Water	19	$10,153	$21,337	$7,732	$4,724	$43,946	$834,971
Domestic Hot Water	16	$12,386	$21,087	$8,218	$5,021	$46,712	$747,394
Potable Water	16	$6,193	$10,544	$4,109	$2,510	$23,356	$373,697
Total	**65**						**$2,270,547**

Table 7-4 below shows the estimated cost for the recommended second priority meters listed in Table 7-2.

Table 7-4. Second Priority Meter Estimated Cost

Meter	QTY	Material	Labor	GC	Contingency	Unit Cost	Total Cost
Electric	7	$3,365	$1,422	$1,175	$718	$6,680	$46,761
Natural Gas	0	$9,639	$7,788	$4,279	$2,614	$24,319	$0
Steam	4	$26,600	$12,134	$9,510	$5,810	$54,054	$216,215
Condensate	12	$10,356	$10,287	$5,068	$3,096	$28,808	$345,699
Chilled Water	0	$10,153	$21,337	$7,732	$4,724	$43,946	$0
Domestic Hot Water	12	$12,386	$21,087	$8,218	$5,021	$46,712	$560,545
Potable Water	12	$6,193	$10,544	$4,109	$2,510	$23,356	$280,273
Total	**47**						**$1,449,493**

Table 7-5 below shows the estimated total cost for all recommended meters listed in Table 7-2.

Table 7-5. Total Meter Estimated Cost

Meter	QTY		Total Cost
Priority Meters	65		$2,270,547
Second Priority meters	47		$1,449,493
Total	**112**		**$3,720,041**

7.3.2 Energy Management System Recommendation

UMassD has a developed sub-metering program with 27 electrical sub meters and 13 steam meters. Additional submeters are recommended in order to gain a better understanding of how and when the campus uses its energy. An energy management system (EMS) is recommended to capture and analyze the campus meter data to better understand the campus' energy use, to identify metering or equipment malfunctions and to troubleshoot. An EMS provides a real time picture of how the campus is operating using dashboards to display the buildings, their utilities metered, and real time meter readings. The EMS can also store and trend meter data to compare energy use over time on a 15-minute, hourly, daily, weekly, monthly or annual basis against previous similar periods. Some additional common features found include utility billing storage and analysis, alarms when an unexpected spike in energy use occurs, weather normalizing, emissions data reporting, and energy project savings tracking. Key performance metrics such as energy use intensity (kBtu/ft2) or energy cost intensity ($/ft2) are also commonly calculated in an EMS to better understand energy performance at the utility, building or campus level. The use of an EMS will result in more efficient operations, timely repairs, elimination of waste and overall reduction in campus energy use.

8. RESILIENCY

UMassD's current resiliency posture and desired future resiliency posture were reviewed and discussed during the May 26, 2020 biweekly coordination meeting and are summarized below.

8.1 Current Resiliency Posture

8.1.1 Electrical Feeder

UMassD has a single electrical grid connection. There used to be a second electrical feeder connection, but it was used during the cogeneration unit upgrade project. UMassD does not currently have the ability to operate in island mode and has not made that a requirement moving forward.

8.1.2 Electrical Outages

Over the past 12 months there were two to three electrical outages. They are commonly attributed to traffic accidents or weather events (typically high winds). The electrical outages typically last less than two hours. The campus has to reset their main breaker and then subsequent breakers which takes additional time and coordination. Local building generators are used to mitigate the electrical outages for life safety and critical infrastructure.

8.1.3 Thermal Systems

UMassD has the ability to operate their steam plant in absence of the electrical grid. Building distribution systems are tied into emergency generation and have the ability to prevent buildings from freezing in the event of a grid disruption. UMassD does not have the ability to produce chilled water during grid disruptions. There is currently N+1 redundancy on the steam system. The cogeneration unit is their "work horse" and is relied upon heavily. There is reliability concern of both the HRSG and the aging boilers. There is not currently N+1 redundancy on the chilled water system. The campus is a single fuel campus with reliance upon natural gas. Consequently, the tariff structure is uninterruptable.

It is expected to replace the "pony" steam boiler with a "full size" boiler which matches the size of the other two boilers. In alternative solutions a second flue source will be included in order to provide diversity in the event of a loss of the primary fuel source which will be an improvement over the existing condition.

8.2 Desired Future Resiliency Posture

8.2.1 Redundancy

N+1 is required on the thermal side; thermal energy storage should be considered for short term measures. N+1 is required on the chilled water side. In subsequent meetings, the team discussed the requirement for N+1 assets when multiple assets were included with a diversity of fuel sources. It was agreed upon that at least N+1 redundancy would be provided including all resources and that additional redundancies will likely be included considering the diversity of assets.

8.2.2 Energy Sources

A second fuel source is desired as part of a solution (electricity, emergency power [diesel, natural gas], natural gas, bio oil) and should be considered. A back up fuel source does not need to be carbon neutral but should be a very reliable technology.

8.2.3 Islanding

There is no requirement to island and separate from the grid. The project would value the opportunity to island, but it should not compromise the project economics or be a primary goal.

8.2.4 Emergency Response

The campus has designated the Library as an emergency response center, and it has a generator which backs up the building. The existing generator does not provide enough power for the electric chiller and there isn't a need to do so in the future.

8.2.5 Emergency Fuel Supply

The campus desired the ability to store between five to seven days of emergency fuel in future scenarios without refueling. The current system does not provide a backup fuel; however, the future scenarios would provide an enhanced level of resiliency as a result of having an emergency fuel.

9. DEFAULT CASE ANAYLSIS AND ALTERNATIVES ANAYLSIS

9.1 Solutions Technology Screening

Ramboll undertook a detailed technology screening study to consider available technologies for the ability to contribute to achieving UMassD's goals. As a first step in the technology screening process, all technologies which were regarded as potentially relevant to supply energy to the campus were identified. Besides technologies for energy conversion and supply, energy storage technologies were also considered.

The technologies identified were based on industry experience and technology availability. At this stage, no filtering was applied, *e.g.* with respect to cost, technical feasibility, etc.

The energy conversion and supply technologies were classified in the following categories:

- Fossil fuel technologies
- Renewable fuel technologies
- Renewable energy technologies
- Electrification technologies

Ramboll then filtered the list down to the viable technologies and screened out the technologies that were cost prohibitive or that had not matured into a reliable system.

Based on the preliminary evaluation of the available technologies the following technologies have been considered viable at this stage, and it was decided to bring them on to the next stage of the evaluation:

<u>Energy conversion and supply units</u>

- Gas boiler
- Biooil engines
- Biomass heat-only boiler (wood chips)
- Biooil boiler
- Electric boiler
- HP (air-to-water) - large scale
- HP (air-to-water) - small scale
- GSHP closed loop, horizontal, individual
- GSHP closed loop, vertical
- Photovoltaics
- Wind turbine
- Large Solar Thermal
- Conventional electric chiller
- Heat-recovery electric chiller

Thermal storage technologies

- TTES (Tank Thermal Energy Storage)
- ATES (Aquifer Thermal Energy Storage)
- PTES (Pit Thermal Energy Storage)
- BTES (Borehole Thermal Energy Storage)

Not all the above-mentioned technologies will necessarily be part of the final scenarios which will be set up for UMassD, because the generation of possible scenarios will consider coupling technologies to achieve UMassD's goals. Each scenario will be considered as a system and some technologies will not be ideal when coupling with other complementary technologies.

The proposed technologies were brought to the next phase of the screening process, where the technologies are combined into possible scenarios. For a detailed summary of the technology screening process, please see Appendix D.

9.2 Possible Scenarios

9.2.1 Business as Usual Scenario

The project desired to maintain an estimate for the business as usual scenario (BAU) in order to use it as a basis of comparison for future scenarios. The BAU scenario assumes that the current approach to heating and cooling buildings is continued and assets are replaced in-kind upon failure or the end of their useful life.

9.2.1.1 Steam Distribution System

The steam distribution system was recently replaced, and no major modifications are anticipated as part of the business as usual scenario.

9.2.1.2 Resiliency Considerations

The BAU scenario recognized the current limitations on thermal redundancy. While the steam plant has N+1 capacity, the summer or "pony" boiler is much smaller in size and if the gas turbine were to be unavailable, the N+1 redundancy would not be achieved on the boilers alone. UMassD has recognized this and began planning the replacement of the pony boiler will another full-size boiler in order to increase the reliability of the system.

The BAU case includes the replacement of the pony boiler along with the additional building space that would be required to house it. Additional costs that were estimated along with the replacement of the boiler are the costs for the building, natural gas fuel train, the steam and condensate piping, an electrical allowance, misc. valves and misc. controls.

9.2.1.3 Central Asset Replacement

The BAU scenario considers the replacement of all three boilers over the next 20 years. While the existing boilers could be maintained indefinitely, maintained costs will naturally rise over time. It is assumed that they will all be replaced by 2030.

9.2.1.4 BAU Capital Costs

The BAU capital costs were estimated in order to recognize the costs that will be incurred regardless of the goal for carbon neutrality. The costs were categorized by the following items

The pony boiler is currently planned for replacement with a boiler that is equal in size to the other two boilers which will require a building addition. The other two boilers are anticipated to be replaced prior to 2030.

Table 9-1. Cost Estimate for BAU

Item	Cost Estimate	Notes
3x 600 HP Boilers	$5,100,000	Based on previous completed project cost
Building addition	$250,000	$200/SF at 1,250 SF
Natural gas train	$20,0000	Allotment
Steam and condensate piping	$75,000	Allotment
Electrical allowance	$150,000	Allotment
Misc. Valves	$50,000	Allotment
Misc. Controls	$50,000	Allotment
Replacement of 50% abs chiller capacity	$3,900,000	Based on unit capacity
Replacement of 50% individual water-cooled chillers	$1,600,000	Based on unit capacity
Replacement of 50% air-cooled chiller capacity	$345,000	Based on unit capacity
Replacement of 50% installed DX chilling capacity	$506,000	Based on unit capacity
Total	**$12,226,000**	

Gas Turbine Repayment and Continued Use

The natural gas turbine was financed with the cost savings that it realized and UMassD provided Ramboll with the repayment schedule through the end of the loan term in 2035. The payment schedule includes the maintenance costs for the gas turbine as well as the periodic replacement of the turbine blade assembly. The final payment for the load is substantially larger than the annual payments that proceed it, but after the final payment the campus will require a maintenance contract to continue to maintain the asset. The continued maintenance contract price was estimated by averaging the annual payments and then applying a 4.5% escalation factor for each subsequent year. Figure 9-1 presents the debt payments from year 2020 through 2035 and then the estimated maintenance payment from year 2036 through 2040.

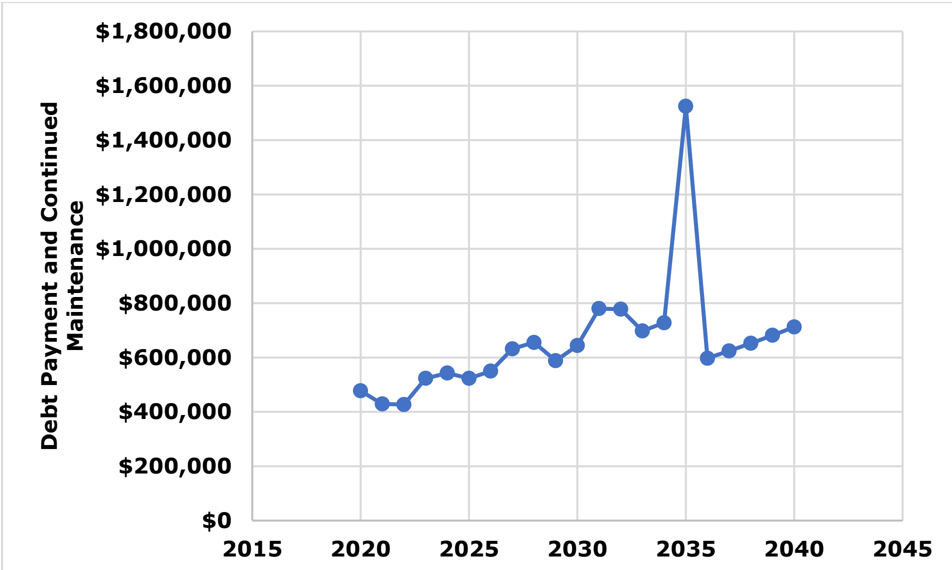


Figure 9-1. Natural Gas Turbine Loan Payment and Continued Maintenance Estimate

9.2.2 Setting Up the Scenarios

The scenarios were considered using the following approach:

- The scenarios should include production of heating and cooling. Some technologies produce heating and cooling simultaneously. This is the case for example a heat recovery chiller (HRC) and ground source heat pumps (GSHP), which, in principle, can be the same machine, *i.e.* a heat pump which can operate both in cooling and heating mode. During summer, the heat pump works as an HRC, producing chilled water on its evaporator side, to cover the cooling demand. The heat, which is simultaneously produced on the condenser side, can be used to cover the heat demand still present in summer (*e.g.* DHW demand).

  Because in summer the cooling demand is much higher than the heating demand, the amount of heat which is to be rejected at the condenser side of the HRC is larger than the head demand for DHW. The excess heat production can be stored in a seasonal storage for later use. In autumn/winter, when the cooling demand is reduced, the heat pump works as a GSHP, extracting heat from the seasonal storage and using it as heat input on the evaporator side. Higher temperature heat is produced on the condenser side of the heat pump and is used to cover the heat demand.

  When the heat extracted from the seasonal storage by the GSHP is roughly the same as the heat which is charged back into the seasonal storage by the HRC, the seasonal storage is kept in balance year after year, ensuring a continuous operation.

- A reduced number of parameters (one additional technology, or different sizes of the energy conversion and production units) is changed from scenario to scenario to make sure that economic consequences can be verified and that the effect of the parameters on the overall performance of the system can be identified.

- Changes in the supply of electricity (from *e.g.* a wind turbine or a solar PV array) is not included in the scenarios. Instead, this will be assessed following the selection of a preferred scenario.

The main technologies for the scenarios are:

- HRC/GSHPBiomass heat only boiler
- Electrical chillers
- Boilers for peaking/backup
- Thermal storage technologies (TTES (*tank thermal energy storage*), ATES, PTES, BTES)

9.2.3 Business as Usual Scenarios

Scenario	Description
0	Continued production of heating and cooling, but including campus extension with new buildings and potential building renovations

9.2.4 Scenarios with Electrification Technologies as Main Technology

In these scenarios electrification technologies such as HRC/GSHP are the main technology for heating and cooling production. Surplus heat from the summer season can be stored in a seasonal storage for use in the wintertime. In winter, the seasonal storage can be discharged and used to produce heat from a heat pump, thereby displacing production from either natural gas or biooil.

Scenario	Description
2A	HRC, gas/biooil heat only for intermediate load and peaking/backup. TTES.
3A	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, **BTES**
3B	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, **PTES**
3C	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, **ATES**
4A	HRC/GSHP (cooling and heating) for base load, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, **ATES**
4B	HRC/GSHP (cooling and heating), biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, **PTES**
4C	HRC/GSHP (cooling and heating), air-source HP, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, **PTES**

9.2.5 Scenarios with Solar Thermal as Main Production

In these scenarios solar thermal is the main production. Respectively heat only boilers, GSHP or biomass will produce the intermediate load and natural gas/biooil boilers will produce peaking/backup.

Scenario	Description
6A	Solar thermal, gas/biooil heat only for intermediate load and peaking/backup. TTES. Electrical chillers
6B	Solar thermal, gas/biooil heat only for intermediate load and peaking/backup. TTES, **PTES**. Electrical chillers
7A	Solar thermal, HRC/GSHP (heating and cooling) for intermediate load, natural gas/biooil for peaking/backup, TTES, boreholes (not for seasonal storage)
7B	Solar thermal, HRC/GSHP (heating and cooling) for intermediate load, natural gas/biooil for peaking/backup, TTES, boreholes (not for seasonal storage), **PTES**
8A	Solar thermal, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES. Electrical chillers
8B	Solar thermal, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, **PTES.** Electrical chillers

9.3 Filtering of the Scenarios

In the selection of the scenarios, it was initially not considered whether the scenarios would be economically viable. Also, it can turn out that some of the technologies are not possible from a technical perspective. The first level of screening out non-viable scenarios is to consider what would not be technically viable or what would not be economically competitive. The goal of the initial filtering was to reduce the number of scenarios to the three to five scenarios that are anticipated to achieve UMassD's goals while providing favorable economics. The methodology for screening out the scenarios is described in the following section.

9.3.1 Seasonal Storage Options

Ramboll retained IF Technology to assessed the potential for ATES. IF Technology reviewed the available geological information for the area of the campus and identified that the geological conditions are not well suited for ATES. Therefore, all scenarios foreseeing the implementation of ATES as seasonal storage were filtered out.

The remaining seasonal storage options were PTES and BTES. Based on an assessment of IF Technology from the Netherlands, who are experts in shallow and deep geothermal, it is evaluated that the underground below Umass Dartmouth consists of:

Top (feet)	Bottom (feet)	Thickness (feet)	Type	Lithology
0	30-80	30-80	Boulders, occasionally sand, gravel and clay	Till
30-80	425	>350	Avalon granite and pelitic rocks	Bedrock

Drilling in bedrock means that the boreholes for BTES will be more expensive than with other lithology types. This aspect will be considered in the economic evaluation of the relevant scenarios.

Given the uncertainty on the information on the soil composition, it is not known at this stage if granite may be found also in the soil layer closer to the surface. If this is the case, the establishment of a PTES would be more expensive than in other soil conditions. In the scenarios with PTES, it was therefore assumed that a location close by the campus can be found, where no granite is present within the depth of the PTES (30-45 feet). Boulders may still be encountered, and this was considered when evaluating the investment cost for PTES.

9.3.2 Scenarios Screened Out

Scenario 2A

In Scenario 2A the main production is from heat recovery chillers. In the summer season the demand for heat is limited. Since there is no seasonal storage available in this scenario, only a limited amount of the heat from the heat recovery chillers can then be utilized (estimate is between 10 and 20%). The remaining 80 to 90% of the heat should be produced on either natural gas or biooil heat only boiler. This is a too extensive production on a fossil fuel and the cost of biooil is relatively high; therefore, this scenario was filtered out.

Scenario 3C

This scenario foresees ATES, which is not technically feasibly at UMassD campus. Therefore, the scenario is filtered out.

Scenario 4A

This scenario includes ATES, which is not technically feasibly at UMassD campus. Therefore, the scenario is filtered out.

Scenario 6A

In this scenario solar thermal is producing the base load and natural gas/biooil produces the intermediate and the peak load. Since there is not seasonal storage in this scenario, the solar thermal plant would be able to produce approximately 20% of the demand for heat, with limited contribution in winter, when the solar radiation is lowest, and the heat demand is highest. This means that natural gas or biooil should produce 80% of the demand which is considered too much. Therefore, this scenario is filtered out.

Scenario 6B

This is the same scenario as 6A with the only difference being that a PTES is available for seasonal storage. With a season storage, solar thermal can produce approximately 40% the demand for heat. The required land area to install the solar collectors is estimated to be in the order of 11 acres and the PTES would be about 110,000 cubic yards. The requirement on land area, the large investment cost for both the solar collector field and the PTES, and the relatively high share of heat still coming from natural gas/biooil boilers are important disadvantages of this scenario. Therefore, this scenario is filtered out.

Scenario 7A
In this scenario solar thermal produces the base load, GSHP the intermediate load and natural gas/biooil the peak load. Since the production from solar thermal is very limited in the wintertime, it would still be necessary to have full production from GSHP, *i.e.* it will not be possible to save anything on the capital expenditures of the GSHP system. Additionally, solar thermal would produce the most heat in summer, when the heat demand is low, and it can be covered anyway through the HRC which run to cover the cooling demand. Therefore, this scenario is filtered out.

Scenario 7B
This scenario is the same scenario 7A with the only difference being that a PTES is installed as a seasonal storage for solar thermal. The availability of a seasonal storage means that it would be possible to produce approximately 50 to 60% of the heat demand from solar thermal.
The necessary area for the solar collectors and the pit thermal energy storage will be approximately 15 acres.

It is estimated that the peak heat demand is approximately 44 MMBtu per hour. The total heat demand in 2030 is estimated to approximately 132,000 MMBtu per year. If the solar thermal produces 60% of the heat demand it will correspond to approximately 80,000 MMBtu per year or an average production of approximately 80,000/8760 = 9.1 MMBtu per hour. This means that the solar thermal facility and the connected season storage will be able to reduce the necessary capacity from the GSHP field by approximately 20%.

Operating solar thermal means that the costs for electricity will be reduced for the heat pumps connected to the GSHP system. However, these saved costs are not high enough to pay back the additional cost for the solar thermal system. Hence, the overall costs in this scenario will be too high to justify an additional investment in solar thermal and connected seasonal storage. Hence, this scenario is filtered out.

Scenario 8A
The scenario has solar thermal as base load, biomass heat only as intermediate load and natural gas/biooil as peaking and backup. In this scenario there is a tank thermal energy storage connected but no seasonal storage is connected.

A tank thermal energy storage is a day-to-day storage. Therefore, it is not possible to store the production of heat from the summer season to the winter season. Based on experiences, the production of heat will correspond to approximately 20% of the annual demand. This means that both biomass boiler and peak boilers (natural gas or biooil) will have extensive time in operation. Therefore, this scenario is filtered out.

Scenario 8B
As Scenario 8A, this scenario has solar thermal as base load, biomass heat-only boiler as intermediate load and natural gas/biooil boilers as peaking and backup. In this scenario there is a tank thermal energy storage as well as a PTES. This means that heat from the summer season can be utilized in part of the winter season. The necessary area for the solar collectors and the pit thermal energy storage will be approximately 15 acres.

A solar thermal facility combined with seasonal storage will be able to cover up to approximately 50 to 60% of the annual demand for heat meaning that a biomass boiler should still produce approximately 30 to 40% of the demand, which is still considered too much production from biomass. Therefore, this scenario is filtered out.

9.3.3 Scenarios for Detailed Techno-/Economic Modeling

After the screening process, the following scenarios are left. These represent the final scenarios for the detailed techno-/economic modeling and are listed below:

Scenario	Description
0	Continued production of heating and cooling, but including campus extension with new buildings and potential building renovations
3A	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, BTES
3B	HRC/GSHP (cooling and heating) for base load, natural gas/biooil boilers for intermediate load/peaking/backup, TTES, PTES
4B	HRC/GSHP (cooling and heating), biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, PTES
4C	HRC/GSHP (cooling and heating), air-source HP, biomass heat only for intermediate load, natural gas/biooil for peaking/backup. TTES, PTES

9.4 Hydraulic Modeling

The centralized distribution system for both hot water and chilled water were modeled in Termis and reviewed with the campus. The primary routing was developed utilizing the existing utility corridors. The energy demands at each building were input into the software platform using the estimates developed in Section 6.10.

Termis requires several inputs in order to size the hydraulic piping including the supply and return temperatures, the pressure loss factor, ambient ground temperatures, materials of construction, and acceptable velocity ranges. The following sections identify the constraints by distribution system.

9.4.1 Low Temperature Hot Water Distribution System

The low temperature hot water distribution (LTHW) system was modeled in Termis as shown in Figure 9-2. The LTHW distribution system was assumed to have a 185°F supply temperature with a 160°F return temperature; yielding a 25°F delta T. A 1.15 pressure loss factor was included and the equivalent full load hours of 2,000 hours was using assuming an average ground temperature of 46°F. The maximum pressure gradient of 0.0053 PSI/ft was also used along with the following table for maximum acceptable pipe velocities.

Table 9-2. Acceptable Pipe Velocities

Size (in)	Velocity (ft/s)
2 - 6	4.9
8 – 10	6.6
12 – 14	8.2
14 <	11.5

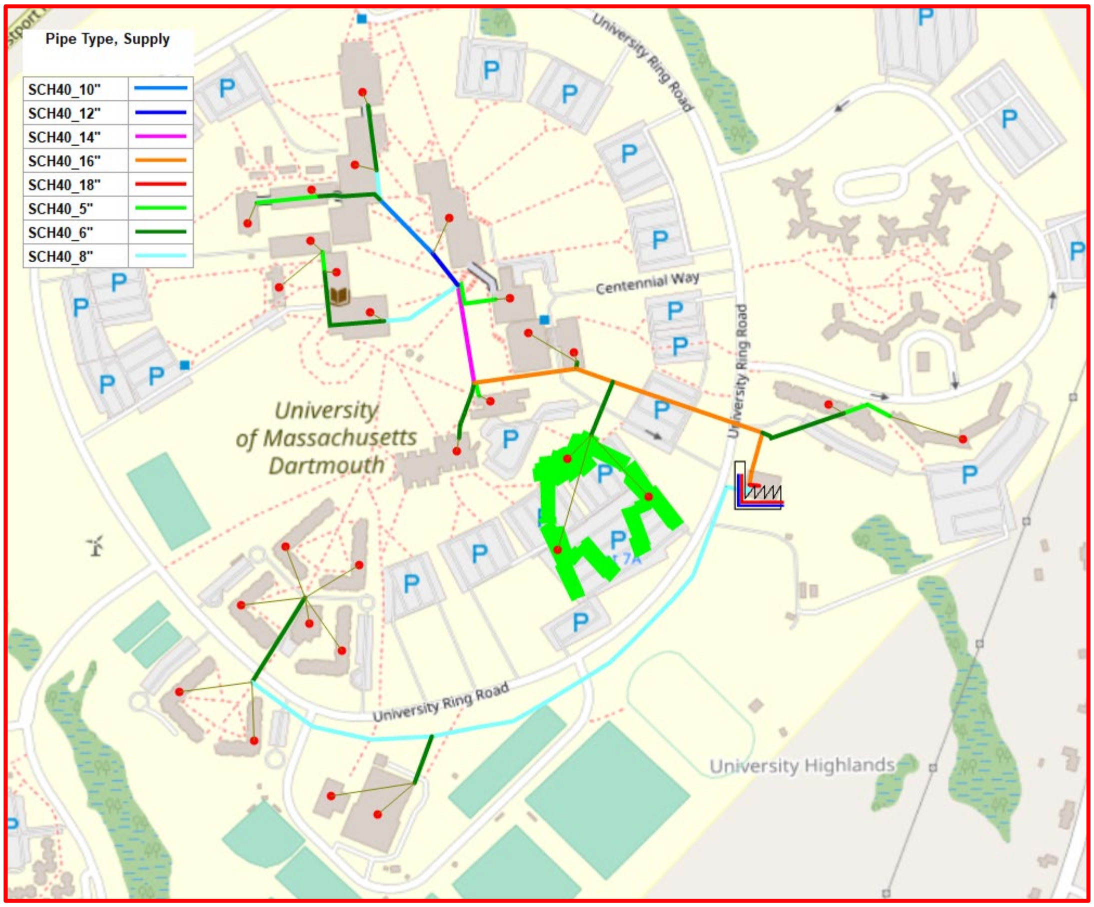


Figure 9-2. Hot Water Distribution Network

9.4.2 Chilled Water Distribution System

The chilled water distribution system was also modeled in Termis as shown in Figure 9-3. The chilled water distribution system was assumed to have a 40°F supply temperature with a 54°F return temperature; yielding a 14°F delta T. A 1.15 pressure loss factor was included and the equivalent full load hours of 1,200 hours was using assuming an average ground temperature of 54°F. The maximum pressure gradient of 0.0133 PSI/ft was also used along with the following table for maximum acceptable pipe velocities.

Table 9-3. Acceptable Pipe Velocities

Size (in)	Velocity (ft/s)
8 – 10	8.2
12 – 14	9.8
14 <	11.5

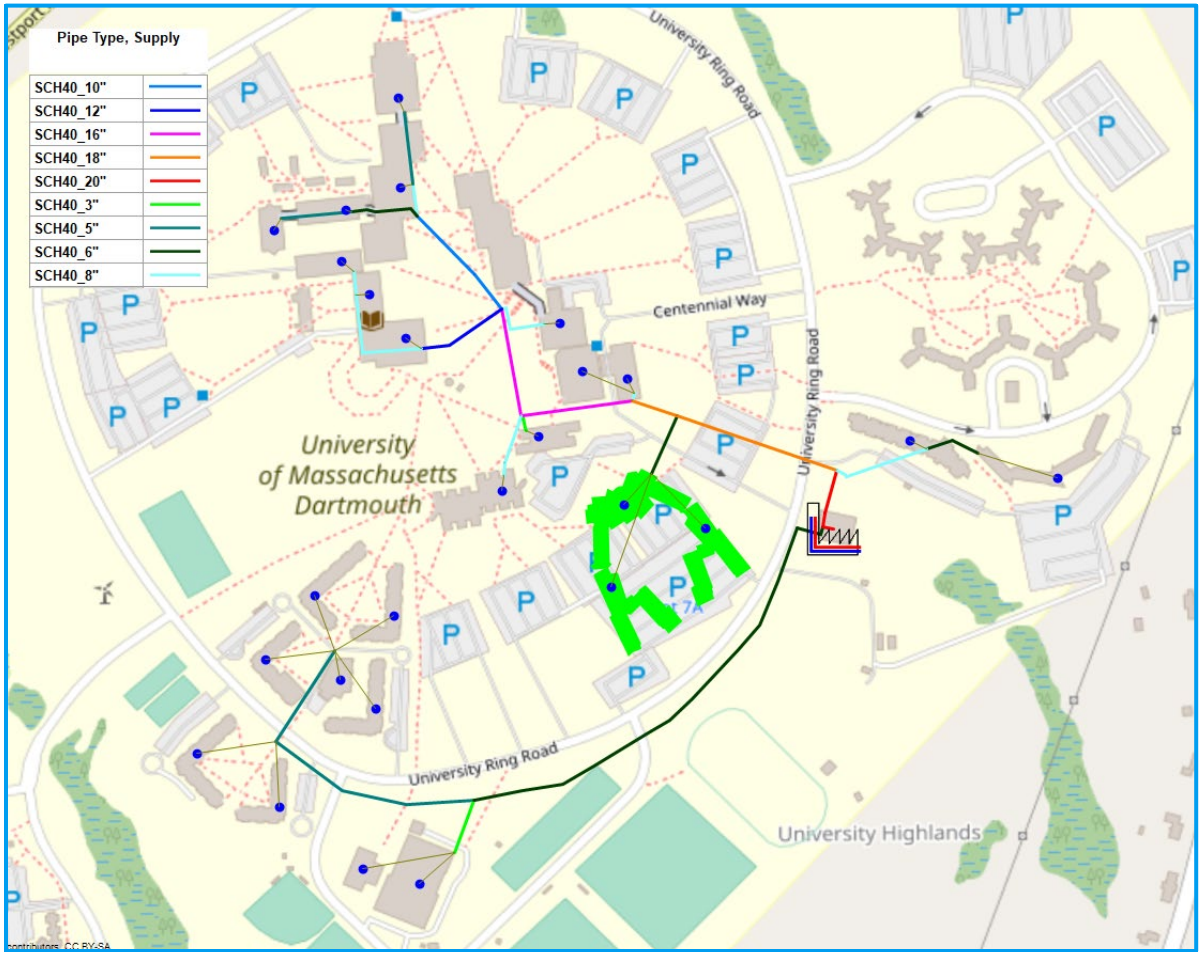


Figure 9-3. Chilled Water Network

9.4.3 Distribution System Phasing

The distribution system buildout warrants a dedicated planning process which should consider the timing of retired steam systems and construction planning. In some cases, it will be required to maintain the steam distribution system while the steam absorption chillers continue to be used. In other cases, the steam lines can be retired as soon as the hot water lines are operational. This complex phasing plan should be generated as a result of detailed engineering processes prior to the solicitation of the proposal for this work.

9.5 Modeling of the Scenarios

9.5.1 EnergyPRO Simulation Tool

The final scenarios identified for the detailed techno-/economic modeling have been modeled through the software EnergyPRO, to access how the different energy production and conversion units, as well as the storage, would be operated, considering technical, economic and environmental aspects.

As an example, the layout of an EnergyPRO model is shown in the figure below, where the EnergyPRO model for Scenario 4C.0 is depicted.

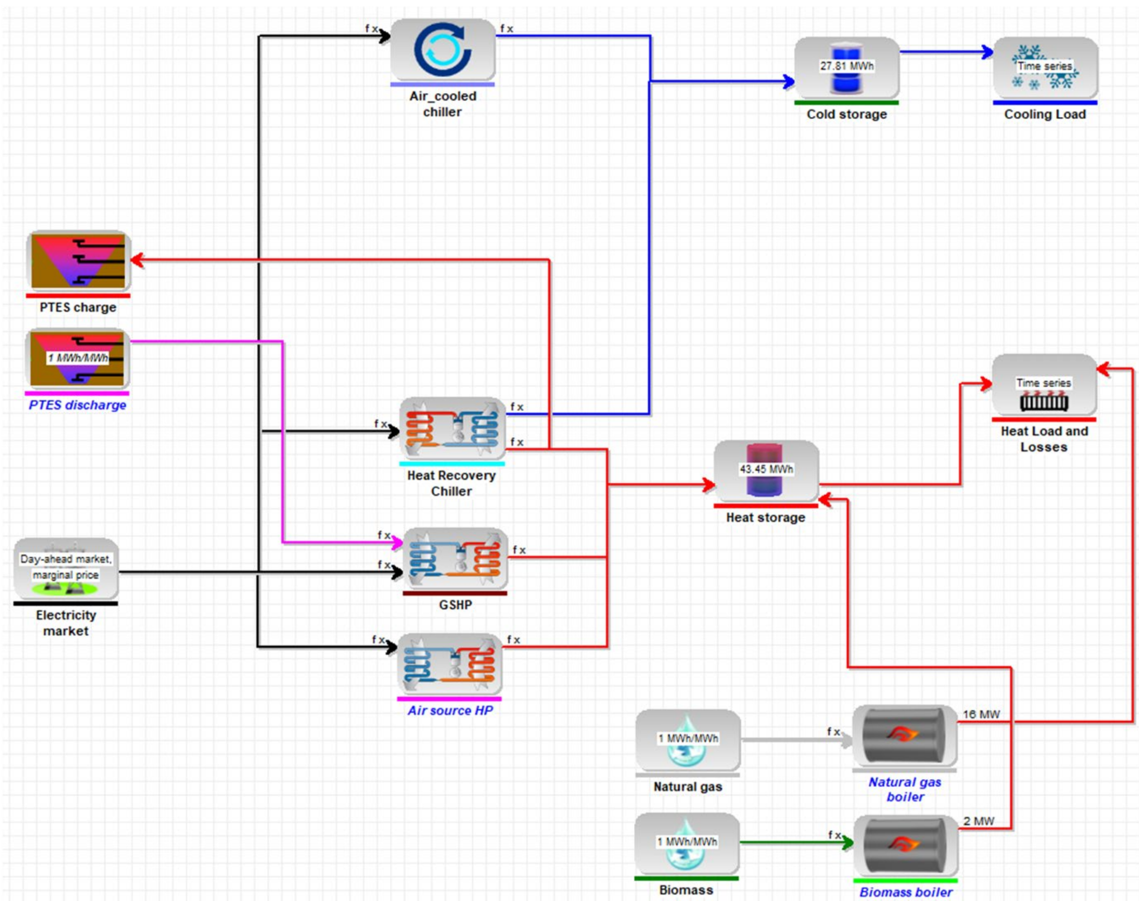


Figure 9-4. EnergyPRO model for Scenario 4C.0

In EnergyPRO, the different colors of the connectors denote a different type of energy flow:

- Blue: "cooling energy";
- Red: "heating energy";
- Black: electricity;
- Pink: "heating energy", but at a lower temperature compared to "heating energy" denoted by the red connectors;
- Grey: natural gas;
- Green: biomass.

On the right-hand side, the "Cooling Load" and "Heat load and Losses" blocks represent the energy demands which must be covered.

For the specific model shown in the Figure 9-4, the energy-production-and-conversion units are the following:

- **Heat recovery chiller/GSHP** - these two units are in fact the same machine, but this needs to be modeled as two units in EnergyPRO, to properly simulate the behavior and operation of the machine.
- **Air-source HP** - this unit works as base/intermediate load unit. Its performance depends on the outdoor ambient temperature. It is assumed that the air-source heat pump has a cut-off temperature of 23°F. The operation of the air-source HP is dependent on the electricity price and on the outdoor ambient temperature. This unit will have higher priority in periods characterized by lower electricity prices and higher outdoor ambient temperature.
- **Biomass boiler** - this unit operates as a low-carbon heat source, when *e.g.* electricity prices are high, so making the use of heat pumps less cost-efficient, and/or when there is need of additional heat capacity to meet the demand.
- **Natural gas boilers** - these units work as peak and backup units. They will run a very limited number of full-load hours during the year, mainly in the hours with the highest peak demand. In this way the investment cost in more CAPEX-intensive technology such as biomass boiler can be reduced significantly. Additionally, the alternative energy source improves the resiliency and reliability of the energy supply.
- **Air-cooled chiller** - this is the peak technology to cover the cooling demand, and therefore will run if the cooling demand is higher than the cooling capacity of the heat recovery chillers.

Between energy-production-and-conversion units and energy demands blocks, two short-term energy storages ("Heat storage" and "Cold storage") work as a buffer between energy supply and energy demand. Their presence allows the system to take advantage of the lower electricity prices on the market, when the electric-drive machines (HRC, GSHP, air-source HP) can run at full capacity covering the demand and charging the storage(s). Later, when the electricity price increases, the stored energy can be discharged to cover the demand, while reducing the output from the energy-production-and-conversion units.

On the left-hand side, two blocks ("PTES charge" and "PTES discharge") are used to model the season water pit thermal energy storage. The charge and discharge process are separated, as a workaround to properly model this technology in EnergyPRO.

The objective of EnergyPRO is to optimize the yearly operation of the energy-production-and-conversion units, so that the energy demands (heating and cooling in this case) are covered at the lowest yearly operation cost. Simplifying, EnergyPRO assigns to each energy-production-and-conversion unit a marginal cost of production in each hour of the year, taking into account relevant external conditions such as ambient temperature (for the air-source HP) and electricity price (for electric-driven machines). The units with the lowest marginal cost of production will be called in operation first. If more production capacity is required to cover demand, units with progressively higher marginal costs of production are called in operation.

The optimization process in EnergyPRO also involves the optimal utilization of the energy storages and technical constraints, such as unavailability periods, minimum duration of operation, etc.

One of the outputs of an EnergyPRO simulation is the hour-by-hour production schedule of the different energy-production-and-conversion units. As an example, the production schedule for Scenario 4C.1 is given in graphical form in Figure 9-5.

It should be noted that the power unit on the y-axis is MW. The legend caption named “Heat Rejection” represents the heat produced by the HRC which charged into the seasonal storage. For both heating and cooling, when the sum of the production from the different energy-production-and-conversion units is higher than the demand, it means that energy is charged into an energy storage. Conversely, if the production is lower than the demand, energy is discharged from the energy storage.

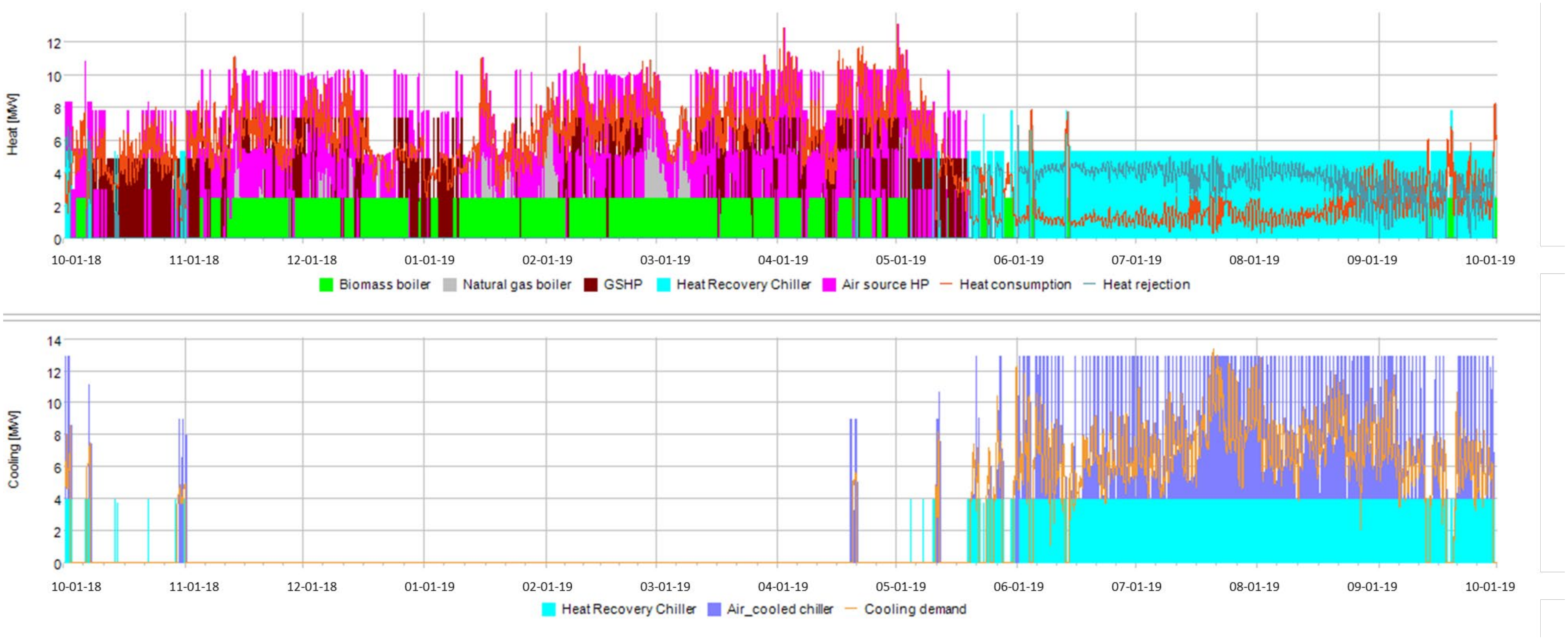


Figure 9-5. Hour-by-Hour Production Schedule of the Different Energy-Production-and-Conversion Units Over One Year in Scenario 4C.1 for Both Heating (Upper Diagram) and Cooling (Lower Diagram) Demand.

9.5.2 Assumptions for Modeling

9.5.2.1 Sizing of Technologies

The final scenarios, as listed in Section 9.3.3, were each modeled.

Under Scenario 4C, two sub-scenarios are considered, identical in terms of technologies and with the only difference being the installed capacity of some of the units. Scenario 4C.1 is developed based on Scenario 4C.0 with the goal of reducing the investment costs. In Scenario 4C.1 the capacity of the HRC/GSHP is reduced. Because the lower capacity of the HRC entails that a lower amount of heat can be recovered in summer, also the size of the PTES can be reduced, so decreasing the investment cost in this seasonal storage technology. To compensate for the reduced capacity of the GSHP, the capacity of the wood chip boiler is increased. To compensate for the reduced capacity of the HRC, the capacity of the air-cooled chiller is increased. The tables below list the installed capacity assumed for the different energy-production and energy-conversion units, as well as for the energy storage technologies, for the different scenarios.

Table 9-4. Installed Capacity of the Energy-Production and Energy-Conversion Technologies in the Different Scenarios

		Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Individual boilers	MMBTU/hr-heat	15.5	0	0	0	0	0
Individual absorption chillers	MMBTU/hr-cool.	39.3	0	0	0	0	0
Individual water-cooled chiller	MMBTU/hr-cool.	10.6	0	0	0	0	0
Individual air-cooled chiller	MMBTU/hr-cool.	1.6	0	0	0	0	0
Individual direct expansion	MMBTU/hr-cool.	2.3	0	0	0	0	0
CUP Boiler 1	MMBTU/hr-heat	6.7	0	0	0	0	0
CUP Boiler 2+3	MMBTU/hr-heat	54.7	0	0	0	0	0
Gas turbine	MW-el	1.6	0	0	0	0	0
Duct burner	MMBTU/hr-heat	15.4	0	0	0	0	0
GSHP	MMBTU/hr-heat	0	23.7	23.7	23.7	23.7	18.9
HRC	MMBTU/hr-cool.	0	17.1	17.1	17.1	17.1	13.6
Wood chip boiler	MMBTU/hr-heat	0	0	0	10.2	6.8	8.5

		Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Centralized gas boiler	MMBTU/hr-heat	0	61.4	61.4	51.2	54.6	52.9
Air-source heat pump	MMBTU/hr-heat	0	0	0	0	10.2	10.2
Air-cooled chiller	MMBTU/hr-cool.	0	44.3	44.3	44.3	44.3	47.7

Table 9-5. Installed Capacity of the Energy Storage Technologies in the Different Scenarios

		Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
BTES	MMBTU/hr	0	22.12	0	0	0	0
PTES	cubic yard	0	0.0	274,670	274,670	274,670	209,272
TTES (cumulated)	cubic yard	0	5,101	5,101	5,101	5,101	5,101

9.5.2.2 Energy Prices

The energy prices listed in Table 9-6 have been assumed. Ramboll worked with CES (UMassD's representative) to estimate future energy prices as well as the general inflation rate. The two escalation rates were very similar and therefore the energy value in today's dollars did not vary much over time.

Table 9-6. Energy Price in 2020-USD

Natural gas	Wood chips	Electricity
USD/MMBTU	USD/MMBTU	USD/MWh-e
$7.0	$9.1	$150.7

The electricity price in Table 9-6 refers to a fixed-price electricity contract as the campus has today. This fixed electricity price is assumed as the value of the electricity produced by the gas turbine (and therefore avoided imported electricity from the grid) in Scenario 0.

In the alternative scenarios, the electric-driven energy-conversion units (heat pumps and chillers) are assumed to be operated based on hourly electricity prices from the day-ahead market. The hourly profile of the assumed electricity price on the day ahead market is shown in the figure below.

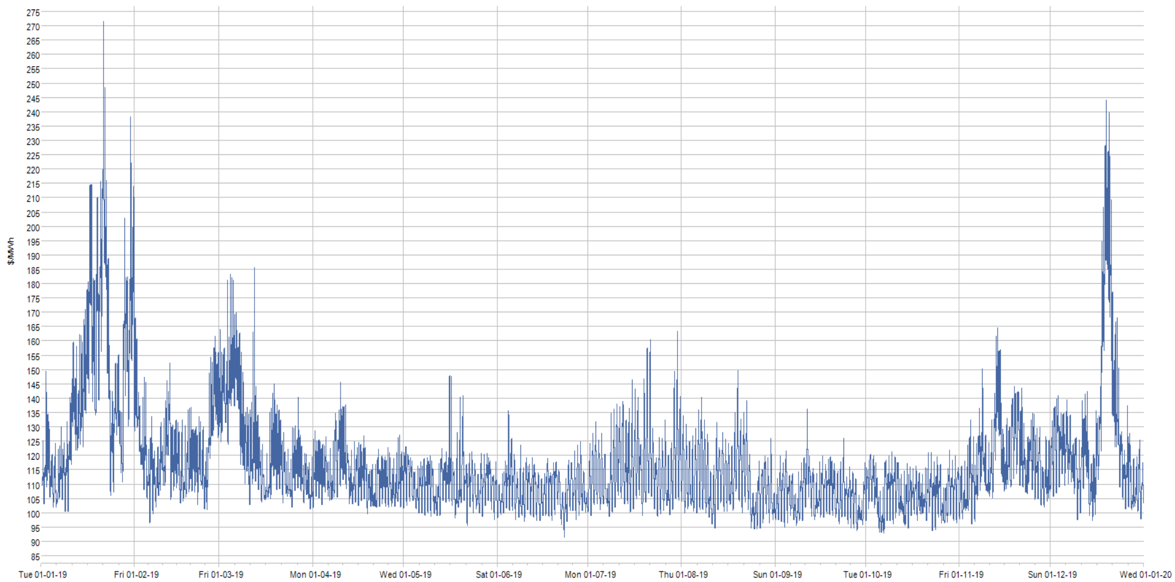


Figure 9-6. Electricity Prices on the Day-ahead Market Assumed in the Modeling

9.5.3 Modeling: Technical Results

Table 9-7 lists the yearly energy production from the main technologies in the different scenarios.

The end-user's heating and cooling demand which is to be covered is the same in all scenarios. However, it is seen that the heat production in Scenario 0 is much higher than the heat production in the alternative scenarios. The main reason for this is that in Scenario 0 the majority of the end-user's cooling demand is covered through absorption chillers which run on steam produced by the Campus' CUP units. Another reason for the larger heat production in Scenario 0 is the higher heat loss characterizing the steam network compared to a new hot water network. The heat losses of the steam network are assumed to be 25% of the yearly heat input into the network, while these are assumed to be 5% for a new hot water network.

Table 9-7. Yearly Energy Demand/Production (in MMBTU) in the Different Scenarios (Year 1)

	Sc. 0	Sc. 3A	Sc. 3B	Sc. 4B	Sc. 4C0	Sc. 4C1
Heating/cooling demand						
End-user's heating demand	131592	131592	131592	131592	131592	131592
End-user's cooling demand	72523	72523	72523	72523	72523	72523
Heat production, MMBTU/y	**Sc. 0**	**Sc. 3A**	**Sc. 3B**	**Sc. 4B**	**Sc. 4C0**	**Sc. 4C1**
Gas CHP + Duct burner + HRSG	204,952	0	0	0	0	0
CUP boilers (1 + 2 + 3)	36,822	0	0	0	0	0
Building-level boilers	36,490	0	0	0	0	0
Biomass boiler	0	0	0	44,097	25,848	34,469
Natural gas boiler	0	59,749	70,854	26,764	13,149	10,813
GSHP	0	57,880	47,988	47,988	47,988	36,721
Heat Recovery Chiller	0	70,944	69,887	69,887	69,134	56,571
Heat rejection (total for site)	0	-49,926	-50,084	-50,084	-50,075	-37,351
ASHP	0	0	0	0	32,613	37,433
Heat Storage Loss (total for site)	0	-132	-130	-137	-141	-142
TOTAL for site	**278,265**	**138,515**	**138,515**	**138,515**	**138,515**	**138,515**
Cooling production MMBTU/y	**Sc. 0**	**Sc. 3A**	**Sc. 3B**	**Sc. 4B**	**Sc. 4C0**	**Sc. 4C1**
Building-level cooling machines	20,752	0	0	0	0	0
Absorption chillers running on CUP's steam	51,771	0	0	0	0	0
Heat Recovery Chiller (baseload)	0	52,753	51,967	51,967	51,407	42,066
Air-cooled chiller (peak)	0	19,769	20,555	20,555	21,115	30,457
Total for site	**72,523**	**72,523**	**72,523**	**72,523**	**72,523**	**72,523**

The main difference between Scenario 3A and 3B is the different technology used for the seasonal storage (BTES in Scenario 3A, PTES in Scenario 3B). The PTES is characterized by higher storage temperatures compared to BTES. On one hand, this entails higher heat losses and therefore a lower amount of heat can be discharged in winter by the GSHP. On the other hand, the GSHP operates with a higher COP. As the amount of heat which is charged into the seasonal storage is roughly the same in Scenario 3A and 3B, the higher heat losses and the higher COP of the GSHP in case of PTES entail that a lower heat output from the GSHP in Scenario 3B compared to Scenario 3A, which is seen in Table 9-7. The lower heat output from the GSHP is compensated by the higher heat output from the gas boilers, which is the only other heat production technology available in winter.

To reduce the use of natural gas and the associated CO_2 emissions, a woodchip boiler is added in 4B compared to Scenario 3B. The impact of this is the partial offset of heat production from the natural gas, which is replaced by biomass. The operation of the GSHP and of the cooling machines is not affected.

It was agreed with UMassD that biofuels could play a smaller role in the project. Therefore, in order to reduce the use of biomass, the Scenarios 4C.0 and 4C.1 introduce air-source heat pump technology as an additional heat production unit. The air-source heat pump not only allows to reduce the use of biomass (in terms of energy use), but it also allows to reduce the installed capacity of the wood chips boiler, so saving on its investment cost. The heat output from the air-source heat pump in Scenario 4C.0 allows to offset both natural gas and biomass use compared to Scenario 4B, while the operation of the GSHP and of the cooling machines is not affected.

In Scenario 4C.1 the smaller size of the HRC/GSHP+PTES system entails that the lower heat output from the GSHP must be compensate by additional production from other units, namely the air-source HP and the wood chips boiler. Therefore, the use of biomass in Scenario 4C.1 is higher than in Scenario 4C.0, but still lower than in Scenario 4B. However, the use of natural gas still decreases in Scenario 4C.1 compared to Scenario 4C.0.

The downsizing of the HRC/GSHP also affects the cooling production, as more cooling needs now to be produced by the air-cooled chillers.

9.5.4 Modeling: Economic Results

Table 9-8 gives an overview of the economic performance of the different scenarios in terms of project net present value (NPV) over the project lifetime. The NPV is utilized in order to level the costs across the scenarios because some assets have different expected lifetimes than others and using the NPV method it offers a comparison between the options despite different expected life of the assets.

Table 9-8. Economic Overview of the Different Scenarios: NPV of the Overall System Cost Over the Project Lifetime in 2020-MUSD

		Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Fuel	Fuel/electricity costs for energy use	43.7	24.1	22.0	23.5	24.9	25.4
	Electricity cost for non-energy use	57.0	57.0	57.0	57.0	57.0	57.0
	Saved electricity from self-production	-21.3	0.0	0.0	0.0	0.0	0.0
CAPEX	Production units and storage	9.5	52.2	50.6	52.7	56.0	52.4
	DH&C networks	0.0	14.8	14.8	14.8	14.8	14.8
	Energy transfer stations	0.0	2.2	2.2	2.2	2.2	2.2
	New building for extended boiler	0.5	0.0	0.0	0.0	0.0	0.0
	Total CAPEX	*9.9*	*69.2*	*67.6*	*69.7*	*73.0*	*69.4*
Residual value	Production units and storage	-3.4	-6.7	-3.3	-3.6	-3.8	-3.8
	DH&C networks	0.0	-3.7	-3.7	-3.7	-3.7	-3.7
	Energy transfer stations	0.0	-0.4	-0.4	-0.4	-0.4	-0.4
	New building for extended boiler	-0.2	0.0	0.0	0.0	0.0	0.0
O&M	Production units	14.5	11.1	11.0	12.7	12.5	12.6
	DH&C networks	0.0	0.9	0.9	0.9	0.9	0.9
	Steam network	2.0	0.0	0.0	0.0	0.0	0.0
Total		**102**	**151**	**151**	**156**	**160**	**157**

It is seen that Scenario 0 is the scenario which has the lowest NPV of the overall system cost. In fact, unlike the alternative scenarios, Scenario 0 does not entail a complete change in the energy system. Capital expenditures mainly relate to the maintenance of existing assets, or to the replacement of fossil-fuel fired units with new fossil-fuel fired units, which are generally characterized by lower specific investment costs compared to greened and more modern technologies such as heat pumps or biomass boilers. The breakdown of the CAPEX expenditures in the different scenario is given in Table 9-9.

Table 9-9. Breakdown of CAPEX (in Terms of NPV, in 2020-MUSD) for the Different Scenarios

	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Individual boilers	0.14	0.00	0.00	0.00	0.00	0.00
Indiv. absorpt. chillers	2.60	0.00	0.00	0.00	0.00	0.00
Indiv. water-c. chiller	2.16	0.00	0.00	0.00	0.00	0.00
Indiv. air-c. chiller	0.23	0.00	0.00	0.00	0.00	0.00
Indiv. direct expansion	0.34	0.00	0.00	0.00	0.00	0.00
CUP Boiler 1	1.08	0.00	0.00	0.00	0.00	0.00
CUP Boiler 2+3	2.16	0.00	0.00	0.00	0.00	0.00
GT	0.74	0.00	0.00	0.00	0.00	0.00
Duct burner	0.00	0.00	0.00	0.00	0.00	0.00
GSHP	0.00	9.17	9.17	9.17	9.17	7.33
HRC	0.00	0.00	0.00	0.00	0.00	0.00
Wood chip boiler	0.00	0.00	0.00	2.31	1.54	1.93
Centralized gas boiler	0.00	1.26	1.26	1.05	1.12	1.09
Air-source heat pump	0.00	0.00	0.00	0.00	4.05	4.05
Air-c. chiller	0.00	22.56	22.56	22.56	22.56	24.30
BTES	0.00	18.02	0.00	0.00	0.00	0.00
PTES	0.00	0.00	16.42	16.42	16.42	12.51
TTES	0.00	1.17	1.17	1.17	1.17	1.17
DH network	0.00	7.96	7.96	7.96	7.96	7.96
DC network	0.00	6.89	6.89	6.89	6.89	6.89
Energy transfer stations	0.00	2.16	2.16	2.16	2.16	2.16
New building for extended boiler	0.47	0.00	0.00	0.00	0.00	0.00
Total	**9.9**	**69.2**	**67.6**	**69.7**	**73.0**	**69.4**

Another reason for the lower cost's NPV in Scenario 0 is the quite significant income (or better, saved expense) coming from the consumption of self-produced electricity from the gas turbine (see Table 9-8).

The wide use of natural gas in Scenario 0 - for steam production for both heating and cooling supply, as well as for electricity generation - makes this Scenario quite intensive in terms of energy costs compared to the alternative scenarios, as shown in Table 9-10.

Table 9-10. Breakdown of Fuel Costs (in Terms of NPV, in 2020-MUSD) in the Different Scenarios

	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Individual boilers	4.8	0.0	0.0	0.0	0.0	0.0
Indiv. absorpt. chillers	0.0	0.0	0.0	0.0	0.0	0.0
Indiv. water-c. chiller	2.4	0.0	0.0	0.0	0.0	0.0
Indiv. air-c. chiller	0.4	0.0	0.0	0.0	0.0	0.0
Indiv. direct expansion	0.6	0.0	0.0	0.0	0.0	0.0
CUP Boiler 1	2.4	0.0	0.0	0.0	0.0	0.0
CUP Boiler 2+3	2.4	0.0	0.0	0.0	0.0	0.0
GT	18.0	0.0	0.0	0.0	0.0	0.0
Duct burner	12.6	0.0	0.0	0.0	0.0	0.0
GSHP	0.0	7.2	3.8	3.8	3.8	2.9
HRC	0.0	8.2	8.1	8.1	8.0	6.6
Wood chip boiler	0.0	0.0	0.0	6.2	3.6	4.8
Centralized gas boiler	0.0	6.3	7.5	2.8	1.4	1.1
Air-source heat pump	0.0	0.0	0.0	0.0	5.4	6.1
Air-c. chiller	0.0	2.5	2.6	2.6	2.6	3.8
Total	**43.7**	**24.1**	**22.0**	**23.5**	**24.9**	**25.4**

Table 9-11 presents the capital costs for each scenario without discounting them through the net present value method.

Table 9-11. Sum of Capital Costs in 2020-USD (not NPV)

	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0
CAPEX	12.2	69.2	67.6	69.7	73.0

9.5.5 Modeling: Environmental Results

Figure 9-7 shows the CO_2-eq emissions for the different scenarios together with the project NPV.

It can be seen that all alternative scenarios reach a strong reduction in CO_2-eq emissions compared to Scenario 0. This is due to:

- The strong reduction in the share of natural gas use to the overall energy production in the alternative scenarios, especially in the different variants of Scenario 4.
- The progressive decarbonization of the grid electricity over time, which entails a lower environmental impact of the alternative scenarios, which are all based on electrification of the energy supply (although with different extents from scenario to scenario).

By comparing the NPV of the overall costs and the CO_2-eq emissions in the different scenarios as shown in Figure 9-7, it is seen that lower CO_2-eq emissions are usually associated to a higher NPV of costs. This is mainly due to the fact that natural gas is simultaneously characterized by a low energy price and high carbon intensity.

Several conclusions can be drawing from these results.

1. The difference between Scenario 3A and 3B is that 3A includes BTES while 3B includes PTES. The NPV of the two scenarios is statistically the same with a 1% difference between them while Scenario 3A has 15% less CO_2 emissions. The comparison of these two scenarios allows the conclusion that BTES is preferred to PTES. BTES is also a more establish technology in the US with a few projects completed. For these reasons, BTES was selected as the preferred seasonal storage technology.
2. Scenario 4C.1 offers the most cost-effective approach in achieving a substantial CO_2 emission reduction. For this reason, the combination of HRC/GSHP and ASHP/air chillers are selected for the preferred solution.
3. Each of the options, as presented, fall short of the carbon neutrality that is sought and as a result, fuel switching will be required to further reduce the emissions. Fuel switching will come in the form of a power purchase agreement from renewable electricity and a biofuel with no emission factor. The project gave consideration to renewable natural gas and bio diesel and chose to base the project on the use of bio diesel as renewable natural gas is not currently available at the site and bio diesel is available. It is recommended that the market availability be reconsidered at the time of implementation given that each market is expected to have substantial growth in the coming years.

The breakdown of the CO_2-eq emissions, both in terms of fuel and technology, is given in Table 9-12, Table 9-13 and Table 9-14 below, for the first and last year of the project period.

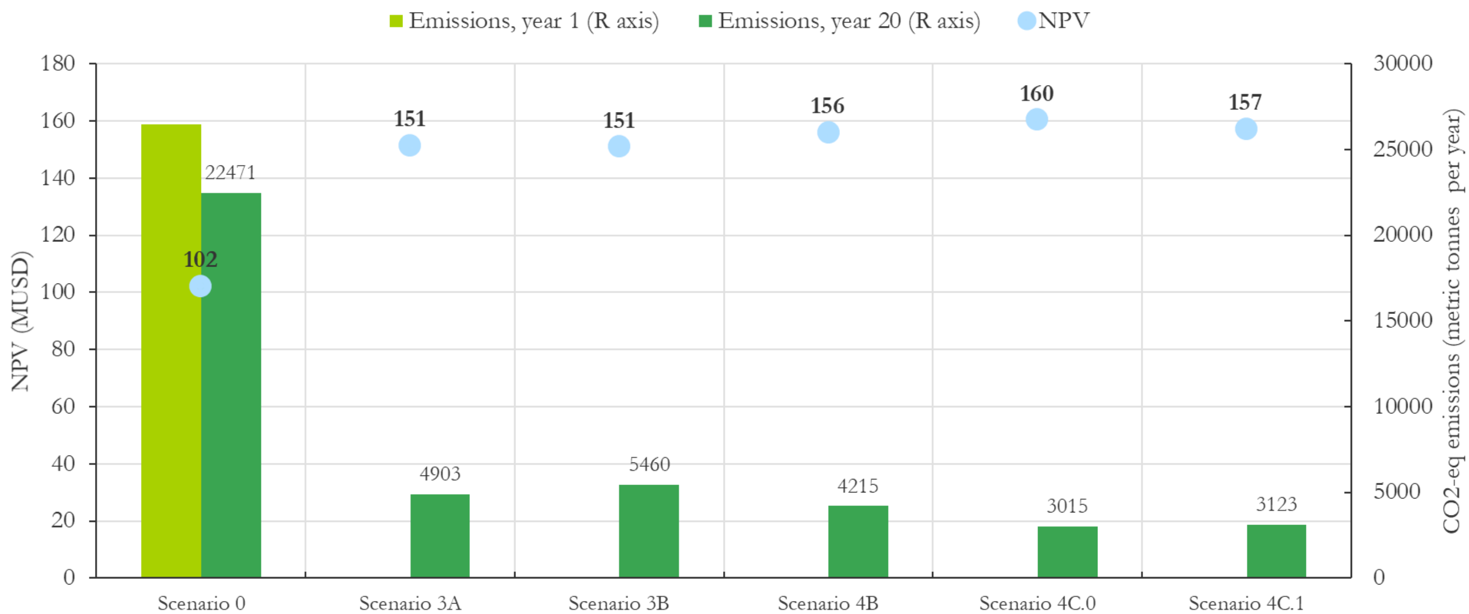


Figure 9-7. CO_2-eq Emissions and Project NPV for the Different Scenarios

Table 9-12. CO_2-eq Emissions (in Metric Tons) Broken Down by Energy Source in the First and Last Year of the Project Period

CO2-eq by fuel (year 1)	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Natural gas	22017	3439	4078	1540	757	622
Wood chips	0	0	0	1293	758	1011
Electricity	4442	9268	8743	8743	9498	9427
Total	**26458**	**12707**	**12821**	**11576**	**11013**	**11060**
CO2-eq by fuel (year 20)						
Natural gas	21769	3439	4078	1540	757	622
Wood chips	0	0	0	1293	758	1011
Electricity	702	1464	1381	1381	1501	1490
Total	**22471**	**4903**	**5460**	**4215**	**3015**	**3123**

Table 9-13. CO_2-eq Emissions (in Metric Tons) Broken Down by Energy Source in the First Year of the Project Period

Technology	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Individual boilers	2604	0	0	0	0	0
Indiv. absorpt. chillers	0	0	0	0	0	0
Indiv. water-c. chiller	276	0	0	0	0	0
Indiv. air-c. chiller	50	0	0	0	0	0
Indiv. direct expansion	70	0	0	0	0	0
CUP Boiler 1	1298	0	0	0	0	0
CUP Boiler 2+3	1413	0	0	0	0	0
GT	9840	0	0	0	0	0
Duct burner	6861	0	0	0	0	0

Technology	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
GSHP	0	1138	616	616	616	471
HRC	0	1277	1258	1258	1244	1018
Wood chip boiler	0	0	0	1293	758	1011
Centralized gas boiler	0	3439	4078	1540	757	622
Air-source heat pump	0	0	0	0	758	870
Air-c. chiller	0	396	412	412	423	611
Net electricity import from grid	4046	6457	6457	6457	6457	6457
Total	**26458**	**12707**	**12821**	**11576**	**11013**	**11060**

Table 9-14. CO_2-eq Emissions (in Metric Tons) Broken Down by Energy Source in the Last Year of the Project Period

Technology	Scenario 0	Scenario 3A	Scenario 3B	Scenario 4B	Scenario 4C.0	Scenario 4C.1
Individual boilers	2604	0	0	0	0	0
Indiv. absorpt. chillers	0	0	0	0	0	0
Indiv. water-c. chiller	44	0	0	0	0	0
Indiv. air-c. chiller	8	0	0	0	0	0
Indiv. direct expansion	11	0	0	0	0	0
CUP Boiler 1	1298	0	0	0	0	0
CUP Boiler 2+3	1166	0	0	0	0	0
GT	9840	0	0	0	0	0
Duct burner	6861	0	0	0	0	0
GSHP	0	180	97	97	97	74
HRC	0	202	199	199	197	161
Wood chip boiler	0	0	0	1293	758	1011
Centralized gas boiler	0	3439	4078	1540	757	622
Air-source heat pump	0	0	0	0	120	137
Air-c. chiller	0	63	65	65	67	96
Net electricity import from grid	639	1020	1020	1020	1020	1020
Total	**22471**	**4903**	**5460**	**4215**	**3015**	**3123**

The results from the EnergyPRO simulations and the economic analysis were discussed with UMassD, identifying pros and cons of each scenarios, cost and environmental performance, risks and resiliency issues.

Based on these discussions, the selected scenario was developed based on the conclusions stated above. The selected scenario is based on Scenario 4C.1 presented in the previous sections, but it differs from it in the following items:

- BTES is preferred to a PTES as a seasonal thermal energy storage;

- in order to further reduce the CO_2 emissions associated to heat production, natural gas boilers and biomass boilers are replaced by bio diesel boilers;
- the backup air-chillers are assumed to be the same machines as the ASHP. This allows to increase the available ASHP installed capacity without additional investment costs.

9.6 The Selected Scenario

9.6.1 Scenario Overview

The selected scenario was further developed by selecting the quantity and size of the central utility assets and dispersing the assets across implementation phases. The following sections discuss the sizing of each component in detail.

Bio Diesel Tank – The bio diesel tank is intended to be one or two tanks that will have secondary containment. The size of the tank is anticipated to be approximately 30,000 gallons. UMassD stated that they desire 5-7 days of fuel reserves in the event of an electrical interruption. Based on that desire, we have assumed that 6 days of bio diesel would be required on site.

The future total heat demand curve shows a peak load of approximately 45 MMBtu/hr of heat demand and an average daily demand during the heating season is approximately 25 MMBtu/hr based on the hourly demand curve. The following equation was the calculation which estimated the storage capacity.

$$Storage\ Capacity\ = \frac{25\frac{MMBtu}{hr} \times 6\ days\ \times 24\frac{hrs}{day} \times 1{,}000{,}000\frac{Btu}{MMBtu}}{118{,}000\frac{Btu}{gallon}}$$

$$Storage\ Capacity\ = 30{,}508\ Gallons$$

Equation 1. Fuel Storage Capacity Calculation

Boilers – The three boilers are expected to be dual fuel with natural gas and bio diesel both being available. The boiler sizes and quantities were selected to match the existing boiler arrangement that UMassD is accustomed to. It is expected that the boilers would provide N+1 redundancy and also provide two fuel backups to the campus. After the full build out, electricity would serve as the primary heating source, bio diesel would serve as the backup/peaking fuel, and natural gas would serve as the second backup/emergency fuel.

Heat Pumps – The EnergyPro model identified the capacity required for the HRC/GSHP systems as well as the ASHP system. Based on experience, Ramboll anticipates that the HRC and the GSHP heat pumps will be the same heat pumps with only the heat rejection method determining the type of use arrangement.

The ASHP system will also have the capability to operate as a chiller system during the summer months as the heat pump can reverse its cycle and operate as a chiller. It is anticipated that there will be two HRC/GSHP systems and two ASHP systems with associated air coolers. Two of each were chosen to reduce the special constraints while also providing diversity during maintenance events or unplanned outages. The EnergyPro model included the agreed upon redundancy coverage which are inherent to the system.

The four 750-ton air cooled chillers were provided to meet the total system capability while also keeping the units small enough so that pre-engineered units could be utilized, and custom unit costing could be avoided.

TTES – One large storage tank is anticipated for the heating system and one large storage tank is anticipated for the cooling system. It is quite common to have one large tank per system as this reduces the complexity of operations and provides economies of scale for the tank buildout. The size of the tank was determined from the EnergyPro model. A detailed cost/benefit analysis was not performed for the TTES as it is recommended for each district energy system that Ramboll designs. Its relatively low cost provides flexibility and a more reliable and resilient system while easing operational concerns. TTES allows for short term interruptions to be undetectable to the performance of the system and allows equipment to be run at more favourable efficiency operating points.

Distribution Systems – The selected scenario includes the addition of a low temperature hot water distribution system and a chilled water distribution system. The layout of these distribution systems can be seen in Section 9.4 of this report. The distribution systems would be required to be installed prior to central assets which would distribute the energy via these systems so naturally the distribution systems would be required early in the implementation of the project. The process flow diagram in Section 9.6.2 shows how the distribution system interacts with the other production and storage technologies.

Building Modifications – The selected scenario takes into account the building level modifications that will be required in order to convert the campus to the selected scenario. Such modifications include removing any direct steam use devise and replacement with a hot water device or (in some cases) providing a local steam generator. Many steam to hot water heat exchangers will be required to be replaced with water-to-water heat exchangers. For the chilled water network, the distributed steam absorption chillers will be removed and connected to the chilled water distribution system using a plate and frame heat exchanger.

Ground Arrays – The four ground arrays for BTES and geothermal systems were chosen due to special constraints. Approximately 25 acres of BTES is required and the four array locations were chosen to limit the removal of forests while utilizing either green space or parking lots that were in close proximity to the NetZero Plant. The four BTES fields shown in Figure 9-13 add up to the required 25 acre area required for each of the 1,125 boreholes that would each be dug to a depth of 333 ft (100 m).

As part of the next steps for this project, a test boring is recommended to further refine the ground conditions, thermal storage potential, and heat transfer potential. This study assumed closed loop, U-bend piping with grout. The included schedule and estimate provide more detail on assumed construction durations and work rates which could also be refined based on the test boring. The ground arrays are anticipated to be completely sub-surface and while the space could still be used for green space and parking lots, some limitations would apply in the event of a pipe leak which would require isolation.

Energy Sourcing – The future heating and cooling loads will be satisfied in different ways as a result of the selected solution. The following pie charts show the current and future pie charts for how energy loads will be satisfied given the current and future percentages.

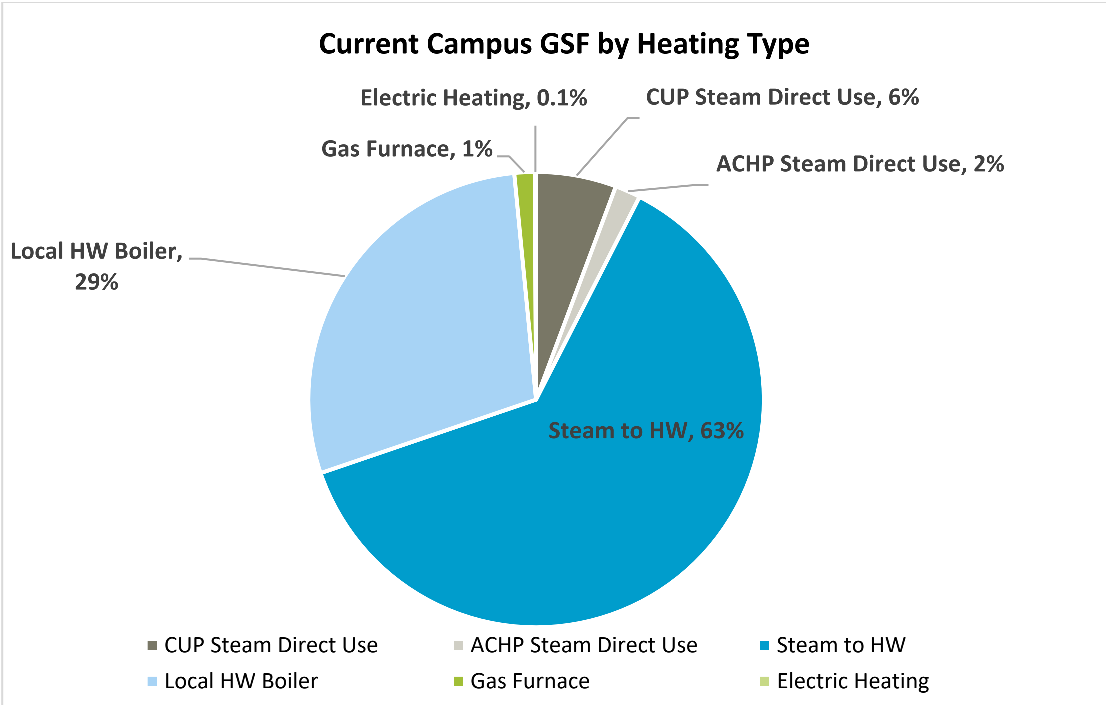


Figure 9-8. Current Percent of Campus GSF by Heating Type

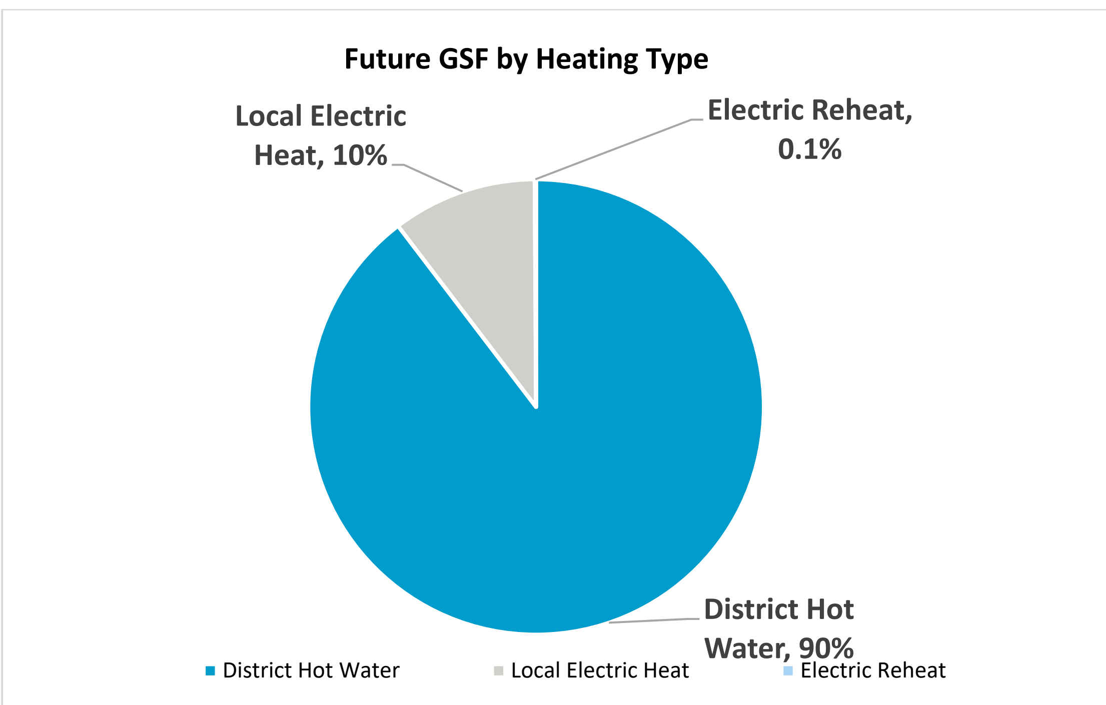


Figure 9-9. Future Percent of Campus GSF by Heating Type

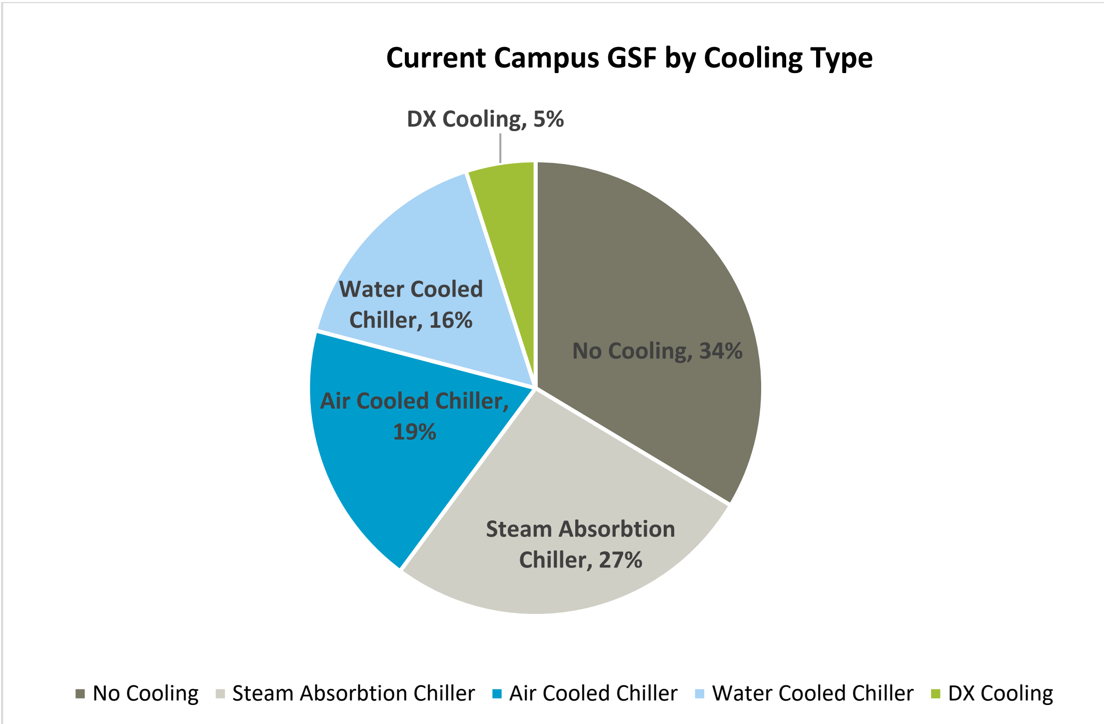


Figure 9-10. Current Percent of Campus GSF by Cooling Type

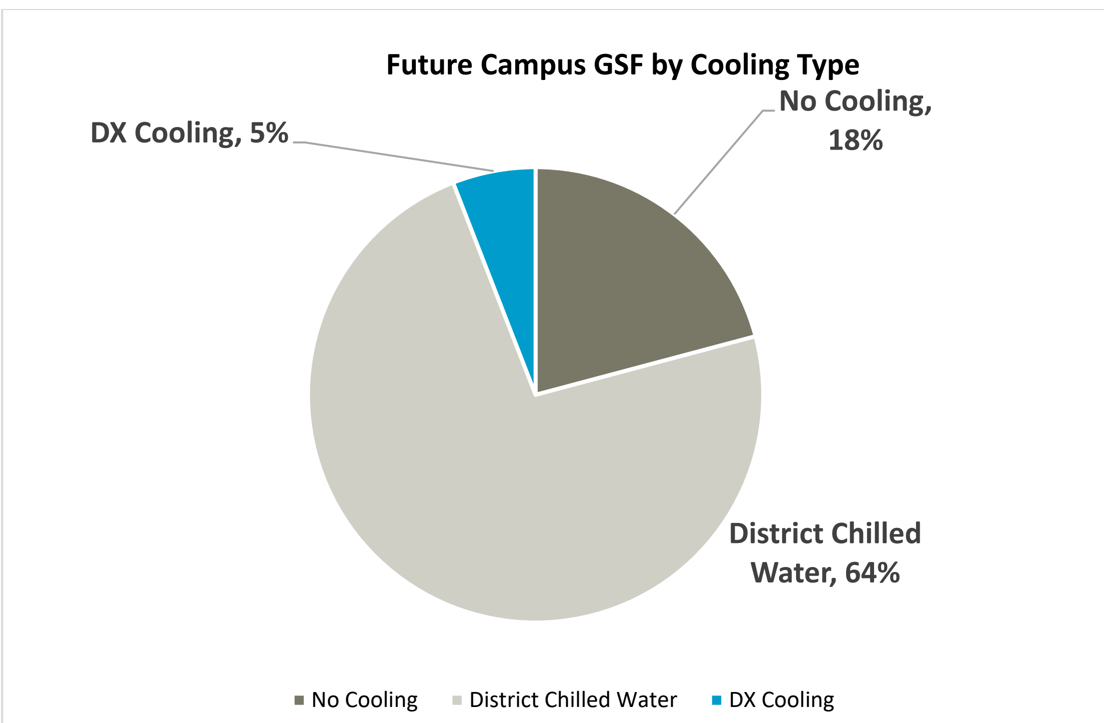


Figure 9-11. Future Percent of Campus GSF by Cooling Type

Distribution Pumps – Both the hot water network and the chilled water network are anticipated to have five distribution pumps. There would be 4x 25% capacity pumps with the fifth pump serving as a redundant unit. The capacity of the pumping system was calculated during the Termis modelling phase of the project.

Resiliency Considerations – The selected scenario provides several levels of resiliency considering that multiple technologies and fuels are provided which can provide heating to the campus. Each technology has sufficient capacity such than any one asset or fuel source could be compromised, and the campus load can be met. This provides the required N+1 redundancy and in many cases multiple failures could occur and the campus load could still be met. The distribution pumps for the campus were also selected to provide the N+1 level of redundancy. Standby generators have been included in the selected scenario such that four 1-MW diesel generators could provide enough power to run the bio-oil boilers and the distribution pumps in order to keep the campus warm in the event of a prolonged electrical outage which could occur when the ambient temperature is below 32°F. The standby generators would also provide the ability to "black start" the NetZero plant in the event of a grid electrical failure.

Phasing – The project is anticipated to be implemented in three phases which are described below.

- **Phase 1 – Enabling and Centralization** – This phase introduces the low temperature hot water and chilled water districts along with the first phase of heat pumps, an energy transfer station, and two tank thermal energy storage (TTES) systems. During this phase some of the existing generating assets will continue to be utilized on natural gas.
- **Phase 2 – Earnest Shift from Fossil Fuels to Electrification** – This phase introduces the full build out of heat pumps along with the seasonal storage of bore hole thermal energy storage (BTES). This phase will retire the steam distribution network and utilize heat pumps as the primary energy source. Limited combustion of fossil fuels will still be utilized and traditional electrical procurement practices will continue.
- **Phase 3 – Alternate Fuel Sourcing for Full Carbon Neutrality** – This phase will achieve 100% carbon neutrality through procurement of carbon neutral fuels which could include, electricity, renewable natural gas or bio diesel, as well as carbon offsets if needed for economic optimization.

Figure 9-12, Figure 9-13, Figure 9-14, and Figure 9-15 present the phased process flow diagram (PFD), the campus spatial arrangement, the NetZero plant general arrangement, and the NetZero plant floor plan that were created in order to support the cost estimate for the project. Each of these documents are pre-schematic in nature and are intended to support the cost estimate and serve as the basis of the estimate for this project. It is recognized that this project does not include design, and this represents "a way" to implement the selected solution. Much more design is required before the campus would be ready to proceed with implementation of this project.

Prior to the implementation of these phases, it is recognized that UMassD will have to continue to replace failing equipment and building mechanical equipment. Since this project anticipated the transfer to a low temperature hot water district and a chilled water district, the replacements are recommended to align with that plan. Luckily, UMassD already utilizes hot water and chilled water distribution systems within the majority of their buildings. This study includes the costs of replacing the direct steam use equipment, but a guiding principal for any maintenance from now until the implementation of this project will be to enable the removal of the steam system and utilized 180

9.6.2 Process Flow Diagram

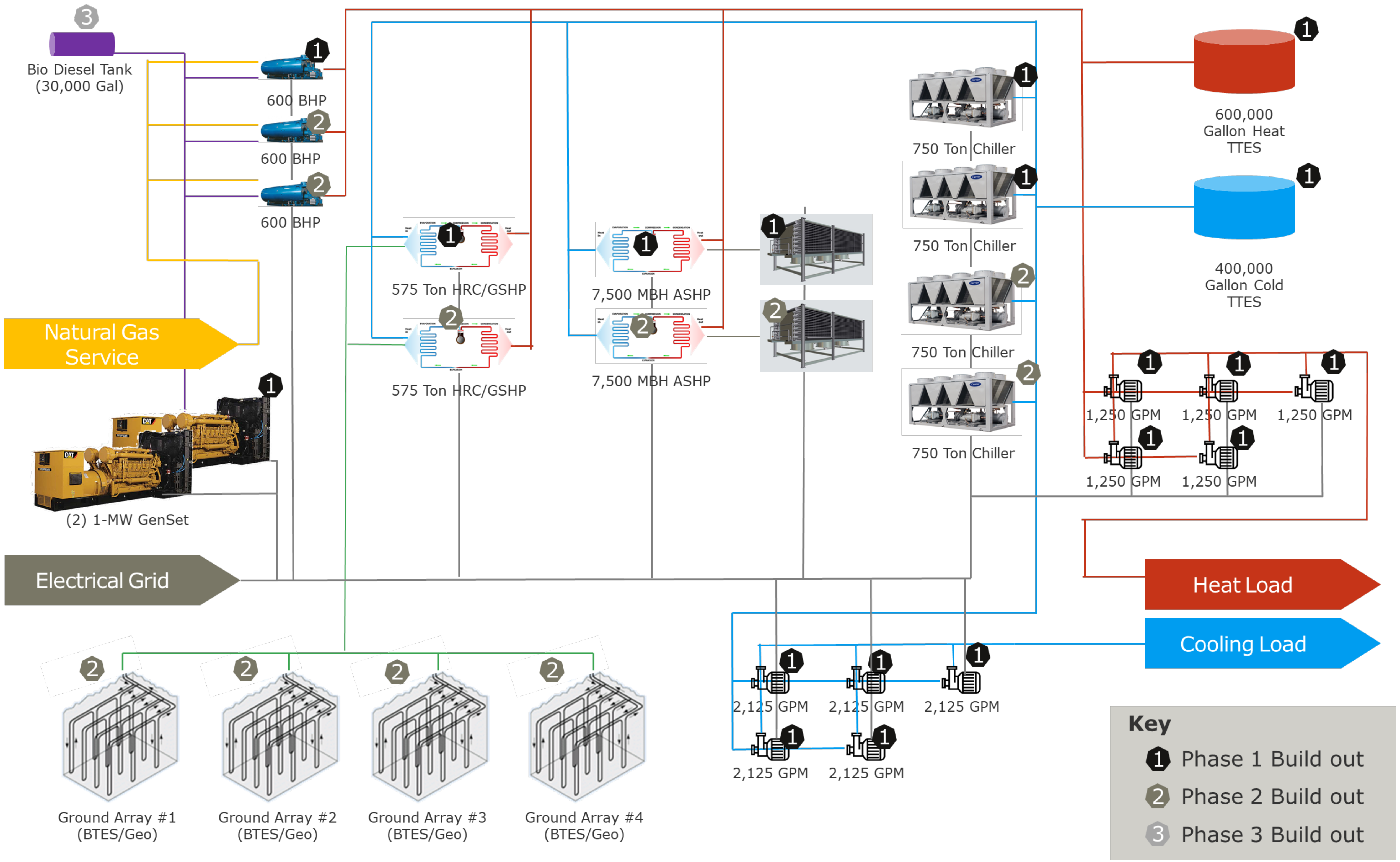


Figure 9-12. Process Flow Diagram for the Selected Scenario

9.6.3 Campus Spatial Layout

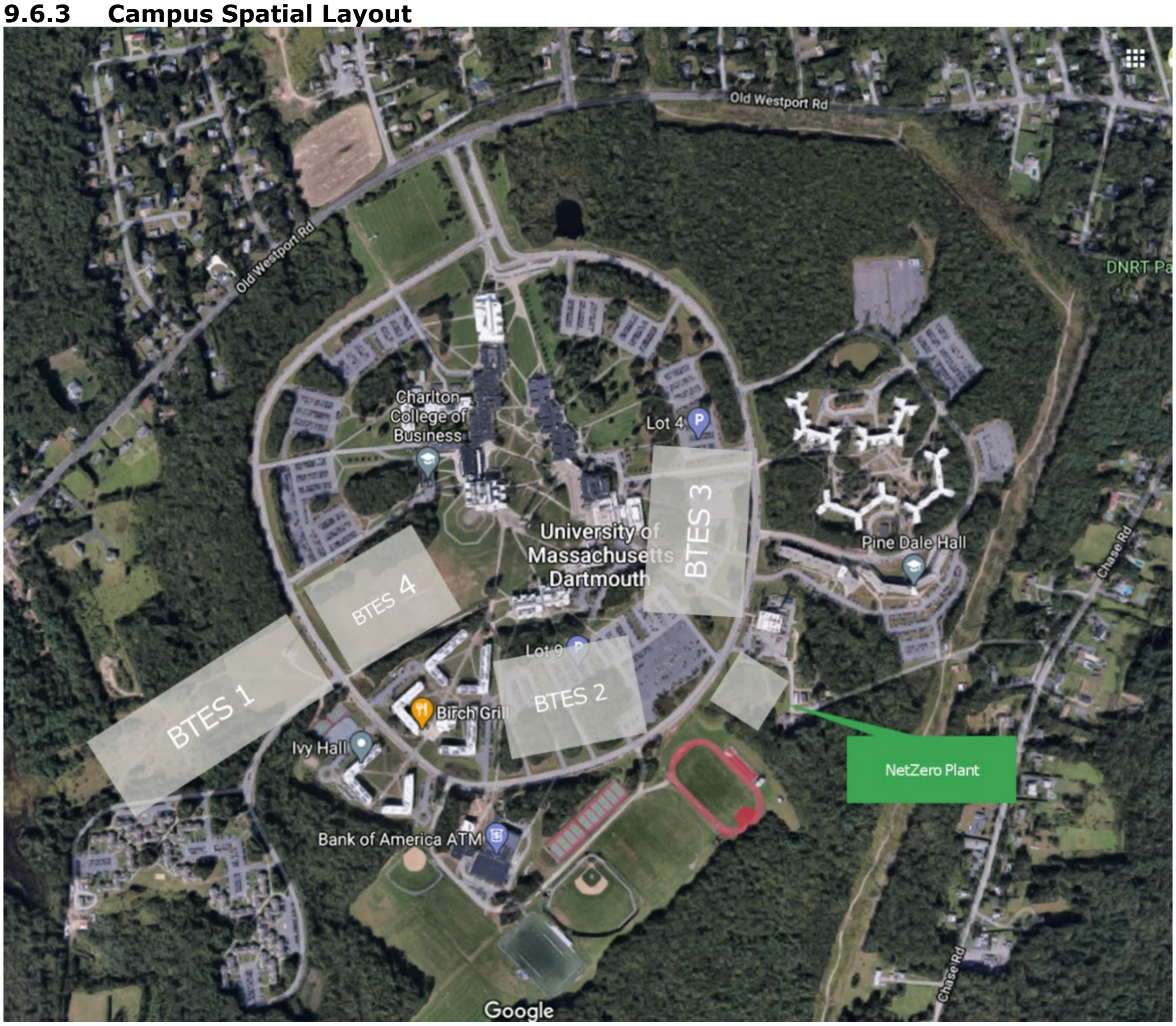


Figure 9-13. Campus Spatial Arrangement for the Selected Scenario

9.6.4 NetZero Plan Spatial Layout

Figure 9-14. NetZero Plant General Arrangement for Selected Scenario

9.6.5 NetZero Floor Plan

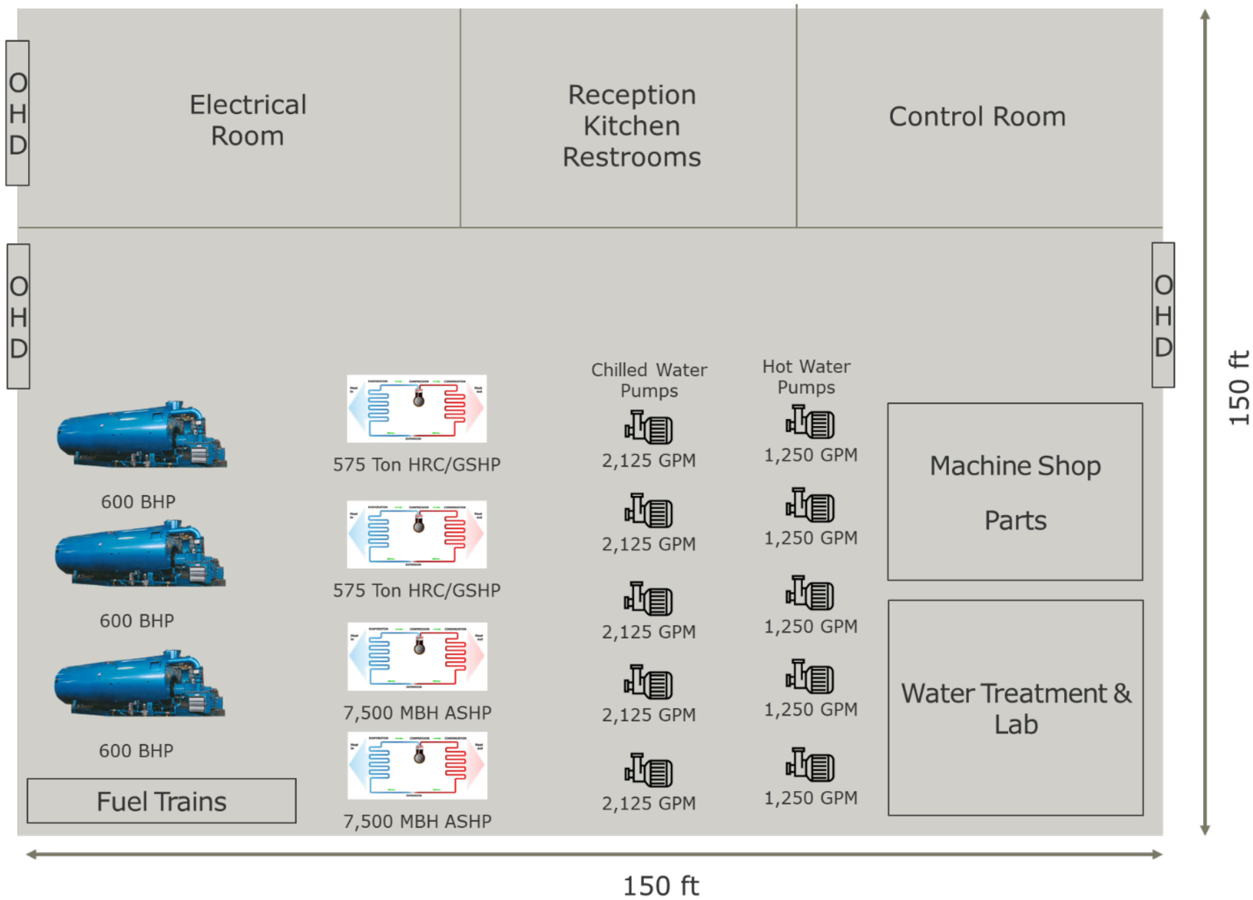


Figure 9-15. NetZero Plant Floor Plan for the Selected Scenario

9.6.6 NetZero Plant 1-Line Diagram

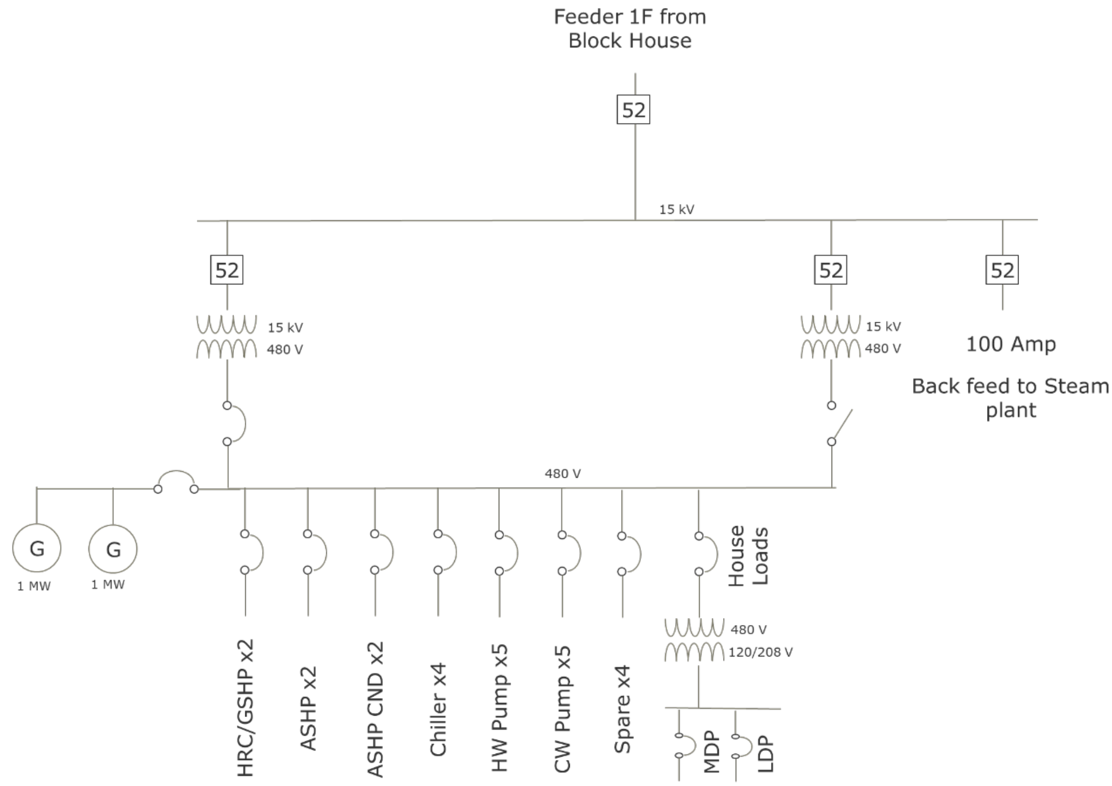


Figure 9-16. NetZero Plant 1-Line Diagram

10. GHG EMISSIONS OF SELECTED SCENARIO

The EnergyPro model that was developed during the selection process was modified to reflect each phase of the build out in order to understand how each piece of equipment would operate in order to meet the demand. By running the model for each phase we are able to estimate how much fuel will be used by each production asset and then estimate the cost for each as well as the GHG emissions by phase.

The current GHG estimate is 21,013 metric tons of CO_2 which was presented in Section 6.2.7. and Figure 10-5 presents the GHG estimates for Phase 1, Phase 2, and Phase 3. The GHG calculations take into account the projections for future emission factors of electricity from the grid and Phase 3 incorporates the campus using renewable electricity.

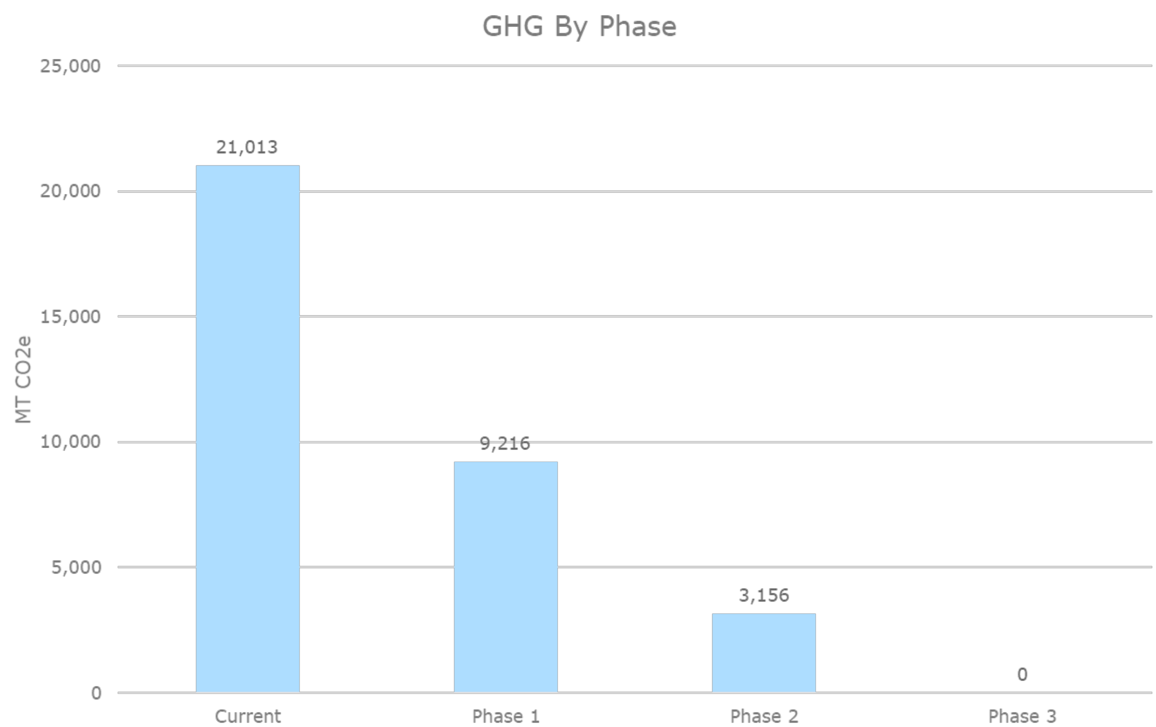


Figure 10-1. GHG Estimates by Phase

During Phase 1 there will be some new equipment while some of the legacy equipment will also be utilized. Since seasonal storage will not be available, all loads will have to be met in real time or through short term energy storage via the tank thermal energy storage. During this phase prioritization will be given to the heat recovery chiller as the first asset to produce chilled water and hot water simultaneously. During appropriate weather conditions the air source heat pump will be the next asset to produce heating. The gas turbine will be the next asset to be prioritized and then the centralized gas boilers will provide the remainder of the load. The air source heat pumps can also provide chilled water and will be the second asset to be called for. Individual building chillers will also be utilized to provide the remaining chilled water demand.

Table 10-1. Phase 1 - 2040 Emission Summary

		Fuel	CO2-eq (kg/MWh-f)	CO2-eq (ton/year)
HRC	MWh-el	Electricity	54.36	122
Centralized gas boiler	MWh-f	Natural gas	182.5	1,306
Air-source heat pump	MWh-el	Electricity	54.36	184
Air-c. chiller	MWh-el	Electricity	54.36	212
GT+HRSG	MWh-f	Natural gas	182.5	5,910
Individual water-cooled chillers	MWh-el	Electricity	54.36	15
Campus Electricity	MWh-e	Electricity	54.36	1,467
			TOTAL per year	**9,216**

During Phase 2 the NetZero plant will be completely built along with the bore hole thermal energy storage (BTES) which will provide the seasonal storage. During this phase the electricity will still have an emission factor and natural gas will be utilized in the centralized hot water boilers. All legacy assets will be retired at the end of Phase 2 so the gas turbine will no longer be available.

Table 10-2. Phase 2 - 2040 Emission Summary

Fuel consumption per year		Fuel	CO2-eq (kg/MWh-f)	CO2-eq (ton/year)
GSHP	MWh-el	Electricity	50.80	181
HRC	MWh-el	Electricity	50.80	215
Centralized gas boiler	MWh-f	Natural gas	182.5	968
Air-source heat pump	MWh-el	Electricity	50.80	291
Air-c. chiller	MWh-el	Electricity	50.80	130
Campus Electricity	MWh-e	Electricity	50.80	1,371
			TOTAL per year	**3,156**

During Phase 3 the switch to renewable fuel sources will have occurred so B100 bio diesel will be utilized in the boilers and renewable electricity will either be procured or generated on site to ensure that there is not an emission factor associated with the use of electricity.

Table 10-3. Phase 3 - 2040 Emission Summary

Fuel consumption per year		Fuel	CO2-eq (kg/MWh-f)	CO2-eq (ton/year)
GSHP	MWh-el	Electricity	0.00	0
HRC	MWh-el	Electricity	0.00	0
Bio oil boiler	MWh-f	Bio oil	0.00	0
Air-source heat pump	MWh-el	Electricity	0.00	0
Air-c. chiller	MWh-el	Electricity	0.00	0
Campus Electricity	MWh-e	Electricity	0.00	0
			TOTAL per year	**0**

It can be seen that carbon neutrality will be achieved at the completion of Phase 3.

The GHG projections were compared back to the EO484 goals that they are mandated to achieve. It is recalled that UMassD has elected to accelerate their commitment to carbon neutrality and this project was charged with identifying a path to carbon neutrality by 2040 and a possible way to accelerate that even further to 2030. See Section 10.1.2 for the accelerated approach.

Figure 10-6 shows the realized GHG emissions from 2003 until today, the projected emissions based on the findings of this plan along a standard construction schedule, an accelerated schedule, and the EO 484 goals mandated upon UMassD. The campus achieved a 28% reduction in GHG emissions in 2020 over the baseline but fell short of the 40% reduction goal. The graph shows that the campus will be ahead of the EO 484 mandate after the completion of Phase 1 and will remain below the mandate until carbon neutrality is achieved in 2040 according to the projected project schedule, but could also achieve carbon neutrality by 2030 if the accelerated project schedule is used.

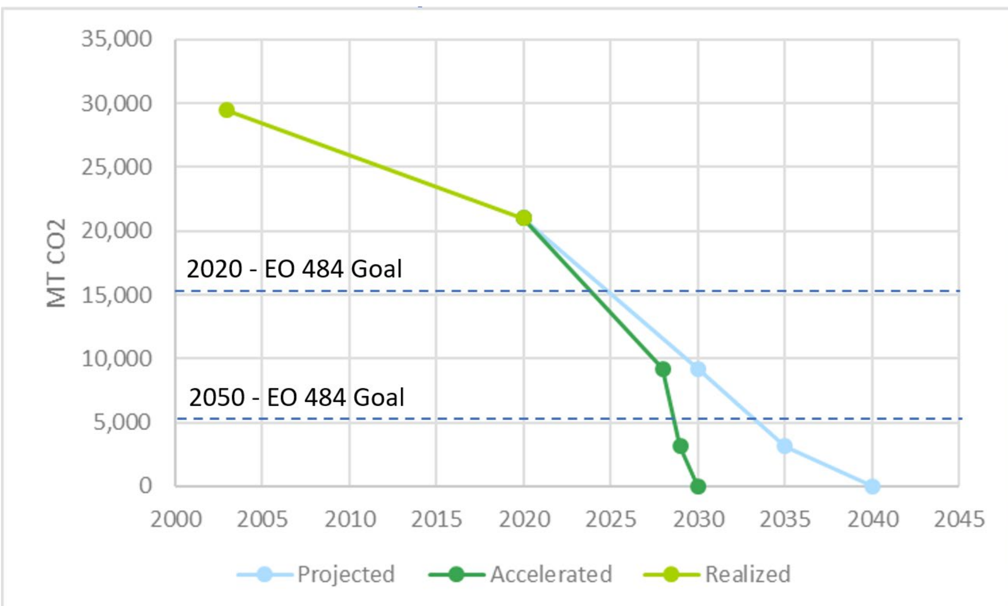


Figure 10-2. GHG Projection vs EO 484 Goals

Ramboll worked closely with CES to understand the amount of supplemental RECs that would be required to achieve carbon neutral electricity by 2030 if the project continued along the projected schedule shown above. Exhibit C of this report includes a detailed approach for CES's analysis and calculations to determining the quantity and price of supplemental renewable energy credits (RECs) which are anticipated. The renewable portfolio standard for ISO New England requires the utility to purchase RECs in order to reduce the emissions of electrical generation so the supplemental RECs are what UMassD would purchase in order to offset the remaining carbon content of the electricity. See Section 11.3.4 for the projected costs.

11. SELECTED SCENARIO IMPLEMENTATION PLAN

11.1 Implementation Schedule

At the onset of this project, Ramboll was challenged with obtaining net carbon neutrality by 2040, but this was also desired to be accelerated to 2030 if possible. After identifying the selected scenario, Ramboll developed two schedules to help support the cost estimating effort for the implementation of the project. These schedules are provided as Appendix B of this report.

11.1.1 Standard Implementation Schedule

Ramboll first approached the implementation schedule using expected funding, procurement, and construction durations given the constraints that were outlines as part of the project and experience. This schedule assumed a five-year funding window for the first phase of the project along with a traditional design, bid, build procurement approach. Given that UMassD is paying a debt service associated with the gas turbine with the savings associated with the project, the project considered that the gas turbine would be retired no earlier than the last payment which is scheduled for 2035.

Special care was given to the level of disruption to the campus and consequentially each phase of the project is completed after the previous one is finished and each BTES field is developed in series to limit the level of disruption to the campus.

Given the expected duration of construction activities and the constraints identified above, the standard implementation schedule estimated that the campus could achieve carbon neutrality in 2037 which is three years prior to the 2040 goal, but shy of the desired accelerated date of 2030.

11.1.2 Accelerated Implementation Schedule

Ramboll developed an accelerated implementation schedule to identify what constraints would need to be removed or what processes would need to be accelerated in order to achieve carbon neutrality in 2030 as desired.

The following modifications were made in order to estimate the project being completed within the calendar year of 2030:

- The constraint to have each phase begin after the previous was completed was removed
- The five-year funding period to being Phase 1 was reduced to three years
- The retirement date of the gas turbine was removed as a constraint
- Two BTES fields were allowed to be drilled in parallel at a time

This accelerated implementation schedule would require an increased standard of care as design for subsequent phases would begin prior to construction being completed for the previous phase. This accelerated implementation schedule is seen as possible, but it is recognized that it would be challenging given the vast nature of the project.

Additional considerations for accelerating the project would to modify the procurement approach and shift to a design build implementation where design and construction can occur in parallel. Another approach could be to bid out the engineering and/or the construction for the entire project at once, instead of bidding each phase in order to remove procurement iterations. It is also expected that efficiencies will be gained by having one engineer on the project and one contractor who are responsible for the implementation of the entire project.

The ability to accelerate the project should also be considered if any policy decisions are made which would warrant the accelerated transition to a netzero carbon campus. Such policies could include a carbon cap-and-trade policy, a price on carbon, or carbon tax.

11.2 Capital Cost Estimate

A cost estimate for the selected scenario was developed utilizing the Timberline cost estimating software. The goal of the estimate was to provide a budgetary estimate in accordance with the AACE Class 4 estimate which is a feasibility level estimate based on up to 15% project definition. The typical methodology for this level of estimate is to use equipment factored estimates or parametric model estimates. Figure 10-1 presents a summary table of the classes of the AACE estimates which was taken from the AACE's Cost Estimate Classifications System.

	Primary Characteristic	***Secondary Characteristic***			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Figure 11-1. AACE Cost Estimate Classes

Ramboll used the Class 4 estimating methodology as the minimum standard and improved the estimate by using semi-detailed unit costs, detailed unit costs with forced detailed take-offs, and equipment quotes. Ramboll used the schematics included in Section 9.6 as primary inputs for the basis of the estimate which is included as Appendix C. The basis of the estimate identifies the unit take offs, other schematics, and also identifies assumptions that enabled the development of the project schedule.

Ramboll reviewed the draft cost estimate with the greater UMassD team in order to receive feedback and to align primary assumptions that affected to final cost estimate. The cost estimate is based on the standard implementation schedule which is presented in Section 10.1.

The estimate was developed by implementation phase with separate estimates for Phase 1, Phase 2, and Phase 3 in order to account for the three separate escalation values given the varying years of implementation. A 4.5% escalation rate was used at the recommendation of DCAMM with escalation rates which are summarized in Table 10-1.

Table 11-1. Escalation Rates Given 4.5% Compounding

Phase	Year	Escalation
Phase 1	2025	24.6%
Phase 2	2030	55.3%
Phase 3	2035	93.5%

Table 11-2. Selected Solution Cost Estimate by Phase

(Values in Millions of Dollars)	Phase 1	Phase 2	Phase 3	Total
Value in 2020	$50.11	$44.30	$11.28	$105.69
Funding Year	2025	2030	2035	-
Escalated 4.5% Annual	$62.44	$68.80	$21.82	$153.06

Estimate Totals

Description	Amount	Totals	Rate	Cost Basis	Percent of Total	
Labor	8,321,950				13.33%	
Material	5,273,478				8.45%	
Subcontract	5,911,730				9.47%	
Rental Equipment	280,604				0.45%	
Major Equipment / Other	11,710,650				18.75%	
	31,498,412	**31,498,412**			**50.44%**	**50.44%**
General Conditions (L,M,S,E %)	1,522,498		8.000 %	C	2.44%	
Contractor OH&P (L,M,S,E%)	1,903,122		10.000 %	C	3.05%	
	3,425,620	**34,924,032**			**5.49%**	**55.93%**
Design Contingency (PREV ST%)	6,984,806		20.000 %	T	11.19%	
Change Order Contingency (PREV ST%)	2,793,923		8.000 %	T	4.47%	
GM Contingency (PREV ST%)	873,101		2.500 %	T	1.40%	
Engineering (PREV ST%)	3,492,403		10.000 %	T	5.59%	
Construction Mgmt (PREV ST%)	1,047,721		3.000 %	T	1.68%	
	15,191,954	**50,115,986**			**24.33%**	**80.26%**
Escalation to 2025	12,328,532		24.600 %	T	19.74%	
Total		***62,444,518***				

Figure 11-2. Phase 1 Estimate Summary Table

Estimate Totals

Description	Amount	Totals	Rate	Cost Basis	Percent of Total	
Labor	2,138,831				3.11%	
Material	718,783				1.04%	
Subcontract	16,753,317				24.35%	
Rental Equipment	21,720				0.03%	
Major Equipment / Other	7,738,500				11.25%	
	27,371,151	**27,371,151**			**39.79%**	**39.79%**
General Conditions (L,M,S,E %)	1,555,057		8.000 %	C	2.26%	
Contractor OH&P (L,M,S,E%)	1,943,821		10.000 %	C	2.83%	
	3,498,878	**30,870,029**			**5.09%**	**44.87%**
Design Contingency (PREV ST%)	6,174,006		20.000 %	T	8.97%	
Change Order Contingency (PREV ST%)	2,469,602		8.000 %	T	3.59%	
GM Contingency (PREV ST%)	771,751		2.500 %	T	1.12%	
Engineering (PREV ST%)	3,087,003		10.000 %	T	4.49%	
Construction Mgmt (PREV ST%)	926,101		3.000 %	T	1.35%	
	13,428,463	**44,298,492**			**19.52%**	**64.39%**
Escalation to 2030	24,497,066		55.300 %	T	35.61%	
Total		***68,795,558***				

Figure 11-3. Phase 2 Estimate Summary

Estimate Totals

Description	Amount	Totals	Rate	Cost Basis	Percent of Total	
Labor	173,107				0.79%	
Material	228,975				1.05%	
Subcontract	400				0.00%	
Equipment	6,393				0.03%	
Solar Canopies	10,625,000				48.70%	
	11,033,875	**11,033,875**			**50.57%**	**50.57%**
General Conditions (L,M,S,E %)	31,451		8.000 %	C	0.14%	
Contractor OH&P (L,M,S,E%)	39,314		10.000 %	C	0.18%	
	70,765	**11,104,640**			**0.32%**	**50.90%**
Design Contingency (L,M,S,E %)	78,628		20.000 %	C	0.36%	
Change Order Contingency (L,M,S,E %)	31,451		8.000 %	C	0.14%	
GM Contingency (L,M,S,E %)	9,828		2.500 %	C	0.05%	
Engineering (L,M,S,E %)	39,314		10.000 %	C	0.18%	
Construction Mgmt (L,M,S,E %)	11,794		3.000 %	C	0.05%	
	171,015	**11,275,655**			**0.78%**	**51.68%**
Escalation to 2035	10,542,737		93.500 %	T	48.32%	
Total		***21,818,392***				

Figure 11-4. Phase 3 Estimate Summary

Two summary tables for the capital costs are presented which breakdown the costs per phase and by the main project components. Table 11-3 shows the cost summary with the backend markups shown and Table 11-4 shows the cost summaries with the backend markups integrated into the line items.

Table 11-3. Capital Cost Summary with Backend Markups

Initiative	Phase 1	Phase 2	Phase 3	TOTAL
Year	(2025 – 2030)	(2030 – 2035)	(2035 – 2040)	-
Central Heating Plant Upgrades and Demolition/Replacement	$ 792,162	$ 954,000	$ -	$ 1,746,162
Distribution Network	$ 5,959,392	$ -	$ -	$ 5,959,392
NetZero Energy Plant	$ 14,474,445	$ 8,390,814	$ 408,875	$ 23,274,134
Geothermal Borings and BTES	$ -	$ 18,026,338	$ -	$ 18,026,338
Thermal Tank Energy Storage Installation	$ 2,108,026	$ -	$ -	$ 2,108,026
Building Upgrades and Conversions	$ 6,303,023	$ -	$ -	$ 6,303,023
Emergency Backup Generation	$ 1,861,364	$ -	$ -	$ 1,861,364
Solar PV Car Canopies	$ -	$ -	$ 10,625,000	$ 10,625,000
SubTotal	$ 31,498,412	$ 27,371,151	$ 11,033,875	$ 69,903,438
General Conditions	$ 1,522,498	$ 1,555,057	$ 31,451	$ 3,109,006
Contractor OH&P	$ 1,903,122	$ 1,943,821	$ 39,314	$ 3,886,257
Design Contingency	$ 6,984,806	$ 6,174,006	$ 78,628	$ 13,237,440
Change Order Contingency	$ 2,793,923	$ 2,469,602	$ 31,451	$ 5,294,976
GM Contingency	$ 873,101	$ 771,751	$ 9,828	$ 1,654,680
Engineering	$ 3,492,403	$ 3,087,003	$ 39,314	$ 6,618,720
Construction Management	$ 1,047,721	$ 926,101	$ 11,794	$ 1,985,616
Escalation	$ 12,328,532	$ 24,497,066	$ 10,542,737	$ 47,368,335
Total	**$ 62,444,518**	**$ 68,795,558**	**$ 21,818,392**	**$153,058,468**

Table 11-4. Capital Cost Summary with Integrated Markups

Initiative	Phase 1	Phase 2	Phase 3	TOTAL
Year	(2025 – 2030)	(2030 – 2035)	(2035 – 2040)	-
Central Heating Plant Upgrades and Demolition/Replacement	$ 1,570,434	$ 2,397,815	$ -	$ 3,968,249
Distribution Network	$ 11,814,290	$ -	$ -	$ 11,814,290
NetZero Energy Plant	$ 28,695,089	$ 21,089,750	$ 808,510	$ 50,593,349
Geothermal Borings and BTES	$ -	$ 45,307,995	$ -	$ 45,307,995
Thermal Tank Energy Storage Installation	$ 4,179,089	$ -	$ -	$ 4,179,089
Building Upgrades and Conversions	$ 12,495,526	$ -	$ -	$ 12,495,526
Emergency Backup Generation	$ 3,690,090	$ -	$ -	$ 3,690,090
Solar PV Car Canopies	$ -	$ -	$ 21,009,882	$ 21,009,882
Total	**$ 62,444,518**	**$ 68,795,558**	**$ 21,818,392**	**$153,058,468**

11.2.1 Cost Estimate Assumptions and Exclusions

General

- Estimate has an accuracy range of +/- 30%. This is based on guidelines for a Class 4 estimate as published by AACE International. This accuracy range should not be considered the same as the estimate contingency. The estimate accuracy range should be applied to estimated cost *after* contingency is applied.
- Project is considered tax exempt. No sales tax has been included on major equipment purchases or material purchases.
- Labor rates are based on Davis-Bacon prevailing wage rates published by the US Department of Labor for Bristol County, MA.
- No costs for permits have been included.
- No costs for special inspections or 3rd party inspection coordination have been included.
- No costs for regulatory requirements have been included.
- Work is assumed to be performed during normal weekday hours. No costs have been included for overtime, weekend, holiday, or 2nd/3rd shift work.
- No costs for operation and maintenance of equipment or systems has been included.
- Estimated costs are based on an open, competitive bid situation. No vendor or subcontractor has been identified for sole sourcing the work to.
- Estimate was performed in US Dollars (USD). Exchange rates may fluctuate, so the estimated cost should not be adjusted to an alternate currency amount.
- Estimate is based on performing work during normal weather conditions. Extreme weather conditions may result in additional costs if the project schedule is delayed.

Scope of Work

- The estimate is based on the scope of work described in the document entitled "UMass Dartmouth Cost Estimating – Basis of Estimate".
- Changes or updates to the scope (based on comparison to the documents identified above), may result in cost increases.

Schedule

- The estimate is based on Phase 1 work starting in 2025, Phase 2 Work Starting in 2030, and Phase 3 Work Starting in 2035.
- The estimate was performed using current market cost. 4.5%/yr was used as a value for calculating cost due to escalation to the start of each phase of work.
- No costs for schedule acceleration have been included.
- It's assumed there will be no liquidated damages.

Indirect Costs / Markups

- A detailed estimate for contractor general conditions costs has not been performed. A markup of 8% has been applied to the direct costs for general conditions costs.
- A markup of 10% was added to the direct costs for contractor Overhead and Profit (OH&P)
- No costs for Builder's Risk Insurance or any other special insurances have been included. Only costs for contractor General Liability insurance should be assumed to be included.

- A detailed estimate for engineering costs has not been performed. A markup of 10% has been applied to the direct costs for project design and a 5% markup has been applied for design services during construction (DSDC)
- A detailed estimate for construction management costs has not been performed. A markup of 3% has been applied to the direct costs for Construction Management (CM).
- A design contingency of 20% has been added to the estimate to account for design risks and uncertainties.
- Estimate includes a GM contingency of 2.5% and a change order contingency of 8%
- No Owner costs have been included in the estimate.

Division 02 – Site Construction

- No costs for rock blasting, rock removal, or underground obstructions has been included. The BTES costs did take into consideration the underground conditions based on publicly available data sources.
- No costs for removing or relocating existing utilities has been included.
- All excavated materials are considered "clean soils" and will be disposed of offsite. No costs for removal, transportation, and disposal of hazardous or contaminated soils was included.
- Excavated trenches will be backfilled with native soil. No costs for imported fill have been included.
- Backfill for the new building foundation is assumed to be native soil. No costs for imported fill have been included.
- Soil conditions at the site are unknown. No cost are included for deep foundation work which may be required due to poor soil conditions.

Division 11 – Equipment (Major)

- Project is considered a capital improvement project or otherwise tax exempt. Sales tax on major equipment purchases was not included.
- Major equipment costs are based on budgetary quotes received from vendors.
- No costs for providing spare parts has been included.
- It's assumed equipment will be provided with standard equipment manufacturer warranties. No costs for extended warranties have been included.
- It's assumed equipment will be provided with standard equipment representative onsite startup and testing time included. No costs for extended site visits from the equipment rep have been included.

Division 15 – Mechanical/Plumbing

- Labor productivity rates are based on those published by the Mechanical Contractors Association of America (MCAA).

Division 16 – Electrical

- Labor productivity rates are based on those published by the National Electrical Contractors Association (NECA).

11.3 Operational Cost Estimate

Ramboll worked with UMassD to understand their operational costs associated with their heating and cooling systems. The operational costs were estimated in three categories; labor, HVAC repairs, and fuel costs.

11.3.1 Labor

UMassD provided a compiled report of labor costs for their central utility plan personnel for the years of 2019 and 2020. These estimates were provided in the fourth quarter of 2020 and all of the 2020 costs had not been realized; however, UMassD expressed that significant overtime had been applied in 2020 and the value had already exceeded that of 2019.

In order to project future labor costs, Ramboll assumed that the value for 2021 would be the average of 2019 and 2020 and then applied a 4.5% escalation factor[14] for each subsequent year out to 2040. Figure 10-7 presents the estimated labor cost from 2020 through 2040.

It should be noted that the staffing requirement may be reduced after the completion of the NetZero plant; however, it is anticipated that the staffing level may be required throughout the duration of the project in order to address the coordination and integration of the new equipment during the transition.

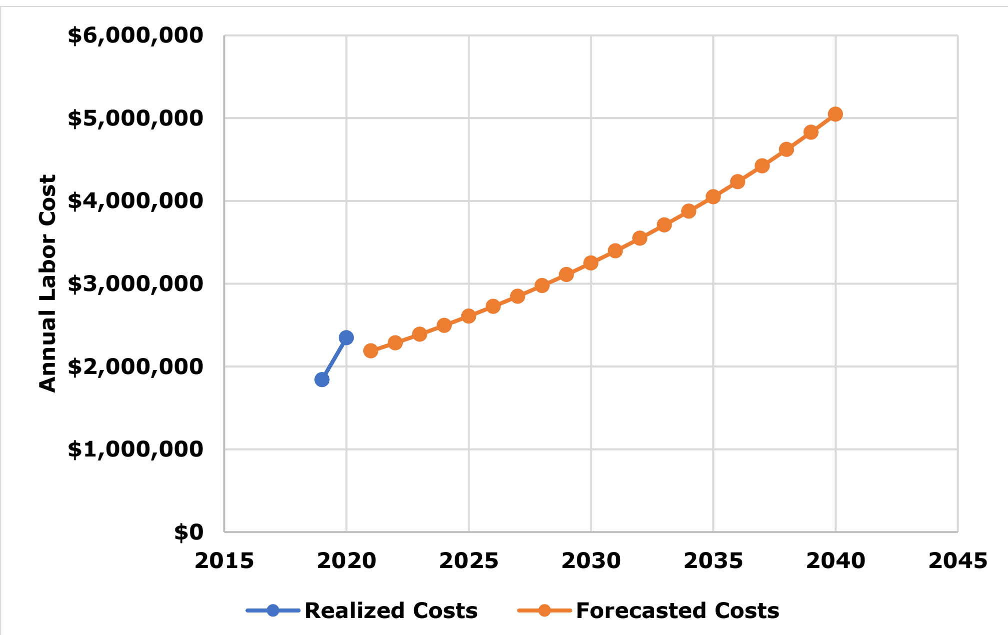


Figure 11-5. Annual Labor Costs

11.3.2 HVAC Repairs

A similar approach was used to estimate and project the HVAC repair costs. UMassD provided 2019 and 2020 realized costs for HVAC Repairs. The two values were averaged to estimate the 2021 costs and then a 4.5% escalation factor was applied for each year thereafter. A 10% reduction was applied to the preferred solution after an interview with UMassD identified that overtime charges contribute to

[14] The 4.5% escalation factor was provided from DCAMM.

the fee and that less overtime should be required as a result of a modernization project. The HVAC costs are assumed to be mostly attributed to terminal units and not to the distribution system. For that reason the previous costs are expected to be representative of future costs.

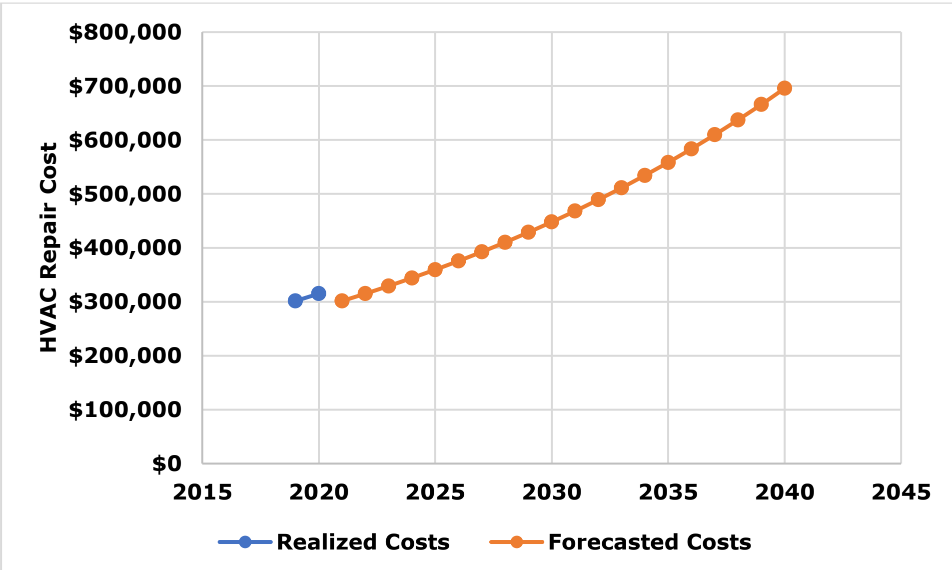


Figure 11-6. Annual HVAC Repair Costs

11.3.3 Fuel Costs

The phased EnergyPro model provides estimates for fuel consumption per asset and the fuel costs per unit were applied to achieve the fuel cost summary per phase. The following tables show a breakdown of fuel costs at the year when the phase will be fully implemented.

Table 11-5. Phase 1 - 2030 Utility Cost Summary

		Fuel	price of fuel (USD/MWh)	Fuel costs (MUSD/year)
HRC	MWh-el	Electricity	$116.90	$0.26
Centralized gas boiler	MWh-f	Natural gas	29.1	$0.21
Air-source heat pump	MWh-el	Electricity	$116.90	$0.40
Air-c. chiller	MWh-el	Electricity	$116.90	$0.46
GT+HRSG	MWh-f	Natural gas	29.1	$0.94
Individual water-cooled chillers	MWh-el	Electricity	$116.90	$0.03
Campus Electricity	MWh-e	Electricity	$116.90	$3.15
			TOTAL per year	**$5.45**

Table 11-6. Phase 2 - 2035 Utility Cost Summary

		Fuel	price of fuel (USD/MWh)	Fuel costs (MUSD/year)
GSHP	MWh-el	Electricity	$126.93	$0.45
HRC	MWh-el	Electricity	$126.93	$0.54
Centralized gas boiler	MWh-f	Natural gas	32.2	$0.17
Air-source heat pump	MWh-el	Electricity	$126.93	$0.73
Air-c. chiller	MWh-el	Electricity	$126.93	$0.33
Campus Electricity	MWh-e	Electricity	$126.93	$3.43
			TOTAL per year	**$5.64**

Table 11-7. Phase 3 - 2040 Utility Cost Summary

Fuel consumption per year		Fuel	price of fuel (USD/MWh)	Fuel costs (MUSD/year)
GSHP	MWh-el	Electricity	$141.17	$0.50
HRC	MWh-el	Electricity	$141.17	$0.60
Bio oil boiler	MWh-f	Bio oil	$67.50	$0.39
Air-source heat pump	MWh-el	Electricity	$141.17	$0.81
Air-c. chiller	MWh-el	Electricity	$141.17	$0.36
Campus Electricity	MWh-e	Electricity	$141.17	$3.81
			TOTAL per year	**$6.47**

Figure 11-7 presents the annual utility cost from 2020 through 2040. Ramboll worked closely with CES in order to develop this curve that accounts for all fuel sources. Cost projections were made for the various fuels which were reviewed with UMassD and refined over various iterations. The curve shows a distinct rise in 2030 with the implementation of Phase 2 which results from an increase in the electrical demand charge. There is also a modest decrease in 2035 when the transition to full electrification takes place and the costs reduce. In 2040 a slight increase in the slope of the line can be seen which reflects the transition to bio diesel which is a more costly, but renewable fuel.

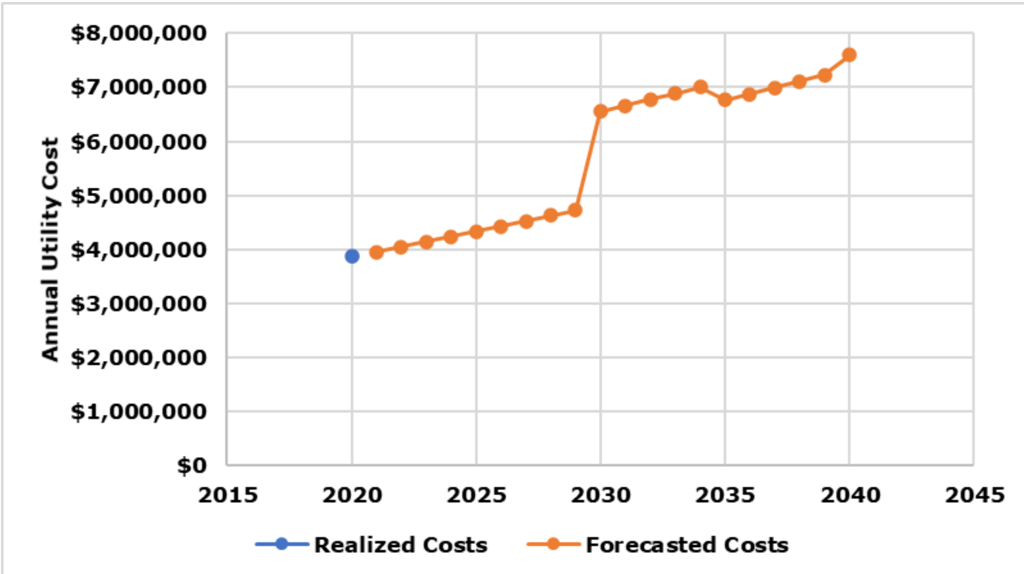


Figure 11-7. Annual Utility Costs

11.3.4 Supplemental REC Costs

Supplement RECs were introduced in Section 10 and Figure 11-8 provides the anticipated costs of the RECs. This graph is extended out to 2050 in order to show that the cost for supplemental RECs peak in 2035 and are reduced to $0 in 2050 because the renewable portfolio standard will require the supplier to purchase 100% RECs at that time.

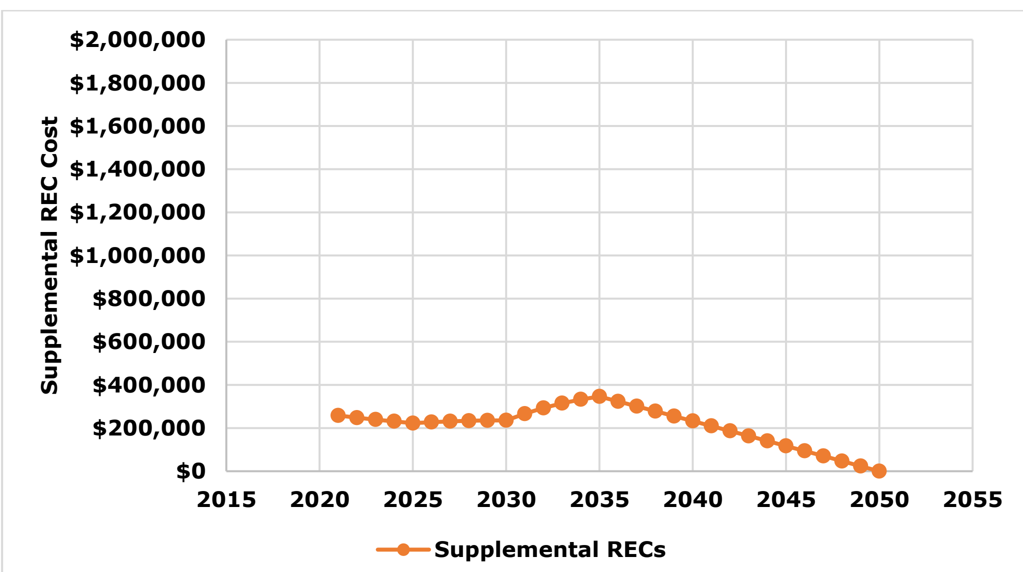


Figure 11-8. Supplemental REC Costs

11.3.5 Debt Cost for Natural Gas Turbine

UMassD informed Ramboll that they are paying a debt service for the natural gas turbine with the savings that it is providing. The payment schedule was provided to Ramboll and Figure 10-10 presents the payment schedule which continues through 2035 when the asset is payed off. It can be seen that the loan is structured such that there is a final payment which is the largest single payment.

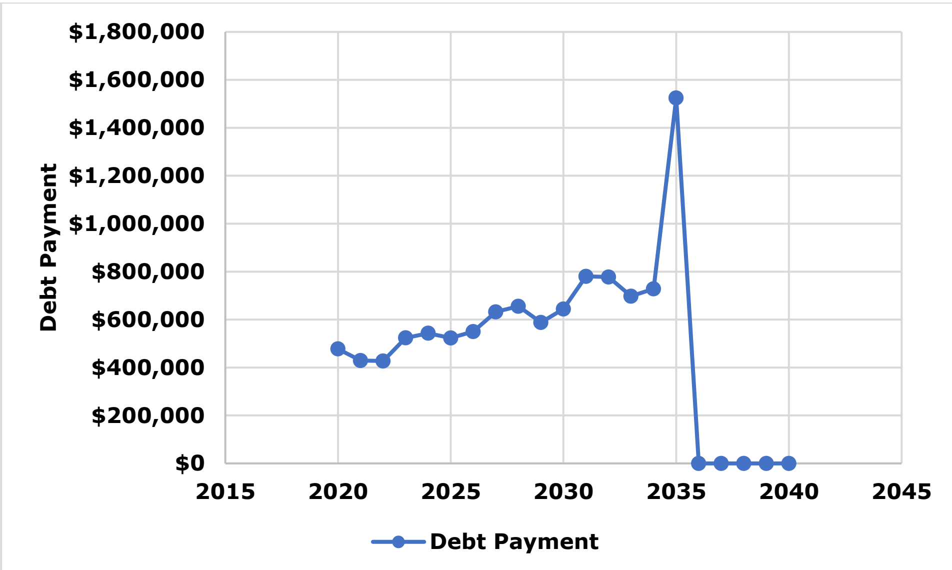


Figure 11-9. Natural Gas Turbine Debt Payment Schedule

11.3.6 Operational Cost Summary

Each of the individual operational costs were summed and Figure 10-11 presents the summary values per year. The stacked bar chart shows the steady annual increase in costs with the exception of 2035 when the final payment for the gas turbine is due and a reduction is seen in 2036. It can be seen that the majority of the operational costs are comprised of the fuel costs and the payroll for plant personnel. These operational costs are for the implementation of the selected scenario and no payback is anticipated.

Over the 20-year timespan a modest 51% increase in operational costs are anticipated despite a 4.5% escalation factor on labor and HVAC costs. The anticipated escalation factor alone represents an escalation of 230% over the 20-year period.

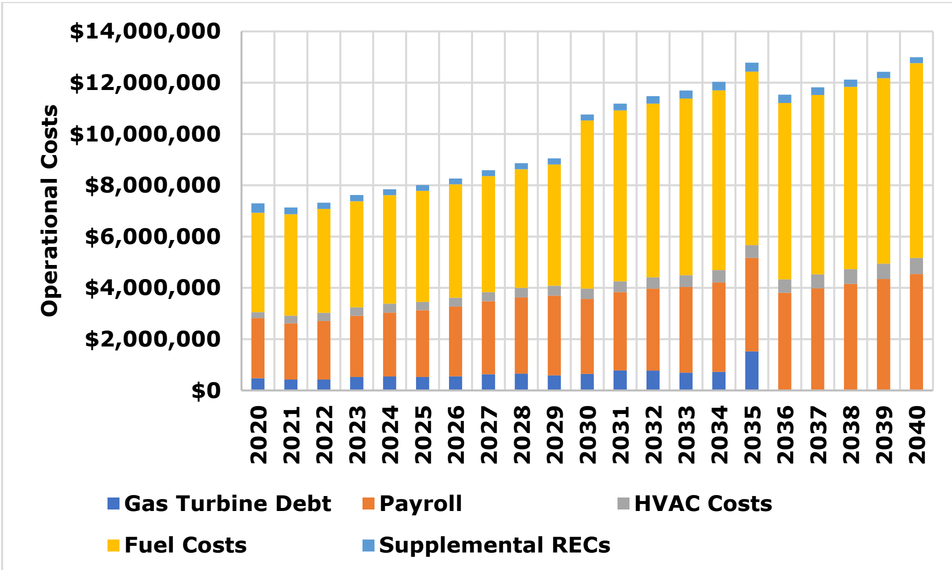


Figure 11-10. Operational Cost Summary

11.4 Comparison of Operational Cost Estimate to BAU

The operational costs for the BAU case were also generated in order to identify the operational cost savings that this project could produce. The operational cost estimate was comprised of the same categories of gas turbine costs, payroll, HVAC costs, fuel costs, and supplemental RECs; however, some considerations had to be given that are unique to the continued use of the BAU scenario.

Frist the gas turbine debt covers the maintenance contract for the gas turbine. In the BAU case the gas turbine is continued to be used through 2040 and the maintenance costs would have to be extended in order to maintain the asset. Figure 11-11 shows the continued maintenance cost of approximately $600,000 in 2036 which is increased at 4.5% annually through 2040.

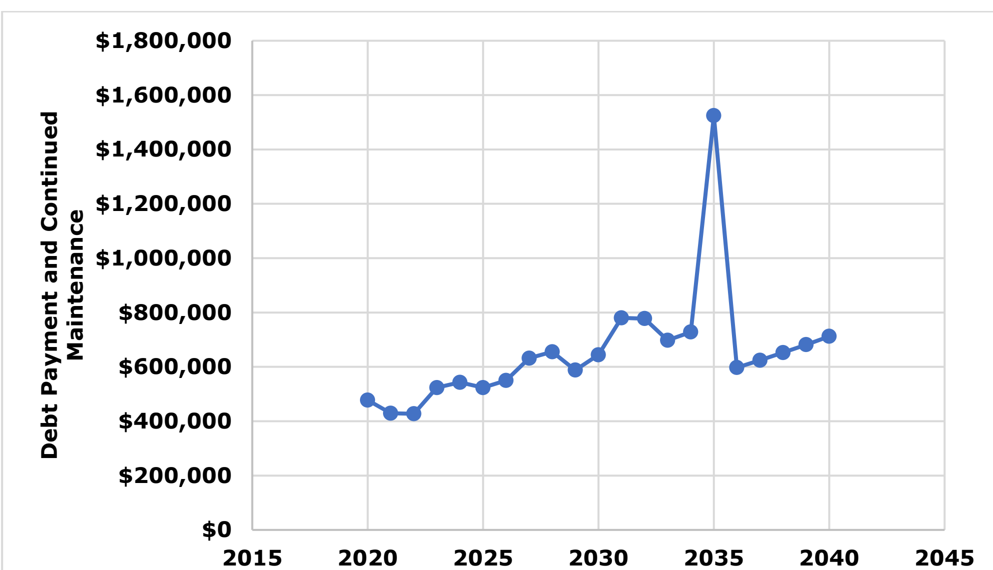


Figure 11-11. Gas Turbine Costs

The second item that is unique to this is this scenario is the calculation of the annual REC cost. The main difference between the BAU scenario and the selected scenario is that the BAU scenario fails to achieve the carbon neutrality goal of UMassD. In order to compare the two scenarios, the cost to offset the emission of the BAU scenario was estimated. First the cost of carbon offsets were assumed to be equal to the $30/MWh that this project estimated. Given the emission factor used on this project, one MWh of electricity has the carbon content of 528 $lbCO_2e$. The emissions for each year of the selected scenario and the BAU scenario were estimated and the quantity of RECs/offsets that would be required for the BAU scenario to have the same "emissions" as the selected scenario was calculated. This enabled the project to level the two scenarios and estimate the cost for doing so.

Figure 11-12 presents the estimated cost from 2021 through 2040. The costs from 2021-2024 are equal to that of the selected scenario. The years of 2025 through 2027 represent the offset required to equal the emission savings of Phase 1 of the selected scenario. The years of 2028-2030 represent the cost for offsetting the emission savings of Phase 2 of the selected scenario and the costs thereafter represent the offsets required for offsetting the remaining emissions. It should also be noted that (unlike the selected scenario) the cost for RECs/offsets would continue indefinitely to offset the use of natural gas where the selected scenario would no longer require RECs after 2050.

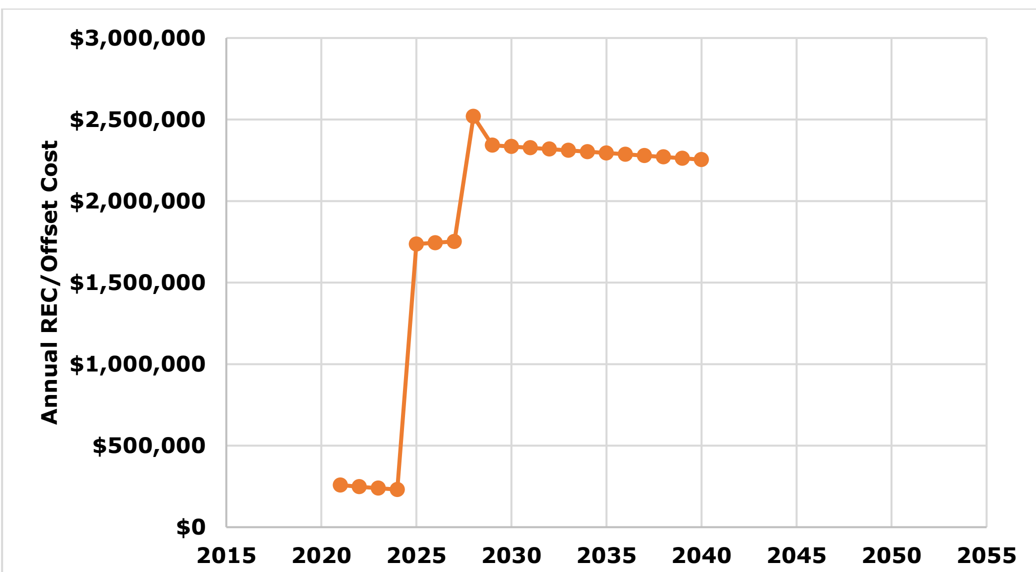


Figure 11-12. Annual REC/Offset Costs for BAU Scenario

The total estimated operational costs for the BAU scenario are identified in Figure 11-13. The BAU scenario sees a 94% increase in operational costs over the 20-year period compared to the 51% increase in the selected scenario; largely on account of the gas turbine maintenance cost and the larger REC/offset cost. The BAU scenario sees a $3.4M increase in operational costs over the selected scenario showing an annual cost savings. Given the capital cost of the project being over $120M, this savings would have over a 35-year payback.

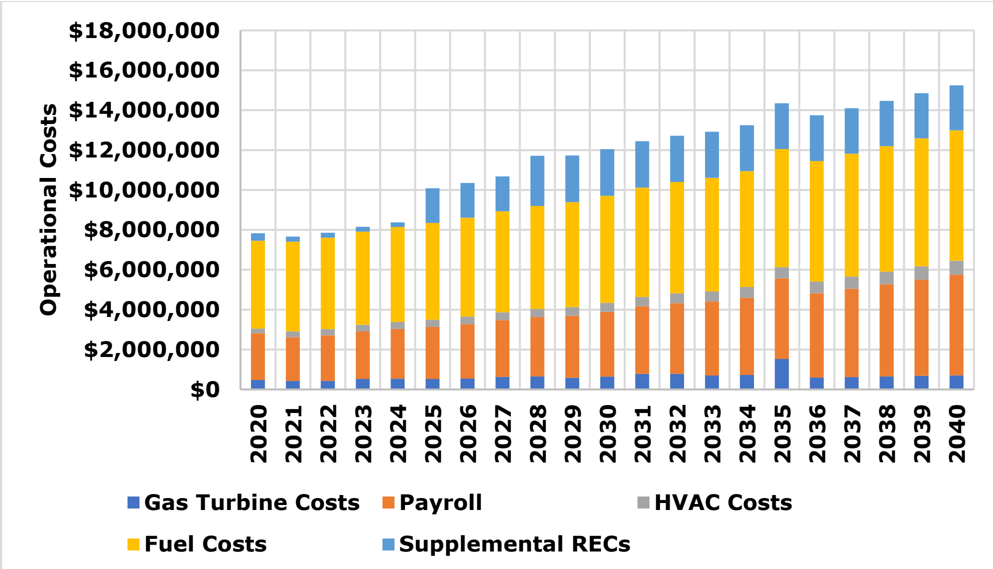


Figure 11-13. BAU Operational Costs

11.5 Renewable Electricity Generation

As part of this project, Ramboll investigated the economics of UMassD generating a portion of their own electricity via solar PV or wind. This could be as a direct owned asset or through a developer power purchase agreement where a separate entity would invest in the infrastructure and UMassD would be an off-taker of the energy that it produces. Given UMassD's history with the recently removed wind turbine, a PPA arrangement would protect them from the uncertainty of unexpected maintenance costs.

A nominal 2.5 MW of capacity was assumed for both PV and onshore wind technology and the resulting production was evaluated. This value was chosen after reviewing Figure 10-12. The electrical demand of 2.5 MW is nearly always exceeded which means that the electricity will always be consumed "behind the meter". This is important because of the high renewable penetration in the area surrounding UMassD and the concern of power quality in the area. As long as UMassD can ensure that they won't export power they should not have to conduct a costly utility power quality assessment. It is anticipated that UMassD can utilize a reverse power relay or other technology to ensure that power isn't exported.

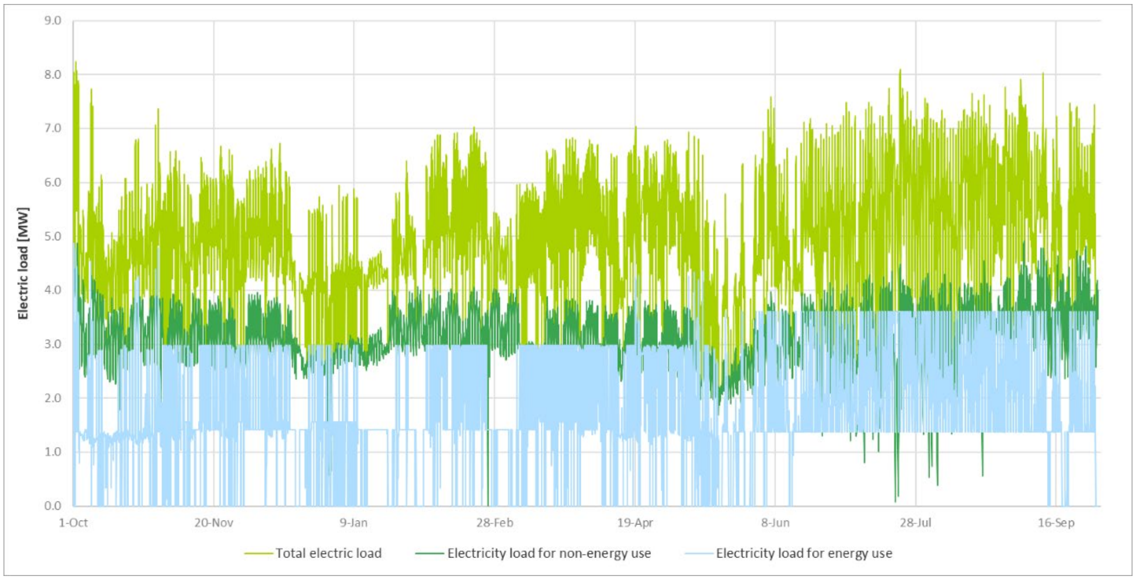


Figure 11-14. Projected Annual Hourly Electricity Consumption Profile

11.5.1 Electricity Production from PV

For the PV field, the electricity production was estimated using the PVGIS online tool[15]. The modules are assumed to be installed with sufficient row spacing that shadow effect can be neglected. The balance of system efficiency is assumed to be 82% for this size of installation. The balance of system accounts for transmission and conversion efficiencies. The optimal tilt angle in the proximity of the Campus was found to be 40°, based on a yearly production optimization automatically carried out by PVGIS.

Under these assumptions the yearly net production from the PV system is 3.34 GWh.
The figure below gives a summary of the results as well as the monthly distribution of the electricity production.

Summary

Provided inputs:	
Location [Lat/Lon]:	41.600, -70.980
Horizon:	Calculated
Database used:	PVGIS-NSRDB
PV technology:	Crystalline silicon
PV installed [kWp]:	2500
System loss [%]:	18
Simulation outputs:	
Slope angle [°]:	40
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	3336940.73
Yearly in-plane irradiation [kWh/m^2]:	1708.57
Year-to-year variability [kWh]:	65658.06
Changes in output due to:	
Angle of incidence [%]:	-2.68
Spectral effects [%]:	NaN
Temperature and low irradiance [%]:	-2.11
Total loss [%]:	-21.88

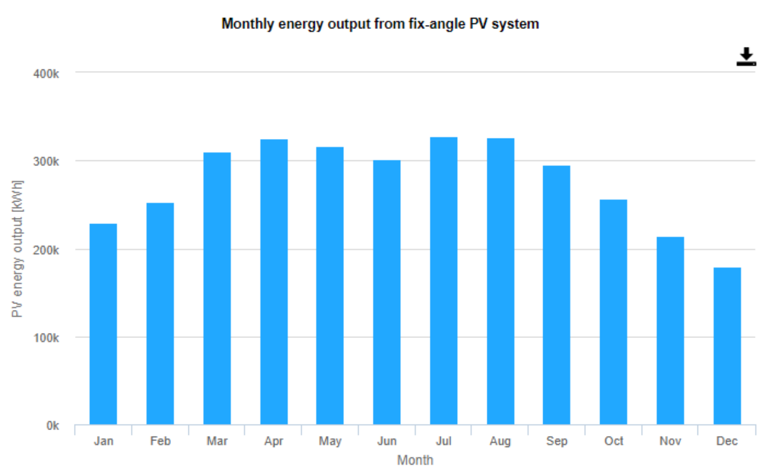


Figure 11-15. Output from PVGIS Online Tool for the Considered PV System.

[15] https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

UMassD has stated that solar canopies would be the best utilization of space on the campus; see Figure 11-16 for an example. The solar canopies would be installed over the existing parking lots which offer ample space without giving up greenspace or clearing additional woodlands on campus.

Using the free on-line PVWatts calculator approximately 180,000 SF of space will be required in order to provide the desired 2.5-MW solar canopy. The cost for car canopy systems are more expensive than ground mounted systems due to the superstructure that is required. Several publicly available on-line resources were used to estimate the cost of the solar canopy which are listed as cost references[16]. The costs ranged from $3.0/watt to $3.93/watt and were generally more expensive than a ground based or roof mounted systems.

Figure 11-16. Solar PV Car Canopy Example

For this estimate the foundation, superstructure, solar panels, and PV infrastructure (transformer, meter, and disconnect) were valued at $4.25/watt given the prevailing wage requirement at the site. This equates to a cost of $10.6M for the solar array including construction costs. Figure 11-17 presents possible parking lots which provide the 180,000 SF required for the panels.

[16] https://powersolarphoenix.com/carport-solar-panels-cost/
https://news.energysage.com/what-is-a-solar-panel-carport/
https://www.cesa.org/wp-content/uploads/Vermont-Solar-Cost-Study.pdf

Figure 11-17. Possible Solar Canopy Draft Locations

A simple payback analysis was completed to understand the financial justification for the project. This simple payback using 2019 electrical rates identifies a 20+ year simple payback for the car canopy system which does not warrant the investment on economics alone. Other tangible benefits for the campus will include that they will generate electricity themselves to a greater degree and in a more visible way. This will also reduce the annual cost for supplemental RECs which need to be purchased as a result of this electrical generation. The RECs are expected to be valued at \$100,080/yr given a rate of \$30/REC and one REC is worth 1-MWh of generation. This brings the payback down to just under 19 years.

$$Simple\ Payback\ = \frac{\$10{,}600{,}000}{3{,}336{,}940\frac{kWh}{yr}\times 0.140\frac{\$}{kWh}} = 22.7\ Years$$

$$Simple\ Payback(with\ REC)\ = \frac{\$10{,}600{,}000}{3{,}336{,}940\frac{kWh}{yr}\times 0.140\frac{\$}{kWh}+\$100{,}080} = 18.7\ Years$$

As part of this evaluation, it is also recommended that any new buildings should be constructed as being "solar ready" with electrical infrastructure and conduit runs installed such that solar can be provided at the time of installation or in the future if desired.

11.5.2 Electricity Production from On-shore Wind Turbine

For the wind energy case, the electricity production was estimated using energyPRO. A single 2.5 MW wind turbine[17] was assumed to be installed. The characteristic power curve of the turbine is shown in the figure below.

[17] https://en.wind-turbine-models.com/turbines/310-ge-general-electric-ge-2.5-120

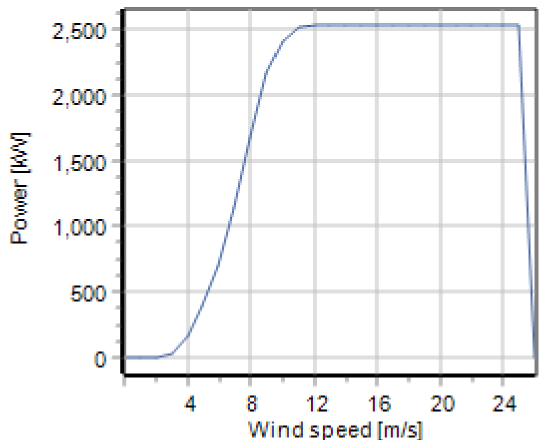


Figure 11-18. Power Curve of the Considered Wind Turbine

The balance of system efficiency for a single turbine installed relatively close to the grid is assumed to be 98%. The wind speed data was taken from the ERA5 weather database for the location 41.73° N and 70.92° W, the closest ERA5 location to the Campus which is approximately 10 miles away.

Under these assumptions the yearly net production from the wind turbine is 7.44 GWh which is approximately 2.2 times the electricity generated from the PV array. The figure below shows the wind electricity production profile during the year.

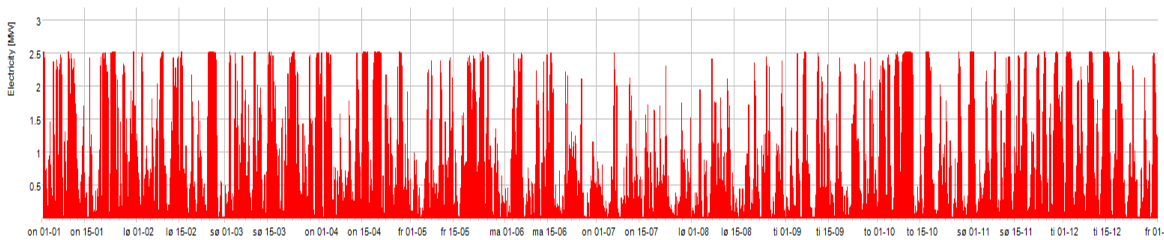


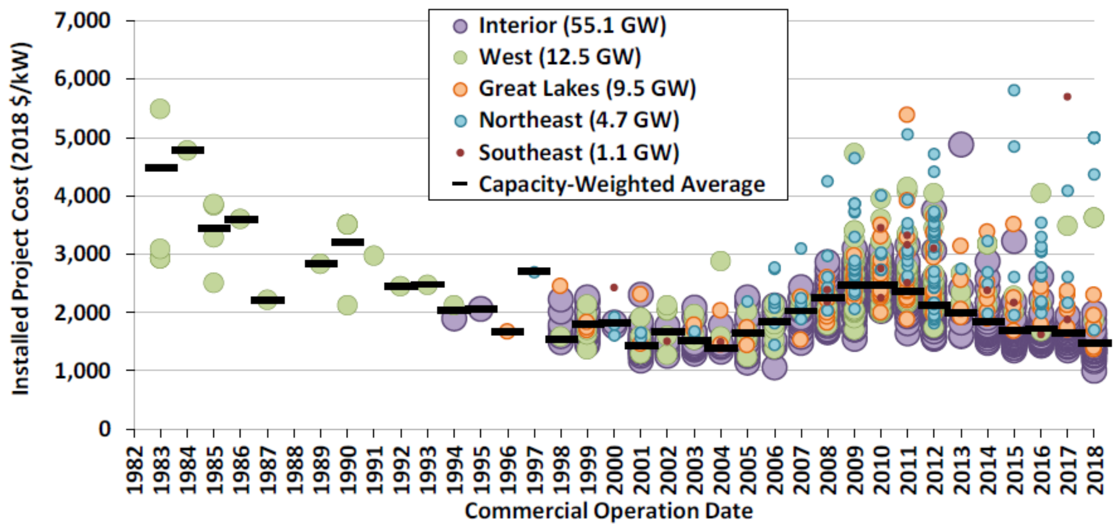
Figure 11-19 Wind Electricity Production Profile During the Year

The cost estimate for the wind turbine was based on the 2018 Wind Technologies Market Report which is published by the US Department of Energy. The capacity-weighted average installed project cost was estimated at $1,470/kW per the publication and Figure 10-16. The data included in the US DOE publication are inclusive of wind farms and since a single (or few) wind turbines would be installed and prevailing wager would be required, a conservative estimate of twice the published rate was used for this project; i.e. $2,940/kW. This would yield a cost estimate of $7,350,000.

A simple payback analysis was completed to understand the financial justification for the project. This simple payback using 2019 electrical rates identifies a 7-year simple payback for the wind system which maybe justifiable. Other tangible benefits for the campus will include that they will generate electricity themselves to a greater degree and in a more visible way. This will also reduce the annual cost for supplemental RECs which need to be purchased as a result of this electrical generation. The RECs are expected to be valued at $232,200/yr given a rate of $30/REC and one REC is worth 1-MWh of generation. This brings the payback down to just under 6 years.

$$Simple\ Payback\ = \frac{\$7{,}350{,}000}{7{,}440{,}000\frac{kWh}{yr}\times 0.140\frac{\$}{kWh}} = 7.1\ Years$$

$$Simple\ Payback(with\ REC) = \frac{\$7{,}350{,}000}{7{,}440{,}000\frac{kWh}{yr} \times 0.140\frac{\$}{kWh} + \$223{,}200} = 5.8\ Years$$



Sources: Berkeley Lab (some data points suppressed to protect confidentiality), Energy Information Administration

Figure 11-20. Wind Turbine Cost Data.[18]

It should be noted that UMassD has Federal Aviation Administration height restrictions due to their proximity to the New Bedford Regional Airport. From discussions with UMassD it is understood that there is a 300-foot elevation limit that cannot be exceeded. This limitation would have to be considered in the selection of the turbine or turbines.

11.6 Confirmation of Electrical Service Capacity

It is important to recognize that the selected solution will add electrical demand to the campus and to confirm that the campus infrastructure can handle the additional load without causing a costly upgrade to the electrical infrastructure. In Section 5.8, it was estimated that the campus infrastructure could support approximately 11.5 MW of demand. Given Figure 11-14, the estimated demand for the selected solution is approximately 8.2 MW which is not anticipated to warrant an upgrade. It is important to recognize that the seasonal and tank thermal energy storage provides some flexibility to managing the load during the highest peak periods.

[18] https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20FINAL.pdf

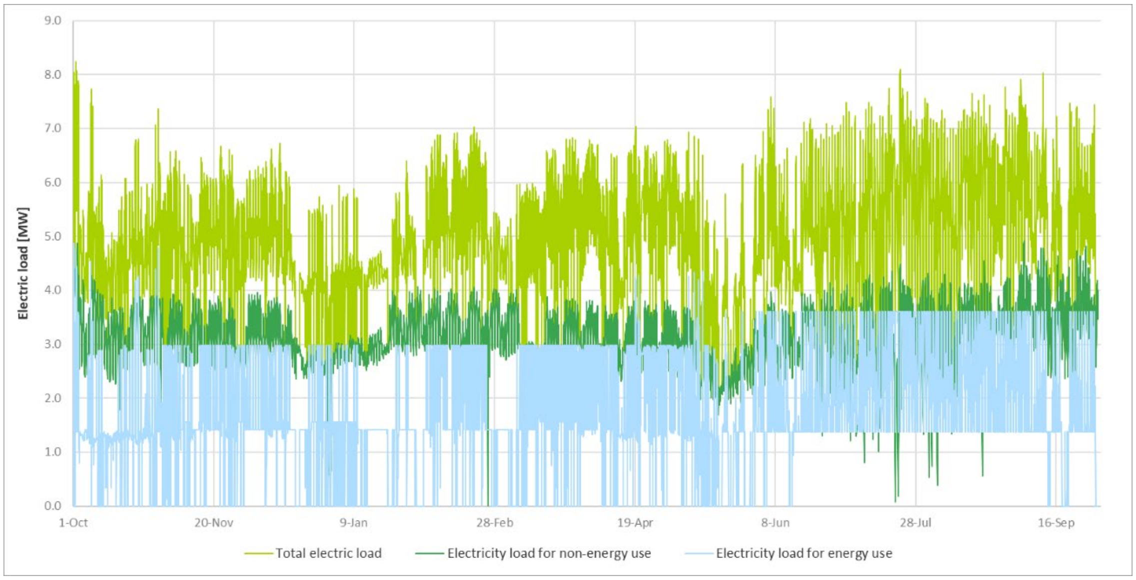


Figure 11-21. Projected Annual Hourly Electricity Consumption Profile

12. CONCLUSION AND RECOMMENDATIONS

12.1 Increased Energy Conservation

Section 6.4 of this report compared the energy performance of UMassD's buildings to that of the CBECS database. It was estimated that UMassD's buildings consume approximately 20% more energy than the average similar buildings when normalized for size and geography. This project identified the planned renovations that are currently funded and estimated the future energy savings associated with those renovations. However, the benchmarking process has identified that that additional energy conservation could be achieved if further renovations were to be completed.

The unique architectural construction techniques utilized at UMassD prevent some challenges to simple energy conservation measures and it is anticipated that more substantive renovations would be required to significantly reduce the energy use intensity of the buildings. The sustainability goals and stewardship within the state of Massachusetts system desires that renovated buildings exceed code required energy conservation and reduce energy consumption to the greatest extent possible.

Table 11-1 presents the current blended campus EUI along with the CBECS blended EUI as well as three additional values which exceed the CBECS average buildings given that newly renovated buildings would be expected to be the best performing within their peers. It can be seen that 20%-44% EUI savings could be achieved if renovations were to occur and this will have a proportional reduction in the cost to supply energy to the campus. If the conservation measures can be implemented prior to the build out of the selected solution then the scale of the generation and distribution systems could also be reduced proportionally for a significant reduction in capital cost of the project.

Table 12-1. Possible Energy Use Intensities in Comparison to CBECS

	Current Blended Campus EUI (kBtu/SF)	CBECS Blended EUI (kBtu/SF)	EUI of 10% less than CBECS	EUI of 20% less than CBECS*	EUI of 30% less than CBECS
Value	159.9	127.5	114.75	**102**	89.25
Reduction	-	32.4	45.15	**57.9**	70.65
Percent Reduction from Current	0%	20%	28%	**36%**	44%

** The value of 20% less than CBECS aligns with the campus goal of reducing overall energy consumption (on a per square foot basis) 35% by 2020 (the exact value is 106 kBtu/SF).*

The 36% reduction from current EUI values is very close to the campus goal of reducing overall energy consumption (on a per square foot basis) 35% by 2020. The cost of the selected scenario is anticipated to have a linear relationship with the capacity of the system. If the campus EUI were reduced ~35% then the selected scenario could have a proportional reduction in the capital cost. The capital cost of the selected solution is approximately $130M and 35% reduction from that would be approximately $47M. There are approximately 44 buildings on campus and the cost to reduce the EUI 35% is anticipated to be more than the cost savings than could be had for the selected solution. For this reason the renovation of the buildings cannot be justified solely on the capital cost savings for the selected solution; however, the cost savings should be considered as an additional benefit when considering if renovations are needed. As the Sightlines report identifies, several buildings are due for refurbishments and the reduced cost of the selected scenario should be considered as an additional benefit in that decision-making processes.

It is recommended that any modernization of the buildings should be prioritized such that savings can be realized prior to the design for the selected solution.

12.2 Alignment with Facility Projects

It is recommended that the campus facility and maintenance personnel become aware of the selected solution and begin to prepare for it when implementing new equipment or utilities projects. The intent would be to incorporate equipment that would be ready to be served via the hot water distribution and chilled water distribution systems. Any piping or electrical projects should consider adding any future tie-in points that make sense. Any new construction projects on campus should also consider being "solar ready" at their completion.

12.3 Renewable Energy Generation

UMassD has expressed an interest in developing a visible renewable electricity source on campus and this study assessed both solar car canopies and wind turbines. While this analysis found that wind turbine generation may be more economical than solar car canopies it is recommended that UMassD continue to pursue renewable electricity generation on campus and size the asset such that it will not export electricity to the grid in order to avoid a costly grid evaluation.

UMassD can continue the renewable energy generation as a direct owned asset or through a power purchase agreement (PPA) which may be more desirable to manage the risks of managing the assets. UMassD can work directly with PPA providers in order to advance this aspect of the project and it can be completed as a stand-alone project if desired.

12.4 Geotechnical Borings

This study utilized publicly available data to estimate the geological conditions and the grounds ability to store seasonal energy. Given the large capital cost associated with the borings, it is recommended that a test boring be conducted at the location of one or each BTES locations in order to refine the cost estimate, work rate projection, and ability to leverage seasonal energy storage at the site. This additional data will enable UMassD to further refine the estimate.

12.5 Assess Funding Options

This project identified the time associated with securing funding for each phase of the project and estimated this to take between two and five years. The higher education sector in the US has implemented some unique funding strategies to finance central utility upgrade projects. The time it takes to asses the options can be measured in years and the goals of UMassD are relatively close with only ten years to the 2030 goal and twenty years to the 2040 goal. It is recommended to advance the funding strategy as soon as possible in order to give the highest likelihood of achieving UMassD's goals.

12.6 Implementation of the Selected Scenario and Continuous Refinement

This study found a pathway to carbon neutrality for the main campus of UMassD. We recognize that the energy market is constantly changing and technologies that aren't considered viable today could be considered a best practice within a short period of time. It is recommended that UMassD use this study as a path forward and begin to plan the implementation of it, but also recognize the improvements that could be made upon it as technologies progress in the future.

This feasibility study is a major step towards carbon neutrality for UMassD. Continued refinement and study are recommended to advance the development into pre-schematic, schematic, and ultimately detailed design phases. Implementation of the submetering recommendations will enable the campus to gather critical data to size components correctly and further minimize the capital costs of the selected solution. The sub-metering program will enable UMassD to also monitor the energy reductions as a result of energy efficiency project and modernization projects.

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IF TECHNOLOGIES REPORT

APPENDIX B
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CAMPUS MASTER PLAN

EXHIBIT B
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COMPETITIVE ENERGY SERVICES – RENEWABLE ENERGY CREDIT ASSESSMENT

APPENDIX A
IF TECHNOLOGIES REPORT

Geothermal energy at University of Massachusetts Dartmouth

Pre-feasibility study

IF Technology **Creating energy**

Date	26 June 2020
Reference	70266/BG/20200626
Subject	Umass Dartmouth pre-feasibility study of geothermal energy
Author	Daan den Hartog
Reviewed by	Bas Godschalk
Version	1

CLIENT

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1 Project information

1.1 LOCATION AND INFORMATION

The University of Massachusetts Dartmouth is located in the town of Dartmouth, Massachusetts.

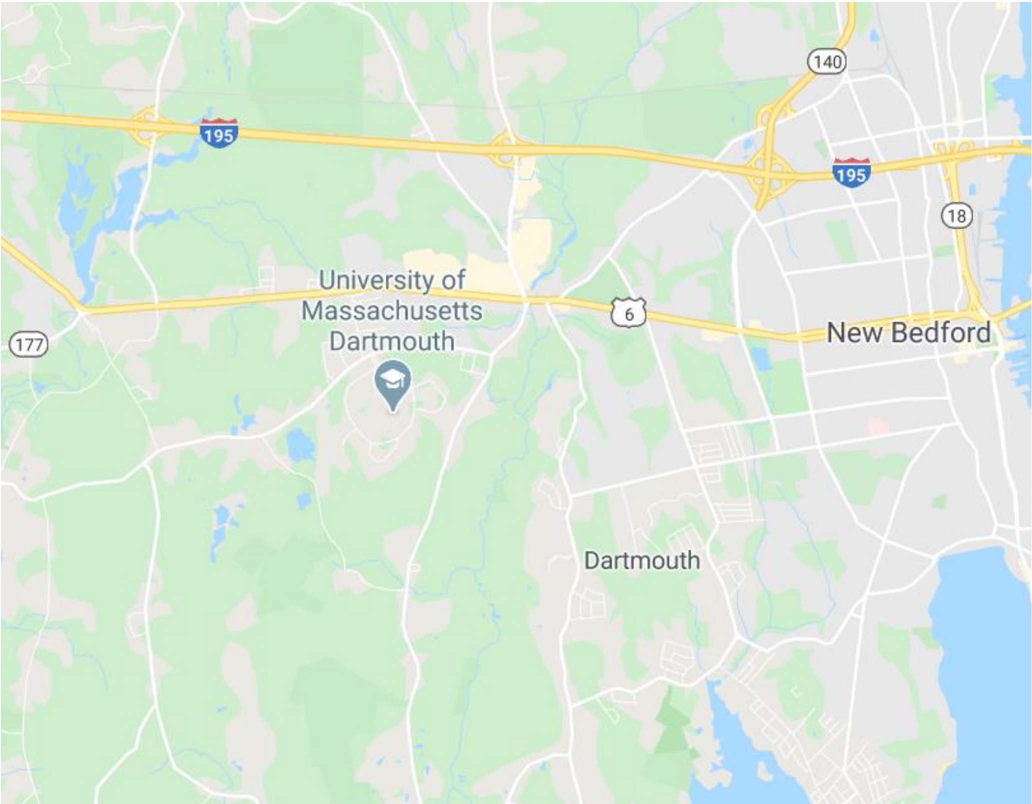


Figure 1.1 | Location University of Massachusetts Dartmouth

1.2 ENERGY DATA FOR UMASS DARTMOUTH

The total heat demand is approx. 40,100 MWh with a peak of 15 MW and an EFLH of 2,675 hours. The total cold demand is approx. 20,300 MWh with a peak of 20 MW and an EFLH of 1,015 hours.

Currently, heat is provided by a steam network, which is used for heating purposes with a T_{supply} of 75 à 80 ºC. Cooling is produced by steam adsorption chillers. The steam network will be phased out in the future, therefore a new energy concept is required with the following considerations:

- A heating grid is considered. The new supply temperature is unknown.
- The heat will be produced centrally.
- Cooling will be provided with electrical chillers or heat recovery chillers.
- Cooling will probably be produced by clusters and not centrally.
- Temporally or seasonal storage of energy will improve the energy concept and is therefore target of investigation.

1.3 PLAN OF APPROACH

Various energy concepts or scenarios are considered by Ramboll for the future energy supply of the campus. The usage of shallow geothermal energy is a possible option. Within shallow geothermal energy, two main solutions can be distinguished: Borehole Thermal Energy Storage (BTES) and Aquifer Thermal Energy Storage (ATES).

In this feasibility study, a brief explanation of the shallow geothermal solutions is given. This is followed by a hydrogeological survey in order to verify the potential of ATES and BTES on the Umass Dartmouth location. In the last chapter, an energy concept is provided with a rough estimation of the costs.

2 Types of energy storage

2.1 PRINCIPLE OF AQUIFER THERMAL ENERGY STORAGE

The principle of Aquifer Thermal Energy Storage (ATES) can be explained as follows: in summer, groundwater is extracted from one or more ‘cold wells’ and used directly for cooling purposes. Depending on the required supply temperature for cooling, the ATES can supply the cooling directly without the use of a heat pump/chiller. If the supply temperature is lower than 6-7°C, additional (peak) cooling with a heat pump/chiller is necessary to reduce the supply temperature to the desired level. However part of the cooling can also be supplied directly by the ATES. During that process, heat is transferred from the building’s cooling system into the extracted water, heating it up, before it is injected into the same number of ‘warm wells’.

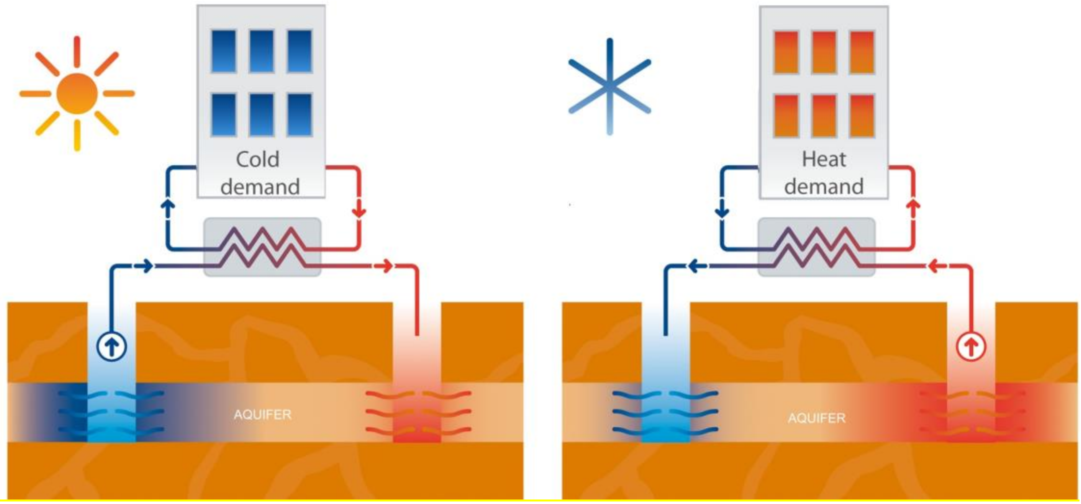


Figure 2.1 | ATES in the cooling and heating mode

In winter the process is reversed, with warm water being extracted from the warm well(s) and used for heating. The warm water is exchanged through a heat exchanger and then used by a heat pump requiring electrical energy. A heat pump typically delivers 3 to 4 times more heat energy than the electrical energy it consumes.
During this process, heat is absorbed by the heat pump and the cooled groundwater is then injected into the cold (injection) well(s).

An advantage of ATES is that less chillers are necessary to generate the cooling medium in summer, when outside temperatures are high. Chillers use relatively large quantities of electrical energy. The use of ATES results in a major saving in electrical energy consumption and associated running costs. In winter, heat pumps supply a large quantity of heating at a high efficiency, thus providing a considerable saving over the use of conventional heating plant, e.g. gas or oil fired boilers.

2.2 PRINCIPLE OF BOREHOLE THERMAL ENERGY STORAGE

A borehole thermal energy storage system (BTES system) uses a closed loop underground. A number of tubes will be placed into the ground to a depth of 50 -150 m (150 – 500 Ft). The tubes are filled with a fluid to exchange heat with the subsurface around it. These vertical heat exchangers exchange heat with the subsurface to heat or cool the building. The figure displays the principle of this technology.

In the US, the BTES system is better known as the GSHP (ground source heat pump). When using BTES, an energy balance will be kept during the years in order to provide both heating and cooling. A GSHP concept is often focussed on providing of heat, whereas the supply of cold is secondary.

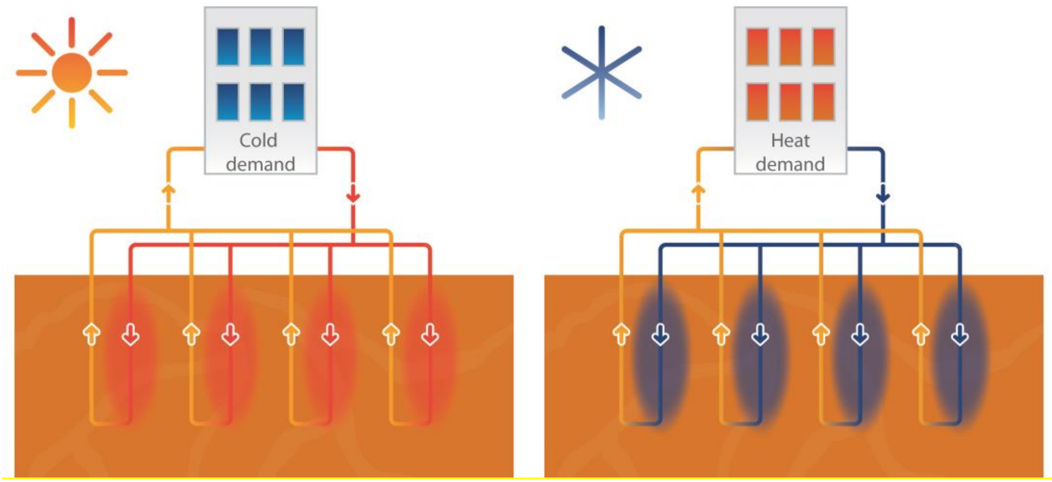


Figure 2.2 | BTES in the cooling and heating mode

The advantage of BTES compared to ATES is that BTES can be applied regardless of the hydrogeological conditions. No aquifer is required. BTES is suitable for small-scale application (residential properties, small offices) and yet remaining economically feasible. The technique is commonly used, especially within the GSHP concept.

Disadvantages of BTES compared to ATES are the lower thermal efficiency and the large amount of boreholes required for bigger applications, such as offices, hospitals or campuses. A significant amount of surface area is required for the installation of boreholes, while for ATES just a few square meters are needed for two or more wells. Therefore, the installation costs of BTES can become substantial, when many boreholes have to be installed. Costs can also increase when the hydrogeological conditions require expensive drilling techniques, which is the case in granite formations.

3 Hydrogeological assessment

3.1 SUBSURFACE DESCRIPTION

The subsurface in the area of the University of Massachusetts Dartmouth is described based on several sources of information:

- Well drilling data[1]
- The Massachusetts OnLIne ViewER (OLIVER)[2]
    - Bedrock lithology data
    - Surficial Geology depth data
    - Surficial Geology type data
- Geologic map showing surficial materials of Massachusetts[3]

The locations of the well drilling data, used for the description of the subsurface, are shown in Figure 3.1. OLIVER provided information on surficial geology depth and bedrock lithology (Figure 3.2 and Figure 3.3). Based on this information, the relevant subsurface at the location of UMass Dartmouth mainly consists of a relatively thin layer of glacial till and bedrock.

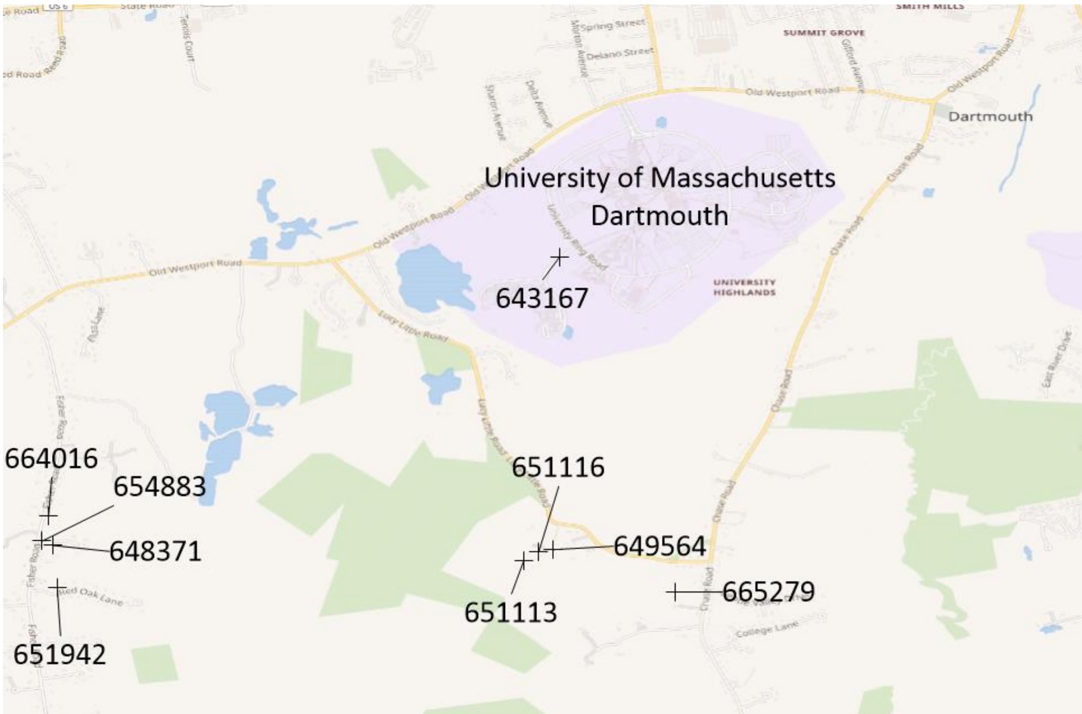
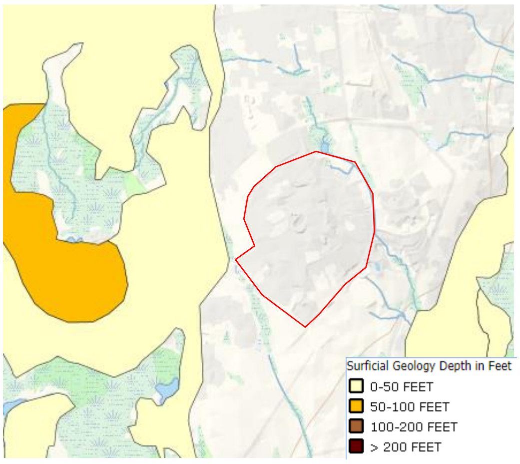


Figure 3.1 | Well locations of drilling data (Energy and Environmental Affairs Data Portal, Commonwealth of Massachusetts, d.d. 18 June 2020)



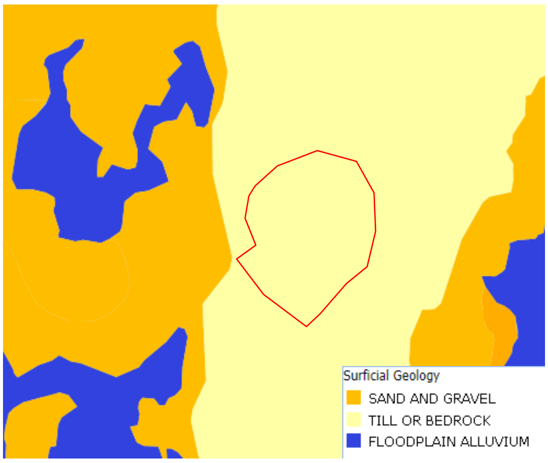


Figure 3.2 | Surficial geology depth in the area of UMass Dartmouth (red outline) (OLIVER, d.d. 18 June 2020)

Figure 3.3 | Surficial geology type in the area of UMass Dartmouth (red outline) (OLIVER, d.d. 18 June 2020)

An inventory of the hydrogeology in the area of the University of Massachusetts Dartmouth, based on the information described above, is shown in Table 3.1.

Table 3.1 | Subsurface description

top	bottom	thickness	type	lithology
[ftbgl]	[ftbgl]	[feet]		
0	30 - 80*	30 - 80	boulders, occasionally sand, gravel and clay	till
30 - 80*	425	> 350	Avalon granite and pelitic rocks	bedrock

* highly variable in available drilling data

The upper subsurface consists of glacial till deposits including large boulders, sand, gravel and clay. The permeability of such glacial layers is highly variable, due to the variability in grain sizes. This is visualized in Figure 3.4, showing the yield of the present aquifers. In the deeper subsurface, bedrock (mainly granite) is the dominant lithology. As can be seen in Figure 3.2, the depth of occurrence of this bedrock layer varies between 0 and 100 ft in the surrounding area.

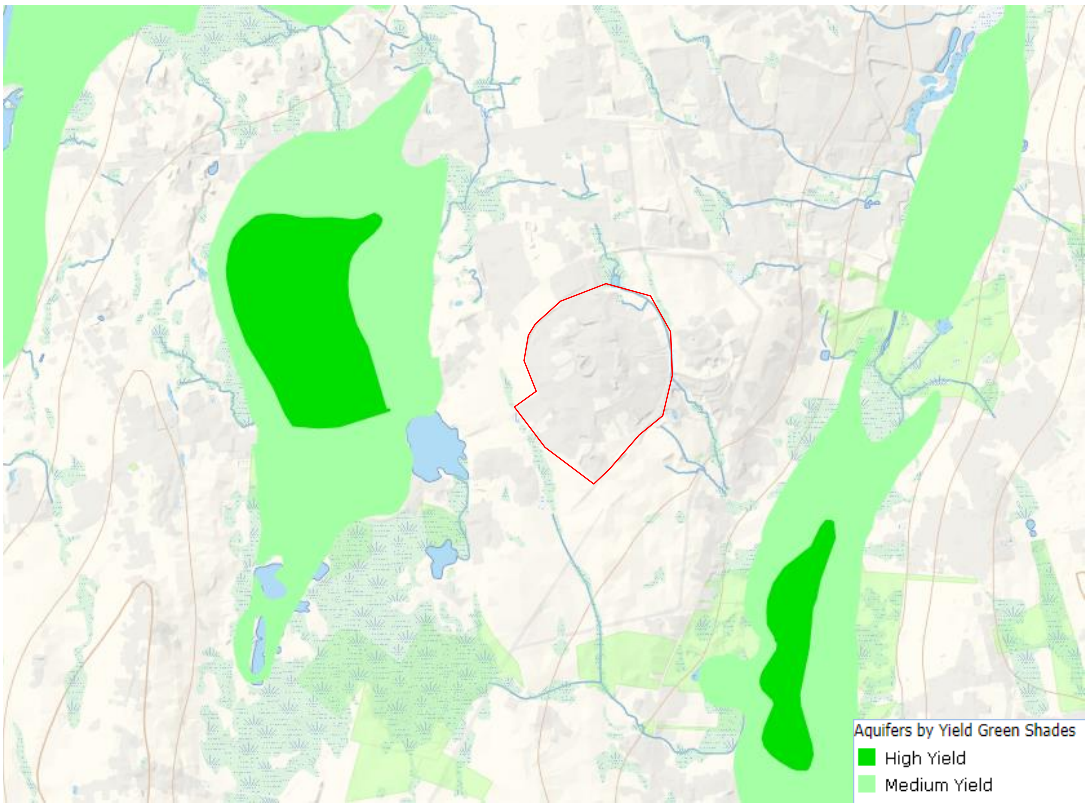


Figure 3.4 | Aquifers by yield surrounding UMass Dartmouth area (red outline) (OLIVER, d.d. 18 June 2020)

3.2 OPTIONS FOR ATES

The subsurface description shows that there are no promising layers for ATES (Aquifer Thermal Energy Storage) at the location of UMass Dartmouth. The upper till layer is not suited for ATES due to its limited thickness and shallow depth. For the expected required flow rates (based on the energy requirements) of more than 2.000 m^3/h this layer is not suitable. Furthermore, a colour gradient from brown to grey is observed in the soil descriptions of the drillings, which indicates the presence of a redox transition, possible from oxic to anoxic conditions. This forms a potential risk for ATES well clogging, resulting from the precipitation of iron oxides.

West of the university area more suitable aquifers are present. However, these areas serve as a source for public drinking water supply (Figure 3.5). Restrictions apply for these areas. Furthermore, long pipelines (> 1 km) are required when using these adjacent aquifers for ATES, resulting to high costs and heat loss.

East of the university area is also an aquifer situated (Figure 3.4 and 3.5). The limited available information shows that an abstraction well is positioned here too, but also that the aquifer is quite thin and at the top.

The west and the east aquifers are relative shallow and lay at the top of the formation. This means that ATES couldn't be applied in a safe way due to the clogging risks and the bursting of injected groundwater to the surface.

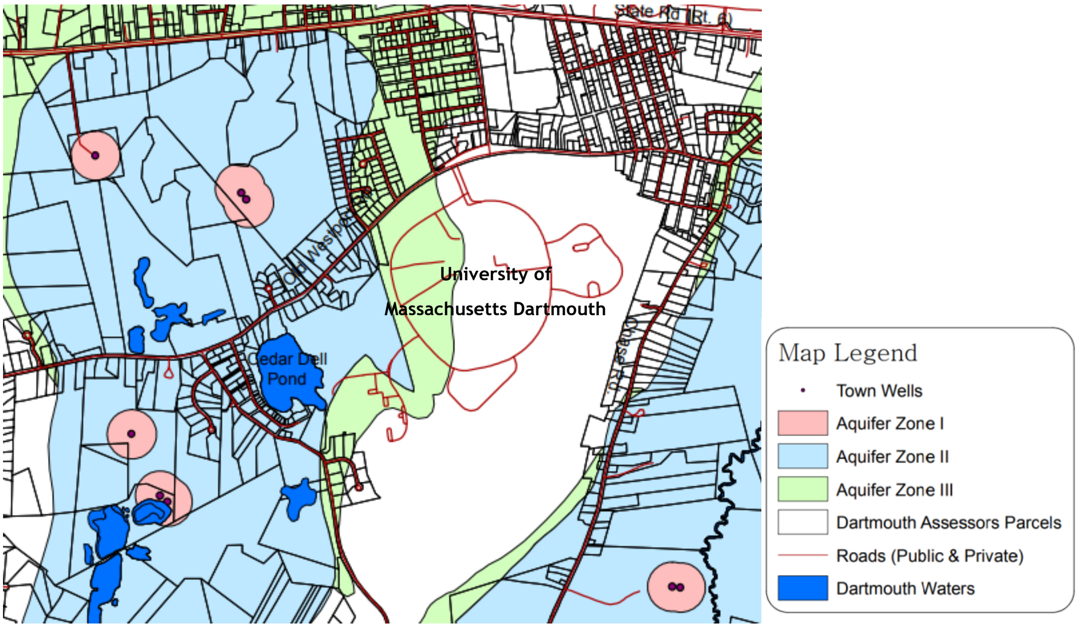


Figure 3.5 | Dartmouth Zoning Map Aquifer Protection Districts[4]

3.3 OPTIONS FOR BTES

The subsurface lithology is less important for BTES compared to ATES. The parameters that are important are thermal conductivity, heat capacity, groundwater level, subsurface temperature and the depth of the borehole. Based on the subsurface description, the thermal conductivity is typically around 2.1 W/(m·K) for till and 3.4 W/(m·K) for granite. These values correspond to soil and bedrock thermal conductivity measurements from the Massachusetts Geological Survey[5]. The heat capacity typically ranges between 2 - 3 MJ/(m^3·K). The groundwater table typically lies at around 12 ft below surface level[1]. This is favourable for both the thermal conductivity and the heat capacity. The subsurface temperature (measured at a depth of 30 – 50 feet) is generally 50°F (10°C) and constant throughout the year[6]. The depth that can be used depends primarily on the applied drilling technology and is yet unknown.

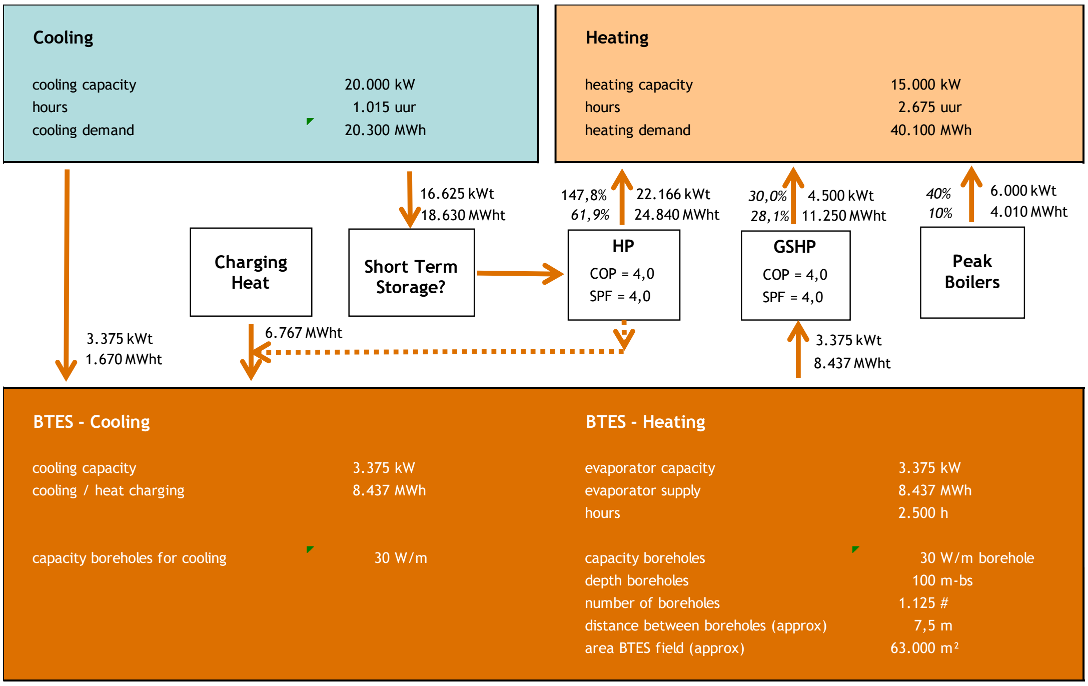
BTES could be applied at the Umass Dartmouth campus due to the good thermal conductivity of the granite. On the other hand, the drilling of the boreholes is an intensive and relative slow process. Based on experiences with the drilling and installation of boreholes in the granite in the US in general, a borehole with a depth of 300-350 feet can be made in one day. From a technical point of view it is recommended to drill and install a borehole at the same day, to prevent the collapse of the borehole or the drop of sediments into a drilled borehole.

4 Energy concept & Costs

4.1 ENERGY CONCEPT

Based on the hydrogeological assessment, it can be concluded that ATES cannot be applied. For BTES there are possibilities due to the good thermal conductivity of the granite. Therefore, an energy concept with BTES is worked out in more detail.

Based on the starting points, as mentioned in Chapter 1, the following energy concept is made:



Explanation and comments on the energy concept:

- Assumption: heating supply GSHP 30% (in kW and 2,500 equivalent hours).
- Heat pumps will be used for simultaneous heat and cold production, with possible short term storage. The capacity is determined based on the cooling capacity. This could be a 4-pipes air heat pump.
- Energy balanced BTES -> charging heat in summer is required. For example by using solar collectors and condensor heat of the HP when running in cooling mode.
- Low temperature heating system for the BTES + HP system.
- A max depth of 100 m (333 Ft) is chosen, because drillers can finish one borehole to 100 m in one day. Deeper is technically possible, but costs/meter can increase rapidly.

Using this energy concept, the following design can be made for the BTES system:

BTES design

- Amount of boreholes 1,125
- Depth 100 m (333 Ft)
- Distance between boreholes 7.5 m
- Required space 6.3 hectares
- Capacity of a borehole 30 W/m (9 W/Ft)
- Capacity of a borehole 3,000 W/borehole

Costs estimation

- Costs per Ft borehole $ 25/Ft borehole (+/- $ 5/Ft)
- Costs of the total BTES $ 9,400,000

4.2 CONCLUSIONS

- ATES can't be applied on the campus due to a lack of suitable aquifers.
- Aquifer west and east of the campus are also not suitable, because they are shallow and at the top of the formation, resulting in high risks of clogging and the burst of injected water to the surface.
- BTES can be used as a part of the energy solution for the heating and cooling of the Umass Dartmouth Campus, due to the good thermal conductivity of the granite.
- A borehole loop can provide 30 W/m based on the actual energy concept with an energy balance in the borehole field.
- The drilling process is a time consuming activity and therefore resulting in relative high costs for the installation of borehole loops. Also the max depth will be reduced by practical and financial incentives.

4.3 RECOMMENDATIONS

We recommend the following:

- Currently, the supply temperature for heating is 75 – 80 ºC. A high supply temperature for heating will result in higher loss of energy and sometimes in a higher cooling demand. It is recommend to investigate if the high supply temperature can be reduced to lower temperatures. This will reduces the energy loss and makes it easier to implement sustainable solutions as BTES and heat pumps.
- When heating and cooling is required at the same time, it might be possible to install a four-pipes air heat pump.

5 Sources

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Commonwealth of Massachusetts Energy and Environmental Affairs Data Portal: Well Drilling
Viewed: 18 June 2020
https://eeaonline.eea.state.ma.us/portal#!/search/welldrilling

2.
The Massachusetts Office of Coastal Zone Management (CZM), the Bureau of Geographic Information (MassGIS), SeaPlan (formerly the Massachusetts Ocean Partnership), Applied Science Associates (ASA), Charlton Galvarino, PeopleGIS
The Massachusetts OnLIne ViewER (OLIVER)
Viewed: 18 June 2020
http://maps.massgis.state.ma.us/map_ol/oliver.php

3.
Stone, B.D., DiGiacomo-Cohen M.L. (2018), Surficial Materials Map of the Fall River East Quadrangle, Massachusetts

4.
Town of Dartmouth Massachusetts, Dartmouth Zoning Map Aquifer Protection Districts
Viewed: 18 June 2020
https://www.town.dartmouth.ma.us/gis-maps-assessors-tax-map-sheets/pages/aquifer-maps

5.
Rhodes, J.M., Koteas, C.G., Mabee, S.B., Ryan, A., Isaacson, M. (2013), The Massachusetts Geothermal Data Project
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6.
Ground Temperatures as a Function of Location, Season, and Depth
https://www.builditsolar.com/Projects/Cooling/EarthTemperatures.htm

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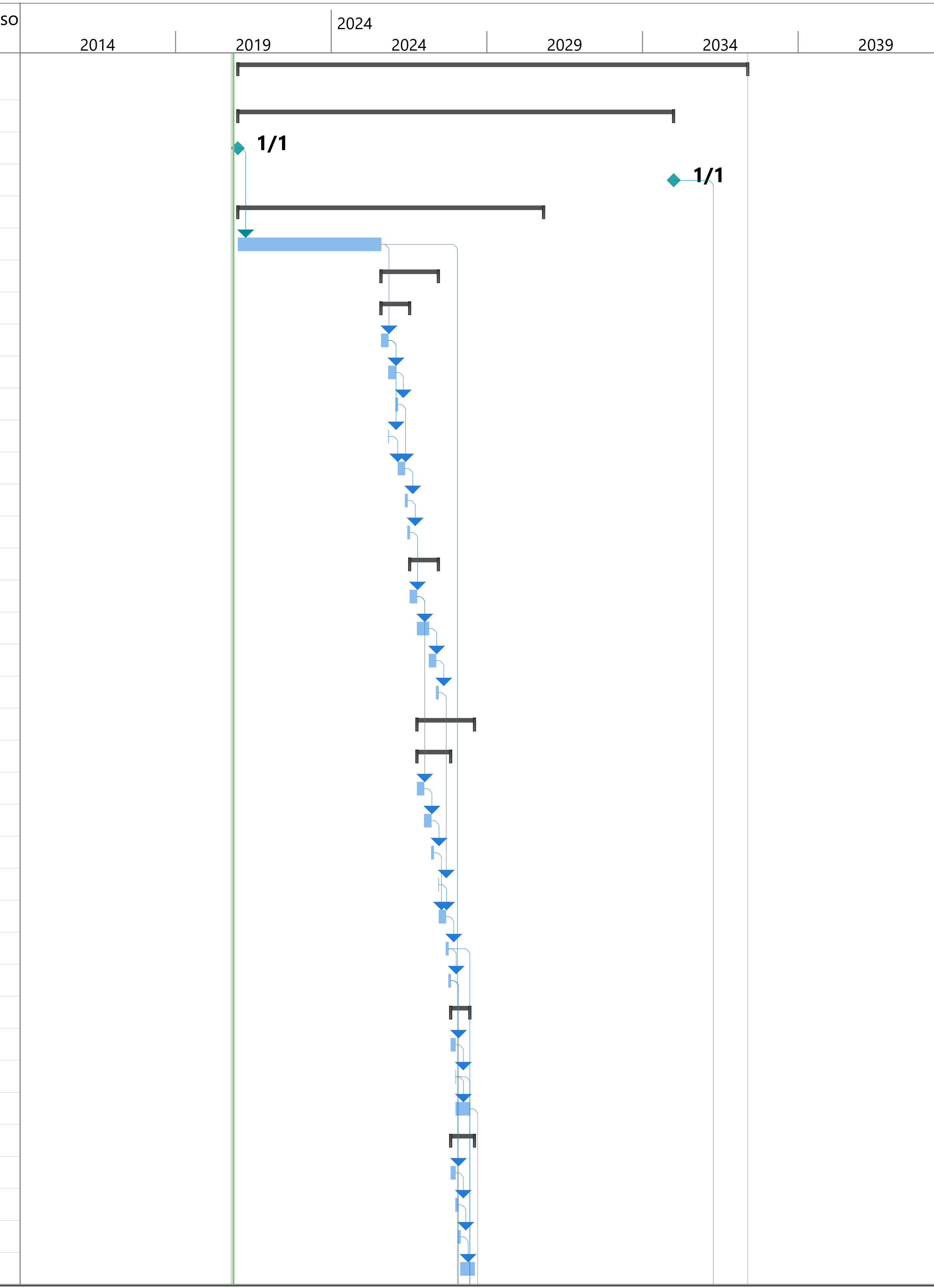
APPENDIX B
IMPLEMENTATION SCHEDULES

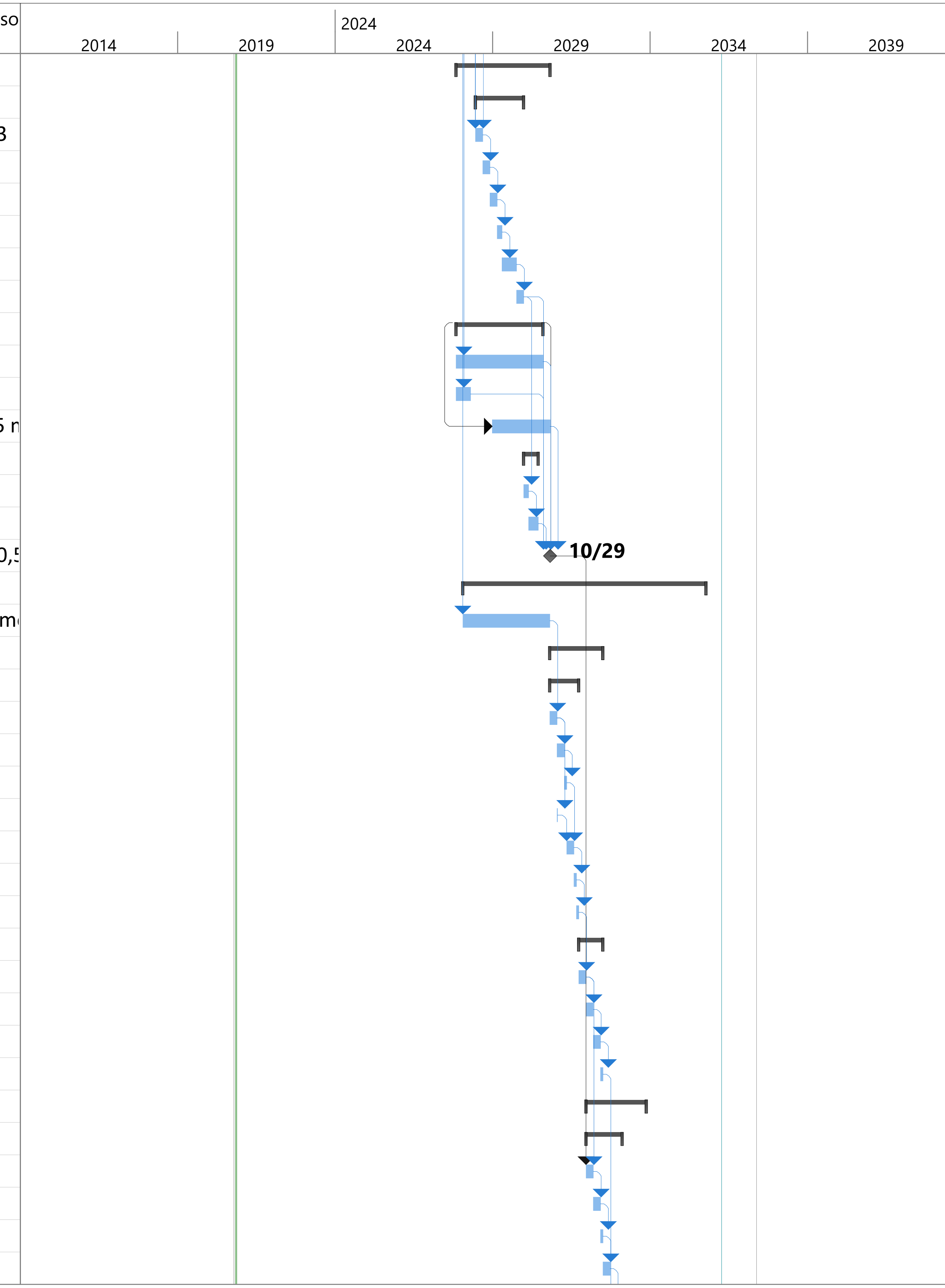
ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		**UMassD Energy Master Plan Schedule**	**4274 days**	**Fri 1/1/21**	**Wed 5/20/37**	
2		**Manual Schedule Inputs**	**3651 days**	**Fri 1/1/21**	**Mon 1/1/35**	
3		Completion of Energy Master Plan	0 days	Fri 1/1/21	Fri 1/1/21	
4		Retirement of Natural Gas Turbine	0 days	Mon 1/1/35	Mon 1/1/35	
5		**Phase 1 - Enabling and Centralization**	**2563 days**	**Fri 1/1/21**	**Tue 10/29/30**	
6		Funding authorization from state for Phase 1	60 mons	Fri 1/1/21	Thu 8/7/25	3
7		**Engineering**	**480 days**	**Fri 8/8/25**	**Thu 6/10/27**	
8		**Procurement**	**240 days**	**Fri 8/8/25**	**Thu 7/9/26**	
9		RFQ Generation	3 mons	Fri 8/8/25	Thu 10/30/25	6
10		RFQ Solicitation	3 mons	Fri 10/31/25	Thu 1/22/26	9
11		Short List	1 mon	Fri 1/23/26	Thu 2/19/26	10
12		RFP Generation	3 days	Fri 10/31/25	Tue 11/4/25	9
13		RFP Solicitation	3 mons	Fri 2/20/26	Thu 5/14/26	12,11
14		Interviews	1 mon	Fri 5/15/26	Thu 6/11/26	13
15		Notification of Award	1 mon	Fri 6/12/26	Thu 7/9/26	14
16		**Design**	**240 days**	**Fri 7/10/26**	**Thu 6/10/27**	
17		30% Design	3 mons	Fri 7/10/26	Thu 10/1/26	15
18		60% Design	5 mons	Fri 10/2/26	Thu 2/18/27	17
19		90% Design	3 mons	Fri 2/19/27	Thu 5/13/27	18
20		100% Design	1 mon	Fri 5/14/27	Thu 6/10/27	19
21		**Procurement**	**483 days**	**Fri 10/2/26**	**Tue 8/8/28**	
22		**Contractor Procurement**	**283 days**	**Fri 10/2/26**	**Tue 11/2/27**	
23		RFQ Generation	3 mons	Fri 10/2/26	Thu 12/24/26	17
24		RFQ Solicitation	3 mons	Fri 12/25/26	Thu 3/18/27	23
25		Short List	1 mon	Fri 3/19/27	Thu 4/15/27	24
26		RFP Generation	3 days	Fri 6/11/27	Tue 6/15/27	20
27		RFP Solicitation	3 mons	Wed 6/16/27	Tue 9/7/27	26,25
28		Interviews	1 mon	Wed 9/8/27	Tue 10/5/27	27
29		Notification of Award	1 mon	Wed 10/6/27	Tue 11/2/27	28
30		**Permitting**	**161 days**	**Wed 11/3/27**	**Wed 6/14/28**	
31		Draft Permit Applications	2 mons	Wed 11/3/27	Tue 12/28/27	29
32		Submit Permit Applications	1 day	Wed 12/29/27	Wed 12/29/27	31
33		Permitting Approvals	6 mons	Thu 12/30/27	Wed 6/14/28	32
34		**Long Lead Equipment**	**200 days**	**Wed 11/3/27**	**Tue 8/8/28**	
35		Solicitation of Bids	2 mons	Wed 11/3/27	Tue 12/28/27	29
36		Recommendation for Award	1 mon	Wed 12/29/27	Tue 1/25/28	35
37		Award	1 mon	Wed 1/26/28	Tue 2/22/28	36
38		Lead Time	6 mons	Wed 2/23/28	Tue 8/8/28	37



Project: UMassD EMP Impleme
Date: Mon 11/9/20

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

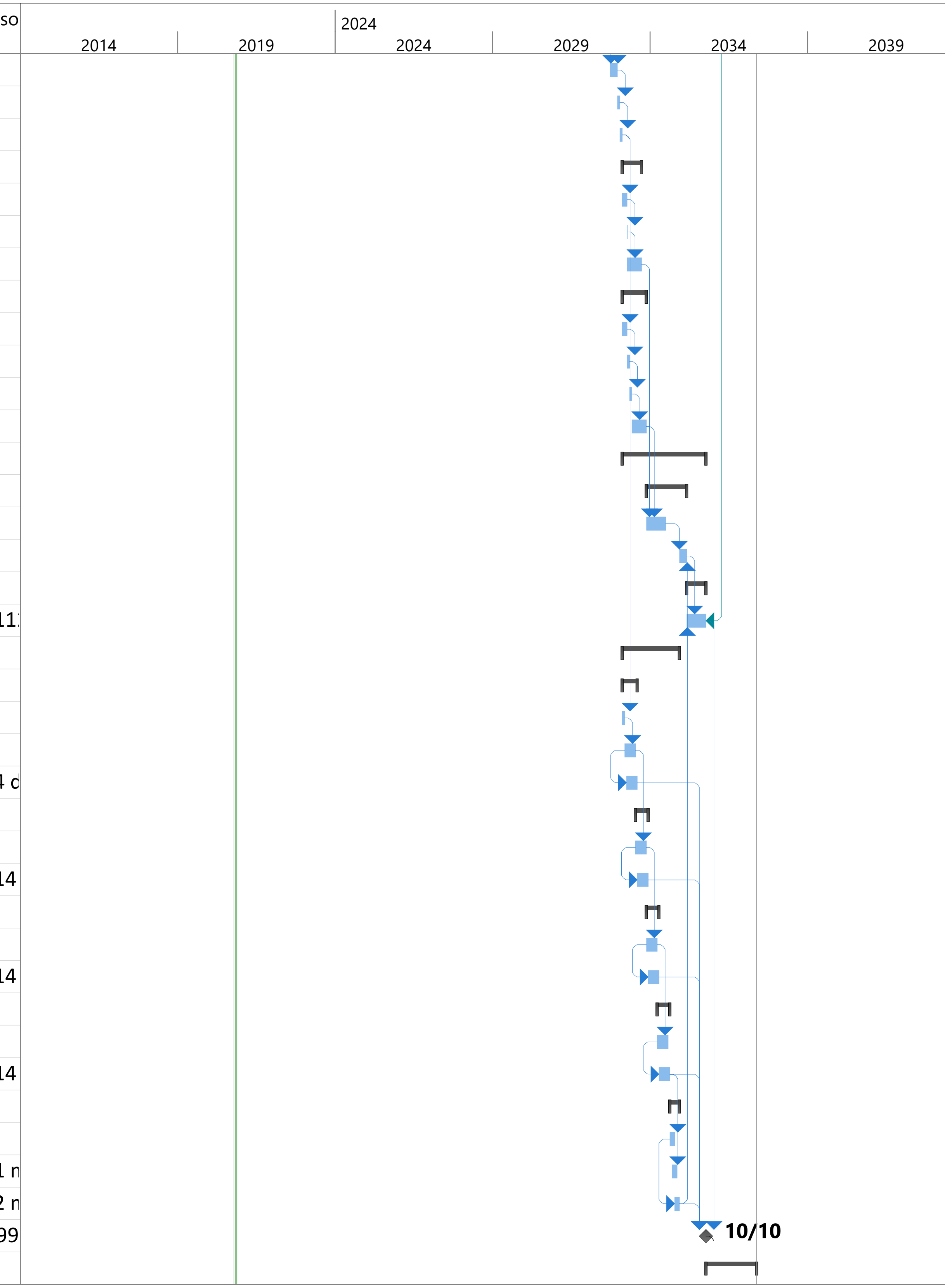
ID	Task Mode	Task Name	Duration	Start	Finish	Predecesso
39		**Construction**	**780 days**	**Wed 11/3/27**	**Tue 10/29/30**	
40		**Net Zero Plant**	**400 days**	**Thu 6/15/28**	**Wed 12/26/29**	
41		Ground Prep	3 mons	Thu 6/15/28	Wed 9/6/28	28,32,33
42		Foundation	3 mons	Thu 9/7/28	Wed 11/29/28	41
43		PEMB	3 mons	Thu 11/30/28	Wed 2/21/29	42
44		Interior Finishes	2 mons	Thu 2/22/29	Wed 4/18/29	43
45		Installation of equipment, piping, electrical	6 mons	Thu 4/19/29	Wed 10/3/29	44
46		Commissioning	3 mons	Thu 10/4/29	Wed 12/26/29	45
47		**Distribution Systems**	**720 days**	**Wed 11/3/27**	**Tue 8/6/30**	
48		Distribution System Construction	36 mons	Wed 11/3/27	Tue 8/6/30	29
49		TTES Construction	6 mons	Wed 11/3/27	Tue 4/18/28	29
50		Building level modifications	24 mons	Wed 12/27/28	Tue 10/29/30	47SS+15 r
51		**Steam Plant Modifications**	**120 days**	**Thu 12/27/29**	**Wed 6/12/30**	
52		Removal of Pony Boiler	2 mons	Thu 12/27/29	Wed 2/20/30	46
53		Installation of Steam to Hot Water Heat Exchangers	4 mons	Thu 2/21/30	Wed 6/12/30	52
54		Phase 1 Complete	0 days	Tue 10/29/30	Tue 10/29/30	47,46,50,5
55		**Phase 2 - Earnest Shift from Fossil Fuels to Electrification**	**2014 days**	**Fri 1/21/28**	**Wed 10/10/35**	
56		Funding authorization from state for Phase 2	36 mons	Fri 1/21/28	Thu 10/24/30	6FS+32 m
57		**Engineering**	**440 days**	**Fri 10/25/30**	**Thu 7/1/32**	
58		**Procurement**	**240 days**	**Fri 10/25/30**	**Thu 9/25/31**	
59		RFQ Generation	3 mons	Fri 10/25/30	Thu 1/16/31	56
60		RFQ Solicitation	3 mons	Fri 1/17/31	Thu 4/10/31	59
61		Short List	1 mon	Fri 4/11/31	Thu 5/8/31	60
62		RFP Generation	3 days	Fri 1/17/31	Tue 1/21/31	59
63		RFP Solicitation	3 mons	Fri 5/9/31	Thu 7/31/31	62,61
64		Interviews	1 mon	Fri 8/1/31	Thu 8/28/31	63
65		Notification of Award	1 mon	Fri 8/29/31	Thu 9/25/31	64
66		**Design**	**200 days**	**Fri 9/26/31**	**Thu 7/1/32**	
67		30% Design	3 mons	Fri 9/26/31	Thu 12/18/31	65
68		60% Design	3 mons	Fri 12/19/31	Thu 3/11/32	67
69		90% Design	3 mons	Fri 3/12/32	Thu 6/3/32	68
70		100% Design	1 mon	Fri 6/4/32	Thu 7/1/32	69
71		**Procurement**	**500 days**	**Fri 12/19/31**	**Thu 11/17/33**	
72		**Contractor Procurement**	**300 days**	**Fri 12/19/31**	**Thu 2/10/33**	
73		RFQ Generation	3 mons	Fri 12/19/31	Thu 3/11/32	67,54
74		RFQ Solicitation	3 mons	Fri 3/12/32	Thu 6/3/32	73
75		Short List	1 mon	Fri 6/4/32	Thu 7/1/32	74
76		RFP Generation	3 mons	Fri 7/2/32	Thu 9/23/32	70



Project: UMassD EMP Impleme
Date: Mon 11/9/20

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecesso
77			RFP Solicitation	3 mons	Fri 9/24/32	Thu 12/16/32	76,75
78			Interviews	1 mon	Fri 12/17/32	Thu 1/13/33	77
79			Notification of Award	1 mon	Fri 1/14/33	Thu 2/10/33	78
80			**Permitting**	**161 days**	**Fri 2/11/33**	**Fri 9/23/33**	
81			Draft Permit Applications	2 mons	Fri 2/11/33	Thu 4/7/33	79
82			Submit Permit Applications	1 day	Fri 4/8/33	Fri 4/8/33	81
83			Permitting Approvals	6 mons	Mon 4/11/33	Fri 9/23/33	82
84			**Long Lead Equipment**	**200 days**	**Fri 2/11/33**	**Thu 11/17/33**	
85			Solicitation of Bids	2 mons	Fri 2/11/33	Thu 4/7/33	79
86			Recommendation for Award	1 mon	Fri 4/8/33	Thu 5/5/33	85
87			Award	1 mon	Fri 5/6/33	Thu 6/2/33	86
88			Lead Time	6 mons	Fri 6/3/33	Thu 11/17/33	87
89			**Construction**	**694 days**	**Fri 2/11/33**	**Wed 10/10/35**	
90			**Net Zero Plant**	**334 days**	**Fri 11/18/33**	**Wed 2/28/35**	
91			Installation of equipment, piping, electrical	8 mons	Fri 11/18/33	Thu 6/29/34	88,83
92			Commissioning	3 mons	Thu 12/7/34	Wed 2/28/35	91,112
93			**Steam Plant Modifications**	**160 days**	**Thu 3/1/35**	**Wed 10/10/35**	
94			Removal of mechanical and electrical equipment	8 mons	Thu 3/1/35	Wed 10/10/35	4FF,92,11
95			**Ground Array**	**474 days**	**Fri 2/11/33**	**Wed 12/6/34**	
96			**BTES-1**	**124 days**	**Fri 2/11/33**	**Wed 8/3/33**	
97			Mobilization	1 mon	Fri 2/11/33	Thu 3/10/33	79
98			Drilling	90 days	Fri 3/11/33	Thu 7/14/33	97
99			Mani folding	90 days	Thu 3/31/33	Wed 8/3/33	98SS+14 c
100			**BTES-2**	**104 days**	**Fri 7/15/33**	**Wed 12/7/33**	
101			Drilling	90 days	Fri 7/15/33	Thu 11/17/33	98
102			Mani folding	90 days	Thu 8/4/33	Wed 12/7/33	101SS+14
103			**BTES-3**	**104 days**	**Fri 11/18/33**	**Wed 4/12/34**	
104			Drilling	90 days	Fri 11/18/33	Thu 3/23/34	101
105			Mani folding	90 days	Thu 12/8/33	Wed 4/12/34	104SS+14
106			**BTES-4**	**104 days**	**Fri 3/24/34**	**Wed 8/16/34**	
107			Drilling	90 days	Fri 3/24/34	Thu 7/27/34	104
108			Mani folding	90 days	Thu 4/13/34	Wed 8/16/34	107SS+14
109			**Homerun to NetZero Plant**	**80 days**	**Thu 8/17/34**	**Wed 12/6/34**	
110			Excavation	2 mons	Thu 8/17/34	Wed 10/11/34	108
111			Piping	2 mons	Thu 9/14/34	Wed 11/8/34	108FS+1 r
112			Backfill	2 mons	Thu 10/12/34	Wed 12/6/34	110SS+2 r
113			Phase 2 Complete	0 days	Wed 10/10/35	Wed 10/10/35	112,94,99
114			**Phase 3 - Alternate Fuel Sourcing for Full Carbon Neutrality**	**420 days**	**Thu 10/11/35**	**Wed 5/20/37**	



Project: UMassD EMP Impleme
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Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecesso
115			**Electricity Procurement**	**262 days**	**Thu 10/11/35**	**Fri 10/10/36**	
116			Alternatives Analysis	4 mons	Thu 10/11/35	Wed 1/30/36	113
117			Procurement Specification	2 days	Thu 1/31/36	Fri 2/1/36	116
118			Solicitation of Bids	3 mons	Mon 2/4/36	Fri 4/25/36	117
119			Contract Negotiations	6 mons	Mon 4/28/36	Fri 10/10/36	118
120			**Bio Diesel - Procurement**	**262 days**	**Thu 10/11/35**	**Fri 10/10/36**	
121			Alternatives Analysis	4 mons	Thu 10/11/35	Wed 1/30/36	113
122			Procurement Specification	2 days	Thu 1/31/36	Fri 2/1/36	121
123			Solicitation of Bids	3 mons	Mon 2/4/36	Fri 4/25/36	122
124			Contract Negotiations	6 mons	Mon 4/28/36	Fri 10/10/36	123
125			Sole Sourced Engineering	3 mons	Thu 10/11/35	Wed 1/2/36	113
126			**Procurement**	**280 days**	**Thu 1/3/36**	**Wed 1/28/37**	
127			**Contractor Procurement**	**120 days**	**Thu 1/3/36**	**Wed 6/18/36**	
128			RFP Generation	2 mons	Thu 1/3/36	Wed 2/27/36	125
129			RFP Solicitation	2 mons	Thu 2/28/36	Wed 4/23/36	128
130			Interviews	1 mon	Thu 4/24/36	Wed 5/21/36	129
131			Notification of Award	1 mon	Thu 5/22/36	Wed 6/18/36	130
132			**Permitting**	**41 days**	**Thu 6/19/36**	**Thu 8/14/36**	
133			Draft Permit Applications	1 mon	Thu 6/19/36	Wed 7/16/36	131
134			Submit Permit Applications	1 day	Thu 7/17/36	Thu 7/17/36	133
135			Permitting Approvals	1 mon	Fri 7/18/36	Thu 8/14/36	134
136			**Long Lead Equipment**	**160 days**	**Thu 6/19/36**	**Wed 1/28/37**	
137			Solicitation of Bids	2 mons	Thu 6/19/36	Wed 8/13/36	131
138			Recommendation for Award	1 mon	Thu 8/14/36	Wed 9/10/36	137
139			Award	1 mon	Thu 9/11/36	Wed 10/8/36	138
140			Lead Time	4 mons	Thu 10/9/36	Wed 1/28/37	139
141			**Construction**	**199 days**	**Fri 8/15/36**	**Wed 5/20/37**	
142			**Bio Diesel Tanks**	**199 days**	**Fri 8/15/36**	**Wed 5/20/37**	
143			Ground Prep	1 mon	Fri 8/15/36	Thu 9/11/36	135
144			Foundation	1 mon	Fri 9/12/36	Thu 10/9/36	143
145			Installation of tanks	1 mon	Thu 1/29/37	Wed 2/25/37	140,144
146			Piping	2 mons	Thu 2/26/37	Wed 4/22/37	145
147			Commissioning	1 mon	Thu 4/23/37	Wed 5/20/37	146
148			Phase 3 Complete	0 days	Wed 5/20/37	Wed 5/20/37	147,124,1

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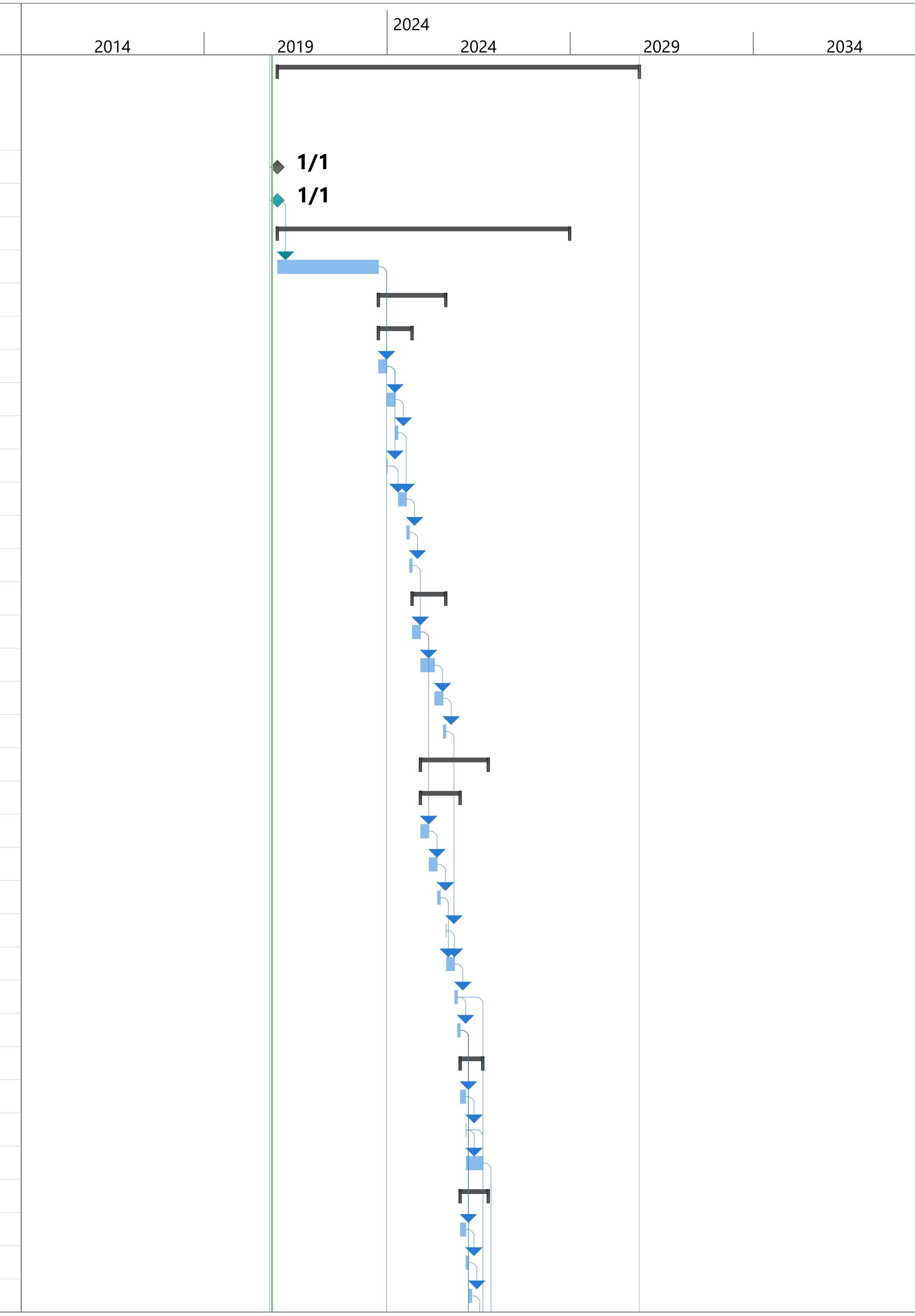
Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		**UMassD Energy Master Plan Accelerated Schedule**	**2580 days**	**Fri 1/1/21**	**Thu 11/21/30**	
2		**Manual Schedule Inputs**	**0 days**	**Fri 1/1/21**	**Fri 1/1/21**	
3		Completion of Energy Master Plan	0 days	Fri 1/1/21	Fri 1/1/21	
4		**Phase 1 - Enabling and Centralization**	**2083 days**	**Fri 1/1/21**	**Tue 12/26/28**	
5		Funding authorization from state for Phase 1	36 mons	Fri 1/1/21	Thu 10/5/23	3
6		**Engineering**	**480 days**	**Fri 10/6/23**	**Thu 8/7/25**	
7		**Procurement**	**240 days**	**Fri 10/6/23**	**Thu 9/5/24**	
8		RFQ Generation	3 mons	Fri 10/6/23	Thu 12/28/23	5
9		RFQ Solicitation	3 mons	Fri 12/29/23	Thu 3/21/24	8
10		Short List	1 mon	Fri 3/22/24	Thu 4/18/24	9
11		RFP Generation	3 days	Fri 12/29/23	Tue 1/2/24	8
12		RFP Solicitation	3 mons	Fri 4/19/24	Thu 7/11/24	11,10
13		Interviews	1 mon	Fri 7/12/24	Thu 8/8/24	12
14		Notification of Award	1 mon	Fri 8/9/24	Thu 9/5/24	13
15		**Design**	**240 days**	**Fri 9/6/24**	**Thu 8/7/25**	
16		30% Design	3 mons	Fri 9/6/24	Thu 11/28/24	14
17		60% Design	5 mons	Fri 11/29/24	Thu 4/17/25	16
18		90% Design	3 mons	Fri 4/18/25	Thu 7/10/25	17
19		100% Design	1 mon	Fri 7/11/25	Thu 8/7/25	18
20		**Procurement**	**483 days**	**Fri 11/29/24**	**Tue 10/6/26**	
21		**Contractor Procurement**	**283 days**	**Fri 11/29/24**	**Tue 12/30/25**	
22		RFQ Generation	3 mons	Fri 11/29/24	Thu 2/20/25	16
23		RFQ Solicitation	3 mons	Fri 2/21/25	Thu 5/15/25	22
24		Short List	1 mon	Fri 5/16/25	Thu 6/12/25	23
25		RFP Generation	3 days	Fri 8/8/25	Tue 8/12/25	19
26		RFP Solicitation	3 mons	Wed 8/13/25	Tue 11/4/25	25,24
27		Interviews	1 mon	Wed 11/5/25	Tue 12/2/25	26
28		Notification of Award	1 mon	Wed 12/3/25	Tue 12/30/25	27
29		**Permitting**	**161 days**	**Wed 12/31/25**	**Wed 8/12/26**	
30		Draft Permit Applications	2 mons	Wed 12/31/25	Tue 2/24/26	28
31		Submit Permit Applications	1 day	Wed 2/25/26	Wed 2/25/26	30
32		Permitting Approvals	6 mons	Thu 2/26/26	Wed 8/12/26	31
33		**Long Lead Equipment**	**200 days**	**Wed 12/31/25**	**Tue 10/6/26**	
34		Solicitation of Bids	2 mons	Wed 12/31/25	Tue 2/24/26	28
35		Recommendation for Award	1 mon	Wed 2/25/26	Tue 3/24/26	34
36		Award	1 mon	Wed 3/25/26	Tue 4/21/26	35



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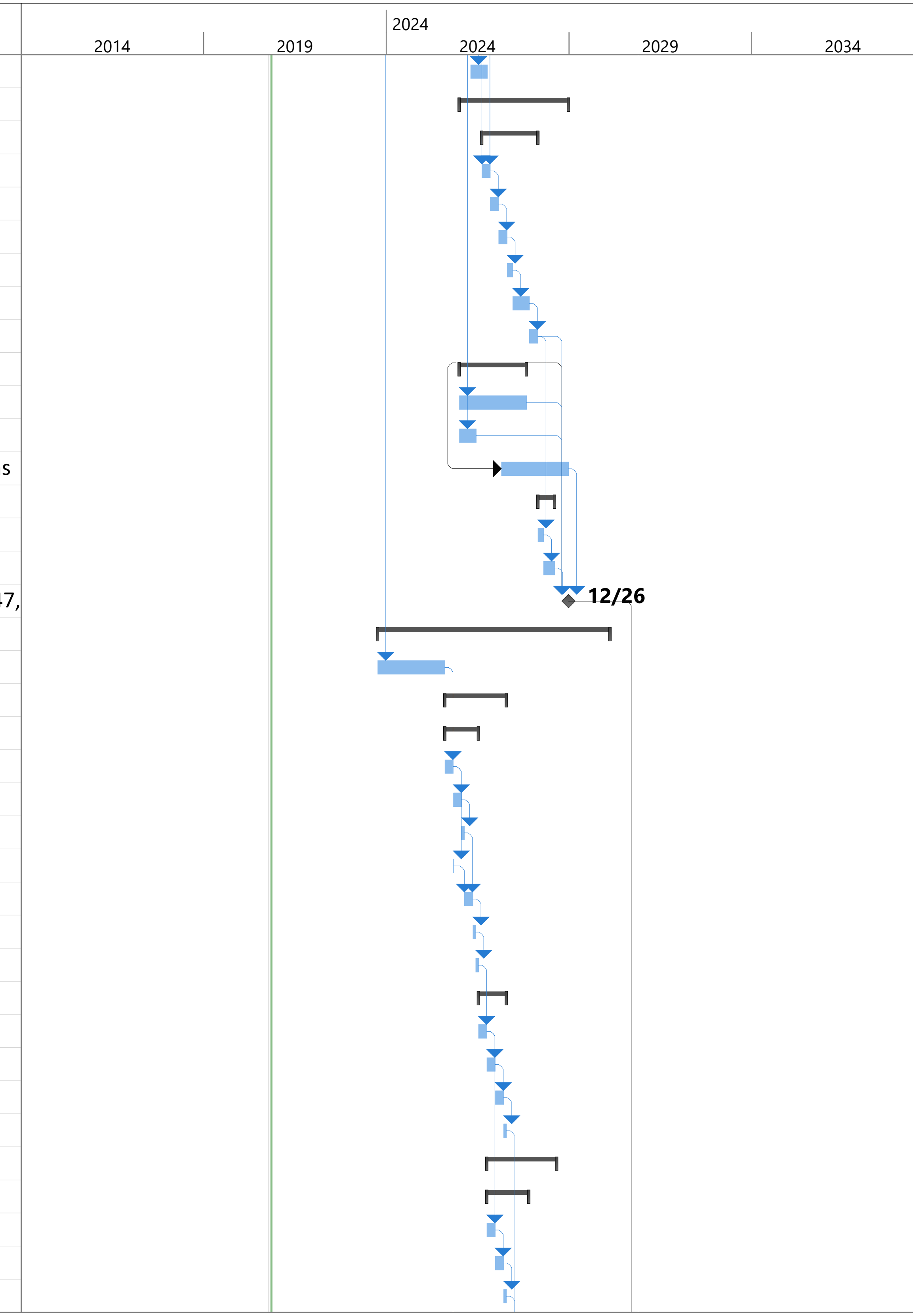
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
37			Lead Time	6 mons	Wed 4/22/26	Tue 10/6/26	36
38			**Construction**	**780 days**	**Wed 12/31/25**	**Tue 12/26/28**	
39			**Net Zero Plant**	**400 days**	**Thu 8/13/26**	**Wed 2/23/28**	
40			Ground Prep	3 mons	Thu 8/13/26	Wed 11/4/26	27,31,32
41			Foundation	3 mons	Thu 11/5/26	Wed 1/27/27	40
42			PEMB	3 mons	Thu 1/28/27	Wed 4/21/27	41
43			Interior Finishes	2 mons	Thu 4/22/27	Wed 6/16/27	42
44			Installation of equipment, piping, electrical	6 mons	Thu 6/17/27	Wed 12/1/27	43
45			Commissioning	3 mons	Thu 12/2/27	Wed 2/23/28	44
46			**Distribution Systems**	**480 days**	**Wed 12/31/25**	**Tue 11/2/27**	
47			Distribution System Construction	24 mons	Wed 12/31/25	Tue 11/2/27	28
48			TTES Construction	6 mons	Wed 12/31/25	Tue 6/16/26	28
49			Building level modifications	24 mons	Wed 2/24/27	Tue 12/26/28	46SS+15 mons
50			**Steam Plant Modifications**	**120 days**	**Thu 2/24/28**	**Wed 8/9/28**	
51			Removal of Pony Boiler	2 mons	Thu 2/24/28	Wed 4/19/28	45
52			Installation of Steam to Hot Water Heat Exchangers	4 mons	Thu 4/20/28	Wed 8/9/28	51
53			Phase 1 Complete	0 days	Tue 12/26/28	Tue 12/26/28	46,45,49,52,47,
54			**Phase 2 - Earnest Shift from Fossil Fuels to Electrification**	**1660 days**	**Fri 10/6/23**	**Thu 2/14/30**	
55			Funding authorization from state for Phase 2	24 mons	Fri 10/6/23	Thu 8/7/25	5
56			**Engineering**	**440 days**	**Fri 8/8/25**	**Thu 4/15/27**	
57			**Procurement**	**240 days**	**Fri 8/8/25**	**Thu 7/9/26**	
58			RFQ Generation	3 mons	Fri 8/8/25	Thu 10/30/25	55
59			RFQ Solicitation	3 mons	Fri 10/31/25	Thu 1/22/26	58
60			Short List	1 mon	Fri 1/23/26	Thu 2/19/26	59
61			RFP Generation	3 days	Fri 10/31/25	Tue 11/4/25	58
62			RFP Solicitation	3 mons	Fri 2/20/26	Thu 5/14/26	61,60
63			Interviews	1 mon	Fri 5/15/26	Thu 6/11/26	62
64			Notification of Award	1 mon	Fri 6/12/26	Thu 7/9/26	63
65			**Design**	**200 days**	**Fri 7/10/26**	**Thu 4/15/27**	
66			30% Design	3 mons	Fri 7/10/26	Thu 10/1/26	64
67			60% Design	3 mons	Fri 10/2/26	Thu 12/24/26	66
68			90% Design	3 mons	Fri 12/25/26	Thu 3/18/27	67
69			100% Design	1 mon	Fri 3/19/27	Thu 4/15/27	68
70			**Procurement**	**500 days**	**Fri 10/2/26**	**Thu 8/31/28**	
71			**Contractor Procurement**	**300 days**	**Fri 10/2/26**	**Thu 11/25/27**	
72			RFQ Generation	3 mons	Fri 10/2/26	Thu 12/24/26	66
73			RFQ Solicitation	3 mons	Fri 12/25/26	Thu 3/18/27	72
74			Short List	1 mon	Fri 3/19/27	Thu 4/15/27	73



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Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
75		RFP Generation	3 mons	Fri 4/16/27	Thu 7/8/27	69
76		RFP Solicitation	3 mons	Fri 7/9/27	Thu 9/30/27	75,74
77		Interviews	1 mon	Fri 10/1/27	Thu 10/28/27	76
78		Notification of Award	1 mon	Fri 10/29/27	Thu 11/25/27	77
79		**Permitting**	**161 days**	**Fri 11/26/27**	**Fri 7/7/28**	
80		Draft Permit Applications	2 mons	Fri 11/26/27	Thu 1/20/28	78
81		Submit Permit Applications	1 day	Fri 1/21/28	Fri 1/21/28	80
82		Permitting Approvals	6 mons	Mon 1/24/28	Fri 7/7/28	81
83		**Long Lead Equipment**	**200 days**	**Fri 11/26/27**	**Thu 8/31/28**	
84		Solicitation of Bids	2 mons	Fri 11/26/27	Thu 1/20/28	78
85		Recommendation for Award	1 mon	Fri 1/21/28	Thu 2/17/28	84
86		Award	1 mon	Fri 2/18/28	Thu 3/16/28	85
87		Lead Time	6 mons	Fri 3/17/28	Thu 8/31/28	86
88		**Construction**	**580 days**	**Fri 11/26/27**	**Thu 2/14/30**	
89		**Net Zero Plant**	**220 days**	**Fri 9/1/28**	**Thu 7/5/29**	
90		Installation of equipment, piping, electrical	8 mons	Fri 9/1/28	Thu 4/12/29	87,82
91		Commissioning	3 mons	Fri 4/13/29	Thu 7/5/29	90,111
92		**Steam Plant Modifications**	**160 days**	**Fri 7/6/29**	**Thu 2/14/30**	
93		Removal of mechanical and electrical equipment	8 mons	Fri 7/6/29	Thu 2/14/30	91,111
94		**Ground Array**	**294 days**	**Fri 11/26/27**	**Wed 1/10/29**	
95		**BTES-1**	**124 days**	**Fri 11/26/27**	**Wed 5/17/28**	
96		Mobilization	1 mon	Fri 11/26/27	Thu 12/23/27	78
97		Drilling	90 days	Fri 12/24/27	Thu 4/27/28	96
98		Mani folding	90 days	Thu 1/13/28	Wed 5/17/28	97SS+14 days
99		**BTES-2**	**104 days**	**Fri 4/28/28**	**Wed 9/20/28**	
100		Drilling	90 days	Fri 4/28/28	Thu 8/31/28	97
101		Mani folding	90 days	Thu 5/18/28	Wed 9/20/28	100SS+14 days
102		**BTES-3**	**104 days**	**Fri 12/24/27**	**Wed 5/17/28**	
103		Drilling	90 days	Fri 12/24/27	Thu 4/27/28	96
104		Mani folding	90 days	Thu 1/13/28	Wed 5/17/28	103SS+14 days
105		**BTES-4**	**104 days**	**Fri 4/28/28**	**Wed 9/20/28**	
106		Drilling	90 days	Fri 4/28/28	Thu 8/31/28	103
107		Mani folding	90 days	Thu 5/18/28	Wed 9/20/28	106SS+14 days
108		**Homerun to NetZero Plant**	**80 days**	**Thu 9/21/28**	**Wed 1/10/29**	
109		Excavation	2 mons	Thu 9/21/28	Wed 11/15/28	107
110		Piping	2 mons	Thu 10/19/28	Wed 12/13/28	107FS+1 mon
111		Backfill	2 mons	Thu 11/16/28	Wed 1/10/29	109SS+2 mons
112		Phase 2 Complete	0 days	Thu 2/14/30	Thu 2/14/30	111,93,98,101,

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ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
113			**Phase 3 - Alternate Fuel Sourcing for Full Carbon Neutrality**	**1380 days**	**Fri 8/8/25**	**Thu 11/21/30**	
114			Funding authorization from state for Phase	48 mons	Fri 8/8/25	Thu 4/12/29	55
115			**Electricity Procurement**	**262 days**	**Fri 4/13/29**	**Mon 4/15/30**	
116			Alternatives Analysis	4 mons	Fri 4/13/29	Thu 8/2/29	114
117			Procurement Specification	2 days	Fri 8/3/29	Mon 8/6/29	116
118			Solicitation of Bids	3 mons	Tue 8/7/29	Mon 10/29/29	117
119			Contract Negotiations	6 mons	Tue 10/30/29	Mon 4/15/30	118
120			**Bio Diesel - Procurement**	**262 days**	**Fri 4/13/29**	**Mon 4/15/30**	
121			Alternatives Analysis	4 mons	Fri 4/13/29	Thu 8/2/29	114
122			Procurement Specification	2 days	Fri 8/3/29	Mon 8/6/29	121
123			Solicitation of Bids	3 mons	Tue 8/7/29	Mon 10/29/29	122
124			Contract Negotiations	6 mons	Tue 10/30/29	Mon 4/15/30	123
125			Sole Sourced Engineering	3 mons	Fri 4/13/29	Thu 7/5/29	114
126			**Procurement**	**280 days**	**Fri 7/6/29**	**Thu 8/1/30**	
127			**Contractor Procurement**	**120 days**	**Fri 7/6/29**	**Thu 12/20/29**	
128			RFP Generation	2 mons	Fri 7/6/29	Thu 8/30/29	125
129			RFP Solicitation	2 mons	Fri 8/31/29	Thu 10/25/29	128
130			Interviews	1 mon	Fri 10/26/29	Thu 11/22/29	129
131			Notification of Award	1 mon	Fri 11/23/29	Thu 12/20/29	130
132			**Permitting**	**41 days**	**Fri 12/21/29**	**Fri 2/15/30**	
133			Draft Permit Applications	1 mon	Fri 12/21/29	Thu 1/17/30	131
134			Submit Permit Applications	1 day	Fri 1/18/30	Fri 1/18/30	133
135			Permitting Approvals	1 mon	Mon 1/21/30	Fri 2/15/30	134
136			**Long Lead Equipment**	**160 days**	**Fri 12/21/29**	**Thu 8/1/30**	
137			Solicitation of Bids	2 mons	Fri 12/21/29	Thu 2/14/30	131
138			Recommendation for Award	1 mon	Fri 2/15/30	Thu 3/14/30	137
139			Award	1 mon	Fri 3/15/30	Thu 4/11/30	138
140			Lead Time	4 mons	Fri 4/12/30	Thu 8/1/30	139
141			**Construction**	**199 days**	**Mon 2/18/30**	**Thu 11/21/30**	
142			**Bio Diesel Tanks**	**199 days**	**Mon 2/18/30**	**Thu 11/21/30**	
143			Ground Prep	1 mon	Mon 2/18/30	Fri 3/15/30	135
144			Foundation	1 mon	Mon 3/18/30	Fri 4/12/30	143
145			Installation of tanks	1 mon	Fri 8/2/30	Thu 8/29/30	140,144
146			Piping	2 mons	Fri 8/30/30	Thu 10/24/30	145
147			Commissioning	1 mon	Fri 10/25/30	Thu 11/21/30	146
148			Phase 3 Complete	0 days	Thu 11/21/30	Thu 11/21/30	147,124,119
149			Project Complete	0 days	Thu 11/21/30	Thu 11/21/30	53,112,148

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APPENDIX C
BASIS OF ESTIMATE

Intended for
Cost Estimating

Document type
Basis of Estimate

Date
December 23, 2020

COST ESTIMATING
BASIS OF ESTIMATE

RAMBOLL Bright ideas. Sustainable change.

COST ESTIMATING
BASIS OF ESTIMATE

Project name	**UMass Dartmouth**
Project no.	**1940074985**
Recipient	**UMass Dartmouth**
Document type	**Report**
Version	**Final**

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CONTENTS

1. PHASE 1

1.1 Central Plant

1.1.1 Central Plant Modifications

Boiler #1 will be removed and the natural gas, steam, breaching and feedwater lines will be capped and isolated. All electrical and controls points will be isolated. Other peripheral equipment will be abandoned in place.

An energy transfer station will be installed in the location of Boiler #1. The energy transfer station will be sized to convert 100% steam load to hot water if required. A tap from the steam header will be created, a shell and tube heat exchanger will be installed, condensate will have to be routed back to condensate recovery systems under steam pressure. Hot water piping (supply and return) will have to be routed from the NetZero Energy Plant to and from the energy transfer station.

The energy transfer station was sized to meet 100% of the thermal heating demand of approximately 50,000 lb/hr of steam. The following sizing was the basis of the estimate.

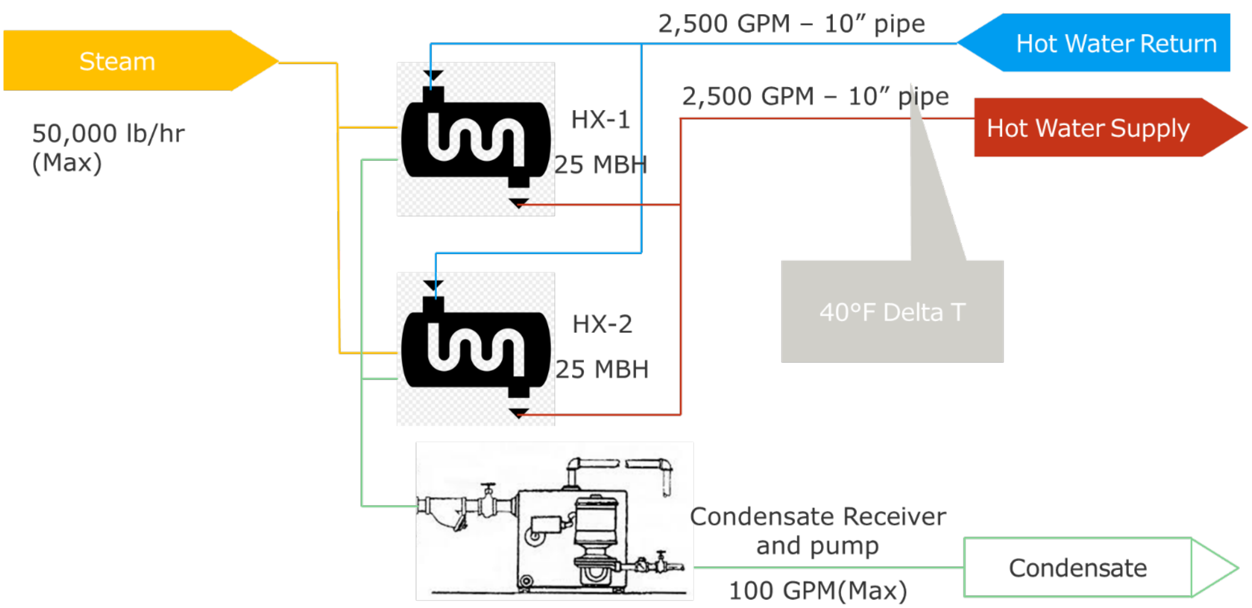


Figure 1. Energy Transfer Station Process Flow Diagram

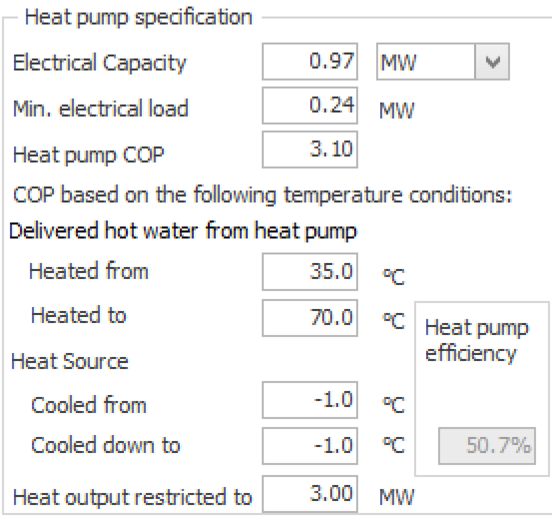
1.1.2 **NetZero Energy Plant**

1.1.2.1 Site work

There is currently a drainage catch basin located where the NetZero Plant is proposed. As part of the site development, the costs to relocate the drainage basin will be captured as an allotment.

1.1.2.2 ASHP

In the scenario, the full size of the ASHP is 3 MW of heat output. The assumptions used to model the HP in EnergyPRO are the following.



1.1.2.3 Heat recovery chiller (HRC)/GSHP

The full roll-out of the HRC is 4 MW cooling. This corresponds to a simultaneous heat output of 5.4 MW_heating. The heat summer load (incl. the hot water network losses) is about 1.2-1.7 MW.

In the model the operating temperatures for the HRC were assumed to be 60/45 °C at the condenser and 6/16 °C at the evaporator. Lorentz efficiency=50% -> COP_heat = 3.9 (COP_cool = COP_heat - 1).

If in this phase we wanted to install HRC just to cover the summer heat demand, the HRC would have a cooling capacity of about 1.1 MW_cooling. The remaining cooling capacity of the HRC should be installed when the BTES is installed too.

However, as John pointed out during our telco, it maybe be more cost effective to install from the beginning a larger HRC (maybe ½ or 1/3 of the total cooling capacity) if this allows to exploit economies of scale.

1.1.2.4 Air-cooled chillers

The full roll-out of the air-cooled chiller is 14 MW_cooling.

The background for this is the following: we said that we would have 2x75% of installed capacity for resiliency. As the peak cooling load is about 12 MW_cooling, we should have 18 MW_cooling installed. As the full roll-out of HRC is 4 MW_cooling, 14 MW_cooling would be of air-cooled chillers.

In the model the operating temperatures for the HRC were assumed to be 40 °C at the condenser (ambient temp.) and 6/16 °C at the evaporator. Lorentz efficiency=42% -> COP_cooling = 3.5.

As in phase 1 the HRC may be deployed to a lower extent (just to cover the heat demand in summer), one can deploy the entire air-cooled chiller capacity already in phase 1, but this could also be divided between phase 1 and 2. The important is that the full deployment of the air-cooled chiller is done before the decommissioning of the steam network and local absorption chillers.

1.1.2.5 Biooil boilers

The full roll-out of the biooil boilers is 18 MW_heat.
The background for this is the following: we said that we would have 2x75% of installed capacity for resiliency. As the peak heating load is about 12 MW, we should have 18 MW installed. We do not consider ASHP nor GSHP feasible for resiliency (the ASHP would not run on very cold days and the GSHP may have exhausted the heat stored in the ground; or in case of lack of electricity the HP would not be able to run anyway).
Part of the biooil boilers can be installed already in phase 1, while the rest in phase 2, in parallel to the decommissioning of the GT and the old gas-fired steam boilers.

1.2 Distribution System

1.2.1 Low Temperature Hot Water Distribution System

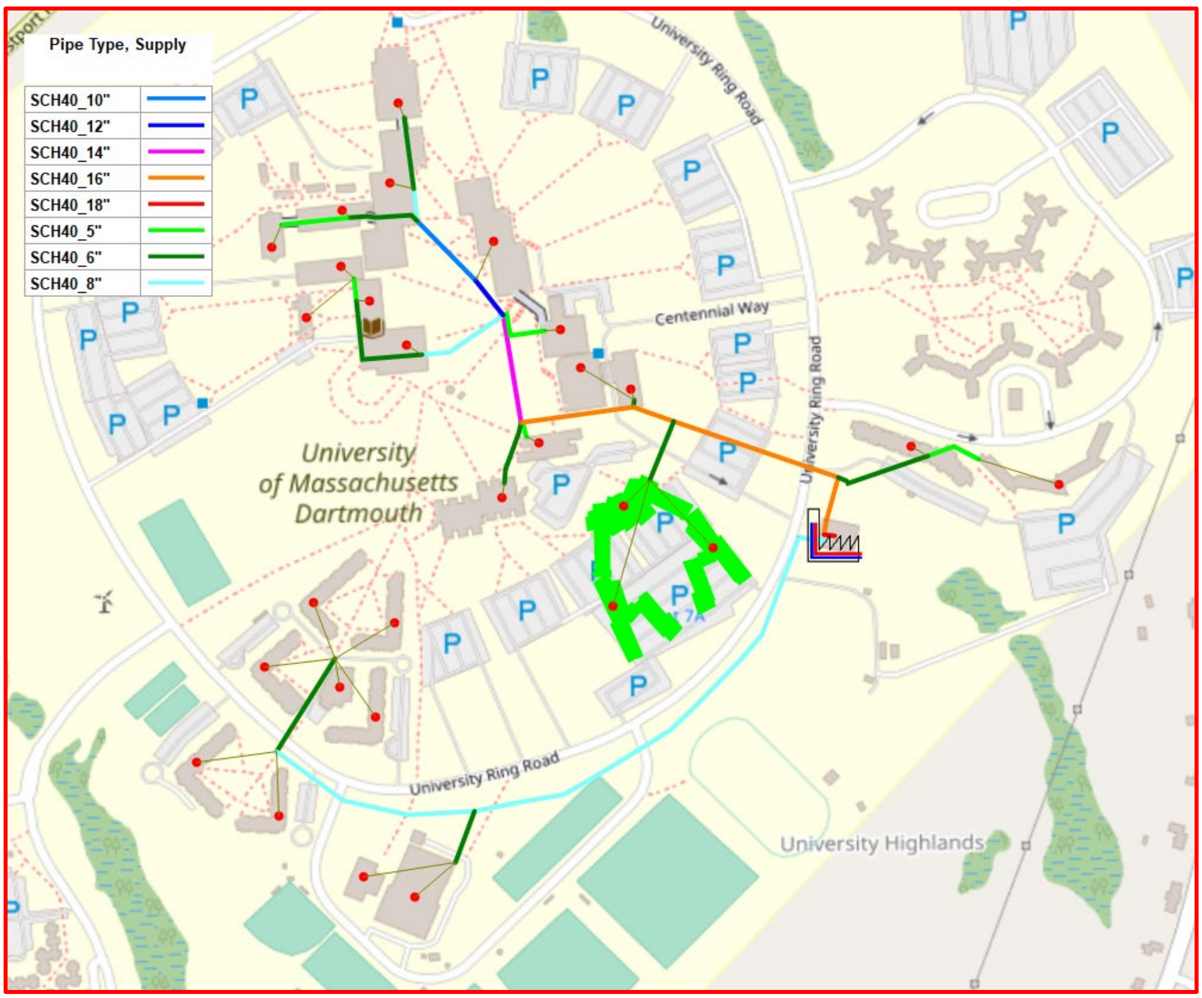


Figure 2. Hot Water Distribution Network

Table 1-1. Hot Water Distribution Lengths

Type	Trench [Ft]
SCH40_5"	947
SCH40_6"	2416
SCH40_8"	2806
SCH40_10"	283
SCH40_12"	147
SCH40_14"	373
SCH40_16"	1320
SCH40_18"	118
Total Length	8411

How water pumping specifications

- Supply temperature 185°F
- Return temperature 160°F
- Minimum dP Network 7.25 psi
- Pumping
  - Flow ~ 5,150 GPM
  - Assume 5x 1,250 GPM pumps (includes N+1 Redundancy)
  - Head ~ 35 psi

1.2.2 Chilled Water Distribution System

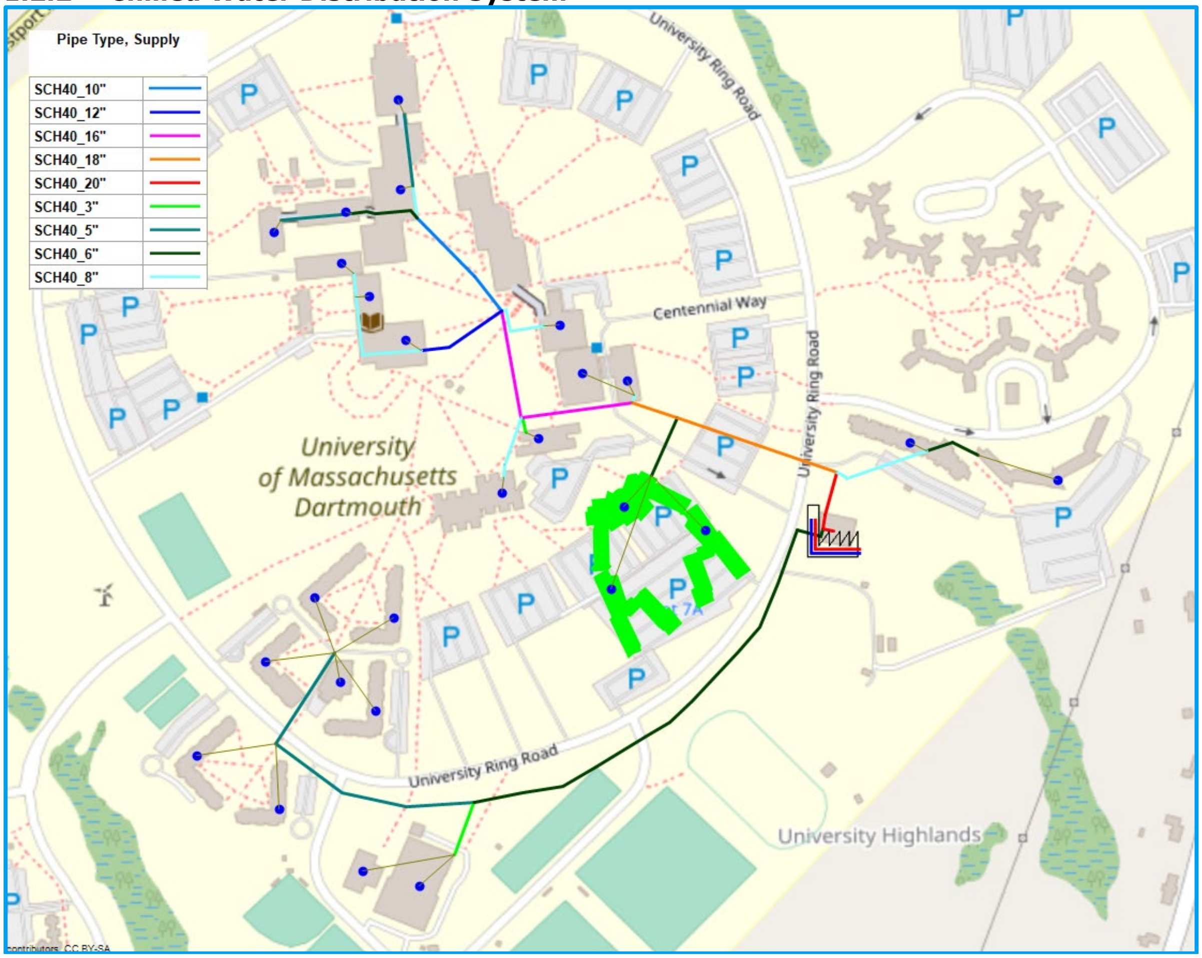


Figure 3. Chilled water network

Table 1-2. Chilled Water Piping Sections

Type	Trench [Ft]
SCH40_3"	250
SCH40_5"	1590
SCH40_6"	2474
SCH40_8"	1536
SCH40_10"	430
SCH40_12"	316
SCH40_16"	756
SCH40_18"	737

SCH40_20"	318
Total Length	8408

Chilled water specifications

- Supply Temperature 40°F
- Return Temperature 54°F
- Minimum dP Network 7.25 psi
- Pumping
  - Flow ~ 8,500 GPM
  - Assume 5x 2,125 GPM pumps (include N+1 redundancy)
  - Head ~ 57 psi

1.3 Energy Storage Systems

1.3.1 TTES

600,000 gallon (2400 m3) of steel storage tank for hot storage.
400,000 gallon (1500 m3) of steel storage tank for cold storage.

Tank storage tanks will be located on concrete pads, include stratification baffles, and 1/3 of tank will be buried to reduce hoop stress and aesthetics.

1.3.2 BTES

There is no work in this area during this phase.

1.4 Building Level Work

1.4.1 Building Level Heating System Modifications

During phase 1 it is anticipated that each building will be connected to the district heating loop. There are two types of conversions that will take place. Some of the buildings are connected to the central steam loop and some buildings have decentralized heating system. The table and descriptions below identify the quantity of each type and the associated work.

Heating Source	Quantity of buildings
Steam to hot water HXs	20
Local hot water boiler	21

Steam to Hot Water HX Building SOW

As part of the conversion, the following demolition will need to occur for each building:

- The steam to hot water shell and tube heat exchanger
- Steam and condensate piping will be removed
- Hot water heat exchanger and storage tank (estimated at 300 gallons) will be removed

As part of the conversion the following installation will occur:
- A hot water to hot water heat exchanger will be installed
- Isolation valves, temperature transmitters, recirculation valves, strainer, and flow meter will be installed.

Local Hot Water Boiler Building SOW

As part of the conversion, the following demolition will need to occur for each building:
- The natural gas service to the boiler plant will need to be isolated and capped. The remaining fuel train will be removed.
- The boilers will be removed.
- The stacks will be removed.
- Electrical service back to the distribution panel will be removed

As part of the conversion the following installation will occur:
- A hot water to how water heat exchanger will be installed
- Isolation valves, temperature transmitters, recirculation valves, strainer, and flow meter will be installed.

Table 1-3. Building level heat exchangers for heating

Heat Exchanger Size (GPM)	Count of Heat Exchangers
0	4
50	19
100	6
150	3
200	1
250	1
Grand Total	34

Table 1-4. Heat exchangers for Domestic Hot Water

Heat Exchanger Size (GPM)	Count of Heat Exchangers
50	41

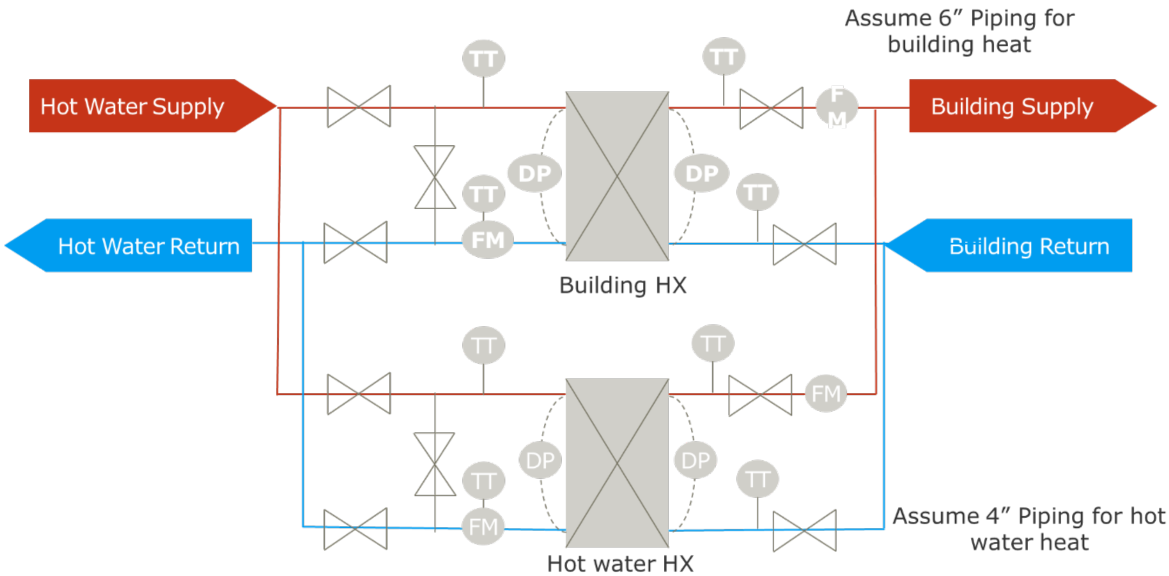


Figure 4. Building Heating Transfer Station

1.4.2 Building Level Cooling System Modifications

Table 1-5. Building level heat exchangers for cooling

Heat Exchanger Size (GPM)	Count of Heat Exchangers
0	8
50	12
100	4
200	4
300	1
400	3
600	1
800	1
Grand Total	34

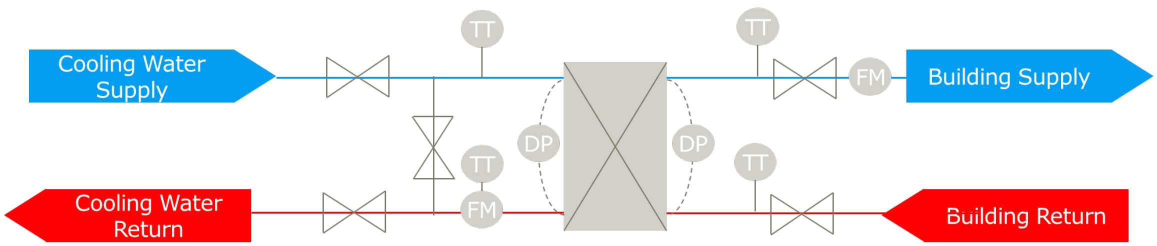


Figure 5. Building level cooling heat exchanger system

1.4.3 Building Level Steam System Modifications

It is understood that most buildings at UMassD utilize hot water for their terminal loads and some of the buildings are provided heat via the central steam system and steam to hot water heat exchangers. Some buildings on campus distribute steam to the terminal units and these units will have to be addressed once the steam distribution system is removed.

If steam direct use is present the following strategies can be used to address the concern:

1. A local steam generator can be installed to supply steam to special equipment that require it. A good example of this would be an autoclave which requires steam for sterilization purposes.
2. A second way is to replace the direct use device with a hot water heating device. This application can be appropriate for general space heating, air handler unit coils, or other applications which do not require elevated temperatures.

Based on the survey of the campus and the information provided form the campus, there aren’t any process or specialized equipment which would require local steam generation. The following facilities are known to use direct steam use as their sole source of heat.

- Tripp Athletic Center is steam heated from the Athletic Center Heating Plant steam boilers
- Public Safety/Steam Plant is steam heated by the CUP

The following buildings use some direct steam in terminal units at the campus in some AHUs.

- Claire T. Carney Library
- Main Auditorium/Annex
- Violette Research
- Research

Ramboll desired to estimate the cost of converting these facilities into hot water use and has based the estimate on the following assumptions:

1. Tripp Athletic Center direct steam use was estimated to include
    a. Two pool heaters
        i. Each steam to hot water heat exchanger would be replaced with a plate and frame heat exchanger. For estimating purposes, it was assumed that

the heat exchangers were 150 GPM each based on the size of existing piping.

b. One hot water heat exchanger
    i. The steam to hot water heat exchanger would be replaced with a plate and frame heat exchanger. For estimating purposes, it was assumed that the heat exchanger had a capacity of 50 GPM based on the size of existing piping.

c. It was assumed that there were two air handling units at the facility. It was assumed that the steam coil in the AHUs would be replaced with a hot water coil. For estimating purposes, it was assumed that 2” supply and return hot water piping would be required and that each AHU would require 100’ of piping (200’ for supply and return).

2. The following buildings have partial steam use in the AHUs. It was assumed that the steam coils would be replaced with hot water coils as part of the conversion in accordance with the table below.

Building	**Number of AHUs**	**Distance for each AHU**	**Pipe size (supply and return)**
Claire T. Carney Library	3	200 ft	2”
Main Auditorium/Annex	2	100 ft	2”
Violette Research	2	100 ft	2”
Research	1	100 ft	2”

1.5 Emergency Generators

Two (2) 1-MW diesel generators will be located outside the access road as shown in the spatial layout in Section 4.3. The generators will be connected to the NetZero. The generators should be equipped with belly tanks, but also tied into the bio diesel storage tank. The generators are anticipated to be 480-V.

2. PHASE 2

2.1 Central Plant

2.1.1 Central Plant Medications

2.1.2 NetZero Energy Plant

2.1.2.1 Heat recovery chiller (HRC)/GSHP

The full roll-out of the HRC is 4 MW_cooling. Whichever missing capacity has not been installed in Phase 1, should be installed by the time the BTES is established.
See section "Heat recovery chiller (HRC)/GSHP" under phase 1.

2.1.2.2 Air-cooled chillers

The full roll-out of the HRC is 14 MW_cooling. Whichever missing capacity has not been installed in Phase 1, should be installed before the decommissioning of the steam network and local absorption chillers.
See section "Air-cooled chillers" under phase 1.

2.1.2.3 Biooil boilers

The full roll-out of the biooil boilers is 18 MW_heat. Whichever missing capacity has not been installed in Phase 1, should be installed before the decommissioning of GT and gas-fired steam boilers.
See section "biooil boilers" under phase 1.

2.2 Distribution System

2.2.1 Low Temperature Hot Water Distribution System

There is no work in this area during this phase.

2.2.2 Chilled Water Distribution System

There is no work in this area during this phase.

2.3 Energy Storage Systems

2.3.1 TTES

There is no work in this area during this phase.

2.3.2 BTES

In the selected Scenario the peak heat charged into the BTES (i.e. max (HRC_heat production – simultaneous heat demand) is about 5 MW. From the IF Technology report, the heat transfer rate of boreholes is 30 W/m and the recommended depth for boreholes is 100 m each.
Therefore, the total length of boreholes is about 5*10^6 / 30 / 100 = 1,667 boreholes.

Borehole estimate figures

Description	Value
Borehole Diameter	
Borehole Depth	330 Feet
Borehole Quantity	1,667
Borehole locations	See Section 4.3

2.4 Building Level Work

Included in Phase 1

3. PHASE 3

3.1 Central Plant

3.1.1 Central Plant Medications
There is no work in this area during this phase.

3.1.2 NetZero Energy Plant
All “green” energy production units are already installed between phase 1 and 2.
I can see that in Tim’s presentation there is still “biooil procurement” marked under phase 3, but I don’t see how this is consistent with the fact that the phase out of the gas boilers is already marked in phase 2.

Bio Diesel Tank
UMassD stated that they desire 5-7 days of fuel reserves in the event of an interruption. Based on that desire, we have assumed that 6 days of bio diesel would be required on site in the even that there was an electrical interruption or failure.

The future total heat demand curve shows a peak load of approximately 45 MMBtu/hr of heat demand and an average daily demand during the heating season is approximately 25 MMBtu/hr based on the hourly demand curve.

$$Storage\ Capacity\ = \frac{25\,\frac{MMBtu}{hr} \times 6\ days\ \times 24\,\frac{hrs}{day}\ \times 1{,}000{,}000\,\frac{Btu}{MMBtu}}{118{,}000\,\frac{Btu}{gallon}}$$

$$Storage\ Capacity\ = 30{,}508\ Gallons$$

Solar PV Canopy System
UMassD desired to maximize their solar production without exporting in order to prevent the possibility of affecting the power quality in the area. As a result, they have selected to install a 2.5-MW solar canopy system over their parking lots similar to Figure 6.

Using the free on-line PVWatts calculator approximately 180,000 SF of space will be required in order to provide the desired 2.5-MW solar canopy. The cost for car canopy systems are more expensive than ground mounted systems due to the superstructure that is required. Several publicly available on-line resources were used to estimate the cost of the solar canopy which are listed as cost references[1]. The costs ranged from $3.0/watt to $3.93/watt and were generally more expensive than a ground based or roof mounted systems.

[1] https://powersolarphoenix.com/carport-solar-panels-cost/
https://news.energysage.com/what-is-a-solar-panel-carport/
https://www.cesa.org/wp-content/uploads/Vermont-Solar-Cost-Study.pdf

Figure 6. Solar PV Car Canopy Example

For this estimate the foundation, superstructure, solar panels, and PV infrastructure (transformer, meter, and disconnect) were valued at $4.25/watt given the prevailing wage requirement at the site. This equates to a cost of $10.6M for the solar array including construction costs.

In addition to these costs the following costs will have to be covered in order to carry an all-in value for the canopies:

- Asphalt repair
  - 180,000 SF of asphalt repair will be included
  - Since the geothermal bore holes already cover the cost of asphalt repair an additional line item will not be covered
- Electrical connection back to campus infrastructure.
  - It will be assumed that 5x separate feeders will be required to connect the lots below back into the campus electrical infrastructure.
  - It is assumed that there will be five separate 500 feet feed consisting of a 4” conduit and conductors.

Figure 7. Solar Canopy Draft Locations

3.2 Distribution System

3.2.1 Low Temperature Hot Water Distribution System
There is no work in this area during this phase.

3.2.2 Chilled Water Distribution System
There is no work in this area during this phase.

3.3 Energy Storage Systems

3.3.1 TTES
There is no work in this area during this phase.

3.3.2 BTES
There is no work in this area during this phase.

3.4 Building Level Work

3.4.1 Building Level Heating System Modifications
There is no work in this area during this phase.

3.4.2 Building Level Cooling System Modifications
There is no work in this area during this phase.

3.4.3 Building Level Steam System Modifications
There is no work in this area during this phase.

4. FULL BUILDOUT COST ESTIMATING SUPPORT DOCUMENTS

4.1 Process Flow Diagram

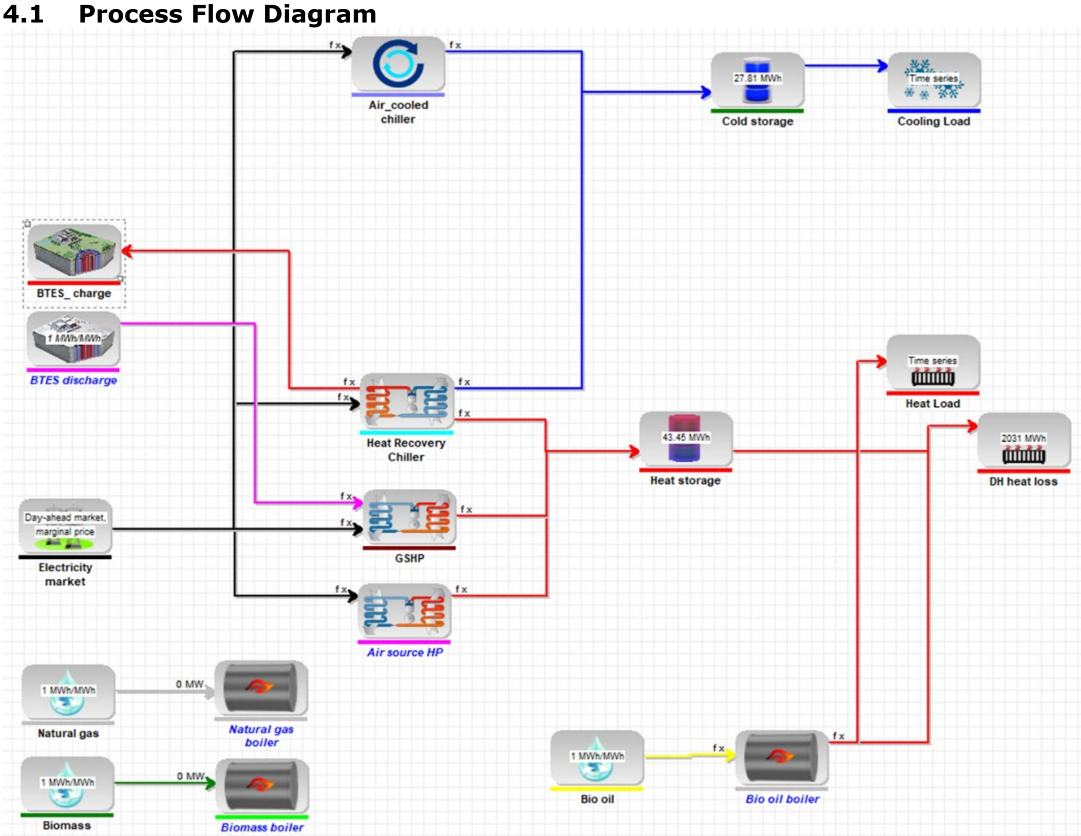


Figure 8. EnergyPro PFD

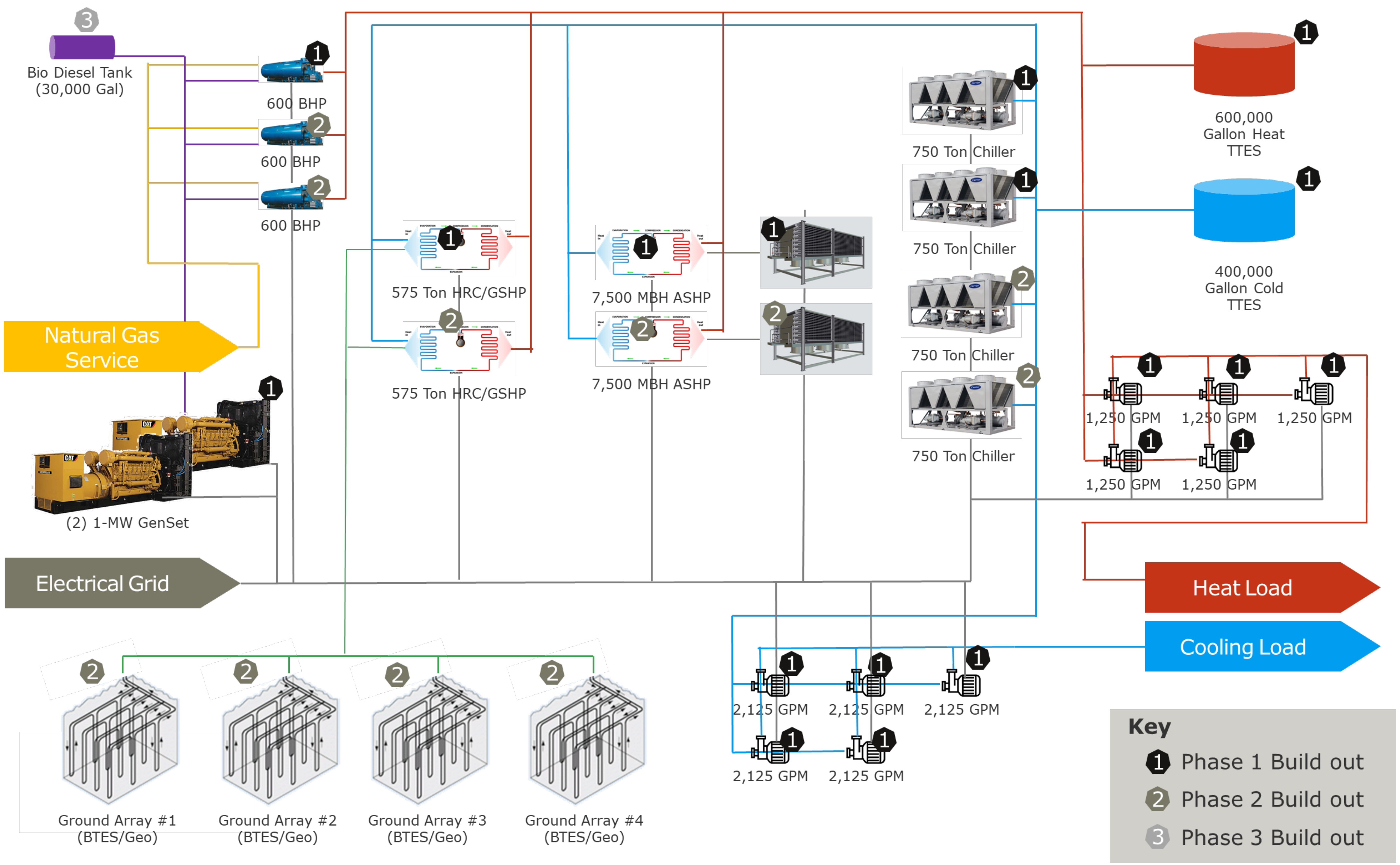
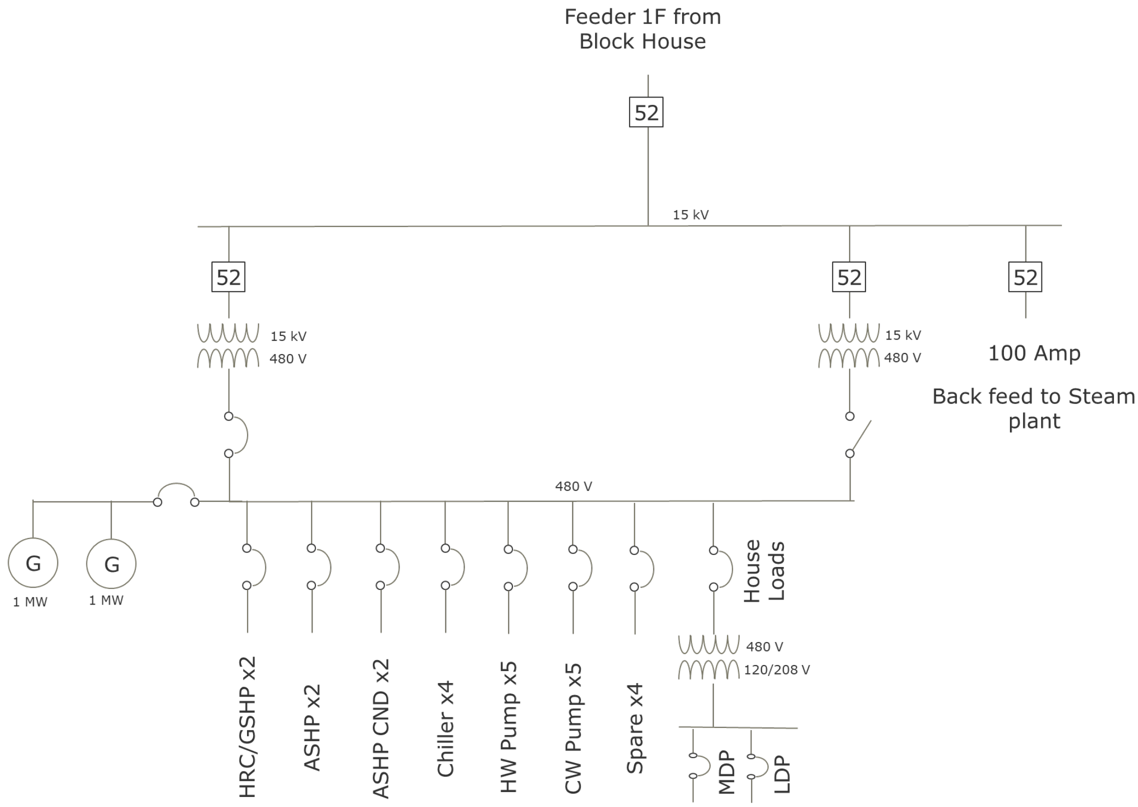


Figure 9. Full Buildout PFD

4.2 Electrical 1-line Drawing



4.3 Spatial Layouts

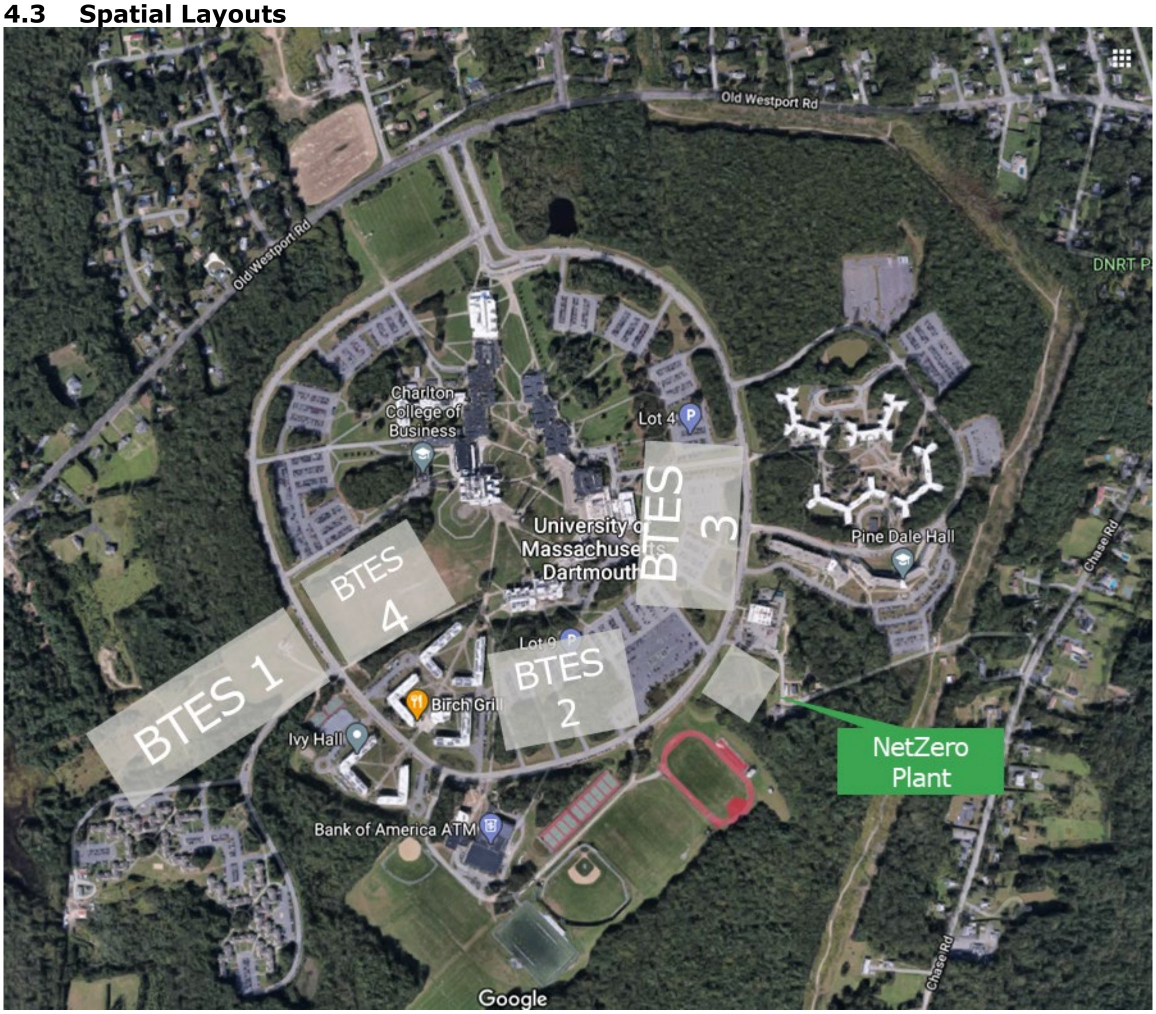


Figure 10. Campus Spatial Arrangement

Figure 11. NetZero Plant General Arrangement

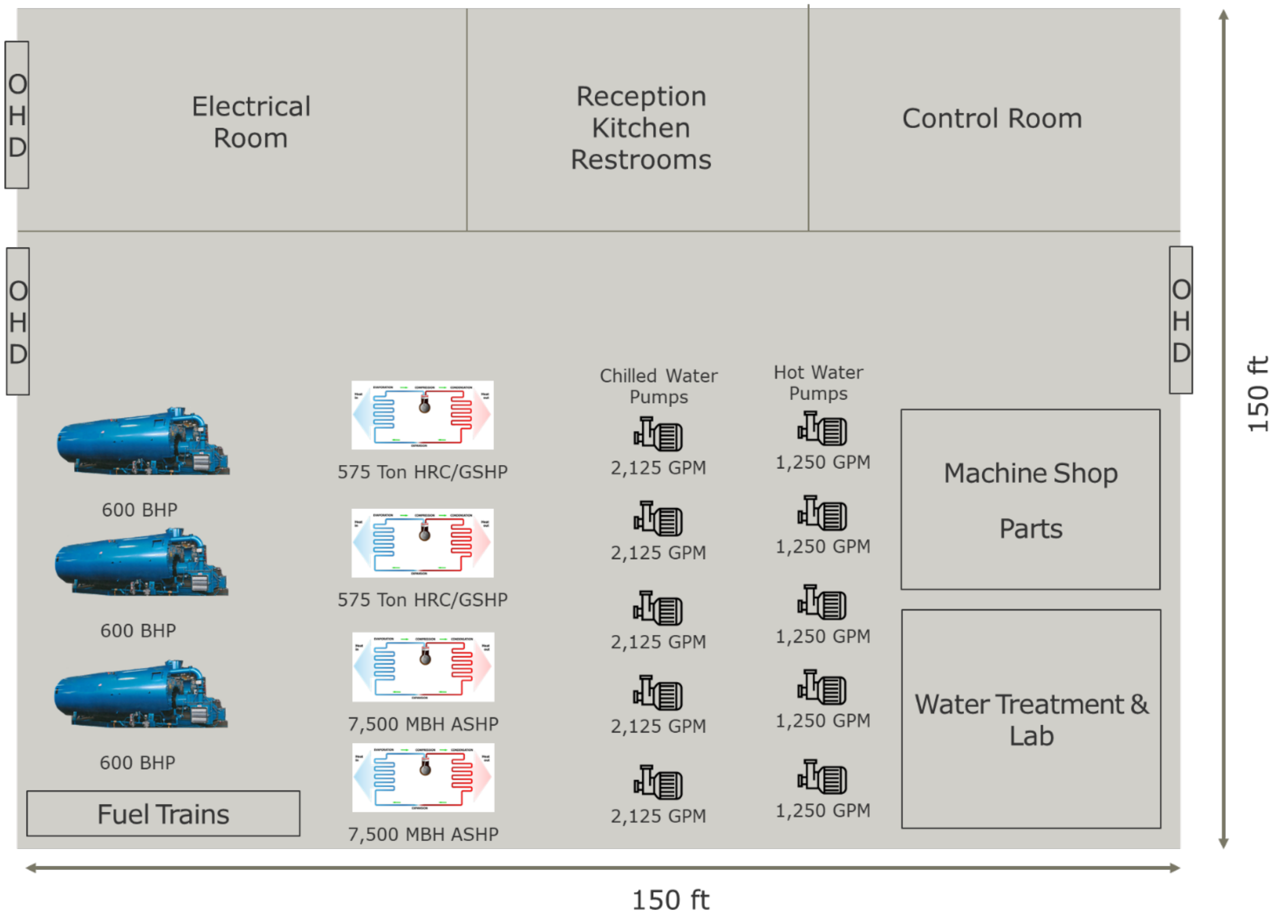


Figure 12. NetZero Plant Floor Pla

5. COST ESTIMATING ASSUMPTIONS

5.1 Escalation

Escalation **4.50%**

	Today									
Year of Implementation	2020	2021	2022	2023	2024	**2025 Phase 1**	2026	2027	2028	2029
Calculated Escalation	1.00	1.05	1.09	1.14	1.19	**1.25**	1.30	1.36	1.42	1.49
Percent Increase	0%	4%	9%	14%	19%	**24.6%**	30%	36%	42%	49%

Year of Implementation	**2030 Phase 2**	2031	2032	2033	2034	**2035 Phase 3**	2036	2037	2038	2039
Calculated Escalation	**1.55**	1.62	1.70	1.77	1.85	**1.94**	2.02	2.11	2.21	2.31
Percent Increase	**55.3%**	62%	70%	77%	85%	**93.5%**	102%	111%	121%	131%

APPENDIX D
TECHNOLOGY SCREENING

1. Technology Screening

Available Technologies

As first step in the technology screening process, all technologies which were regarded as potentially relevant to supply energy to the campus were identified. Besides technologies for energy conversion and supply, energy storage technologies were also considered.

The technologies identified were based on industry experience and technology availability. At this stage, no filtering was applied, *e.g.* with respect to cost, technical feasibility, etc.

The energy conversion and supply technologies were classified in the following categories:

- Fossil fuel technologies
- Renewable fuel technologies
- Renewable energy technologies
- Electrification technologies

The identified energy conversion and energy supply technologies, grouped according to the above-mentioned categories are listed in the tables from Table 1-1 to
Table 1-4 below.

Table 1-1. List of Available Technologies in the Fossil fuel Category

Technology	Generation
Gas turbine (simple cycle)	Combined heat and power
Gas turbine (combined cycle)	Combined heat and power
Gas engine	Combined heat and power
Solid oxide fuel cell CHP	Combined heat and power
Gas boiler	Heat only
Oil boiler	Heat only
Gas-fired Rankine steam turbine	Combined heat and power

Table 1-2. List of Available Technologies in the Renewable Fuel Category

Technology	Generation
Bio-oil fired gas turbine (simple cycle)	Combined heat and power
Bio-oil engine	Combined heat and power
Biomass ORC cogeneration unit (wood chips)	Combined heat and power

Biomass ORC cogeneration unit (wood pellets)	Combined heat and power
Biomass HOB (wood chips)	Heat only
Biomass HOB (wood pellets)	Heat only
Bio oil boiler	Heat only
Biogas production - anaerobic digester	Heat only

Table 1-3. List of Available Technologies in the Renewable Energy Category

Technology	Generation
Photovoltaics	Power only
Wind turbine	Power only
Large Solar Thermal	Heat only

Table 1-4. List of Available Technologies in the Electrification Category

Technology	Generation
Electric boiler	Heat only
HP (air-to-water) - large scale	Heat only
HP (air-to-water) - small scale	Heat only
GSHP open loop (2300 m depth)	Heat only
GSHP closed loop, horizontal, individual	Heat only
GSHP closed-loop, vertical	Heat only
HP (sewage water-to water)	Heat only
Heat recovery chiller	Heating and cooling
Conventional chiller	Cooling only

Regarding thermal energy storage technologies, the following technologies are available:

Table 1-5. List of Available Energy Storage

Technology	Category
Tank thermal energy storage (TTES)	Energy storage
Aquifer thermal energy storage (ATES)	Energy storage
Water pit thermal energy storage (PTES)	Energy storage

Borehole thermal energy storage (BTES)	Energy storage

Filtering of Available Technologies to Viable Technologies

The technologies presented in the previous section were analyzed and compared to each other in terms of investment cost (CAPEX), marginal production cost (OPEX + fuel cost), environmental impact in terms of GHG intensity, matureness of the technology, operational risks, flexibility.
The investment cost for the different technologies has been estimated based on the Danish technology catalogues[1] as well as on Ramboll's experience from previous projects.
Based on the above-mentioned considerations, the technologies have been either ruled out or regarded sufficiently viable to continue to the next phase of the evaluation.

Fossil fuel technologies

As shown in

Table 1-6, most of the fossil fuel technologies were ruled out, as these do not comply with the long-term objective of the campus to decarbonize its energy supply. Although these technologies positively affect the security of supply for the campus, the recently installed cogeneration unit already ensures this.

The only fossil fuel technology which was regarded viable to continue to the next phase of the evaluation consists of gas boilers. Although not carbon neutral, this is a very reliable and mature technology, well known by the local staff. These characteristics are important for a backup technology. Given its fast start-up time and low investment cost, it can be used for peaking/backup purposes, considerably increasing the security of supply. The expected number of operation hours during the year would therefore be very low, so resulting in minor CO_2 emission.

Table 1-6. Viability of Available Technologies in the Fossil Fuel Category

Technology	Viable	Notes on selection
Gas turbine (simple cycle)	No	Not carbon neutral
Gas turbine (combined cycle)	No	Not carbon neutral
Gas engine	No	Not carbon neutral
Solid oxide fuel cell CHP	No	High CAPEX. Still many issues. Not a mature technology. Not carbon neutral, if operated on gas
Gas boiler	Yes	Not carbon neutral. However, very reliable and mature technology. Fast start-up time. Well known technology for the operational staff. Can be used for peaking/backup purposes
Oil boiler	No	Not carbon neutral
Gas-fired Rankine steam turbine	No	It could potentially be operated with biooil, but it would then be very expensive as base load, due the high fuel cost.

[1] https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger

Renewable fuel technologies

Table 1-7 lists the renewable fuel technologies and gives a preliminary evaluation of their viability. The technologies are in principle all technically feasible, and therefore have been filtered based on economic-feasibility considerations.

Table 1-7. Viability of Available Technologies in the Renewable Fuel Category

Technology	Viable	Notes on selection
Biooil-fired turbine (simple cycle)	No	It has a high CAPEX. Therefore, it should be operated as baseload technology. However, given the very high fuel cost, it would be expensive to operate as such. Additionally, it would be redundant with respect to currently installed cogeneration unit.
Biooil engine	Yes	It may be viable on the longer term. However, it should not operate in base load due to high fuel costs. It can provide electricity backup. Very simple, well-proven and reliable technology. It is important to clarify the perception on biooil as a carbon neutral source.
Biomass ORC cogeneration unit (wood chips or wood pellets)	No	It has low electric efficiency and high CAPEX. It is redundant with respect to currently installed cogeneration unit. This technology has an overall economic balance over the lifetime, which is comparable to that of biomass boilers, as the higher CAPEX of the former is counterbalanced by the revenues (saved costs) from the electricity production. However, higher initial CAPEX and need of more trained personnel makes this technology less preferable than biomass boiler in the campus context.
Biomass heat-only boiler (wood chips)	Yes	This technology is very relevant for the decarbonization of the heat supply, but its viability depends on the perception on biomass as a carbon neutral source. Note: biomass supply to campus is a concern for the client, but this can potentially be addressed by changing location of the Energy Center. Potential sourcing of biomass should be looked further into.
Biomass heat-only boiler (wood pellets)	No	Similar considerations to the previous technology (*biomass heat-only boilers, wood chips*). However, wood pellets are significantly more expensive than wood chips. Therefore, wood chips are preferred as fuel.
Biooil boiler	Yes	As biooil is an expensive fuel, this technology is not suited as base load, but only for peaking/backup purposes, with a limited number of operation hours during the year. Biooil boilers could be installed at the central heating plant (possibly retrofitting the current gas boilers) or possibly be the heat source for buildings which are not viable to be connected to the DH network (possibly retrofitting the current gas boilers).
Biogas production - anaerobic digestion	No	Based on the preliminary information received, the limited organic waste available would not make this technology viable, as this is a very expensive technology (both in terms of CAPEX and OPEX) and requires large economies of scale to be economically feasible. See more in Section 0.

Biogas production - anerobic digestion

Below is the estimate on the smaller plant shown at the technology screening process. This smaller plant still receives far higher amount of food waste (approximately 1,500 ton wet/year) than UMassD expects to have available. If understood correctly, the availability of food waste at UMass Dartmouth is approximately 1 ton per week which would correspond to 52 tons per year.

Important assumptions are:

- Person equivalents: 10,000 persons
- Food waste: 0.68 kg/wet per day
- Assumed fraction of food waste usable: 60% (This amount could be increased to 70%-90%, if source sorting is introduced)
- Waste dry content: 30%
- Total collected food waste: 1489 kg wet per year
- Specific biogas plant investment: $60,000 per (m3/h) (only valid for this plant capacity. Smaller plants have higher specific investment costs)
- Total plant investment approximately: $1.8M
- Discount factor: 3%
- Planning period: 15 years

Biogas cost is $40/MMBtu, excluding investment in reciprocation engine (cogeneration) for production of electricity and heat. In comparison is the price for natural gas for UMass Dartmouth is approximately $8/MMBtu. The costs of $40/MMBtu could be even higher, since the actual amount of food waste is expected to be lower, which increases the specific costs.

Based on these preliminary calculations, it is concluded that the costs of the production of biogas, that this solution is not economically feasible under the boundary conditions of UMass Dartmouth campus.

Table 1-8. Biogas Calculations Model

Food-waste-for-biogas model			klf/Ramboll		
Biogas process	SI units		US units		
No. of person equivalence	PE	10,000	PE	10,000	
Food waste (FW) kg/person per day	kg wet /day	0.68			
Food into sink/disintegrator		60%			
Accessible FW per person per day	kg wet /day	0.41			
Waste dry content (Organic dry matter)		30%			
Waste per person per day	g dry / day	122			
Total dry waste per year	t dry/year	447			
Total wet waste per year	t wet/year	1,489			
FW methane production factor	Nm3 CH4/kg, dry	0.34			
Methane production	1000 m3 CH4/yr	152			
Aux. proces heat from methane	1000 m3 CH4/yr	-12			8%
Methane net production	1000 m3 CH4/yr	140			
Biogas net production	1000 m3/yr	254			55%
Methane energi content LHV	kWh/m3 CH4	9.97			
Energy production	MWh/yr	1,393			
Wet degassed sludge (soil fertilizer)	t wet/year	1,213			
Biogas energy utilization in gas engine	SI units		US units		
Gas engine power production	MWh e/yr	474			34%
Process power own-consumption	MWh e/yr	-30			20%
Net power production	MWh e/yr	443			
Gas engine heat production	MWh th/yr	725			52%
Design capacities	SI units		US units		
Biogas plant capacity	m3 biogas/h	31.5			
Biogas plant capacity	MW out	0.16			
Specific biogas plant investment	MUSD/m3/h	0.06			
Total biogas plant investment	MUSD	1.79			
Specific O&M cost ex el & heat	USD/t wet/yr	28			
Total O&M costs ex el& heat	MUSD/yr	0.04			
Gas engine input capacity	MW input	0.16			
Power capacity	MW e	0.05			
Heat capacity	MW th	0.08			
Specific biogas CHP plant investment	MUSD/MW e	1.8			
Total biogas plant investment	MUSD	0.09			
Specific O&M	USD/MWh e	15			
Total O&M	MUSD/yr	0.01			

The flow process of a biogas plant is shown in Figure 1-1 below.

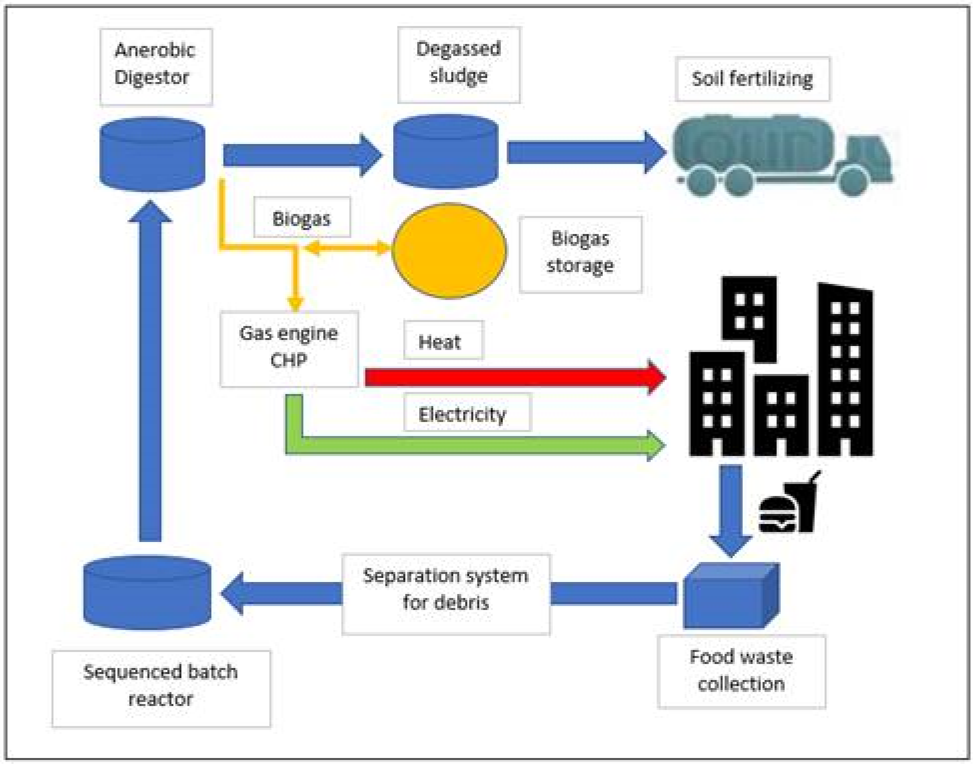


Figure 1-1. Principle Scheme of a Biogas Production Plant

The following illustration shows the economies of scale that can be obtained for a biogas production plant. It is evident that larger facilities are much more economical due to their scale.

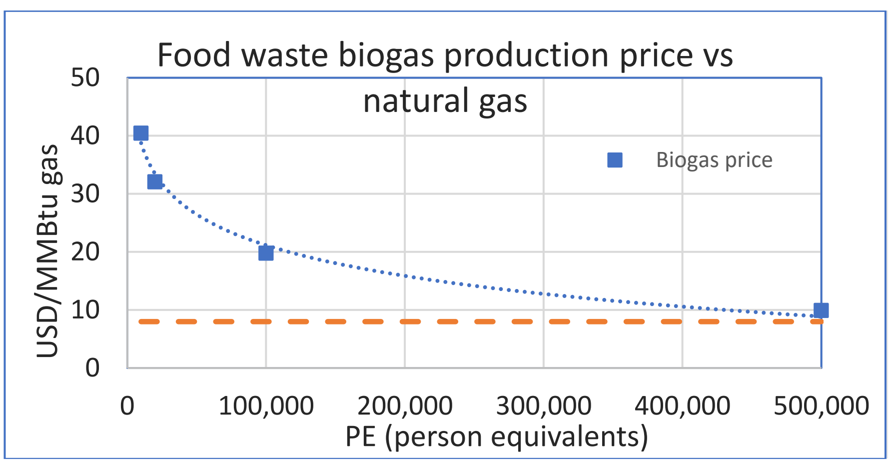


Figure 1-2. Food Waste Biogas Production Cost Versus Natural Gas Price

Biomass Considerations
The Commonwealth of Massachusetts Department of Energy Resources (DOER) commissioned and funded a study called the Biomass Sustainability and Carbon Policy Study which was produced in June 2010[2]. Given that UMassD is a state institution, it is expected that UMassD would have to follow state guidelines for their position on the renewable and carbon accounting of bio-based fuels.

One of the three goals of the study was to answer, "What are the atmospheric greenhouse gas implications of shifting energy production from fossil fuel sources to forest biomass?" This project is charged with finding a carbon neutral by 2030 and UMassD has committed to carbon neutrality to 2050.

The study states that forest biomass generally emits more greenhouse gases than fossil fuels per unit of energy produced and they define this excess emission as a carbon debt. Over time and through re-growth of the harvested forest removes this carbon from the atmosphere and reduces the carbon debt. Once the carbon debt is "paid off" any future carbon sequestration (over the fossil fuel equivalent) is considered a carbon dividend, but this might not occur until many years in the future. The study goes on to say that the full recovery of the biomass carbon debt and the magnitude of the carbon dividend benefits also depend on future forest management actions and natural disturbance events allowing that recovery to occur.

Figure 1-3 is the schematic which presents this carbon debt and dividend. In this example, the time of equal cumulative carbon flux is identified as 32 years in the future. If UMassD were to commission a biomass plant in 2025 this schematic portrays that the earth would not see the net carbon reduction until the year 2057.

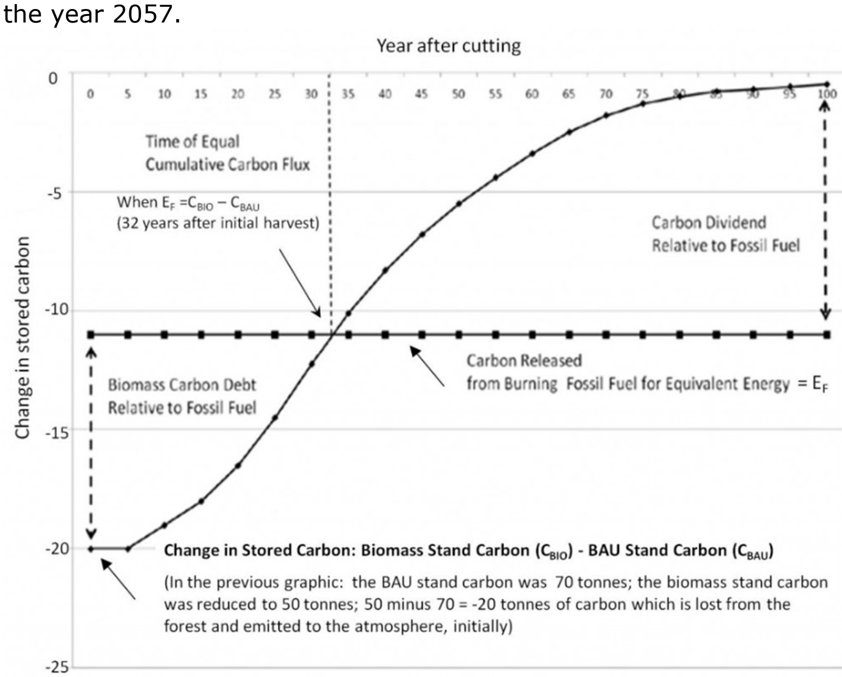


Figure 1-3. Carbon Debt and Divident Relative to Fossil Fuel (from Manomet Report)

[2] http://gfmc.online/vfe/Manomet-Biomass-Report-June-2010.pdf

The implications of this report were reviewed during the May 26, 2020 biweekly coordination meeting and it was collectively agreed that the goals of this project are to achieve carbon neutrality by 2030 and that a biomass based solution (where biomass would serve the base load) would not achieve this goal given that the carbon debt would not be paid off within this timeframe.

It was also agreed that biofuels could play a smaller role in the project by serving shoulder or peaking loads that would occur for a small duration of the year. Biofuels could also be considered for resiliency or redundancy purposes to complement other energy sources.

Biomass GHG Emission Factor

Ramboll worked with UMassD to identify an emission factor that is reflective of the State of Massachusetts' policies. UMassD in conjunction with the Massachusetts Department of Energy Resources provided a "Guideline on the Reduction of Greenhouse Gases for Eligible RTGUs Using Eligible Biomass Woody Fuel" which is an excel based calculating tool which can identify the emission factor for biomass using the fuel properties, the use rate of biomass, and the useful energy delivery rate. Given these values, the tool will identify the overall efficiency of the unit along with the percent reduction of the emission factor over a traditional natural gas boiler.

The project was seeking an emission factor to be utilized as an input for the EnergyPro modeling, so the spreadsheet tool was used to derive the percent reduction of the emission factor given the boiler efficiency. The "general efficiency range of stoker and fluidized bed boilers is between 65 and 85 percent ..."[3] according to the EPA Combined Heat and Power Partnership – Biomass CHP Catalog. For the purpose of this screening phase, a minimum efficiency of 75.2% was required to obtain the regulatory requirement of at least 50% GHG reduction 30 years in the future.

The emission factor of 117 lb CO_2/MMBtu is being utilized for natural gas on this project and therefor the green woody chip biomass boiler emission factor for the project will be 58.5 lb CO_2/MMBtu.

$$FactorEmission\ Factor_{Biomass} = FactorEmission\ Factor_{Natural\ Gas} \times 50\%$$

$$58.5\,\frac{lb\ CO2}{MMBtu} = 117\,\frac{lb\ CO2}{MMBtu} \times 50\%$$

Renewable energy technologies

Table 1-9 lists the renewable energy technologies and gives a preliminary evaluation of their viability.

At the current stage, all the available technologies are considered viable. The main issue to be addressed for solar technologies (PV and solar thermal) is the availability and usability of land in the campus premises.

Table 1-9. Viability of Available Technologies in the Renewable Energy Category

[3] https://19january2017snapshot.epa.gov/sites/production/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_5._biomass_conversion_technologies.pdf

Technology	Viable	Notes on selection
Photovoltaics (PV)	Yes	It produces only power, so it does not directly cover the thermal demand of the campus. However, it would provide cheap electricity to run heat pumps/chillers during daytime. It has a quite high CAPEX, but negligible OPEX. It requires a discrete amount of available space, if mounted on ground (roof top installation is also possible, but it comes with higher installation costs).
Wind turbine	Yes	It produces only power, so it does not directly cover the thermal demand of the campus. However, it would provide cheap electricity to run heat pumps/chillers. Unlike solar, it is not affected by day/night cycles. The cost of the resulting electricity production can be expected to be roughly 50% of that from solar PV, due to higher number of full load hours. The wind turbines could either be installed locally or elsewhere. In the latter case, these would feed into the grid and UMassD would enter into an agreement with the grid operator on how to handle the feed-in/supply of wind electricity. UMassD could also enter into a power purchase agreement (PPA) for wind electricity from another supplier. An important aspect to keep in mind for the installation of new turbines is the presence of an airport in the area, which puts limits on the height of the wind turbines.
Large Solar Thermal	Yes	Fully renewable heat production. Can cover 15-20% of heat demand with a small size tank storage (daily storage), and up to 50% with a larger (seasonal) storage, such as a water pit thermal energy storage.

Electrification technologies

Table 1-10 lists the electrification technologies and gives a preliminary evaluation of their viability.

Table 1-10. Viability of Available Technologies in the Electrification Category

Technology	Viable	Notes on selection
Electric boiler	Yes	Due to the low CAPEX and high “fuel” (electricity) cost, this technology can be a heat source for backup/peak load purposes, with no/very limited operation in normal operating conditions. As it requires high electric capacity, an upgrade of electrical feeder may be necessary. Due to the characteristics similar to biooil boilers (Table 1-7) (low CAPEX, high “fuel” cost, load type), these two technologies can be considered mutually exclusive.
HP (air-to-water) - large scale	Yes	Depending on the electricity price, it can operate as a base load or 2nd base load unit. As ambient air is used as heat source, it reaches high efficiencies in summer, but has low-efficiency/no operation in the coldest hours of the year, when the heat demand is highest.
HP (air-to-water) - small scale	Yes	Similar consideration as previous technology (*HP (air-to-water) - large scale*). Small-scale HP can be installed at buildings which are not viable to be connected to the DH network. Due to low-efficiency/no operation occurs in the coldest hours of the year, a backup/peak unit is necessary (*e.g.* gas or biooil boiler).
GSHP open loop (2300 m depth)	No	It is a risky and very expensive technology. Its feasibility depends on the geological conditions of the site.

Technology	Viable	Notes on selection
GSHP closed loop, horizontal, individual	Yes	It can be considered for buildings which are not viable to be connected to the DH network. It is less affected by lower ambient temperatures compared to air-to-water HP, as the ground temperature reacts more slowly to ambient temperature variations. However, as horizontal pipes are not laid too deep, the efficiency of the HP will lower in case of longer cold periods. It requires a lot of space to bury the horizontal-pipes ground-to-water heat exchanger. A horizontal system would require approximately 7,500 sqf for a 8 kW system unit (approximately 27 kBtu/h). Source: http://sourceenergy.co.uk/how-much-space-do-you-need-for-a-ground-source-heat-pump/
GSHP closed-loop, vertical	Yes	The deep vertical boreholes ensure that the soil temperature is not affected by the ambient temperature. Hence, high efficiencies can be reached also in winter. On the other hand, the geothermal heat source will progressively get colder due to continuous withdrawal of heat by the HP. To avoid this, it is important that the heat balance of the soil is restored between a heating season and the following one. This could *e.g.* be achieved by coupling the geothermal heat exchanger to a cooling demand in summer, which rejects its condensing heat to the soil. Alternatively, return water from the DH network or ambient-air-to-water HX can be used to recharge the soil. If the GSHP is used for both heating and cooling, the number of operation hours can be increased, and the specific cost of the system is reduced.
HP (sewage water-to water)	No	In this technology wastewater -preferably treated wastewater- is used as a heat source for the HP. The technology is expected to be relevant, if a wastewater plant was located in near proximity (maximum 2,000 to 3,000 feet). According to the collected information, the nearest wastewater treatment plant is located 4.4 miles away from the campus. Consequently, this technology was filtered out.
Conventional electric chiller	Yes	It is a very mature technology, where the condensing heat is dissipated to the environment, through a refrigerant-to-air heat exchanger. In the long run, electric-driven chillers are expected to replace the current steam-driven absorption chillers in the campus, as the steam network is will progressively be phased out.
Heat-recovery electric chiller	Yes	In a heat recovery chiller, the condensing heat is removed from the cooling loop by a refrigerant-to-water heat exchanger. The cooling water can be *e.g.* the return water from the DH network or the water circulating in an underground pipe heat exchanger (see Technology *GSHP closed-loop, vertical* above). In such a way, the condensing heat from the cooling demand is not lost, but it is reused to cover the heating demand. In the long run electric-driven chillers are expected to replace the current steam-driven absorption chillers in the campus, as the steam network is will progressively be phased out. Although a more detailed analysis will be required, it can be preliminary expected that this technology would be mutually exclusive with respect to Large Solar Thermal (Table 1-9), as both of them would supply heat especially in summer, when the heat demand is low.

Electricity Grid Supply Cost and Composition

The charts included in this section were obtained from www.ISO-NE.com/isoexpress and were taken during the COVID-19 pandemic. The pandemic has been known to impact the electrical demand and the values may not be representative of historical conditions.
https://www.iso-ne.com/isoexpress/

Utility Electrical Composition

The New England ISO website provides a real time dashboard that identifies the fuel mix associated with the electrical production and Figure 1-4 shows a sample of the fuel mix for a given day.

On this particular day, the renewable contribution was identified as 18% while the hydro power contributed an additional 18% for a total of 36% carbon free electrical production. The New England ISO website states that "Hydro is not included in the renewables category primarily because the various sources that make up hydroelectric generation (*i.e.*, conventional hydroelectric, run-of-river, pumped storage) are not universally defined as renewable in the six New England states."

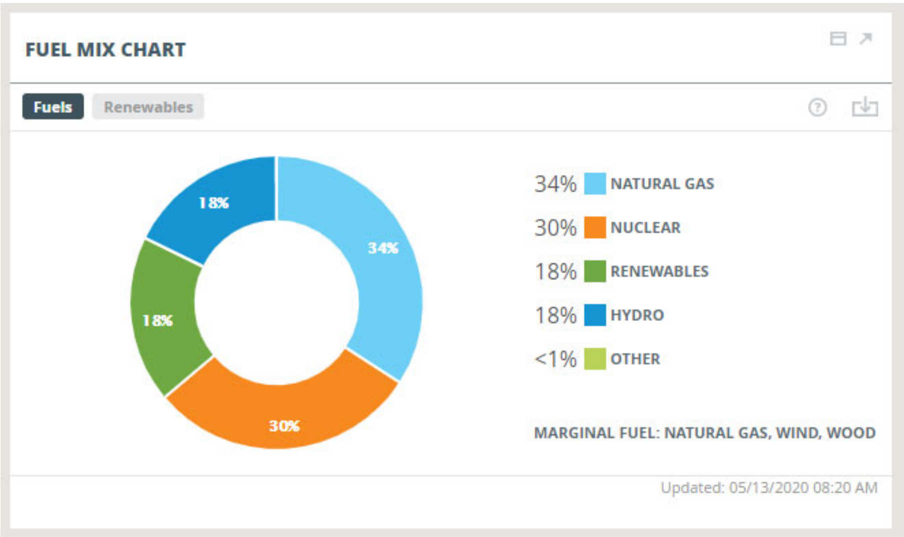


Figure 1-4. New England ISO Dashboard Fuel Mix Chart for Electricity on 5/13/2020

New England ISO's dashboard goes further and breaks down the renewable generation in the generation from wind, refuse, wood, solar, and landfill gas. Figure 1-5 shows a sample day and on this particular day at 8:20 AM the renewable generation consisted of 61% wind and only 8% solar. These renewable sources are largely dependent on the time of day and will fluctuate throughout the day as the weather conditions change.

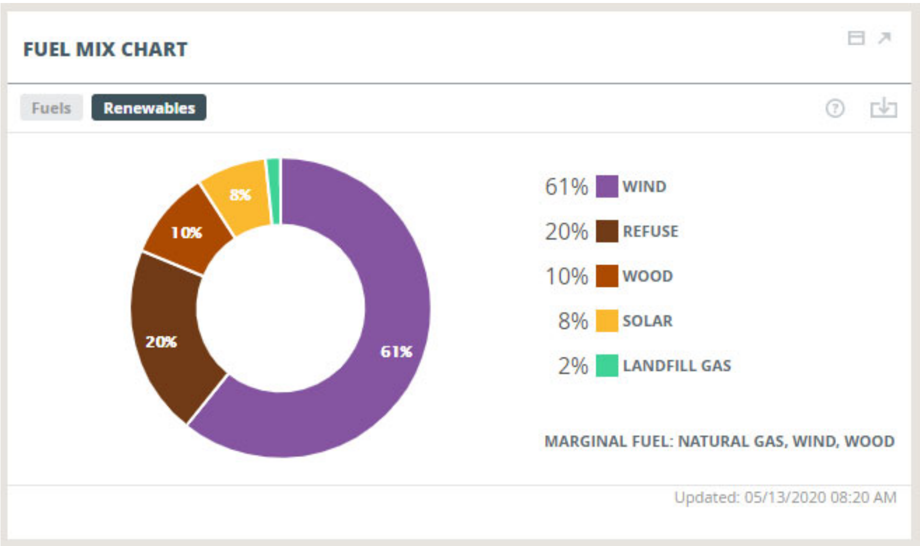


Figure 1-5. New England ISO Dashboard Fuel Mix Chart for Renewable Electricity on 5/13/2020

New England ISO also tracks historical generation and in 2019 11.4% of the annual electricity was generated via renewables and 8.9% was from hydro[4].

Utility Electrical Composition – Renewable Portfolio Standards

The state of Massachusetts currently has a goal of 15% in 2020 and increases to 45% by 2040. UMassD has committed to carbon neutrality by 2050 and has an aspirational goal of 2030. If UMassD continues to use the electrical grid, the renewable contribution of that electricity will affect the emission factor associated with that electrical consumption.

Figure 1-6. presents the clean energy standard goals for New England. The Massachusetts Renewable Energy Portfolio Standard (RPS) Class I production includes solar photovoltaic, wind energy, small hydropower, as well as several additional sources[5]. The RPS Class II production is Similar to RPS Class I, this class pertains to generation units that use eligible renewable resources but have an operation date prior to January 1,1998. Beginning in 2018, the Clean Energy Standard (CES) sets a minimum percentage of electricity sales that utilities and competitive retail suppliers must procure from clean energy sources.[6] In 2019 the MassDEP proposed expanding the CES to achieve 100% decarbonization by 2050. Figure 1-6. presents the expansion which would achieve that goal.

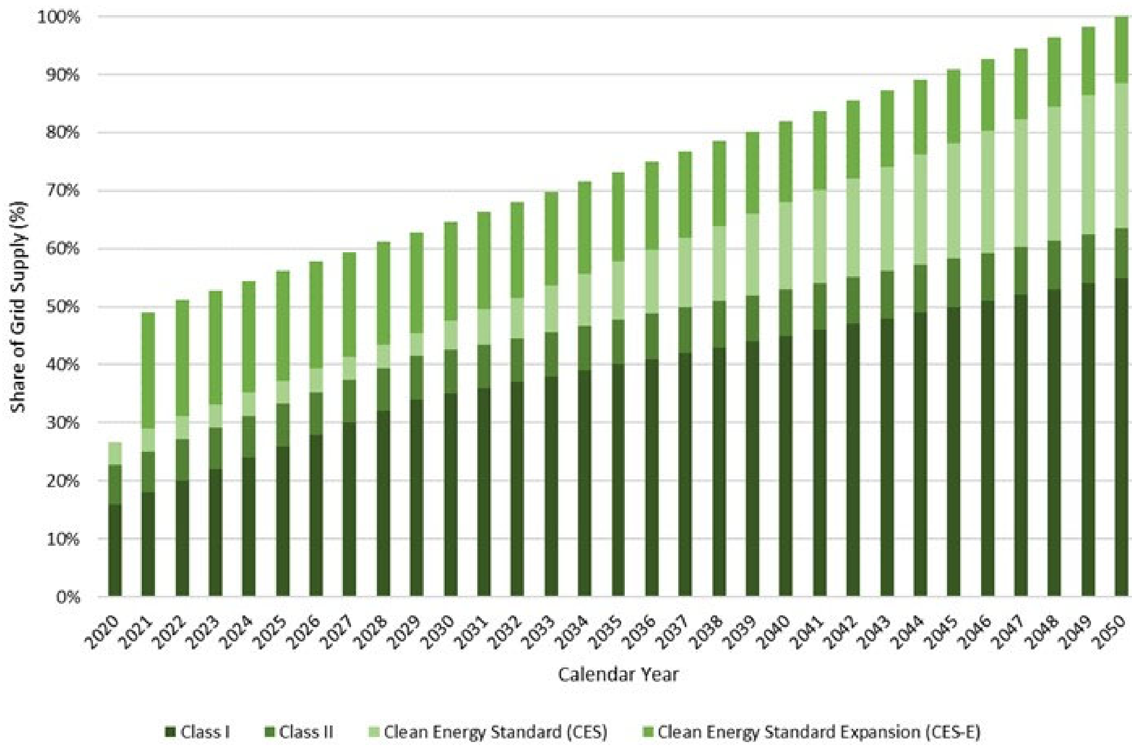


Figure 1-6. Clean Energy Standard and Proposed Expansion

[4] https://www.iso-ne.com/about/key-stats/resource-mix

[5] https://www.mass.gov/service-details/program-summaries

[6] https://www.mass.gov/service-details/program-summaries

Pricing

Figure 1-7 provides real-time and day ahead-pricing as obtained from the ISO New England web site.

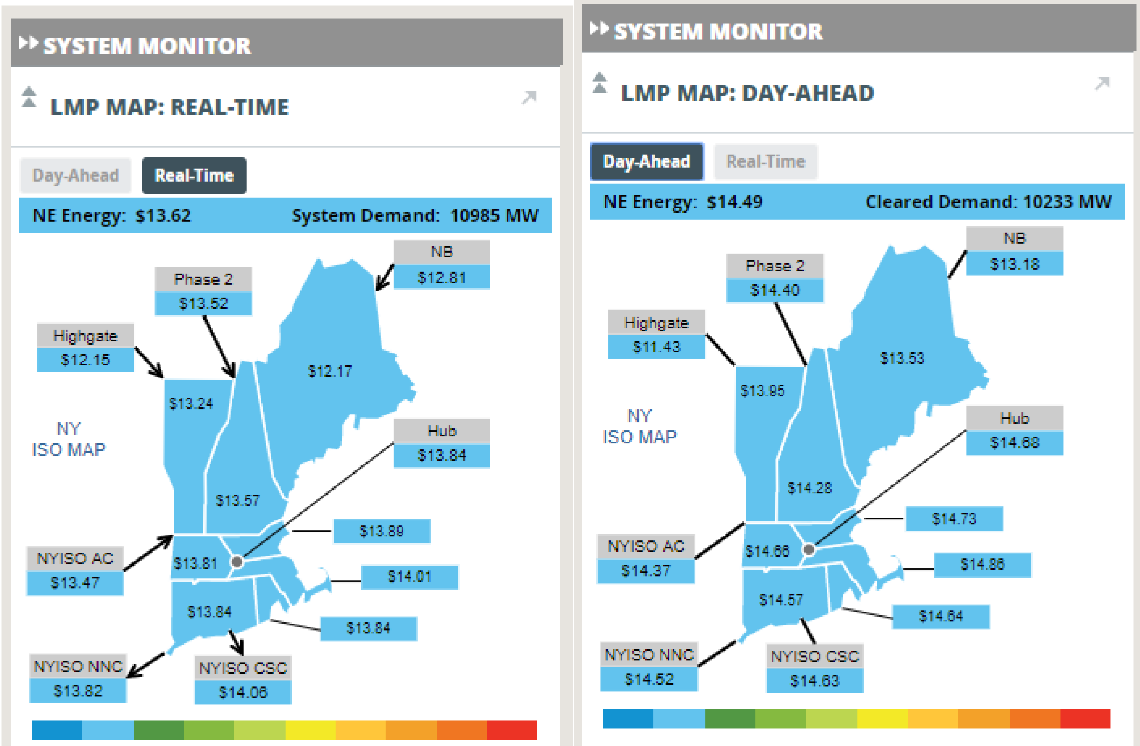


Figure 1-7. Real-time and Day-ahead Electrical Pricing

Thermal storage technologies

Table 1-11 lists the electrification technologies and gives a preliminary evaluation of their viability.

Table 1-11. Viability of Thermal Storage Technologies

Technology	Viable	Notes on selection
TTES (Tank Thermal Energy Storage)	Yes	It is a very mature and low-cost technology. When coupled with a cogeneration unit, it allows the supply of heat to be decoupled from the electricity output. It is also a cornerstone technology in low emission society, as it helps integrating renewable energy sources, which are often intermittent.
ATES (Aquifer Thermal Energy Storage)	Yes	This technology maximises the use of heat from chillers. However, it requires very specific geological conditions. For a preliminary evaluation of the feasibility of this technology at the campus, the involvement from IF Technologies (The Netherlands) is considered, given their long experience in this field.
PTES (Pit Thermal Energy Storage)	Yes	When very large storage volumes are required (approximately >10^6 gallons), this technology becomes very interesting, given the much lower investment cost per unit volume compared to TTES and the much less stringent requirements in terms of geological conditions compared to ATES. Storages of these types are for example used in Denmark as seasonal storages in connection to large solar thermal plants, although this technology would be a novelty in the US. However, a PTES can be established also in connection to other technologies (*e.g.* excess heat), as long as the storage volumes and storage temperatures make it feasible.

BTES (Borehole Thermal Energy Storage)	Yes	BTES is an expensive technology, because the low heat transfer rate per unit length of borehole entails that many wells will be needed. On the other hand, BTES has much less stringent requirements in terms of geological conditions compared to ATES and is a better-known technology in the US compared to PTES.

Conclusion on technologies

Based on the preliminary evaluation of the available technologies given in Section 0, the following technologies have been considered viable at this stage, and it was decided to bring them on to the next stage of the evaluation:

Energy conversion and supply units

- Gas boiler
- Biooil engines
- Biomass heat-only boiler (wood chips)
- Biooil boiler
- Electric boiler
- HP (air-to-water) - large scale
- HP (air-to-water) - small scale
- GSHP closed loop, horizontal, individual
- GSHP closed loop, vertical
- Photovoltaics
- Wind turbine
- Large Solar Thermal
- Conventional electric chiller
- Heat-recovery electric chiller

Thermal storage technologies

- TTES (Tank Thermal Energy Storage)
- ATES (Aquifer Thermal Energy Storage)
- PTES (Pit Thermal Energy Storage)
- BTES (Borehole Thermal Energy Storage)

Not all the above-mentioned technologies will necessarily be part of the final scenarios which will be set up for UMass Dartmouth, because the generation of possible scenarios will consider coupling technologies to achieve UMassD’s goals. Each scenario will be considered as a system and some technologies will not be ideal when coupling with other complementary technologies.

The proposed technologies were brought to the next phase of the screening process, where the technologies are combined into possible scenarios.

APPENDIX E
COST ESTIMATE

UMass Dartmouth
Energy Master Plan Cost Estimate
Phase 1 Construction

Project name	UMass Dartmouth EMP
Labor rate table	Labor - Bare
Equipment rate table	Equipment
Report format	Sorted by 'Alternate/Location/Bid Item/System' 'Detail' summary Allocate addons
Alternates	Including: 22500, Phase 1, Phase 2, Phase 3

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Phase 1														
Building Mods														
15 Mechanical														
Bldg Heating														
	Plate and Frame Heat Exchangers 0 -50 gpm	5.00 ea	40	4,752	2,500.00 /ea	12,500	-	-	-	-	-	-	3,450.40 /ea	17,252
	Plate and Frame Heat Exchangers 50 gpm	21.00 ea	168	19,958	5,000.00 /ea	105,000	-	-	-	-	-	-	5,950.40 /ea	124,958
	Plate and Frame Heat Exchangers 100 gpm	7.00 ea	112	13,306	11,250.00 /ea	78,750	-	-	-	-	-	-	13,150.80 /ea	92,056
	Plate and Frame Heat Exchangers 150 gpm	4.00 ea	64	7,603	18,750.00 /ea	75,000	-	-	-	-	-	-	20,650.80 /ea	82,603
	Plate and Frame Heat Exchangers 200 gpm	2.00 ea	64	7,603	22,500.00 /ea	45,000	-	-	-	-	-	-	26,301.60 /ea	52,603
	Plate and Frame Heat Exchangers 250 gpm	2.00 ea	64	7,603	27,500.00 /ea	55,000	-	-	-	-	-	-	31,301.60 /ea	62,603
	Transmitter - Differential Pressure (41 HX's @ 2 Per HX)	82.00 ea	328	38,966	500.00 /ea	41,000	-	-	-	-	-	-	975.20 /ea	79,966
	Transmitter - Liquid Flow (41 HX's @ 2 Per HX)	82.00 ea	328	38,966	500.00 /ea	41,000	-	-	-	-	-	-	975.20 /ea	79,966
	Transmitter - RH & Temperature (41 HX's @ 3 Per HX)	123.00 ea	492	58,450	500.00 /ea	61,500	-	-	-	-	-	-	975.20 /ea	119,950
	Gasket/Nuts/Bolt Kit 6" (4 Per HX)	164.00 ea	82	9,742	22.40 /ea	3,674	-	-	-	-	-	-	81.80 /ea	13,415
	CS Pipe A-53E ERW Grade B Std Wgt 6" (40 LF per HX)	1,640.00 lf	705	83,778	15.73 /lf	25,797	-	-	-	-	-	-	66.81 /lf	109,575
	CS Std Wgt 90° Ell LR 6" (8 Per HX)	328.00 ea	2,066	245,488	105.53 /ea	34,614	-	-	-	-	-	-	853.97 /ea	280,102
	CS Flange WN 150 RF Std Wgt 6" (4 Per HX)	164.00 ea	705	83,778	45.54 /ea	7,469	-	-	-	-	-	-	556.38 /ea	91,246
	Valve Flanged 150# Ball 6" (41 HX's @ 5 Per HX)	205.00 ea	820	97,416	500.00 /ea	102,500	-	-	-	-	-	-	975.20 /ea	199,916
	Clevis Hanger 6" (4 Per HX)	164.00 ea	246	29,225	19.78 /ea	3,244	-	-	-	-	-	-	197.98 /ea	32,469
	Bldg Heating	*41.00* **bldg**	**6,285**	**746,634**		**692,047**							**35,089.79 /bldg**	**1,438,681**
Cooling														
	Plate and Frame Heat Exchangers 0 -50 gpm	9.00 ea	72	8,554	2,500.00 /ea	22,500	-	-	-	-	-	-	3,450.40 /ea	31,054
	Plate and Frame Heat Exchangers 50 gpm	13.00 ea	104	12,355	5,000.00 /ea	65,000	-	-	-	-	-	-	5,950.40 /ea	77,355
	Plate and Frame Heat Exchangers 100 gpm	5.00 ea	80	9,504	11,250.00 /ea	56,250	-	-	-	-	-	-	13,150.80 /ea	65,754
	Plate and Frame Heat Exchangers 200 gpm	5.00 ea	160	19,008	22,500.00 /ea	112,500	-	-	-	-	-	-	26,301.60 /ea	131,508
	Plate and Frame Heat Exchangers 300 gpm	2.00 ea	64	7,603	33,750.00 /ea	67,500	-	-	-	-	-	-	37,551.60 /ea	75,103
	Plate and Frame Heat Exchangers 400 gpm	4.00 ea	128	15,206	45,000.00 /ea	180,000	-	-	-	-	-	-	48,801.60 /ea	195,206
	Plate and Frame Heat Exchangers 600 gpm	2.00 ea	96	11,405	60,000.00 /ea	120,000	-	-	-	-	-	-	65,702.40 /ea	131,405
	Plate and Frame Heat Exchangers 800 gpm	1.00 ea	48	5,702	80,000.00 /ea	80,000	-	-	-	-	-	-	85,702.40 /ea	85,702
	Transmitter - Differential Pressure	82.00 ea	185	21,919	500.00 /ea	41,000	-	-	-	-	-	-	767.30 /ea	62,919
	Transmitter - Liquid Flow	82.00 ea	328	38,966	500.00 /ea	41,000	-	-	-	-	-	-	975.20 /ea	79,966
	Transmitter - RH & Temperature	123.00 ea	492	58,450	500.00 /ea	61,500	-	-	-	-	-	-	975.20 /ea	119,950
	Gasket/Nuts/Bolt Kit 4" (4 Per HX)	164.00 ea	82	9,742	15.04 /ea	2,467	-	-	-	-	-	-	74.44 /ea	12,208
	CS Pipe A-53E ERW Grade B Std Wgt 4" (40 LF per HX)	1,640.00 lf	541	64,295	12.54 /lf	20,566	-	-	-	-	-	-	51.74 /lf	84,860
	CS Std Wgt 90° Ell LR 4" (8 Per HX)	328.00 ea	1,574	187,039	47.86 /ea	15,698	-	-	-	-	-	-	618.10 /ea	202,737
	CS Flange WN 150 RF Std Wgt 4" (4 Per HX)	164.00 ea	574	68,191	30.02 /ea	4,923	-	-	-	-	-	-	445.82 /ea	73,114
	Valve Flanged 150# Ball 4" (41 HX's @ 5 Per HX)	205.00 ea	615	73,062	250.00 /ea	51,250	-	-	-	-	-	-	606.40 /ea	124,312
	Clevis Hanger 4" (4 Per HX)	164.00 ea	164	19,483	12.08 /ea	1,981	-	-	-	-	-	-	130.88 /ea	21,464
	Cooling	*41.00* **bldg**	**5,307**	**630,483**		**944,135**							**38,405.32 /bldg**	**1,574,618**
Demo Boilers														
	Demo and Cap Boiler Fuel Trains	21.00 bldg	672	73,920	-	-	-	-	-	-	-	-	3,520.00 /bldg	73,920
	Demo Building Boilers and Stacks	21.00 bldg	1,680	184,800	-	-	-	-	-	-	-	-	8,800.00 /bldg	184,800
	Demo Boiler Electricsl	21.00 bldg	672	73,920	-	-	-	-	-	-	-	-	3,520.00 /bldg	73,920
	Demo Boilers	*21.00* **bldg**	**3,024**	**332,640**									**15,840.00 /bldg**	**332,640**
Demo Stm HX's														
	Dem Steam to HW HX's	20.00 bldg	800	88,000	-	-	-	-	-	-	-	-	4,400.00 /bldg	88,000
	Demo Steam/Condensate Piping	20.00 bldg	480	52,800	-	-	-	-	-	-	-	-	2,640.00 /bldg	52,800
	Demo HW HX and Tank	20.00 bldg	640	70,400	-	-	-	-	-	-	-	-	3,520.00 /bldg	70,400

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	Demo Stm HX's	*20.00* **bldg**	1,920	211,200									**10,560.00 /bldg**	211,200
DHW														
	Plate and Frame Heat Exchangers - 50 gpm	41.00 ea	328	38,966	5,000.00 /ea	205,000	-	-	-	-	-	-	5,950.40 /ea	243,966
	Transmitter - Differential Pressure	82.00 ea	185	21,919	500.00 /ea	41,000	-	-	-	-	-	-	767.30 /ea	62,919
	Transmitter - Liquid Flow	82.00 ea	328	38,966	500.00 /ea	41,000	-	-	-	-	-	-	975.20 /ea	79,966
	Transmitter - RH & Temperature	123.00 ea	492	58,450	500.00 /ea	61,500	-	-	-	-	-	-	975.20 /ea	119,950
	Gasket/Nuts/Bolt Kit 4" (4 Per HX)	164.00 ea	82	9,742	15.04 /ea	2,467	-	-	-	-	-	-	74.44 /ea	12,208
	CS Pipe A-53E ERW Grade B Std Wgt 4" (40 LF per HX)	1,640.00 lf	541	64,295	12.54 /lf	20,566	-	-	-	-	-	-	51.74 /lf	84,860
	CS Std Wgt 90° Ell LR 4" (8 Per HX)	328.00 ea	1,574	187,039	47.86 /ea	15,698	-	-	-	-	-	-	618.10 /ea	202,737
	CS Flange WN 150 RF Std Wgt 4" (4 Per HX)	164.00 ea	574	68,191	30.02 /ea	4,923	-	-	-	-	-	-	445.82 /ea	73,114
	Valve Flanged 150# Ball 4" (41 HX's @ 5 Per HX)	205.00 ea	615	73,062	200.00 /ea	41,000	-	-	-	-	-	-	556.40 /ea	114,062
	Clevis Hanger 4" (4 Per HX)	164.00 ea	164	19,483	12.08 /ea	1,981	-	-	-	-	-	-	130.88 /ea	21,464
	DHW	*41.00* **bldg**	4,883	580,112		435,135							**24,762.12 /bldg**	1,015,247
Direct Steam Use														
	Demo Steam to Hot Water HX	3.00 ea	96	11,405	-	-	/ea		-	-	-	-	3,801.60 /ea	11,405
	Plate and Frame Heat Exchangers 50 gpm	1.00 ea	16	1,901	5,000.00 /ea	5,000	-	-	-	-	-	-	6,900.80 /ea	6,901
	Plate and Frame Heat Exchangers 150 gpm	2.00 ea	64	7,603	18,750.00 /ea	37,500	-	-	-	-	-	-	22,551.60 /ea	45,103
	Demo Steam Coils	10.00 ea	160	19,008	/ea		-	-	-	-	-	-	1,900.80 /ea	19,008
	Install HW Coils (Modify Existing AHU)	10.00 ea	640	76,032	15,000.00 /ea	150,000	-	-	-	-	-	-	22,603.20 /ea	226,032
	Zinc Plated Hanger - Clevis 2	700.00 ea	2,100	249,480	4.82 /ea	3,374	-	-	-	-	-	-	361.22 /ea	252,854
	CS Lug Butterly Valve 2" (Handle)	30.00 ea	150	17,820	275.00 /ea	8,250	-	-	-	-	-	-	869.00 /ea	26,070
	Gal. Steel Stud Bolt/Nut/Washer Set 2"	75.00 ea	38	4,455	7.52 /ea	564	-	-	-	-	-	-	66.92 /ea	5,019
	CS Sch 40 A53 BW PE 2"	1,400.00 lf	504	59,875	3.71 /lf	5,194	-	-	-	-	-	-	46.48 /lf	65,069
	CS Std Wgt 90° Ell LR 2"	140.00 ea	876	104,116	19.64 /ea	2,750	-	-	-	-	-	-	763.33 /ea	106,866
	CS Std Wgt Tee 2"	20.00 ea	188	22,334	47.31 /ea	946	-	-	-	-	-	-	1,164.03 /ea	23,281
	CS Flange WN 150 RF Std Wgt 2"	75.00 ea	315	37,422	20.76 /ea	1,557	-	-	-	-	-	-	519.72 /ea	38,979
	Direct Steam Use	*1.00* **ls**	5,147	611,452		215,135							**826,586.52 /ls**	826,587
	15 Mechanical	**0.00**	26,566	3,112,522		2,286,451								5,398,973
17 Inst & Controls														
BMS Points														
	Bldg Heating - Tie In to BMS (7 Pts per HX)	287.00 pts			-	-	- /pts	-	-	-	1,050.00 /pts	301,350	1,050.00 /pts	301,350
	Bldg Cooling Tie In to BMS (7 Pts per HX)	287.00 pts			-	-	- /pts	-	-	-	1,050.00 /pts	301,350	1,050.00 /pts	301,350
	DHW Tie in to BMS (7 Pts per HX)	287.00 pts			-	-	- /pts	-	-	-	1,050.00 /pts	301,350	1,050.00 /pts	301,350
	BMS Points	*41.00* **bldg**										904,050	**22,050.00 /bldg**	904,050
	17 Inst & Controls	**0.00**										904,050		904,050
	Building Mods	*41.00* **bldg**	26,566	3,112,522		2,286,451						904,050	153,732.27 /bldg	6,303,023
Central Utility Plant														
03 Concrete														
Inerior Pads Large														
	Equipment Pad Form 6"	79.20 sf	8	871	1.25 /sf	104	-	-	-	-	-	-	12.31 /sf	975
	Strip & Oil Equipment Pad Form	79.20 sf	0	44	-	-	-	-	-	-	-	-	0.55 /sf	44
	Chamfer	158.40 lf	2	261	0.19 /lf	32	-	-	-	-	-	-	1.85 /lf	293
	Rebar # 5	0.43 ton	6	714	1,200.00 /ton	546	-	-	-	-	-	-	2,911.00 /ton	1,260

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Inerior Pads Large														
	Rebar # 5	0.43 ton	6	714	1,200.00 /ton	546	-	-	-	-	-	-	2,910.95 /ton	1,260
	3500 psi Concrete	14.67 cy		-	125.00 /cy	1,925	-	-	-	-	-	-	131.25 /cy	1,925
	Truck Place Equipment Pads	14.67 cy	7	807	-	-	-	-	-	-	-	-	55.00 /cy	807
	Finish- Float	792.00 sf	8	871	0.01 /sf	6	-	-	-	-	-	-	1.11 /sf	878
	Liquid Curing Compounds	792.00 sf	2	174	0.02 /sf	16	-	-	-	-	-	-	0.24 /sf	190
	Inerior Pads Large	***2.00*** **ea**	41	4,457		3,175							**3,815.92 /ea**	7,632
	03 Concrete	**0.00**	41	4,457		3,175								7,632
15 Mechanical														
Demo														
	Demo Boiler #1	200.00 mh	200	22,000	-	-	-	-	-	-	-	-	110.00 /mh	22,000
	Demo Boiler #1 Steam Piping	200.00 mh	200	23,760	-	-	-	-	-	-	-	-	118.80 /mh	23,760
	Demo Boiler #1 NG Piping	200.00 mh	200	23,760	-	-	-	-	-	-	-	-	118.80 /mh	23,760
	Demo Boiler #1 FW Piping	200.00 mh	200	23,760	-	-	-	-	-	-	-	-	118.80 /mh	23,760
	Demo Boiler Breaching	120.00 mh	120	14,256	-	-	/mh		-	-	-	-	118.80 /mh	14,256
	Demo	***1.00*** **ls**	920	107,536									**107,536.00 /ls**	107,536
Energy Xfer HX's														
	Steam to HW HX's - 25 MBH	2.00 ea	144	15,840	/ea		-	-	-	-	147,000.00 /ea	294,000	154,920.00 /ea	309,840
	Energy Xfer HX's	**0.00**	144	15,840								294,000		309,840
Hot Water Return														
	Hanger Blk Clevis 10	10.00 ea	20	2,376	175.39 /ea	1,754	-	-	-	-	-	-	412.99 /ea	4,130
	Valve Butterfly 10"	2.00 ea	8	950	1,800.00 /ea	3,600	-	-	-	-	-	-	2,275.20 /ea	4,550
	Gasket/Nuts/Bolt Kit 10"	6.00 ea	11	1,269	69.12 /ea	415	-	-	-	-	-	-	280.58 /ea	1,684
	CS Pipe A-53E ERW Grade B Std Wgt 10	200.00 lf	129	15,373	43.19 /lf	8,638	-	-	-	-	-	-	120.05 /lf	24,011
	CS Std Wgt 90° Ell LR 10"	20.00 ea	183	21,740	396.00 /ea	7,920	-	-	-	-	-	-	1,483.02 /ea	29,660
	CS Std Wgt Tee 10"	2.00 ea	30	3,614	601.00 /ea	1,202	-	-	-	-	-	-	2,407.95 /ea	4,816
	CS Flange WN 150 RF Std Wgt 10"	6.00 ea	42	4,990	128.00 /ea	768	-	-	-	-	-	-	959.60 /ea	5,758
	Hot Water Return	***200.00*** **lf**	424	50,312		24,297							**373.04 /lf**	74,608
Hot Water Supply														
	Hanger Blk Clevis 10	10.00 ea	20	2,376	175.39 /ea	1,754	-	-	-	-	-	-	412.99 /ea	4,130
	Valve Butterfly 10"	2.00 ea	8	950	1,800.00 /ea	3,600	-	-	-	-	-	-	2,275.20 /ea	4,550
	Gasket/Nuts/Bolt Kit 10"	6.00 ea	11	1,269	69.12 /ea	415	-	-	-	-	-	-	280.58 /ea	1,684
	CS Pipe A-53E ERW Grade B Std Wgt 10	200.00 lf	129	15,373	43.19 /lf	8,638	-	-	-	-	-	-	120.05 /lf	24,011
	CS Std Wgt 90° Ell LR 10"	20.00 ea	183	21,740	396.00 /ea	7,920	-	-	-	-	-	-	1,483.02 /ea	29,660
	CS Std Wgt Tee 10"	2.00 ea	30	3,614	601.00 /ea	1,202	-	-	-	-	-	-	2,407.95 /ea	4,816
	CS Flange WN 150 RF Std Wgt 10"	6.00 ea	42	4,990	128.00 /ea	768	-	-	-	-	-	-	959.60 /ea	5,758
	Hot Water Supply	***200.00*** **lf**	424	50,312		24,297							**373.04 /lf**	74,608
HX Condensate														
	Gasket/Nuts/Bolt Kit 8"	4.00 ea	2	238	23.60 /ea	94	-	-	-	-	-	-	83.00 /ea	332
	CS Pipe A-53E ERW Std Wgt 8"	60.00 lf	32	3,778	22.64 /lf	1,358	-	-	-	-	-	-	85.60 /lf	5,136
	CS Std Wgt 90° Ell LR 8"	6.00 ea	49	5,788	199.00 /ea	1,194	-	-	-	-	-	-	1,163.66 /ea	6,982
	CS Flange WN 150 RF Std Wgt 8"	4.00 ea	21	2,519	45.24 /ea	181	-	-	-	-	-	-	674.88 /ea	2,700
	Valve Butt Weld 150# Gate 8"	1.00 ea	3	395	1,125.00 /ea	1,125	-	-	-	-	-	-	1,520.00 /ea	1,520
	Steam/HW HX Level Control Valve	1.00 ea	16	1,901	2,500.00 /ea	2,500	-	-	-	-	-	-	4,400.80 /ea	4,401
	Clevis Hanger 8"	6.00 ea	12	1,426	61.49 /ea	369	-	-	-	-	-	-	299.09 /ea	1,795

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	HX Condensate	*60.00* lf	135	16,043		6,822							381.08 /lf	22,865
HX Steam Supply														
	Gasket/Nuts/Bolt Kit 16"	5.00 ea	10	1,188	127.00 /ea	635	-	-	-	-	-	-	364.60 /ea	1,823
	CS Pipe A-53S SMLS Grade B S 40 16"	40.00 lf	38	4,514	110.00 /lf	4,400	-	-	-	-	-	-	222.86 /lf	8,914
	CS Sch 40 90° Ell LR 16"	4.00 ea	72	8,554	1,171.00 /ea	4,684	-	-	-	-	-	-	3,309.40 /ea	13,238
	CS Flange WN 150 RF Std Wgt 16"	5.00 ea	55	6,534	400.00 /ea	2,000	-	-	-	-	-	-	1,706.80 /ea	8,534
	Valve Butt Weld 150# Gate 16"	1.00 ea	11	1,354	2,500.00 /ea	2,500	-	-	-	-	-	-	3,854.32 /ea	3,854
	Steam Pressure Regulators 150# 16"	1.00 ea	24	2,851	5,000.00 /ea	5,000	-	-	-	-	-	-	7,851.20 /ea	7,851
	Clevis Hanger 16"	4.00 ea	12	1,426	168.00 /ea	672	-	-	-	-	-	-	524.40 /ea	2,098
	HX Steam Supply	*40.00* lf	222	26,421		19,891							1,157.80 /lf	46,312
	15 Mechanical	0.00	2,268	266,464		75,306						294,000		635,770
16 Electrical														
Demo														
	Demo Boiler #1 Electical	200.00 mh	200	23,760	-	-	-	-	-	-	-	-	118.80 /mh	23,760
	Demo	*1.00* ls	200	23,760									23,760.00 /ls	23,760
	16 Electrical	0.00	200	23,760										23,760
17 Inst & Controls														
Demo														
	Isolate Boiler # Control Points	1.00 allo			-	-	25,000.00 /allo	25,000	-	-	-	-	25,000.00 /allo	25,000
	Demo	*1.00* ls						25,000					25,000.00 /ls	25,000
Steam to HW HX's														
	Controls for Steam to HW HX's by Point (Assume 50 Per HX)	100.00 pt			-	-	1,000.00 /pt	100,000	-	-	-	-	1,000.00 /pt	100,000
	Steam to HW HX's	0.00						100,000						100,000
	17 Inst & Controls	0.00						125,000						125,000
	Central Utility Plant	*1.00* ls	2,509	294,681		78,481		125,000				294,000	792,161.83 /ls	792,162
Distribution System														
02 Site Work														
Exc. and B'fill														
	Place and Compact Trench Backfill - Re-using Spolls	11,337.00 cy	578	60,421	/cy		-	-	0.95 /cy	10,770	-	-	6.28 /cy	71,191
	Place and Compact Pipe Bedding	4,858.50 cy	1,815	189,631	17.00 /cy	82,595	-	-	2.85 /cy	13,847	-	-	58.88 /cy	286,072
	Filter Fabric	8,449.50 sy	89	7,319	1.51 /sy	14,035	-	-	-	-	-	-	2.53 /sy	21,354
	Excavate Trench - 8420 LF	14,083.50 cy	1,796	187,645	/cy		-	-	5.75 /cy	80,980	-	-	19.07 /cy	268,625
	Haul Material Offsite	4,858.50 cy			-	-	5.00 /cy	24,293	5.00 /cy	24,293	-	-	10.00 /cy	48,585
	Exc. and B'fill	*8,420.00* lf	4,277	445,016		96,629		24,293		129,890			82.64 /lf	695,827
CW Pipe 3"														
	3" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	500.00 lf	160	19,008	21.00 /lf	10,500	-	-	2.00 /lf	1,000	-	-	61.02 /lf	30,508
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	13.00 ea	26	3,089	38.10 /ea	495	-	-	-	-	-	-	275.70 /ea	3,584
	Direct Buried Piping Elbows 22.5, 45, 90 - 3"	5.00 ea	20	2,376	23.00 /ea	115	-	-	-	-	-	-	498.20 /ea	2,491
	CW Pipe 3"	*500.00* lf	206	24,473		11,110				1,000			73.17 /lf	36,583

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
CW Pipe 5"														
	5" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	3,180.00 lf	1,526	181,336	30.00 /lf	95,400	-	-	2.00 /lf	6,360	-	-	89.02 /lf	283,096
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	80.00 ea	160	19,008	48.86 /ea	3,909	-	-	-	-	-	-	286.46 /ea	22,917
	Direct Buried Piping Elbows 22.5, 45, 90 - 5"	31.00 ea	140	16,573	65.00 /ea	2,015	-	-	-	-	-	-	599.60 /ea	18,588
	CW Pipe 5"	***3,180.00*** **lf**	1,826	216,917		101,324				6,360			**102.08 /lf**	324,601
CW Pipe 6"														
	6" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	4,948.00 lf	2,672	317,424	37.00 /lf	183,076	-	-	2.00 /lf	9,896	-	-	103.15 /lf	510,396
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	125.00 ea	250	29,700	59.93 /ea	7,491	-	-	-	-	-	-	297.53 /ea	37,191
	Direct Buried Piping Elbows 22.5, 45, 90 - 6"	49.00 ea	270	32,017	84.00 /ea	4,116	-	-	-	-	-	-	737.40 /ea	36,133
	CW Pipe 6"	***4,948.00*** **lf**	3,191	379,141		194,683				9,896			**117.97 /lf**	583,720
CW Pipe 8"														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	3,072.00 lf	1,920	228,096	50.00 /lf	153,600	-	-	2.00 /lf	6,144	-	-	126.25 /lf	387,840
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	77.00 ea	154	18,295	70.61 /ea	5,437	-	-	-	-	-	-	308.21 /ea	23,732
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	30.00 ea	180	21,384	140.00 /ea	4,200	-	-	-	-	-	-	852.80 /ea	25,584
	CW Pipe 8"	***3,072.00*** **lf**	2,254	267,775		163,237				6,144			**142.30 /lf**	437,156
CW Pipe 10"														
	10" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	860.00 lf	581	68,963	66.00 /lf	56,760	-	-	2.00 /lf	1,720	-	-	148.19 /lf	127,443
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	22.00 ea	44	5,227	76.36 /ea	1,680	-	-	-	-	-	-	313.96 /ea	6,907
	Direct Buried Piping Elbows 22.5, 45, 90 - 10"	8.00 ea	56	6,653	280.00 /ea	2,240	-	-	-	-	-	-	1,111.60 /ea	8,893
	CW Pipe 10"	***860.00*** **lf**	681	80,843		60,680				1,720			**166.56 /lf**	143,243
CW Pipe 12"														
	12 Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	632.00 lf	474	56,311	76.00 /lf	48,032	-	-	2.00 /lf	1,264	-	-	167.10 /lf	105,607
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	16.00 ea	32	3,802	86.01 /ea	1,376	-	-	-	-	-	-	323.61 /ea	5,178
	Direct Buried Piping Elbows 22.5, 45, 90 - 12"	6.00 ea	48	5,702	396.00 /ea	2,376	-	-	-	-	-	-	1,346.40 /ea	8,078
	CW Pipe 12"	***632.00*** **lf**	554	65,815		51,784				1,264			**188.08 /lf**	118,863
CW Pipe 16"														
	16" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	1,512.00 lf	1,285	152,682	99.00 /lf	149,688	-	-	2.00 /lf	3,024	-	-	201.98 /lf	305,394
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	38.00 ea	76	9,029	114.00 /ea	4,332	-	-	-	-	-	-	351.60 /ea	13,361
	Direct Buried Piping Elbows 22.5, 45, 90 - 16"	15.00 ea	150	17,820	720.00 /ea	10,800	-	-	-	-	-	-	1,908.00 /ea	28,620
	CW Pipe 16"	***1,512.00*** **lf**	1,511	179,531		164,820				3,024			**229.75 /lf**	347,375
CW Pipe 18"														
	18" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	1,474.00 lf	1,400	166,356	120.00 /lf	176,880	-	-	2.00 /lf	2,948	-	-	234.86 /lf	346,184
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	37.00 ea	74	8,791	121.00 /ea	4,477	-	-	-	-	-	-	358.60 /ea	13,268
	Direct Buried Piping Elbows 22.5, 45, 90 - 18"	14.00 ea	154	18,295	1,150.00 /ea	16,100	-	-	-	-	-	-	2,456.80 /ea	34,395
	CW Pipe 18"	***1,474.00*** **lf**	1,628	193,442		197,457				2,948			**267.20 /lf**	393,847
CW Pipe 20"														

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
CW Pipe 20"														
	20" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	636.00 lf	636	75,557	133.00 /lf	84,588	-	-	2.00 /lf	1,272	-	-	253.80 /lf	161,417
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	16.00 ea	32	3,802	131.00 /ea	2,096	-	-	-	-	-	-	368.60 /ea	5,898
	Direct Buried Piping Elbows 22.5, 45, 90 - 20"	6.00 ea	72	8,554	1,500.00 /ea	9,000	-	-	-	-	-	-	2,925.60 /ea	17,554
	CW Pipe 20"	***636.00* lf**	**740**	**87,912**		**95,684**				**1,272**			**290.67 /lf**	**184,868**
LTHW Pipe 5"														
	5" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	1,894.00 lf	909	108,003	30.00 /lf	56,820	-	-	2.00 /lf	3,788	-	-	89.02 /lf	168,611
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	48.00 ea	96	11,405	48.86 /ea	2,345	-	-	-	-	-	-	286.46 /ea	13,750
	Direct Buried Piping Elbows 22.5, 45, 90 - 5"	18.00 ea	81	9,623	65.00 /ea	1,170	-	-	-	-	-	-	599.60 /ea	10,793
	LTHW Pipe 5"	***1,894.00* lf**	**1,086**	**129,031**		**60,335**				**3,788**			**101.98 /lf**	**193,154**
LTHW Pipe 6"														
	6" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	4,832.00 lf	2,609	309,982	37.00 /lf	178,784	-	-	2.00 /lf	9,664	-	-	103.15 /lf	498,430
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	120.00 ea	240	28,512	59.93 /ea	7,192	-	-	-	-	-	-	297.53 /ea	35,704
	Direct Buried Piping Elbows 22.5, 45, 90 - 6"	48.00 ea	264	31,363	84.00 /ea	4,032	-	-	-	-	-	-	737.40 /ea	35,395
	LTHW Pipe 6"	***4,832.00* lf**	**3,113**	**369,858**		**190,008**				**9,664**			**117.87 /lf**	**569,529**
LTHW Pipe 8"														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	5,612.00 lf	3,508	416,691	50.00 /lf	280,600	-	-	2.00 /lf	11,224	-	-	126.25 /lf	708,515
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	140.00 ea	280	33,264	70.61 /ea	9,885	-	-	-	-	-	-	308.21 /ea	43,149
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	56.00 ea	336	39,917	140.00 /ea	7,840	-	-	-	-	-	-	852.80 /ea	47,757
	LTHW Pipe 8"	***5,612.00* lf**	**4,124**	**489,872**		**298,325**				**11,224**			**142.45 /lf**	**799,421**
LTHW Pipe 10"														
	10" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	566.00 lf	382	45,388	66.00 /lf	37,356	-	-	2.00 /lf	1,132	-	-	148.19 /lf	83,876
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	14.00 ea	28	3,326	76.36 /ea	1,069	-	-	-	-	-	-	313.96 /ea	4,395
	Direct Buried Piping Elbows 22.5, 45, 90 -10"	5.00 ea	35	4,158	280.00 /ea	1,400	-	-	-	-	-	-	1,111.60 /ea	5,558
	LTHW Pipe 10"	***566.00* lf**	**445**	**52,872**		**39,825**				**1,132**			**165.78 /lf**	**93,829**
LTHW Pipe 12"														
	12 Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	294.00 lf	221	26,195	76.00 /lf	22,344	-	-	2.00 /lf	588	-	-	167.10 /lf	49,127
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	8.00 ea	16	1,901	86.01 /ea	688	-	-	-	-	-	-	323.61 /ea	2,589
	Direct Buried Piping Elbows 22.5, 45, 90 - 12"	3.00 ea	24	2,851	396.00 /ea	1,188	-	-	-	-	-	-	1,346.40 /ea	4,039
	LTHW Pipe 12"	***294.00* lf**	**261**	**30,947**		**24,220**				**588**			**189.64 /lf**	**55,755**
LTHW Pipe 14"														
	14" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	746.00 lf	615	73,115	87.00 /lf	64,902	-	-	2.00 /lf	1,492	-	-	187.01 /lf	139,509
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	19.00 ea	38	4,514	87.21 /ea	1,657	-	-	-	-	-	-	324.81 /ea	6,171
	Direct Buried Piping Elbows 22.5, 45, 90 - 14"	8.00 ea	76	9,029	585.00 /ea	4,680	-	-	-	-	-	-	1,713.60 /ea	13,709
	LTHW Pipe 14"	***746.00* lf**	**729**	**86,659**		**71,239**				**1,492**			**213.66 /lf**	**159,390**
LTHW Pipe 16"														

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
LTHW Pipe 16"														
	16" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	2,640.00 lf	2,244	266,587	99.00 /lf	261,360	-	-	2.00 /lf	5,280	-	-	201.98 /lf	533,227
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	66.00 ea	132	15,682	114.00 /ea	7,524	-	-	-	-	-	-	351.60 /ea	23,206
	Direct Buried Piping Elbows 45 16"	26.00 ea	260	30,888	720.00 /ea	18,720	-	-	-	-	-	-	1,908.00 /ea	49,608
	LTHW Pipe 16"	***2,640.00* lf**	**2,636**	**313,157**		**287,604**				**5,280**			**229.56 /lf**	**606,041**
LTHW Pipe 18"														
	18" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	236.00 lf	224	26,635	120.00 /lf	28,320	-	-	2.00 /lf	472	-	-	234.86 /lf	55,427
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	6.00 ea	12	1,426	121.00 /ea	726	-	-	-	-	-	-	358.60 /ea	2,152
	Direct Buried Piping Elbows 22.5, 45, 90 - 18"	3.00 ea	33	3,920	1,150.00 /ea	3,450	-	-	-	-	-	-	2,456.80 /ea	7,370
	LTHW Pipe 18"	***236.00* lf**	**269**	**31,981**		**32,496**				**472**			**275.21 /lf**	**64,949**
Parkin Lot Crossing														
	Flaggers for Traffic Control @ Parking Lot Crossing	1.00 ea	32	2,640	-	-	- /sf	-	-	-	-	-	2,640.00 /ea	2,640
	Demo Bituminous Pave Greater than 4" @ Parking Lot Crossing	1.00 ea		0	-	-	20.00 /sy	3,500	0.00 /mh	0	-	-	3,500.00 /ea	3,500
	Sub by SY - Bituminous by SY - 5" @ Parking Lot Crossing	1.00 ea		-	-	-	60.00 /sy	10,500	-	-	-	-	10,500.00 /ea	10,500
	Parkin Lot Crossing	***1.00* ea**	**32**	**2,640**				**14,000**					**16,640.00 /ea**	**16,640**
Road Crossings														
	Flaggers for Traffic Control @ Road Crossing	5.00 ea	80	6,600	-	-	/sf		-	-	-	-	1,320.00 /ea	6,600
	Demo Bituminous Pave Greater than 4" @ Road Crossing	5.00 ea			-	-	20.00 /sy	4,000	/mh		-	-	800.00 /ea	4,000
	Sub by SY - Bituminous by SY - 5" @ Road Crossing	5.00 ea		-	-	-	60.00 /sy	24,000	-	-	-	-	4,800.00 /ea	24,000
	Road Crossings	***5.00* ea**	**80**	**6,600**				**28,000**					**6,920.00 /ea**	**34,600**
Utility Crossings														
	Allowance for Utility Crossings	20.00 ea			- /ea	-	5,000.00 /ea	100,000	/ch		-	-	5,000.00 /ea	100,000
	Utility Crossings	***10.00* ea**						**100,000**					**10,000.00 /ea**	**100,000**
	02 Site Work	**0.00**	**29,644**	**3,454,481**		**2,141,461**		**166,293**		**197,158**			**/ls**	**5,959,392**
	Distribution System	***8,420.00* lf**	**29,644**	**3,454,481**		**2,141,461**		**166,293**		**197,158**			**707.77 /lf**	**5,959,392**
Net Zero Energy														
02 Site Work														
Access Road														
	Rough Grading	6,000.00 sf	7	641	-	-	-	-	150.00 /ch	257	-	-	0.15 /sf	898
	Fine Grade	6,000.00 sf	11	293	-	-	-	-	185.00 /ch	493	-	-	0.13 /sf	787
	Sub by SY - Bituminous Pavement (5" Asphalt w/ Stone base)	667.00 sy		-	-	-	50.00 /sy	33,350	-	-	-	-	50.00 /sy	33,350
	Access Road	***1.00* ls**	**18**	**934**				**33,350**		**750**			**35,034.94 /ls**	**35,035**
Drains														
	Storm Sewer	1.00 ls			/ls		30,000.00 /ls	30,000	-	-	-	-	30,000.00 /ls	30,000
	Sanitary Sewer	1.00 ls			/ls		30,000.00 /ls	30,000	/mh		-	-	30,000.00 /ls	30,000
	Drains	***1.00* ls**						**60,000**					**60,000.00 /ls**	**60,000**
Exc. Foundation														
	Structure Excavation - Moderate Soils to Haul Offsite	219.04 cy	21	1,845	-	-	-	-	190.00 /ch	1,301	-	-	14.36 /cy	3,145
	Structure Backfill - Crushed Stone - From Hauled From Offsite	164.28 cy	20	1,054	25.00 /cy	4,107	-	-	300.00 /ch	1,173	-	-	38.56 /cy	6,335
	Haul Material Offsite 60 Minutes Round Trip	219.04 cy		-	-	-	5.00 /cy	1,095	5.00 /cy	1,095	/cy		10.00 /cy	2,190

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	Exc. Foundation	*1.00* ls	40	2,899		4,107		1,095		3,569			11,670.25 /ls	11,670
Excavate SOG														
	Structure Excavation - Moderate Soils to Haul Offsite	822.14 cy	77	6,924	-	-	-	-	190.00 /ch	4,881	-	-	14.36 /cy	11,805
	Structure Backfill - Crushed Stone - From Hauled From Offsite	822.14 cy	98	5,275	25.00 /cy	20,554	-	-	300.00 /ch	5,872	-	-	38.56 /cy	31,701
	Haul Material Offsite 60 Minutes Round Trip	411.07 cy		-	-	-	5.00 /cy	2,055	5.00 /cy	2,055	/cy		10.00 /cy	4,111
	Excavate SOG	*1.00* ls	175	12,199		20,554		2,055		12,809			47,617.46 /ls	47,617
Exterior Pads														
	Excavate and Place Stone - Exterior Pads	5.00 ea	40	4,180	200.00 /ea	1,000	/ea		250.00 /ea	1,250	-	-	1,286.00 /ea	6,430
	Exterior Pads	*7.00* ea	40	4,180		1,000				1,250			918.57 /ea	6,430
Natural Gas Service														
	Pipe Cover - Crushed Stone	134.02 cy	32	2,300	25.00 /cy	3,351	-	-	/mh		-	-	42.16 /cy	5,650
	Pipe Bedding - Crushed Stone	134.02 cy	32	2,300	25.00 /cy	3,351	-	-	/mh		-	-	42.16 /cy	5,650
	Trench Exclave & Backfill Only	800.00 lf	320	26,400	2.50 /lf	2,000	-	-	500.00 /cd	8,000	-	-	45.50 /lf	36,400
	Spoils to Waste	268.05 cy		-	-	-	5.00 /cy	1,340	/cd		-	-	5.00 /cy	1,340
	HD Polyethylene Butt Fused Pipe 4	800.00 lf	704	14,080	15.16 /lf	12,130	-	-	500.00 /cd	8,000	-	-	42.76 /lf	34,210
	Butt Fuse Machine Rental by Day - Small Bore	10.00 day		-	-	-	-	-	643.08 /day	6,431	-	-	643.08 /day	6,431
	Mod-Demob Costs for Butt Weld Fusion Machine	2.00 ls		-	-	-	-	-	500.00 /ls	1,000	-	-	500.00 /ls	1,000
	HD Polyethylene Butt Fused Elbow 22-1/2 4"	4.00 ea	6	440	15.16 /ea	61	-	-	-	-	-	-	125.27 /ea	501
	HD Polyethylene Butt Fused Elbow 90 4"	16.00 ea	25	1,762	15.16 /ea	243	-	-	-	-	-	-	125.27 /ea	2,004
	HD Polyethylene Butt Fused Elbow 45 4"	8.00 ea	12	881	15.16 /ea	121	-	-	-	-	-	-	125.27 /ea	1,002
	Gas Pressure Regulator	2.00 ea	48	4,752	2,500.00 /ea	5,000	-	-	-	-	-	-	4,876.00 /ea	9,752
	Natural Gas Service	*800.00* lf	1,179	52,915		26,256		1,340		23,431			129.93 /lf	103,942
Parking Lot														
	Rough Grading	22,500.00 sf	26	2,404	-	-	-	-	150.00 /ch	964	-	-	0.15 /sf	3,369
	Fine Grade	22,500.00 sf	40	1,100	-	-	-	-	185.00 /ch	1,850	-	-	0.13 /sf	2,950
	Sub by SY - Bituminous Pavement (5" Asphalt w/ Stone base)	2,500.00 sy		-	-	-	50.00 /sy	125,000	-	-	-	-	50.00 /sy	125,000
	Sub by EA - Parking Spaces	100.00 ea		-	-	-	50.00 /ea	5,000	-	-	-	-	50.00 /ea	5,000
	Parking Lot	*1.00* ls	66	3,504				130,000		2,814			136,318.58 /ls	136,319
Site Prep														
	Clear and Grub Site/Remove Trees	1.00 allo			-	-	40,000.00 /allo	40,000	-	-	-	-	40,000.00 /allo	40,000
	Allowance - Relocate Drainage Basin	1.00 ls			/ls		-	-	-	-	52,500.00 /ls	52,500	52,500.00 /ls	52,500
	Grading	37,000.00 sf	85	7,907	-	-	-	-	150.00 /ch	3,171	-	-	0.30 /sf	11,079
	Site Fills - Earth - From Hauled From Offsite	888.00 cy	396	41,863	12.00 /cy	10,656	-	-	318.75 /ch	20,218	/cy		81.91 /cy	72,737
	Site Prep	*1.00* ls	481	49,770		10,656		40,000		23,389		52,500	176,315.56 /ls	176,316
	02 Site Work	*1.00* ls	1,999	126,402		62,573		267,841		68,013		52,500	577,328.73 /ls	577,329
03 Concrete														
Bldg Footing														
	Continuous Footing Forms < 12"	740.00 sf	74	6,105	1.25 /sf	971	-	-	-	-	-	-	9.56 /sf	7,076
	Strip & Oil Footing Forms	740.00 sf	4	305	-	-	-	-	-	-	-	-	0.41 /sf	305
	Rebar # 5	1.76 ton	26	2,183	1,200.00 /ton	2,222	-	-	-	-	-	-	2,497.36 /ton	4,405
	Rebar # 5	1.28 ton	19	1,578	1,200.00 /ton	1,607	-	-	-	-	-	-	2,497.74 /ton	3,185
	3500 psi Concrete	41.11 cy		-	125.00 /cy	5,396	-	-	-	-	-	-	131.25 /cy	5,396
	Truck Place Wall Footings	41.11 cy	16	1,357	-	-	-	-	-	-	-	-	33.00 /cy	1,357
	Shape & Grade of Footings	1,110.00 sf	3	229	-	-	-	-	-	-	-	-	0.21 /sf	229

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	Bldg Footing	***41.11*** **cy**	143	11,757		10,196							**534.01 /cy**	21,953
Bldg Slab														
	S-O-G Edge Form 12"	600.00 lf	40	3,307	1.23 /lf	776	-	-	-	-	-	-	6.80 /lf	4,082
	S-O-G Construction Joints 12"	555.00 lf	78	6,410	1.23 /lf	717	-	-	-	-	-	-	12.84 /lf	7,127
	Strip & Oil SOG Form	1,110.00 sf	6	458	-	-	-	-	-	-	-	-	0.41 /sf	458
	Rebar # 5	13.28 ton	199	16,430	1,200.00 /ton	16,729	-	-	-	-	-	-	2,497.51 /ton	33,159
	Rebar # 5	13.30 ton	199	16,458	1,200.00 /ton	16,757	-	-	-	-	-	-	2,497.51 /ton	33,214
	3500 psi Concrete	822.22 cy		-	125.00 /cy	107,917	-	-	-	-	-	-	131.25 /cy	107,917
	Truck Place Slab on Grade	822.22 cy	370	30,528	-	-	-	-	-	-	-	-	37.13 /cy	30,528
	Finish- Hard Trowel	22,500.00 sf	337	27,842	0.04 /sf	855	-	-	-	-	-	-	1.28 /sf	28,697
	Liquid Curing Compounds	22,500.00 sf	45	3,713	0.02 /sf	449	-	-	-	-	-	-	0.19 /sf	4,161
	Bldg Slab	***822.22*** **cy**	1,274	105,145		144,199							**303.26 /cy**	249,345
Ext. Equip Pads														
	Equipment Pad Form 6"	245.66 sf	25	2,027	1.25 /sf	322	-	-	-	-	-	-	9.56 /sf	2,349
	Strip & Oil Equipment Pad Form	245.66 sf	1	101	-	-	-	-	-	-	-	-	0.41 /sf	101
	Chamfer	491.33 lf	7	608	0.19 /lf	98	-	-	-	-	-	-	1.44 /lf	706
	Rebar # 5	1.61 ton	24	1,996	1,200.00 /ton	2,033	-	-	-	-	-	-	2,497.77 /ton	4,029
	Rebar # 5	1.61 ton	24	1,996	1,200.00 /ton	2,033	-	-	-	-	-	-	2,497.76 /ton	4,029
	3500 psi Concrete	54.59 cy		-	125.00 /cy	7,165	-	-	-	-	-	-	131.25 /cy	7,165
	Truck Place Equipment Pads	54.59 cy	27	2,252	-	-	-	-	-	-	-	-	41.25 /cy	2,252
	Finish- Float	2,947.96 sf	29	2,432	0.01 /sf	24	-	-	-	-	-	-	0.83 /sf	2,456
	Liquid Curing Compounds	2,947.96 sf	6	486	0.02 /sf	59	-	-	-	-	-	-	0.19 /sf	545
	Ext. Equip Pads	***5.00*** **ea**	144	11,899		11,734							**4,726.46 /ea**	23,632
Foundation Wall														
	Rented Form System 0-4'	2,220.00 sf	278	22,894	1.25 /sf	2,914	-	-	-	-	-	-	11.63 /sf	25,808
	Strip & Oil Wall Forms	2,220.00 sf	11	916	-	-	-	-	-	-	-	-	0.41 /sf	916
	Rebar # 5	1.76 ton	26	2,183	1,200.00 /ton	2,222	-	-	-	-	-	-	2,497.37 /ton	4,405
	Rebar # 5	1.28 ton	19	1,578	1,200.00 /ton	1,607	-	-	-	-	-	-	2,497.74 /ton	3,185
	3500 psi Concrete	41.11 cy		-	125.00 /cy	5,396	-	-	-	-	-	-	131.25 /cy	5,396
	Truck Place Walls	41.11 cy	23	1,866	-	-	-	-	-	-	-	-	45.38 /cy	1,866
	Finish- Top of Wall & Curb	370.00 sf	3	244	-	-	-	-	-	-	-	-	0.66 /sf	244
	Liquid Curing Compounds	2,220.00 sf	4	366	0.02 /sf	44	-	-	-	-	-	-	0.19 /sf	411
	Foundation Wall	***41.11*** **cy**	364	30,046		12,183							**1,027.23 /cy**	42,230
Inerior Pads Large														
	Equipment Pad Form 6"	120.00 sf	12	1,320	1.25 /sf	158	-	-	-	-	-	-	12.31 /sf	1,478
	Strip & Oil Equipment Pad Form	120.00 sf	1	66	-	-	-	-	-	-	-	-	0.55 /sf	66
	Chamfer	240.00 lf	4	396	0.19 /lf	48	-	-	-	-	-	-	1.85 /lf	444
	Rebar # 5	0.66 ton	10	1,082	1,200.00 /ton	827	-	-	-	-	-	-	2,910.37 /ton	1,909
	Rebar # 5	0.66 ton	10	1,082	1,200.00 /ton	827	-	-	-	-	-	-	2,910.37 /ton	1,909
	3500 psi Concrete	22.22 cy		-	125.00 /cy	2,917	-	-	-	-	-	-	131.25 /cy	2,917
	Truck Place Equipment Pads	22.22 cy	11	1,222	-	-	-	-	-	-	-	-	55.00 /cy	1,222
	Finish- Float	1,200.00 sf	12	1,320	0.01 /sf	10	-	-	-	-	-	-	1.11 /sf	1,330
	Liquid Curing Compounds	1,200.00 sf	2	264	0.02 /sf	24	-	-	-	-	-	-	0.24 /sf	288
	Inerior Pads Large	***3.00*** **ea**	61	6,753		4,809							**3,854.04 /ea**	11,562
Interior Pads Small														
	Equipment Pad Form 4"	160.00 sf	16	1,760	1.25 /sf	210	-	-	-	-	-	-	12.31 /sf	1,970

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Interior Pads Small														
	Strip & Oil Equipment Pad Form	160.00 sf	1	88	-	-	-	-	-	-	-	-	0.55 /sf	88
	Chamfer	480.00 lf	7	792	0.19 /lf	96	-	-	-	-	-	-	1.85 /lf	888
	Rebar # 5	0.35 ton	5	578	1,200.00 /ton	442	-	-	-	-	-	-	2,911.70 /ton	1,019
	Rebar # 5	0.35 ton	5	578	1,200.00 /ton	442	-	-	-	-	-	-	2,911.70 /ton	1,019
	3500 psi Concrete	7.90 cy		-	125.00 /cy	1,037	-	-	-	-	-	-	131.25 /cy	1,037
	Truck Place Equipment Pads	7.90 cy	4	435	-	-	-	-	-	-	-	-	55.00 /cy	435
	Finish- Float	640.00 sf	6	704	0.01 /sf	5	-	-	-	-	-	-	1.11 /sf	709
	Liquid Curing Compounds	640.00 sf	1	141	0.02 /sf	13	-	-	-	-	-	-	0.24 /sf	154
	Interior Pads Small	***10.00*** **ea**	**46**	**5,074**		**2,244**							**731.84 /ea**	**7,318**
	03 Concrete	**0.00**	**2,033**	**170,674**		**185,366**								**356,040**
04 Masonry														
Interior Walls														
	Mortar	745.20 cf		-	3.74 /cf	2,928	-	-	-	-	-	-	3.93 /cf	2,928
	Grout Fill 12" Block Cells	516.68 cf	19	2,131	3.54 /cf	1,919	-	-	/cf		-	-	7.84 /cf	4,051
	Grout Fill 12 "Bond Beam	234.90 cf	9	969	3.54 /cf	873	-	-	/cf		-	-	7.84 /cf	1,842
	Dur-O-Wall 12"	6,800.00 lf		-	0.18 /lf	1,264	-	-	-	-	-	-	0.19 /lf	1,264
	Masonry Rebar # 5	1,668.80 lbs	5	501	0.34 /lbs	626	-	-	/lbs		-	-	0.68 /lbs	1,127
	Masonry Rebar # 5	14,441.38 lbs	39	4,333	0.34 /lbs	5,417	-	-	/lbs		-	-	0.68 /lbs	9,750
	Extruded Control Joints 1/2"	800.00 lf	5	503	1.58 /lf	1,326	-	-	/lf		-	-	2.29 /lf	1,829
	12" Block Bond Beam	600.00 ea	96	10,543	2.07 /ea	1,306	-	-	/mh		-	-	19.75 /ea	11,849
	12" Fire Rated Add 4 hr	8,400.00 ea	1,375	151,228	2.04 /ea	18,002	-	-	/mh		-	-	20.15 /ea	169,229
	Staging to 30'	8,000.00 sf	40	4,400	0.20 /sf	1,632	-	-	/sf		-	-	0.75 /sf	6,032
	Interior Walls	***8,000.00*** **sf**	**1,587**	**174,608**		**35,293**							**26.24 /sf**	**209,901**
	04 Masonry	**0.00**	**1,587**	**174,608**		**35,293**								**209,901**
08 Openings														
Exterior Doors														
	Single Hollow Metal Doors w/ Frame	4.00 ea	64	5,280	1,000.00 /ea	4,000	-	-	-	-	-	-	2,320.00 /ea	9,280
	Overhead Doors for Boiler Tube Work	2.00 ea	128	10,560	8,000.00 /ea	16,000	/ea		-	-	-	-	13,280.00 /ea	26,560
	Exterior Doors	***1.00*** **ls**	**192**	**15,840**		**20,000**							**35,840.00 /ls**	**35,840**
Interior Doors														
	Single Hollow Metal Doors w/ Frame	5.00 ea	80	6,600	1,000.00 /ea	5,000	-	-	-	-	-	-	2,320.00 /ea	11,600
	Interior Doors	***1.00*** **ls**	**80**	**6,600**		**5,000**							**11,600.00 /ls**	**11,600**
	08 Openings	**0.00**	**272**	**22,440**		**25,000**								**47,440**
09 Finishes														
Interior Finishes														
	Electrical Room (Paint/Flooring)	2,000.00 sf			/sf		5.00 /sf	10,000	-	-	-	-	5.00 /sf	10,000
	Restroom/Breakroom (Paint/Flooring/Drop Ceiling/Cabinets etc.)	2,000.00 sf			/sf		50.00 /sf	100,000	-	-	-	-	50.00 /sf	100,000
	Control Room (Paint/Flooring/Drop Ceiling/Cabinets etc.)	2,000.00 sf			/sf		50.00 /sf	100,000	-	-	-	-	50.00 /sf	100,000
	Equipment Area	16,500.00 sf			/sf		2.50 /sf	41,250	-	-	-	-	2.50 /sf	41,250
	Interior Finishes	***1.00*** **ls**						**251,250**					**251,250.00 /ls**	**251,250**
	09 Finishes	**0.00**						**251,250**						**251,250**

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
11 Equipment														
Install														
	Air Cooled Chillers 750 Ton Capacity	2.00 ea	400	33,000	/ea		-	-	-	-	-	-	16,500.00 /ea	33,000
	Hot Water Circulating Pumps	5.00 ea	240	19,800	/ea		-	-	-	-	-	-	3,960.00 /ea	19,800
	Chilled Water Circulating Pumps	5.00 ea	240	19,800	/ea		-	-	-	-	-	-	3,960.00 /ea	19,800
	Hot Water Boilers 600 HP	1.00 ea	400	33,000	/ea		-	-	-	-	-	-	33,000.00 /ea	33,000
	Rig and Set HRC/GSHP 575 Ton Capacity	1.00 ea	200	16,500	/ea		-	-	-	-	-	-	16,500.00 /ea	16,500
	HRC/GSHP Misc. Installs (Piping, Valves, etc.)	1.00 ea	480	39,600	/ea		-	-	-	-	-	-	39,600.00 /ea	39,600
	Rig and Set ASHP 750 MBH/hr	1.00 ea	200	16,500	/ea		-	-	-	-	-	-	16,500.00 /ea	16,500
	ASHP Misc. Installs (Piping, Valves, etc.)	1.00 ea	480	39,600	/ea		-	-	-	-	-	-	39,600.00 /ea	39,600
	Install	***1.00*** **ls**	**2,640**	**217,800**									**217,800.00 /ls**	**217,800**
Supply														
	Air Cooled Chillers 750 Ton Capacity	2.00 ea			/ea		-	-	-	-	288,750.00 /ea	577,500	288,750.00 /ea	577,500
	Hot Water Circulating Pumps 1250 GPM	5.00 ea			/ea		-	-	-	-	19,845.00 /ea	99,225	19,845.00 /ea	99,225
	Chilled Water Circulating Pumps 2125 GPM	5.00 ea			/ea		-	-	-	-	23,625.00 /ea	118,125	23,625.00 /ea	118,125
	Hot Water Boilers 600 HP	3.00 ea			/ea		-	-	-	-	430,500.00 /ea	1,291,500	430,500.00 /ea	1,291,500
	HRC/GSHP 575 Ton Capacity	1.00 ea			/ea		-	-	-	-	1,648,500.00 /ea	1,648,500	1,648,500.00 /ea	1,648,500
	ASHP 750 MBH/hr	1.00 ea			/ea		-	-	-	-	1,501,500.00 /ea	1,501,500	1,501,500.00 /ea	1,501,500
	HRC/GSHP Evaporator/Condenser Sections	1.00 ls			/ls		-	-	-	-	525,000.00 /ls	525,000	525,000.00 /ls	525,000
	ASHP Evaporator/Condenser Sections	1.00 ls			/ls		-	-	-	-	525,000.00 /ls	525,000	525,000.00 /ls	525,000
	HRC/GSHP Piping, Instruments, and Valves	1.00 ls			/ls		-	-	-	-	787,500.00 /ls	787,500	787,500.00 /ls	787,500
	ASHP Piping, Instruments, and Valves	1.00 ls			/ls		-	-	-	-	787,500.00 /ls	787,500	787,500.00 /ls	787,500
	Supply	***1.00*** **ls**										**7,861,350**	**7,861,350.00 /ls**	**7,861,350**
	11 Equipment	**0.00**	**2,640**	**217,800**								**7,861,350**		**8,079,150**
13 Specialties														
Pre-Engineerd Bldg														
	Pre Engineered Metal Building - Purchase	22,500.00 sf		-	/sf		65.00 /sf	1,462,500	-	-	-	-	65.00 /sf	1,462,500
	Allotment for Architectural/Sustainability Features	22,500.00 sf		-	/sf		30.00 /sf	675,000	-	-	-	-	30.00 /sf	675,000
	Pre-Engineerd Bldg	***22,500.00*** **sf**						**2,137,500**					**95.00 /sf**	**2,137,500**
	13 Specialties	**0.00**						**2,137,500**						**2,137,500**
15 Mechanical														
Air Cooled CH Pipe														
	Gasket/Nuts/Bolt Kit 8"	20.00 ea	10	1,188	23.60 /ea	472	-	-	-	-	-	-	83.00 /ea	1,660
	CS Pipe A-53E ERW Std Wgt 8"	200.00 lf	106	12,593	22.64 /lf	4,528	-	-	-	-	-	-	85.60 /lf	17,121
	CS Std Wgt 90° Ell LR 8"	24.00 ea	195	23,152	199.00 /ea	4,776	-	-	-	-	-	-	1,163.66 /ea	27,928
	CS Flange WN 150 RF Std Wgt 8"	20.00 ea	106	12,593	45.24 /ea	905	-	-	-	-	-	-	674.88 /ea	13,498
	Valve 150# Butterfly 8"	8.00 ea	27	3,160	1,500.00 /ea	12,000	-	-	-	-	-	-	1,895.01 /ea	15,160
	Flanged Strainers 150# 8"	4.00 ea	13	1,580	2,000.00 /ea	8,000	-	-	-	-	-	-	2,395.01 /ea	9,580
	Clevis Hanger 8"	20.00 ea	40	4,752	61.49 /ea	1,230	-	-	-	-	-	-	299.09 /ea	5,982
	Air Cooled CH Pipe	***200.00*** **lf**	**497**	**59,017**		**31,911**							**454.64 /lf**	**90,928**
ASHP Pipe														
	Gasket/Nuts/Bolt Kit 4"	10.00 ea	5	594	23.60 /ea	236	-	-	-	-	-	-	83.00 /ea	830
	CS Pipe A-53E ERW Std Wgt 8"	100.00 lf	53	6,296	22.64 /lf	2,264	-	-	-	-	-	-	85.60 /lf	8,560
	CS Std Wgt 90° Ell LR 8"	12.00 ea	97	11,576	199.00 /ea	2,388	-	-	-	-	-	-	1,163.66 /ea	13,964

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
ASHP Pipe														
	CS Std Wgt Con Red 8x6"	4.00 ea	26	3,136	109.00 /ea	436	-	-	-	-	-	-	893.08 /ea	3,572
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	53	6,296	45.24 /ea	452	-	-	-	-	-	-	674.88 /ea	6,749
	Valve 150# Butterfly 8"	4.00 ea	13	1,580	1,500.00 /ea	6,000	-	-	-	-	-	-	1,895.01 /ea	7,580
	Flanged Strainers 150# 8"	2.00 ea	7	790	2,000.00 /ea	4,000	-	-	-	-	-	-	2,395.01 /ea	4,790
	Clevis Hanger 8"	10.00 ea	20	2,376	61.49 /ea	615	-	-	-	-	-	-	299.09 /ea	2,991
	ASHP Pipe	***100.00* lf**	275	32,645		16,391							**490.36 /lf**	49,036
Boiler HW Pipe														
	Gasket/Nuts/Bolt Kit 8"	10.00 ea	5	594	23.60 /ea	236	-	-	-	-	-	-	83.00 /ea	830
	CS Pipe A-53E ERW Std Wgt 8"	100.00 lf	53	6,296	22.64 /lf	2,264	-	-	-	-	-	-	85.60 /lf	8,560
	CS Std Wgt 90° Ell LR 8"	12.00 ea	97	11,576	199.00 /ea	2,388	-	-	-	-	-	-	1,163.66 /ea	13,964
	CS Std Wgt Con Red 8x6"	4.00 ea	26	3,136	109.00 /ea	436	-	-	-	-	-	-	893.08 /ea	3,572
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	53	6,296	45.24 /ea	452	-	-	-	-	-	-	674.88 /ea	6,749
	Valve 150# Butterfly 8"	4.00 ea	13	1,580	1,500.00 /ea	6,000	-	-	-	-	-	-	1,895.01 /ea	7,580
	Flanged Strainers 150# 8"	2.00 ea	7	790	2,000.00 /ea	4,000	-	-	-	-	-	-	2,395.01 /ea	4,790
	Clevis Hanger 8"	10.00 ea	20	2,376	61.49 /ea	615	-	-	-	-	-	-	299.09 /ea	2,991
	Boiler HW Pipe	***100.00* lf**	275	32,645		16,391							**490.36 /lf**	49,036
Drains														
	Foor Drains	1.00 ls			/ls		20,000.00 /ls	20,000	-	-	-	-	20,000.00 /ls	20,000
	Drains	***1.00* ls**						20,000					**20,000.00 /ls**	20,000
Header CW														
	CS Pipe A-53S SMLS Grade B S 40 24"	150.00 lf	132	15,682	110.00 /lf	16,500	-	-	-	-	-	-	214.54 /lf	32,182
	CS Sch 40 90° Ell LR 24"	15.00 ea	270	32,076	1,170.00 /ea	17,550	-	-	-	-	-	-	3,308.40 /ea	49,626
	CS Sch 40 Tee 24x10"	5.00 ea	125	14,850	1,200.00 /ea	6,000	-	-	-	-	-	-	4,170.00 /ea	20,850
	Clevis Hanger 20"	15.00 ea	45	5,346	168.00 /ea	2,520	-	-	-	-	-	-	524.40 /ea	7,866
	Header CW	***150.00* lf**	572	67,954		42,570							**736.82 /lf**	110,524
Header HW														
	CS Pipe A-53S SMLS Grade B S 40 18"	150.00 lf	116	13,721	51.92 /lf	7,788	-	-	-	-	-	-	143.40 /lf	21,509
	CS Sch 40 90° Ell LR 18"	15.00 ea	180	21,384	587.00 /ea	8,805	-	-	-	-	-	-	2,012.60 /ea	30,189
	CS Sch 40 Tee 18x8"	5.00 ea	90	10,692	1,000.00 /ea	5,000	-	-	-	-	-	-	3,138.40 /ea	15,692
	Clevis Hanger 18"	15.00 ea	45	5,346	111.00 /ea	1,665	-	-	-	-	-	-	467.40 /ea	7,011
	Header HW	***150.00* lf**	431	51,143		23,258							**496.01 /lf**	74,401
HRC/GSHP Pipe														
	Gasket/Nuts/Bolt Kit 8"	15.00 ea	8	891	23.60 /ea	354	-	-	-	-	-	-	83.00 /ea	1,245
	CS Pipe A-53E ERW Std Wgt 8"	150.00 lf	80	9,445	22.64 /lf	3,396	-	-	-	-	-	-	85.60 /lf	12,841
	CS Std Wgt 90° Ell LR 8"	15.00 ea	122	14,470	199.00 /ea	2,985	-	-	-	-	-	-	1,163.66 /ea	17,455
	CS Std Wgt Con Red 8x6"	4.00 ea	26	3,136	109.00 /ea	436	-	-	-	-	-	-	893.08 /ea	3,572
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	53	6,296	45.24 /ea	452	-	-	-	-	-	-	674.88 /ea	6,749
	Valve 150# Butterfly 8"	6.00 ea	20	2,370	1,500.00 /ea	9,000	-	-	-	-	-	-	1,895.01 /ea	11,370
	Flanged Strainers 150# 8"	3.00 ea	10	1,185	2,000.00 /ea	6,000	-	-	-	-	-	-	2,395.01 /ea	7,185
	Clevis Hanger 8"	15.00 ea	30	3,564	61.49 /ea	922	-	-	-	-	-	-	299.09 /ea	4,486
	HRC/GSHP Pipe	***150.00* lf**	348	41,357		23,546							**432.69 /lf**	64,903
HVAC														
	sub by SF - Additional Ductwork Cooling	22,500.00 sl			/sl		15.00 /sl	337,500	-	-	-	-	15.00 /sl	337,500

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	HVAC	*22,500.00* sf						337,500					15.00 /sf	337,500
NG to Boiler														
	Hanger Clevis 2.5	15.00 ea	15	1,470	33.50 /ea	503	-	-	-	-	-	-	131.51 /ea	1,973
	2.5" CS SCH40 Pipe	150.00 lf	38	3,802	3.96 /lf	594	-	-	-	-	-	-	29.30 /lf	4,396
	2.5" CS SCH40 90 Elbow	15.00 ea	38	3,717	35.00 /ea	525	-	-	-	-	-	-	282.80 /ea	4,242
	2.5" CS SCH40 Tee	8.00 ea	31	3,025	79.50 /ea	636	-	-	-	-	-	-	457.68 /ea	3,661
	Flange WN 150 FF Sch 40 2-½	20.00 ea	30	2,964	37.00 /ea	740	-	-	-	-	-	-	185.20 /ea	3,704
	2.5" Ball Valve	5.00 ea	6	619	397.28 /ea	1,986	-	-	-	-	-	-	521.03 /ea	2,605
	NG to Boiler	*150.00* lf	158	15,597		4,984							137.21 /lf	20,581
Sprinklers														
	Sub by SF - Fire Suppression/Sprinklers	22,500.00 sf		-	-	-	5.00 /sf	112,500	-	-	-	-	5.00 /sf	112,500
	Sprinklers	*22,500.00* sf						112,500					5.00 /sf	112,500
	15 Mechanical	0.00	2,555	300,359		159,051		470,000						929,410
16 Elec. Dist.														
Backfeed to CUP														
	Demo Bituminous Pave up to 5"	760.00 sy			-	-	15.00 /sy	11,400	/mh		-	-	15.00 /sy	11,400
	Concrete Subcontractor by CY - Duct Bank Concrete	19.94 cy		-	-	-	800.00 /cy	15,948	-	-	-	-	800.00 /cy	15,948
	Cable Terminations	8.00 ea	8	704	/ea		-	-	-	-	-	-	88.00 /ea	704
	Copper THHN-THWN Stranded 1/C # 4/0	8.25 clf	35	3,122	256.00 /clf	2,281	-	-	-	-	-	-	654.88 /clf	5,403
	MV Cable 15 kV # 500 (3 Sets of 3)	24.75 clf	165	19,975	1,075.00 /clf	28,735	-	-	-	-	-	-	1,968.07 /clf	48,710
	PVC Sch 80 Conduit @ Underground 4" (4 Conduits 3 Active, 1 Spare)	1,100.00 lf	117	10,329	5.00 /lf	5,775	-	-	-	-	-	-	14.64 /lf	16,104
	PVC Sch 80 Elbow 90 deg 4"	26.00 ea	26	2,288	35.00 /ea	910	-	-	-	-	-	-	123.00 /ea	3,198
	Asphalt Restoration	760.00 sy		-	-	-	60.00 /sy	45,600	-	-	-	-	60.00 /sy	45,600
	Trench Exclave & Backfill Only	275.00 lf	110	9,075	2.50 /lf	688	-	-	500.00 /cd	2,750	-	-	45.50 /lf	12,513
	Spoils to Waste	162.09 cy		-	-	-	5.00 /cy	810	/cd		-	-	5.00 /cy	810
	Manhole - 4' Diameter - 0 - 6' Deep	3.00 ea	48	3,432	1,296.00 /ea	3,888	-	-	78.00 /mh	3,744	-	-	3,688.00 /ea	11,064
	Backfeed to CUP	*275.00* lf	510	48,924		42,276		73,758		6,494			623.47 /lf	171,453
Distribution Equip.														
	480V Emergency Generator Package Sets (w/ enclosure, batt charger, day tank)	2.00 ea	400	48,400	-	-	-	-	-	-	210,000.00 /ea	420,000	234,200.00 /ea	468,400
	480V Paralleling Switchgear @ DG output	1.00 ls			-	-	-	-	-	-	183,750.00 /ls	183,750	183,750.00 /ls	183,750
	15 kV Switchgear @ Net Zero Plant	1.00 ls			-	-	-	-	-	-	525,000.00 /ls	525,000	525,000.00 /ls	525,000
	Dry Type Transformer 3Ph 480 - 120/208V 75 kVA	1.00 ea	16	1,936	11,000.00 /ea	11,000	-	-	-	-	-	-	12,936.00 /ea	12,936
	Distribution Panelboard 480v MCB 1Phase 1200a	2.00 ea	48	5,808	6,000.00 /ea	12,000	-	-	-	-	-	-	8,904.00 /ea	17,808
	Motor Control Center	1.00 ea	200	24,200	100,000.00 /ea	100,000	-	-	-	-	-	-	124,200.00 /ea	124,200
	Transformer - 15 kV Primary/480V Secondary (Assume 4000 kva)	4.00 ea	480	58,080	/ea		-	-	-	-	105,000.00 /ea	420,000	119,520.00 /ea	478,080
	Distribution Equip.	*1.00* ls	1,144	138,424		123,000						1,548,750	1,810,174.00 /ls	1,810,174
Emergency Gen to SWG														
	Concrete Subcontractor by CY - Duct Bank Concrete	8.16 cy		-	-	-	800.00 /cy	6,528	-	-	-	-	800.00 /cy	6,528
	Cable Terminations	12.00 ea	12	1,452	95.00 /ea	1,140	-	-	-	-	-	-	216.00 /ea	2,592
	Copper THHN-THWN Stranded 1/C # 4/0	4.00 clf	17	2,081	256.00 /clf	1,106	-	-	-	-	-	-	796.78 /clf	3,187
	MV Cable 15 kV # 500 (3 Sets of 3)	12.00 clf	80	9,685	1,075.00 /clf	13,932	-	-	-	-	-	-	1,968.07 /clf	23,617
	PVC Sch 80 Conduit @ Underground 4" (2 Conduits @ 200 LF) ea	400.00 lf	43	5,164	5.00 /lf	2,100	-	-	-	-	-	-	18.16 /lf	7,264
	PVC Sch 80 Elbow 90 deg 4"	20.00 ea	20	2,420	35.00 /ea	700	-	-	-	-	-	-	156.00 /ea	3,120

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Emergency Gen to SWG														
	Trench Exclave & Backfill Only	100.00 lf	40	3,300	2.50 /lf	250	-	-	500.00 /cd	1,000	-	-	45.50 /lf	4,550
	Spoils to Waste	66.30 cy		-	-	-	5.00 /cy	332	0.00 /cd	0	-	-	5.00 /cy	332
	Emergency Gen to SWG	***200.00*** **lf**	**212**	**24,102**		**19,228**		**6,860**		**1,000**			**255.95 /lf**	**51,190**
Feed to Net Zero														
	Concrete Subcontractor by CY - Duct Bank Concrete	24.02 cy		-	-	-	800.00 /cy	19,213	-	-	-	-	800.00 /cy	19,213
	Cable Terminations	24.00 ea	24	2,904	95.00 /ea	2,280	-	-	-	-	-	-	216.00 /ea	5,184
	Copper THHN-THWN Stranded 1/C # 4/0	9.90 clf	43	5,151	256.00 /clf	2,737	-	-	-	-	-	-	796.78 /clf	7,888
	MV Cable 15 kV # 500 (3 Sets of 3)	29.70 clf	198	23,970	1,075.00 /clf	34,482	-	-	-	-	-	-	1,968.07 /clf	58,452
	PVC Sch 80 Conduit @ Underground 4" (4 Conduits, 3 Active 1 Spare)	1,320.00 lf	141	17,042	5.00 /lf	6,930	-	-	-	-	-	-	18.16 /lf	23,972
	PVC Sch 80 Elbow 90 deg 4"	40.00 ea	40	4,840	35.00 /ea	1,400	-	-	-	-	-	-	156.00 /ea	6,240
	Trench Exclave & Backfill Only	330.00 lf	132	10,890	2.50 /lf	825	-	-	500.00 /cd	3,300	-	-	45.50 /lf	15,015
	Spoils to Waste	195.28 cy		-	-	-	5.00 /cy	976	/cd		-	-	5.00 /cy	976
	Manhole - 4' Diameter - 0 - 6' Deep	2.00 ea	32	3,379	1,296.00 /ea	2,592	-	-	78.00 /mh	2,496	-	-	4,233.60 /ea	8,467
	Feed to Net Zero	***330.00*** **lf**	**610**	**68,176**		**51,246**		**20,189**		**5,796**			**440.63 /lf**	**145,407**
MCC to AC CHLRS (2)														
	Rigid Conduit Galvanized - 3"	400.00 lf	100	12,100	11.73 /lf	4,692	-	-	-	-	-	-	41.98 /lf	16,792
	Hangers, conduit supports, hanger, with bolt, 3" diameter	40.00 ea	23	2,759	20.00 /ea	800	-	-	-	-	-	-	88.97 /ea	3,559
	Cable terminations, terminal lugs, solderless, #2 to #1	4.00 ea	1	81	/ea		-	-	-	-	-	-	20.21 /ea	81
	Cable terminations, terminal lugs, solderless, 4/0	12.00 ea	2	242	/ea		-	-	-	-	-	-	20.21 /ea	242
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	4.00 clf	10	1,150	108.10 /clf	432	-	-	-	-	-	-	395.48 /clf	1,582
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	12.00 clf	43	5,256	256.80 /clf	3,082	-	-	-	-	-	-	694.82 /clf	8,338
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	40.00 ea	100	12,100	118.15 /ea	4,726	-	-	-	-	-	-	420.65 /ea	16,826
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	4.00 ea	16	1,936	184.50 /ea	738	-	-	-	-	-	-	668.50 /ea	2,674
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	2.00 ea	19	2,330	865.00 /ea	1,730	-	-	-	-	-	-	2,030.23 /ea	4,060
	MCC to AC CHLRS (2)	***400.00*** **lf**	**314**	**37,954**		**16,200**							**135.39 /lf**	**54,154**
MCC to ASHP (1)														
	Rigid Conduit Galvanized - 3"	150.00 lf	38	4,538	11.73 /lf	1,760	-	-	-	-	-	-	41.98 /lf	6,297
	Hangers, conduit supports, hanger, with bolt, 3" diameter	15.00 ea	9	1,035	20.00 /ea	300	-	-	-	-	-	-	88.97 /ea	1,335
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.21 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	1.50 clf	4	431	108.10 /clf	162	-	-	-	-	-	-	395.47 /clf	593
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	4.50 clf	16	1,971	256.80 /clf	1,156	-	-	-	-	-	-	694.82 /clf	3,127
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	15.00 ea	38	4,538	118.15 /ea	1,772	-	-	-	-	-	-	420.65 /ea	6,310
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	2.00 ea	8	968	184.50 /ea	369	-	-	-	-	-	-	668.50 /ea	1,337
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.22 /ea	2,030
	MCC to ASHP (1)	***150.00*** **lf**	**122**	**14,807**		**6,384**							**141.27 /lf**	**21,190**
MCC to ASHP CND (1)														
	Rigid Conduit Galvanized - 3"	200.00 lf	50	6,050	11.73 /lf	2,346	-	-	-	-	-	-	41.98 /lf	8,396
	Hangers, conduit supports, hanger, with bolt, 3" diameter	20.00 ea	11	1,379	20.00 /ea	400	-	-	-	-	-	-	88.97 /ea	1,779
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.21 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	2.00 clf	5	575	108.10 /clf	216	-	-	-	-	-	-	395.47 /clf	791
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	6.00 clf	22	2,628	256.80 /clf	1,541	-	-	-	-	-	-	694.82 /clf	4,169
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	20.00 ea	50	6,050	118.15 /ea	2,363	-	-	-	-	-	-	420.65 /ea	8,413
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	2.00 ea	8	968	184.50 /ea	369	-	-	-	-	-	-	668.50 /ea	1,337

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
MCC to ASHP CND (1)														
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.24 /ea	2,030
	MCC to ASHP CND (1)	*200.00* lf	157	18,977		8,100							135.39 /lf	27,077
MCC to CW Pumps (5)														
	Rigid Conduit Galvanized - 2" (5 Pumps @ 150 LF Ea)	750.00 lf	103	12,433	5.49 /lf	4,118	-	-	-	-	-	-	22.07 /lf	16,551
	Hangers, conduit supports, hanger, with bolt, 2" diameter	75.00 ea	40	4,810	14.00 /ea	1,050	-	-	-	-	-	-	78.13 /ea	5,860
	Cable terminations, terminal lugs, solderless, #8 to #4	5.00 ea	1	101	/ea		-	-	-	-	-	-	20.21 /ea	101
	Cable terminations, terminal lugs, solderless, #2 to #1	15.00 ea	3	303	/ea		-	-	-	-	-	-	20.21 /ea	303
	Wire, 600 volt, type THWN-THHN, copper, stranded, #6	7.50 clf	10	1,248	36.30 /clf	272	-	-	-	-	-	-	202.68 /clf	1,520
	Wire, 600 volt, type THWN-THHN, copper, stranded, #2	22.50 clf	48	5,785	86.00 /clf	1,935	-	-	-	-	-	-	343.13 /clf	7,720
	Conduit to 15' high, rigid galv steel, elbow, 2" dia	75.00 ea	94	11,344	48.70 /ea	3,653	-	-	-	-	-	-	199.95 /ea	14,996
	Pull box, NEMA 1, type SC, 18"W x 18"H x 6"D	5.00 ea	10	1,210	82.28 /ea	411	-	-	-	-	-	-	324.28 /ea	1,621
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 100 A	5.00 ea	28	3,328	601.00 /ea	3,005	-	-	-	-	-	-	1,266.50 /ea	6,333
	MCC to CW Pumps (5)	*750.00* lf	335	40,561		14,444							73.34 /lf	55,005
MCC to GSHP (1)														
	Rigid Conduit Galvanized - 3"	100.00 lf	25	3,025	11.73 /lf	1,173	-	-	-	-	-	-	41.98 /lf	4,198
	Hangers, conduit supports, hanger, with bolt, 3" diameter	10.00 ea	6	690	20.00 /ea	200	-	-	-	-	-	-	88.97 /ea	890
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.21 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	1.00 clf	2	287	108.10 /clf	108	-	-	-	-	-	-	395.47 /clf	395
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	3.00 clf	11	1,314	256.80 /clf	770	-	-	-	-	-	-	694.82 /clf	2,084
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	10.00 ea	25	3,025	118.15 /ea	1,182	-	-	-	-	-	-	420.65 /ea	4,207
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	1.00 ea	4	484	184.50 /ea	185	-	-	-	-	-	-	668.50 /ea	669
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.24 /ea	2,030
	MCC to GSHP (1)	*100.00* lf	84	10,152		4,483							146.35 /lf	14,635
MCC to HW Pumps (5)														
	Rigid Conduit Galvanized - 2" (5 Pumps @ 150 LF Ea)	750.00 lf	103	12,433	5.49 /lf	4,118	-	-	-	-	-	-	22.07 /lf	16,551
	Hangers, conduit supports, hanger, with bolt, 2" diameter	75.00 ea	40	4,810	14.00 /ea	1,050	-	-	-	-	-	-	78.13 /ea	5,860
	Cable terminations, terminal lugs, solderless, #8 to #4	5.00 ea	1	101	/ea		-	-	-	-	-	-	20.21 /ea	101
	Cable terminations, terminal lugs, solderless, #2 to #1	15.00 ea	3	303	/ea		-	-	-	-	-	-	20.21 /ea	303
	Wire, 600 volt, type THWN-THHN, copper, stranded, #6	7.50 clf	10	1,248	36.30 /clf	272	-	-	-	-	-	-	202.68 /clf	1,520
	Wire, 600 volt, type THWN-THHN, copper, stranded, #2	22.50 clf	48	5,785	86.00 /clf	1,935	-	-	-	-	-	-	343.13 /clf	7,720
	Conduit to 15' high, rigid galv steel, elbow, 2" dia	75.00 ea	94	11,344	48.70 /ea	3,653	-	-	-	-	-	-	199.95 /ea	14,996
	Pull box, NEMA 1, type SC, 18"W x 18"H x 6"D	5.00 ea	10	1,210	82.28 /ea	411	-	-	-	-	-	-	324.28 /ea	1,621
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 100 A	5.00 ea	28	3,328	601.00 /ea	3,005	-	-	-	-	-	-	1,266.50 /ea	6,333
	MCC to HW Pumps (5)	*750.00* lf	335	40,561		14,444							73.34 /lf	55,005
	16 Elec. Dist.	0.00	3,823	442,640		299,803		100,807		13,290		1,548,750		2,405,290
16 Elec. Misc.														
Conv. Elec														
	Electrical Cost Per SF - Convenience Electric	22,500.00 sf		-	-	-	1.00 /sf	22,500	-	-	-	-	1.00 /sf	22,500
	Conv. Elec	*22,500.00* sf						22,500					1.00 /sf	22,500
Fire Detection														
	Sub by SF - Fire Detection and Alarms	22,500.00 sf			/M		5.00 /sf	112,500	-	-	-	-	5.00 /sf	112,500
	Fire Detection	*22,500.00* sf						112,500					5.00 /sf	112,500

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Lighting														
	Electrical Cost Per SF - Lighting	22,500.00 sf		-	-	-	7.00 /sf	157,500	-	-	-	-	7.00 /sf	157,500
	Lighting	*22,500.00* **sf**						**157,500**					**7.00 /sf**	**157,500**
	16 Elec. Misc.	**0.00**						**292,500**						**292,500**
17 Inst & Controls														
Controls/Programming														
	Master Control Panel for Net Zero Energy	1.00 allo			-	-	-	-	-	-	525,000.00 /allo	525,000	525,000.00 /allo	525,000
	Control Points (Incle Conduit, Cable, Programming)	500.00 pts			-	-	-	-	-	-	1,050.00 /pts	525,000	1,050.00 /pts	525,000
	Controls/Programming	**0.00**										**1,050,000**		**1,050,000**
	17 Inst & Controls	**0.00**										**1,050,000**		**1,050,000**
	Net Zero Energy	*22,500.00* **sf**	**14,908**	**1,454,923**		**767,085**		**3,519,898**		**81,303**		**10,512,600**	**726.04 /sf**	**16,335,809**
Storage Sys. TTES														
02 Site Work														
TTES														
	Clearing/Grubbing/Tree Removal	1.00 allo			-	-	40,000.00 /allo	40,000	-	-	-	-	40,000.00 /allo	40,000
	1500 m3 CH-TTES-1	396,258.00 gal			/gal		2.00 /gal	792,516	-	-	-	-	2.00 /gal	792,516
	2400 m3 HW-TTES-1	634,012.00 gal			/gal		2.00 /gal	1,268,024	-	-	-	-	2.00 /gal	1,268,024
	Grading	50,000.00 sf	57	5,343	-	-	-	-	150.00 /ch	2,143	-	-	0.15 /sf	7,486
	TTES	**0.00**	**57**	**5,343**				**2,100,540**		**2,143**				**2,108,026**
	02 Site Work	**0.00**	**57**	**5,343**				**2,100,540**		**2,143**			**/ls**	**2,108,026**
	Storage Sys. TTES	*1.00* **ls**	**57**	**5,343**				**2,100,540**		**2,143**			**2,108,025.72 /ls**	**2,108,026**
	Phase 1	**0.00**	**73,684**	**8,321,950**		**5,273,478**		**5,911,730**		**280,604**		**11,710,650**		**31,498,412**

Estimate Totals

Description	Amount	Totals	Rate		Cost Basis	Percent of Total	
Labor	8,321,950					13.33%	
Material	5,273,478					8.45%	
Subcontract	5,911,730					9.47%	
Rental Equipment	280,604					0.45%	
Major Equipment / Other	11,710,650					18.75%	
	31,498,412	**31,498,412**				**50.44%**	**50.44%**
General Conditions (L,M,S,E %)	1,522,498		8.000	%	C	2.44%	
Contractor OH&P (L,M,S,E%)	1,903,122		10.000	%	C	3.05%	
	3,425,620	**34,924,032**				**5.49%**	**55.93%**
Design Contingency (PREV ST%)	6,984,806		20.000	%	T	11.19%	
Change Order Contingency (PREV ST%)	2,793,923		8.000	%	T	4.47%	
GM Contingency (PREV ST%)	873,101		2.500	%	T	1.40%	
Engineering (PREV ST%)	3,492,403		10.000	%	T	5.59%	
Construction Mgmt (PREV ST%)	1,047,721		3.000	%	T	1.68%	
	15,191,954	**50,115,986**				**24.33%**	**80.26%**
Escalation to 2025	12,328,532		24.600	%	T	19.74%	
Total		***62,444,518***					

UMass Dartmouth
Energy Master Plan Cost Estimate
Phase 3 Construction

Project name	UMass Dartmouth EMP
Labor rate table	Labor - Bare
Equipment rate table	Equipment
Report format	Sorted by 'Alternate/Location/Bid Item/System' 'Detail' summary Allocate addons
Alternates	Including: 22500, Phase 1, Phase 2, Phase 3

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Phase 3														
Net Zero Energy														
02 Site Work														
Exc. Foundation														
	Structure Excavation - Moderate Soils to Haul Offsite	80.00 cy	30	2,695	-	-	-	-	190.00 /ch	1,900	-	-	57.44 /cy	4,595
	Structure Backfill - Crushed Stone - From Hauled From Offsite	20.00 cy	10	513	25.00 /cy	500	-	-	300.00 /ch	571	-	-	79.24 /cy	1,585
	Haul Material Offsite 60 Minutes Round Trip	60.00 cy		-	-	-	5.00 /cy	300	5.00 /cy	300	/cy		10.00 /cy	600
	Exc. Foundation	*1.00* **ls**	**40**	**3,208**		**500**		**300**		**2,771**			**6,779.76 /ls**	**6,780**
Excavate SOG														
	Structure Excavation - Moderate Soils to Haul Offsite	40.00 cy	15	1,348	-	-	-	-	190.00 /ch	950	-	-	57.44 /cy	2,298
	Structure Backfill - Crushed Stone - From Hauled From Offsite	20.00 cy	10	513	25.00 /cy	500	-	-	300.00 /ch	571	-	-	79.24 /cy	1,585
	Haul Material Offsite 60 Minutes Round Trip	20.00 cy		-	-	-	5.00 /cy	100	5.00 /cy	100	/cy		10.00 /cy	200
	Excavate SOG	*1.00* **ls**	**25**	**1,861**		**500**		**100**		**1,621**			**4,082.28 /ls**	**4,082**
	02 Site Work	*1.00* **ls**	**64**	**5,069**		**1,000**		**400**		**4,393**			**10,862.04 /ls**	**10,862**
03 Concrete														
Bio Diesel Tk Footer														
	Continuous Footing Forms < 12"	260.00 sf	33	2,681	1.25 /sf	341	-	-	-	-	-	-	11.63 /sf	3,022
	Strip & Oil Footing Forms	260.00 sf	1	107	-	-	-	-	-	-	-	-	0.41 /sf	107
	Keyway 4"	130.00 lf	2	161	0.44 /lf	60	-	-	-	-	-	-	1.70 /lf	221
	Rebar # 5	0.31 ton	5	384	1,200.00 /ton	391	-	-	-	-	-	-	2,499.45 /ton	775
	Rebar # 5	0.23 ton	3	278	1,200.00 /ton	283	-	-	-	-	-	-	2,496.13 /ton	562
	3500 psi Concrete	14.44 cy		-	125.00 /cy	1,896	-	-	-	-	-	-	131.25 /cy	1,896
	Truck Place Wall Footings	14.44 cy	6	477	-	-	-	-	-	-	-	-	33.00 /cy	477
	Shape & Grade of Footings	390.00 sf	1	80	-	-	-	-	-	-	-	-	0.21 /sf	80
	Bio Diesel Tk Footer	*14.44* **cy**	**51**	**4,169**		**2,972**							**494.49 /cy**	**7,140**
BioDiesel Tank Pad														
	S-O-G Edge Form 6"	130.00 lf	12	975	1.25 /lf	171	-	-	-	-	-	-	8.81 /lf	1,146
	Strip & Oil SOG Form	130.00 sf	1	54	-	-	-	-	-	-	-	-	0.41 /sf	54
	Rebar # 5	1.09 ton	16	1,354	1,200.00 /ton	1,379	-	-	-	-	-	-	2,497.83 /ton	2,733
	Rebar # 5	1.09 ton	16	1,354	1,200.00 /ton	1,379	-	-	-	-	-	-	2,497.83 /ton	2,733
	3500 psi Concrete	37.04 cy		-	125.00 /cy	4,861	-	-	-	-	-	-	131.25 /cy	4,861
	Truck Place Slab on Grade	37.04 cy	17	1,375	-	-	-	-	-	-	-	-	37.13 /cy	1,375
	Finish- Hard Trowel	1,000.00 sf	15	1,237	0.04 /sf	38	-	-	-	-	-	-	1.28 /sf	1,275
	Liquid Curing Compounds	1,000.00 sf	2	165	0.02 /sf	20	-	-	-	-	-	-	0.19 /sf	185
	BioDiesel Tank Pad	*37.04* **cy**	**79**	**6,514**		**7,847**							**387.72 /cy**	**14,361**
Foundation Wall														
	Panel Form System 0-4'	780.00 sf	98	8,044	1.25 /sf	1,024	-	-	-	-	-	-	11.63 /sf	9,068
	Strip & Oil Wall Forms	780.00 sf	4	322	-	-	-	-	-	-	-	-	0.41 /sf	322
	Rebar # 5	0.62 ton	9	767	1,200.00 /ton	781	-	-	-	-	-	-	2,497.52 /ton	1,548
	Rebar # 5	0.45 ton	7	558	1,200.00 /ton	569	-	-	-	-	-	-	2,498.67 /ton	1,127
	3500 psi Concrete	14.44 cy		-	125.00 /cy	1,896	-	-	-	-	-	-	131.25 /cy	1,896
	Truck Place Walls	14.44 cy	8	655	-	-	-	-	-	-	-	-	45.38 /cy	655
	Finish- Top of Wall & Curb	130.00 sf	1	86	-	-	-	-	-	-	-	-	0.66 /sf	86
	Liquid Curing Compounds	780.00 sf	2	129	0.02 /sf	16	-	-	-	-	-	-	0.19 /sf	144
	Foundation Wall	*14.44* **cy**	**128**	**10,561**		**4,285**							**1,028.11 /cy**	**14,846**

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
	03 Concrete	*1.00* ls	257	21,243		15,104							36,347.59 /ls	36,348
15 Mechanical														
Bio Diesel Tank														
	Tank Leak Detection	1.00 ea	16	1,760	2,000.00 /ea	2,000	-	-	-	-	-	-	3,760.00 /ea	3,760
	Tank High Level & Low Level Sensor	1.00 ea	16	1,760	5,000.00 /ea	5,000	-	-	-	-	-	-	6,760.00 /ea	6,760
	Aboveground Tank Install Subcontractor 20,001 - 50,000 Gallon	1.00 ea	80	8,800	-	-	/ea		2,000.00 /ea	2,000	-	-	10,800.00 /ea	10,800
	Aboveground Oil Tank - Commercial - Single Wall/Containment 40,000 gal	1.00 ea			150,000.00 /ea	150,000	-	-	-	-	-	-	150,000.00 /ea	150,000
	Fuel Oil Transfer Pumps	2.00 ea	32	3,520	5,000.00 /ea	10,000	-	-	-	-	-	-	6,760.00 /ea	13,520
	Bio Diesel Tank	*1.00* ls	144	15,840		167,000				2,000			184,840.00 /ls	184,840
Fuel Oil to Boilers														
	Gasket/Nuts/Bolt Kit 4"	10.00 ea	5	594	7.52 /ea	75	-	-	-	-	-	-	66.92 /ea	669
	CS Sch 40 A53 BW PE 4"	400.00 lf	168	19,958	25.54 /lf	10,216	-	-	-	-	-	-	75.44 /lf	30,174
	CS Std Wt 90 Ell LR 4	40.00 ea	240	28,512	155.00 /ea	6,200	-	-	-	-	-	-	867.80 /ea	34,712
	CS Std Wgt Tee 4"	20.00 ea	180	21,384	227.00 /ea	4,540	-	-	-	-	-	-	1,296.20 /ea	25,924
	CS Flange WN RF XH 4"	10.00 ea	43	5,049	57.78 /ea	578	-	-	-	-	-	-	562.68 /ea	5,627
	Valve Flanged 150# Ball 4"	5.00 ea	13	1,538	1,135.00 /ea	5,675	-	-	-	-	-	-	1,442.69 /ea	7,213
	Clevis Hanger 4"	30.00 ea	60	7,128	12.06 /ea	362	-	-	-	-	-	-	249.66 /ea	7,490
	Fuel Oil to Boilers	*400.00* lf	708	84,164		27,646							279.52 /lf	111,810
Fuel Oil to Diesels														
	Gasket/Nuts/Bolt Kit 4"	10.00 ea	5	594	7.52 /ea	75	-	-	-	-	-	-	66.92 /ea	669
	CS Sch 40 A53 BW PE 4"	300.00 lf	126	14,969	25.54 /lf	7,662	-	-	-	-	-	-	75.44 /lf	22,631
	CS Std Wt 90 Ell LR 4	20.00 ea	120	14,256	155.00 /ea	3,100	-	-	-	-	-	-	867.80 /ea	17,356
	CS Std Wgt Tee 4"	10.00 ea	90	10,692	227.00 /ea	2,270	-	-	-	-	-	-	1,296.20 /ea	12,962
	CS Flange WN RF XH 4"	10.00 ea	43	5,049	57.78 /ea	578	-	-	-	-	-	-	562.68 /ea	5,627
	Valve Flanged 150# Ball 4"	4.00 ea	10	1,231	1,135.00 /ea	4,540	-	-	-	-	-	-	1,442.69 /ea	5,771
	Fuel Oil to Diesels	*300.00* lf	394	46,791		18,225							216.72 /lf	65,016
	15 Mechanical	*1.00* ls	1,246	146,794		212,871				2,000			361,665.22 /ls	361,665
	Net Zero Energy	*1.00* ls	1,568	173,107		228,975		400		6,393			408,874.85 /ls	408,875
Parking Lots														
16 Electrical														
PV Solar Canopies														
	Solar Car Canopy - Cost per MW	2.50 MW		-	-	-	-	-	-	-	4,250,000.00 /MW	10,625,000	4,250,000.00 /MW	10,625,000
	PV Solar Canopies	*1.00* ls										10,625,000	10,625,000.00 /ls	10,625,000
	16 Electrical	*1.00* ls										10,625,000	10,625,000.00 /ls	10,625,000
	Parking Lots	*1.00* ls										10,625,000	10,625,000.00 /ls	10,625,000
	Phase 3	*1.00* ls	1,568	173,107		228,975		400		6,393		10,625,000	11,033,874.85 /ls	11,033,875

Estimate Totals

Description	Amount	Totals	Rate		Cost Basis	Percent of Total	
Labor	173,107					0.79%	
Material	228,975					1.05%	
Subcontract	400					0.00%	
Equipment	6,393					0.03%	
Solar Canopies	10,625,000					48.70%	
	11,033,875	**11,033,875**				**50.57%**	**50.57%**
General Conditions (L,M,S,E %)	31,451		8.000	%	C	0.14%	
Contractor OH&P (L,M,S,E%)	39,314		10.000	%	C	0.18%	
	70,765	**11,104,640**				**0.32%**	**50.90%**
Design Contingency (L,M,S,E %)	78,628		20.000	%	C	0.36%	
Change Order Contingency (L,M,S,E %)	31,451		8.000	%	C	0.14%	
GM Contingency (L,M,S,E %)	9,828		2.500	%	C	0.05%	
Engineering (L,M,S,E %)	39,314		10.000	%	C	0.18%	
Construction Mgmt (L,M,S,E %)	11,794		3.000	%	C	0.05%	
	171,015	**11,275,655**				**0.78%**	**51.68%**
Escalation to 2035	10,542,737		93.500	%	T	48.32%	
Total		***21,818,392***					

UMass Dartmouth
Energy Master Plan Cost Estimate
Phase 2 Construction

Project name	UMass Dartmouth EMP
Labor rate table	Labor - Bare
Equipment rate table	Equipment
Report format	Sorted by 'Alternate/Location/Bid Item/System' 'Detail' summary Allocate addons
Alternates	Including: 22500, Phase 1, Phase 2, Phase 3

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Phase 2														
Central Utility Plant														
02 Demo Existing														
Demo Steam Equipment														
	Steam Plant Demolition - 5 Person Crew (8 Months)	8.00 mnth	**6,400**	**704,000**	-	**-**	-	**-**	/mh		-	**-**	88,000.00 /mnth	**704,000**
	Allowance for Asbestos Abatement/Hazmat Testing	1.00 ls			-	**-**	250,000.00 /ls	**250,000**	/mh		-	**-**	250,000.00 /ls	**250,000**
	Demo Steam Equipment	**0.00**	**6,400**	**704,000**				**250,000**						**954,000**
	02 Demo Existing	**0.00**	**6,400**	**704,000**				**250,000**						**954,000**
	Central Utility Plant	**0.00**	**6,400**	**704,000**				**250,000**						**954,000**
Net Zero Energy														
03 Concrete														
Ext. Equip Pads														
	Equipment Pad Form 6"	148.50 sf	**15**	**1,225**	1.25 /sf	**195**	-	**-**	-	**-**	-	**-**	9.56 /sf	**1,420**
	Strip & Oil Equipment Pad Form	148.50 sf	**1**	**61**	-	**-**	-	**-**	-	**-**	-	**-**	0.41 /sf	**61**
	Chamfer	297.00 lf	**4**	**368**	0.19 /lf	**59**	-	**-**	-	**-**	-	**-**	1.44 /lf	**427**
	Rebar # 5	0.98 ton	**15**	**1,207**	1,200.00 /ton	**1,229**	-	**-**	-	**-**	-	**-**	2,497.81 /ton	**2,435**
	Rebar # 5	0.98 ton	**15**	**1,207**	1,200.00 /ton	**1,229**	-	**-**	-	**-**	-	**-**	2,497.83 /ton	**2,435**
	3500 psi Concrete	33.00 cy		**-**	125.00 /cy	**4,331**	-	**-**	-	**-**	-	**-**	131.25 /cy	**4,331**
	Truck Place Equipment Pads	33.00 cy	**17**	**1,361**	-	**-**	-	**-**	-	**-**	-	**-**	41.25 /cy	**1,361**
	Finish- Float	1,782.00 sf	**18**	**1,470**	0.01 /sf	**14**	-	**-**	-	**-**	-	**-**	0.83 /sf	**1,484**
	Liquid Curing Compounds	1,782.00 sf	**4**	**294**	0.02 /sf	**36**	-	**-**	-	**-**	-	**-**	0.19 /sf	**330**
	Ext. Equip Pads	***3.00* ea**	**87**	**7,192**		**7,093**							**4,761.76 /ea**	**14,285**
Inerior Pads Large														
	Equipment Pad Form 6"	159.60 sf	**16**	**1,756**	1.25 /sf	**209**	-	**-**	-	**-**	-	**-**	12.31 /sf	**1,965**
	Strip & Oil Equipment Pad Form	159.60 sf	**1**	**88**	-	**-**	-	**-**	-	**-**	-	**-**	0.55 /sf	**88**
	Chamfer	319.20 lf	**5**	**527**	0.19 /lf	**64**	-	**-**	-	**-**	-	**-**	1.85 /lf	**590**
	Rebar # 5	0.87 ton	**13**	**1,439**	1,200.00 /ton	**1,099**	-	**-**	-	**-**	-	**-**	2,910.55 /ton	**2,538**
	Rebar # 5	0.87 ton	**13**	**1,439**	1,200.00 /ton	**1,099**	-	**-**	-	**-**	-	**-**	2,910.55 /ton	**2,538**
	3500 psi Concrete	29.56 cy		**-**	125.00 /cy	**3,879**	-	**-**	-	**-**	-	**-**	131.25 /cy	**3,879**
	Truck Place Equipment Pads	29.56 cy	**15**	**1,626**	-	**-**	-	**-**	-	**-**	-	**-**	55.00 /cy	**1,626**
	Finish- Float	1,596.00 sf	**16**	**1,756**	0.01 /sf	**13**	-	**-**	-	**-**	-	**-**	1.11 /sf	**1,768**
	Liquid Curing Compounds	1,596.00 sf	**3**	**351**	0.02 /sf	**32**	-	**-**	-	**-**	-	**-**	0.24 /sf	**383**
	Inerior Pads Large	***4.00* ea**	**82**	**8,980**		**6,395**							**3,843.80 /ea**	**15,375**
	03 Concrete	**0.00**	**169**	**16,172**		**13,488**								**29,660**
11 Equipment														
Install														
	Air Cooled Chillers 750 Ton Capacity	2.00 ea	**400**	**33,000**	/ea		-	**-**	-	**-**	-	**-**	16,500.00 /ea	**33,000**
	Hot Water Boilers 600 HP	2.00 ea	**800**	**66,000**	/ea		-	**-**	-	**-**	-	**-**	33,000.00 /ea	**66,000**
	Rig and Set HRC/GSHP 575 Ton Capacity	1.00 ea	**200**	**16,500**	/ea		-	**-**	-	**-**	-	**-**	16,500.00 /ea	**16,500**
	HRC/GSHP Misc. Installs (Piping, Valves, etc.)	1.00 ea	**480**	**39,600**	/ea		-	**-**	-	**-**	-	**-**	39,600.00 /ea	**39,600**
	Rig and Set ASHP 750 MBH/hr	1.00 ea	**200**	**16,500**	/ea		-	**-**	-	**-**	-	**-**	16,500.00 /ea	**16,500**
	ASHP Misc. Installs (Piping, Valves, etc.)	1.00 ea	**480**	**39,600**	/ea		-	**-**	-	**-**	-	**-**	39,600.00 /ea	**39,600**
	Install	***1.00* ls**	**2,560**	**211,200**									**211,200.00 /ls**	**211,200**
Supply														
	Air Cooled Chillers 750 Ton Capacity	2.00 ea			/ea		-	**-**	-	**-**	288,750.00 /ea	**577,500**	288,750.00 /ea	**577,500**
	Hot Water Boilers 600 HP	2.00 ea			/ea		-	**-**	-	**-**	430,500.00 /ea	**861,000**	430,500.00 /ea	**861,000**
	HRC/GSHP 575 Ton Capacity	1.00 ea			/ea		-	**-**	-	**-**	1,648,500.00 /ea	**1,648,500**	1,648,500.00 /ea	**1,648,500**
	ASHP 750 MBH/hr	1.00 ea			/ea		-	**-**	-	**-**	1,501,500.00 /ea	**1,501,500**	1,501,500.00 /ea	**1,501,500**
	HRC/GSHP Evaporator/Condenser Sections	1.00 ls			/ls		-	**-**	-	**-**	525,000.00 /ls	**525,000**	525,000.00 /ls	**525,000**
	ASHP Evaporator/Condenser Sections	1.00 ls			/ls		-	**-**	-	**-**	525,000.00 /ls	**525,000**	525,000.00 /ls	**525,000**
	HRC/GSHP Piping, Instruments, and Valves	1.00 ls			/ls		-	**-**	-	**-**	787,500.00 /ls	**787,500**	787,500.00 /ls	**787,500**
	ASHP Piping, Instruments, and Valves	1.00 ls			/ls		-	**-**	-	**-**	787,500.00 /ls	**787,500**	787,500.00 /ls	**787,500**
	Supply	***1.00* ls**										**7,213,500**	**7,213,500.00 /ls**	**7,213,500**
	11 Equipment	**0.00**	**2,560**	**211,200**								**7,213,500**		**7,424,700**
15 Mechanical														
Air Cooled CH Pipe														
	Gasket/Nuts/Bolt Kit 4"	20.00 ea	**10**	**1,188**	23.60 /ea	**472**	-	**-**	-	**-**	-	**-**	83.00 /ea	**1,660**

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
Air Cooled CH Pipe														
	CS Pipe A-53E ERW Std Wgt 8"	200.00 lf	**106**	**12,593**	22.64 /lf	**4,528**	-	-	-	-	-	-	85.60 /lf	**17,121**
	CS Std Wgt 90° Ell LR 8"	24.00 ea	**195**	**23,152**	199.00 /ea	**4,776**	-	-	-	-	-	-	1,163.66 /ea	**27,928**
	CS Flange WN 150 RF Std Wgt 8"	20.00 ea	**106**	**12,593**	45.24 /ea	**905**	-	-	-	-	-	-	674.88 /ea	**13,498**
	Valve 150# Butterfly 8"	8.00 ea	**27**	**3,160**	1,500.00 /ea	**12,000**	-	-	-	-	-	-	1,895.01 /ea	**15,160**
	Flanged Strainers 150# 8"	4.00 ea	**13**	**1,580**	2,000.00 /ea	**8,000**	-	-	-	-	-	-	2,395.01 /ea	**9,580**
	Clevis Hanger 8"	20.00 ea	**40**	**4,752**	61.49 /ea	**1,230**	-	-	-	-	-	-	299.09 /ea	**5,982**
	Air Cooled CH Pipe	***200.00* lf**	**497**	**59,017**		**31,911**							**454.64 /lf**	**90,928**
ASHP Pipe														
	Gasket/Nuts/Bolt Kit 4"	10.00 ea	**5**	**594**	23.60 /ea	**236**	-	-	-	-	-	-	83.00 /ea	**830**
	CS Pipe A-53E ERW Std Wgt 8"	100.00 lf	**53**	**6,296**	22.64 /lf	**2,264**	-	-	-	-	-	-	85.60 /lf	**8,560**
	CS Std Wgt 90° Ell LR 8"	12.00 ea	**97**	**11,576**	199.00 /ea	**2,388**	-	-	-	-	-	-	1,163.66 /ea	**13,964**
	CS Std Wgt Con Red 8x6"	4.00 ea	**26**	**3,136**	109.00 /ea	**436**	-	-	-	-	-	-	893.08 /ea	**3,572**
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	**53**	**6,296**	45.24 /ea	**452**	-	-	-	-	-	-	674.88 /ea	**6,749**
	Valve 150# Butterfly 8"	4.00 ea	**13**	**1,580**	1,500.00 /ea	**6,000**	-	-	-	-	-	-	1,895.01 /ea	**7,580**
	Flanged Strainers 150# 8"	2.00 ea	**7**	**790**	2,000.00 /ea	**4,000**	-	-	-	-	-	-	2,395.01 /ea	**4,790**
	Clevis Hanger 8"	10.00 ea	**20**	**2,376**	61.49 /ea	**615**	-	-	-	-	-	-	299.09 /ea	**2,991**
	ASHP Pipe	***100.00* lf**	**275**	**32,645**		**16,391**							**490.36 /lf**	**49,036**
Boiler HW Pipe														
	Gasket/Nuts/Bolt Kit 4"	10.00 ea	**5**	**594**	23.60 /ea	**236**	-	-	-	-	-	-	83.00 /ea	**830**
	CS Pipe A-53E ERW Std Wgt 8"	100.00 lf	**53**	**6,296**	22.64 /lf	**2,264**	-	-	-	-	-	-	85.60 /lf	**8,560**
	CS Std Wgt 90° Ell LR 8"	12.00 ea	**97**	**11,576**	199.00 /ea	**2,388**	-	-	-	-	-	-	1,163.66 /ea	**13,964**
	CS Std Wgt Con Red 8x6"	4.00 ea	**26**	**3,136**	109.00 /ea	**436**	-	-	-	-	-	-	893.08 /ea	**3,572**
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	**53**	**6,296**	45.24 /ea	**452**	-	-	-	-	-	-	674.88 /ea	**6,749**
	Valve 150# Butterfly 8"	4.00 ea	**13**	**1,580**	1,500.00 /ea	**6,000**	-	-	-	-	-	-	1,895.01 /ea	**7,580**
	Flanged Strainers 150# 8"	2.00 ea	**7**	**790**	2,000.00 /ea	**4,000**	-	-	-	-	-	-	2,395.01 /ea	**4,790**
	Clevis Hanger 8"	10.00 ea	**20**	**2,376**	61.49 /ea	**615**	-	-	-	-	-	-	299.09 /ea	**2,991**
	Boiler HW Pipe	***100.00* lf**	**275**	**32,645**		**16,391**							**490.36 /lf**	**49,036**
HRC/GSHP Pipe														
	Gasket/Nuts/Bolt Kit 4"	15.00 ea	**8**	**891**	23.60 /ea	**354**	-	-	-	-	-	-	83.00 /ea	**1,245**
	CS Pipe A-53E ERW Std Wgt 8"	150.00 lf	**80**	**9,445**	22.64 /lf	**3,396**	-	-	-	-	-	-	85.60 /lf	**12,841**
	CS Std Wgt 90° Ell LR 8"	15.00 ea	**122**	**14,470**	199.00 /ea	**2,985**	-	-	-	-	-	-	1,163.66 /ea	**17,455**
	CS Std Wgt Con Red 8x6"	4.00 ea	**26**	**3,136**	109.00 /ea	**436**	-	-	-	-	-	-	893.08 /ea	**3,572**
	CS Flange WN 150 RF Std Wgt 8"	10.00 ea	**53**	**6,296**	45.24 /ea	**452**	-	-	-	-	-	-	674.88 /ea	**6,749**
	Valve 150# Butterfly 8"	6.00 ea	**20**	**2,370**	1,500.00 /ea	**9,000**	-	-	-	-	-	-	1,895.01 /ea	**11,370**
	Flanged Strainers 150# 8"	3.00 ea	**10**	**1,185**	2,000.00 /ea	**6,000**	-	-	-	-	-	-	2,395.01 /ea	**7,185**
	Clevis Hanger 8"	15.00 ea	**30**	**3,564**	61.49 /ea	**922**	-	-	-	-	-	-	299.09 /ea	**4,486**
	HRC/GSHP Pipe	***150.00* lf**	**348**	**41,357**		**23,546**							**432.69 /lf**	**64,903**
NG to Boiler														
	Hanger Clevis 2.5	30.00 ea	**30**	**2,940**	33.50 /ea	**1,005**	-	-	-	-	-	-	131.51 /ea	**3,945**
	2.5" CS SCH40 Pipe	300.00 lf	**77**	**7,603**	3.96 /lf	**1,188**	-	-	-	-	-	-	29.30 /lf	**8,791**
	2.5" CS SCH40 90 Elbow	30.00 ea	**75**	**7,434**	35.00 /ea	**1,050**	-	-	-	-	-	-	282.80 /ea	**8,484**
	2.5" CS SCH40 Tee	16.00 ea	**61**	**6,051**	79.50 /ea	**1,272**	-	-	-	-	-	-	457.68 /ea	**7,323**
	Flange WN 150 FF Sch 40 2-½	40.00 ea	**60**	**5,928**	37.00 /ea	**1,480**	-	-	-	-	-	-	185.20 /ea	**7,408**
	2.5" Ball Valve	10.00 ea	**13**	**1,238**	397.28 /ea	**3,973**	-	-	-	-	-	-	521.03 /ea	**5,210**
	NG to Boiler	***300.00* lf**	**315**	**31,194**		**9,968**							**137.21 /lf**	**41,162**
	15 Mechanical	**0.00**	**1,710**	**196,859**		**98,207**								**295,065**
16 Elec. Dist.														
MCC to AC CHLRS (2)														
	Rigid Conduit Galvanized - 3"	400.00 lf	**100**	**12,100**	11.73 /lf	**4,692**	-	-	-	-	-	-	41.98 /lf	**16,792**
	Hangers, conduit supports, hanger, with bolt, 3" diameter	40.00 ea	**23**	**2,759**	20.00 /ea	**800**	-	-	-	-	-	-	88.97 /ea	**3,559**
	Cable terminations, terminal lugs, solderless, #2 to #1	4.00 ea	**1**	**81**	/ea		-	-	-	-	-	-	20.21 /ea	**81**
	Cable terminations, terminal lugs, solderless, 4/0	12.00 ea	**2**	**242**	/ea		-	-	-	-	-	-	20.21 /ea	**242**
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	4.00 clf	**10**	**1,150**	108.10 /clf	**432**	-	-	-	-	-	-	395.48 /clf	**1,582**
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	12.00 clf	**43**	**5,256**	256.80 /clf	**3,082**	-	-	-	-	-	-	694.82 /clf	**8,338**
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	40.00 ea	**100**	**12,100**	118.15 /ea	**4,726**	-	-	-	-	-	-	420.65 /ea	**16,826**
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	4.00 ea	**16**	**1,936**	184.50 /ea	**738**	-	-	-	-	-	-	668.50 /ea	**2,674**
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	2.00 ea	**19**	**2,330**	865.00 /ea	**1,730**	-	-	-	-	-	-	2,030.23 /ea	**4,060**
	MCC to AC CHLRS (2)	***400.00* lf**	**314**	**37,954**		**16,200**							**135.39 /lf**	**54,154**
MCC to ASHP (1)														

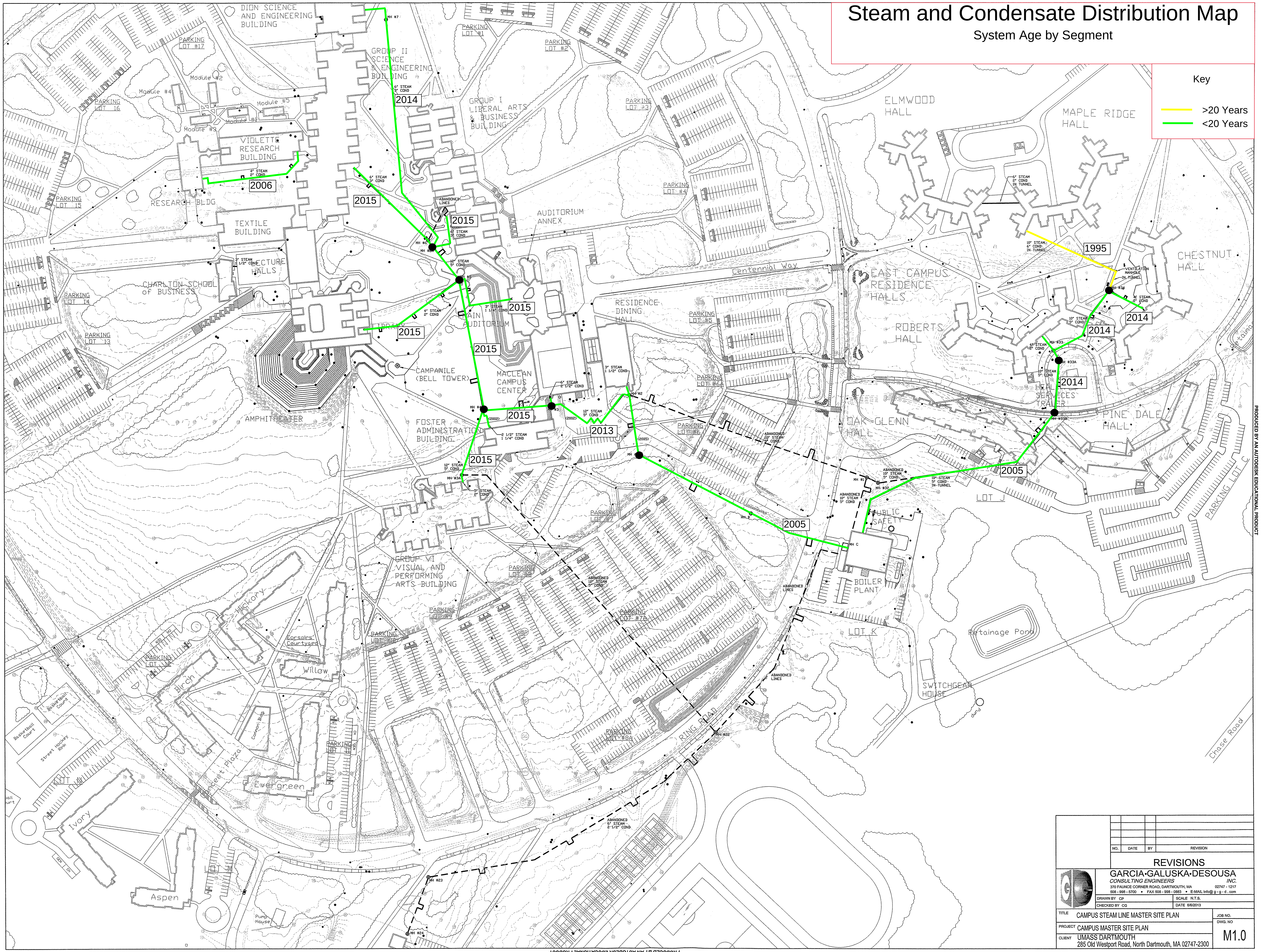
Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
MCC to ASHP (1)														
	Rigid Conduit Galvanized - 3"	150.00 lf	38	4,538	11.73 /lf	1,760	-	-	-	-	-	-	41.98 /lf	6,297
	Hangers, conduit supports, hanger, with bolt, 3" diameter	15.00 ea	9	1,035	20.00 /ea	300	-	-	-	-	-	-	88.97 /ea	1,335
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.21 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	1.50 clf	4	431	108.10 /clf	162	-	-	-	-	-	-	395.49 /clf	593
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	4.50 clf	16	1,971	256.80 /clf	1,156	-	-	-	-	-	-	694.82 /clf	3,127
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	15.00 ea	38	4,538	118.15 /ea	1,772	-	-	-	-	-	-	420.65 /ea	6,310
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	1.00 ea	4	484	184.50 /ea	185	-	-	-	-	-	-	668.50 /ea	669
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.24 /ea	2,030
	MCC to ASHP (1)	***150.00* lf**	**118**	**14,323**		**6,199**							**136.81 /lf**	**20,522**
MCC to ASHP CND (1)														
	Rigid Conduit Galvanized - 3"	200.00 lf	50	6,050	11.73 /lf	2,346	-	-	-	-	-	-	41.98 /lf	8,396
	Hangers, conduit supports, hanger, with bolt, 3" diameter	20.00 ea	11	1,379	20.00 /ea	400	-	-	-	-	-	-	88.97 /ea	1,779
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.20 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	2.00 clf	5	575	108.10 /clf	216	-	-	-	-	-	-	395.48 /clf	791
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	6.00 clf	22	2,628	256.80 /clf	1,541	-	-	-	-	-	-	694.82 /clf	4,169
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	20.00 ea	50	6,050	118.15 /ea	2,363	-	-	-	-	-	-	420.65 /ea	8,413
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	2.00 ea	8	968	184.50 /ea	369	-	-	-	-	-	-	668.50 /ea	1,337
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.22 /ea	2,030
	MCC to ASHP CND (1)	***200.00* lf**	**157**	**18,977**		**8,100**							**135.39 /lf**	**27,077**
MCC to GSHP (1)														
	Rigid Conduit Galvanized - 3"	100.00 lf	25	3,025	11.73 /lf	1,173	-	-	-	-	-	-	41.98 /lf	4,198
	Hangers, conduit supports, hanger, with bolt, 3" diameter	10.00 ea	6	690	20.00 /ea	200	-	-	-	-	-	-	88.97 /ea	890
	Cable terminations, terminal lugs, solderless, #2 to #1	2.00 ea	0	40	/ea		-	-	-	-	-	-	20.21 /ea	40
	Cable terminations, terminal lugs, solderless, 4/0	6.00 ea	1	121	/ea		-	-	-	-	-	-	20.21 /ea	121
	Wire, 600 volt, type THWN-THHN, copper, stranded, #1	1.00 clf	2	287	108.10 /clf	108	-	-	-	-	-	-	395.47 /clf	395
	Wire, 600 volt, type THWN-THHN, copper, stranded, 4/0	3.00 clf	11	1,314	256.80 /clf	770	-	-	-	-	-	-	694.82 /clf	2,084
	Conduit to 15' high, rigid galv steel, elbow, 3" dia	10.00 ea	25	3,025	118.15 /ea	1,182	-	-	-	-	-	-	420.65 /ea	4,207
	Pull box, NEMA 1, type SC, 24"W x 24"H x 8"D	1.00 ea	4	484	184.50 /ea	185	-	-	-	-	-	-	668.50 /ea	669
	Safety switches, heavy duty, 600 volt, 3 pole NEMA 1, fusible, 200 A	1.00 ea	10	1,165	865.00 /ea	865	-	-	-	-	-	-	2,030.24 /ea	2,030
	MCC to GSHP (1)	***100.00* lf**	**84**	**10,152**		**4,483**							**146.35 /lf**	**14,635**
	16 Elec. Dist.	**0.00**	**673**	**81,406**		**34,982**								**116,388**
17 Inst & Controls														
Controls/Programming														
	Control Points (Incle Conduit, Cable, Programming)	500.00 pts			-	-	-	-	-	-	1,050.00 /pts	525,000	1,050.00 /pts	525,000
	Controls/Programming	**0.00**										**525,000**		**525,000**
	17 Inst & Controls	**0.00**										**525,000**		**525,000**
	Net Zero Energy	***1.00* ls**	**5,111**	**505,637**		**146,676**						**7,738,500**	**8,390,813.54 /ls**	**8,390,814**
Storage Sys. BTES														
02 Site Work														
Borings														
	BTES Boreholes (Includes Boring, Piping, Spacers, Grouting)	1,667.00 ea			-	-	30.00 /ft	16,503,317	-	-	-	-	9,900.01 /ea	16,503,317
	Borings	***1,667.00* ea**						**16,503,317**					**9,900.01 /ea**	**16,503,317**
BTES #1 Distribution														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	4,600.00 lf	2,875	341,550	50.00 /lf	230,000	-	-	2.00 /lf	9,200	-	-	126.25 /lf	580,750
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	85.00 ea	170	20,196	70.61 /ea	6,002	-	-	-	-	-	-	308.21 /ea	26,198
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	40.00 ea	240	28,512	140.00 /ea	5,600	-	-	-	-	-	-	852.80 /ea	34,112
	BTES #1 Distribution	***4,600.00* lf**	**3,285**	**390,258**		**241,602**				**9,200**			**139.36 /lf**	**641,060**
BTES #2 Distribution														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	560.00 lf	350	41,580	50.00 /lf	28,000	-	-	2.00 /lf	1,120	-	-	126.25 /lf	70,700
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	13.00 ea	26	3,089	70.61 /ea	918	-	-	-	-	-	-	308.21 /ea	4,007
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	8.00 ea	48	5,702	140.00 /ea	1,120	-	-	-	-	-	-	852.80 /ea	6,822
	BTES #2 Distribution	***560.00* lf**	**424**	**50,371**		**30,038**				**1,120**			**145.59 /lf**	**81,529**

Spreadsheet Level	Description	Takeoff Quantity	Labor Hours	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Other Price	Other Amount	Total Cost/Unit	Total Amount
BTES #3 Distribution														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	1,100.00 lf	**688**	**81,675**	50.00 /lf	**55,000**	-	**-**	2.00 /lf	**2,200**	-	**-**	126.25 /lf	**138,875**
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	25.00 ea	**50**	**5,940**	70.61 /ea	**1,765**	-	**-**	-	**-**	-	**-**	308.21 /ea	**7,705**
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	15.00 ea	**90**	**10,692**	140.00 /ea	**2,100**	-	**-**	-	**-**	-	**-**	852.80 /ea	**12,792**
	BTES #3 Distribution	***1,100.00* lf**	**828**	**98,307**		**58,865**				**2,200**			**144.88 /lf**	**159,372**
BTES #4 Distribution														
	8" Direct Buried Piping (CS Carrier Pipe w/ Insulation and HDPE Jacket)	4,600.00 lf	**2,875**	**341,550**	50.00 /lf	**230,000**	-	**-**	2.00 /lf	**9,200**	-	**-**	126.25 /lf	**580,750**
	Direct Buried Piping Joint Kits (Foam,HDPE, Heat Shrink Sleeve)	85.00 ea	**170**	**20,196**	70.61 /ea	**6,002**	-	**-**	-	**-**	-	**-**	308.21 /ea	**26,198**
	Direct Buried Piping Elbows 22.5, 45, 90 - 8"	40.00 ea	**240**	**28,512**	140.00 /ea	**5,600**	-	**-**	-	**-**	-	**-**	852.80 /ea	**34,112**
	BTES #4 Distribution	***4,600.00* lf**	**3,285**	**390,258**		**241,602**				**9,200**			**139.36 /lf**	**641,060**
	02 Site Work	**0.00**	**7,822**	**929,194**		**572,107**		**16,503,317**		**21,720**			**/ls**	**18,026,338**
	Storage Sys. BTES	***1.00* ls**	**7,822**	**929,194**		**572,107**		**16,503,317**		**21,720**			**18,026,337.58 /ls**	**18,026,338**
	Phase 2	**0.00**	**19,333**	**2,138,831**		**718,783**		**16,753,317**		**21,720**		**7,738,500**		**27,371,151**

Estimate Totals

Description	Amount	Totals	Rate		Cost Basis	Percent of Total	
Labor	2,138,831					3.11%	
Material	718,783					1.04%	
Subcontract	16,753,317					24.35%	
Rental Equipment	21,720					0.03%	
Major Equipment / Other	7,738,500					11.25%	
	27,371,151	**27,371,151**				**39.79%**	**39.79%**
General Conditions (L,M,S,E %)	1,555,057		8.000	%	C	2.26%	
Contractor OH&P (L,M,S,E%)	1,943,821		10.000	%	C	2.83%	
	3,498,878	**30,870,029**				**5.09%**	**44.87%**
Design Contingency (PREV ST%)	6,174,006		20.000	%	T	8.97%	
Change Order Contingency (PREV ST%)	2,469,602		8.000	%	T	3.59%	
GM Contingency (PREV ST%)	771,751		2.500	%	T	1.12%	
Engineering (PREV ST%)	3,087,003		10.000	%	T	4.49%	
Construction Mgmt (PREV ST%)	926,101		3.000	%	T	1.35%	
	13,428,463	**44,298,492**				**19.52%**	**64.39%**
Escalation to 2030	24,497,066		55.300	%	T	35.61%	
Total		***68,795,558***					

APPENDIX F
STEAM AND CONDENSATE DISTRIBUTION MAP



Steam and Condensate Distribution Map
System Age by Segment
Key
>20 Years
<20 Years
2014
2006
2015
2015
2015
2015
2015
2015
2015
2013
2015
2005
2005
1995
2014
2014
2014
2014
DION SCIENCE AND ENGINEERING BUILDING
GROUP II SCIENCE & ENGINEERING BUILDING
GROUP I LIBERAL ARTS & BUSINESS BUILDING
VIOLETTE RESEARCH BUILDING
RESEARCH BLDG
TEXTILE BUILDING
LECTURE HALLS
CHARLTON SCHOOL of BUSINESS
LIBRARY
MAIN AUDITORIUM
AUDITORIUM ANNEX
CAMPANILE (BELL TOWER)
MACLEAN CAMPUS CENTER
FOSTER ADMINISTRATION BUILDING
AMPHITHEATER
RESIDENCE DINING HALL
GROUP VI VISUAL AND PERFORMING ARTS BUILDING
ELMWOOD HALL
MAPLE RIDGE HALL
CHESTNUT HALL
EAST CAMPUS RESIDENCE HALLS
ROBERTS HALL
HEALTH SERVICES TRAILER
PINE DALE HALL
OAK GLENN HALL
PUBLIC SAFETY
BOILER PLANT
SWITCHGEAR HOUSE
Retainage Pond
Centennial Way
RING ROAD
Chase Road
Hickory
Willow
Birch
Evergreen
Ivory
Aspen
Corsairs' Courtyard
Pump House
PARKING LOT #1
PARKING LOT #2
PARKING LOT #3
PARKING LOT #4
PARKING LOT #5
PARKING LOT #6
PARKING LOT #6A
PARKING LOT #7
PARKING LOT #7A
PARKING LOT #8A
PARKING LOT 13
PARKING LOT 14
PARKING LOT 15
PARKING LOT 16
PARKING LOT #17
LOT J
LOT K
LOT M
NO. DATE BY REVISION
REVISIONS
GARCIA•GALUSKA•DESOUSA INC.
CONSULTING ENGINEERS
370 FAUNCE CORNER ROAD, DARTMOUTH, MA 02747-1217
DRAWN BY CP
CHECKED BY CG
SCALE N.T.S.
DATE 6/6/2013
TITLE CAMPUS STEAM LINE MASTER SITE PLAN
PROJECT CAMPUS MASTER SITE PLAN
CLIENT UMASS DARTMOUTH
285 Old Westport Road, North Dartmouth, MA 02747-2300
JOB NO.
DWG. NO
M1.0

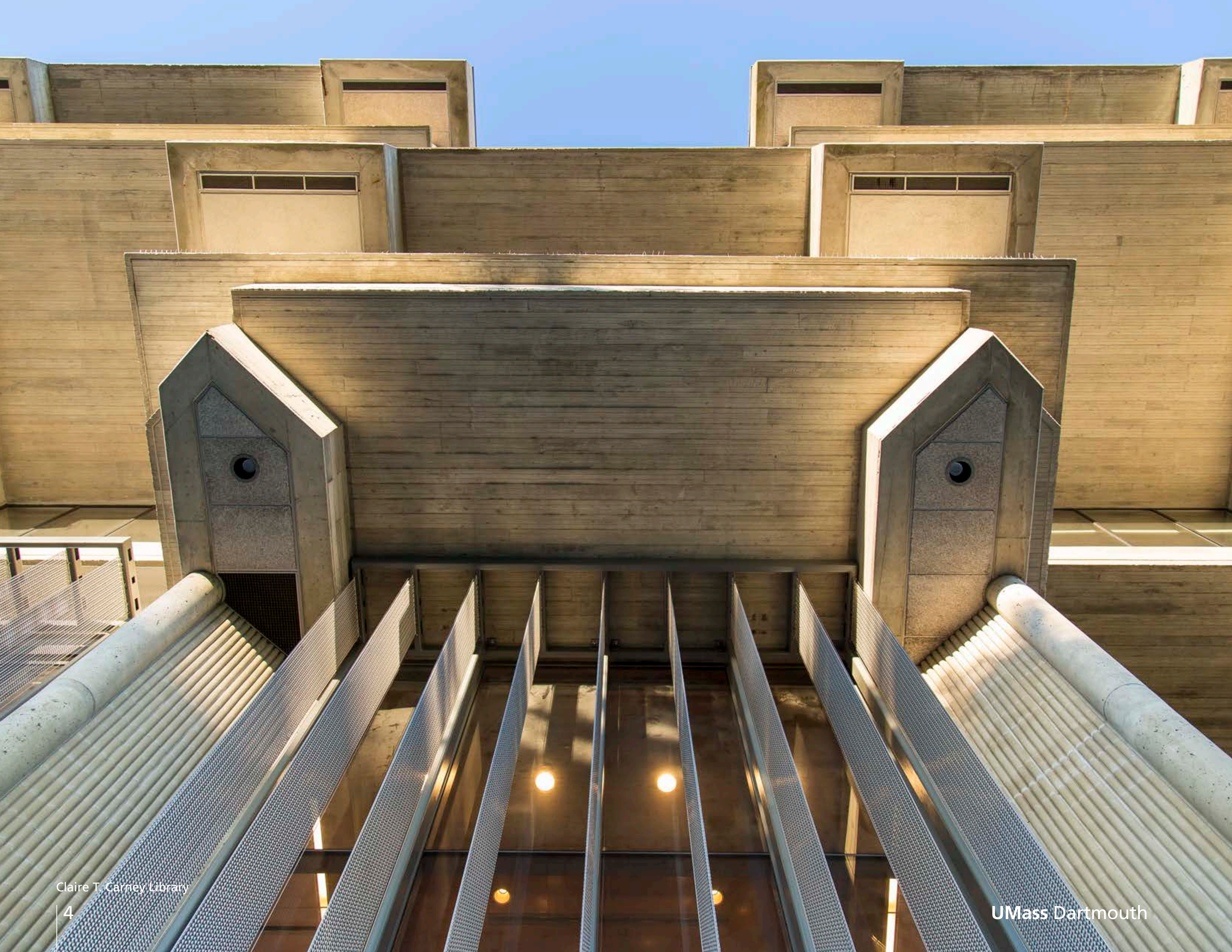
EXHIBIT A
CAMPUS MASTER PLAN

UMass | Dartmouth

2017 Campus Master Plan Final Report

Table of Contents

I. Chancellor’s Letter



Claire T. Carney Library

University of Massachusetts Dartmouth
Campus Master Plan
Chancellor's Letter

UMass Dartmouth has been transforming the lives of individuals and communities since its beginnings as two textile schools in 1895. Throughout its 122-year existence, including more than a half century on its spectacular 710-acre Dartmouth campus, the university has constantly evolved to meet the needs and aspirations of the region and Commonwealth. Our recent ascension to Tier 1 national research university status is proof of the excellence and determination of our faculty and staff, and positions the university to succeed in a fast-changing higher education environment.

This Campus Master Plan, completed after 18 months of detailed study and diverse feedback, presents a clear blueprint for UMass Dartmouth's future as the only Massachusetts research university south of Boston. The ideas presented here also challenge us to acquire the financial resources and pursue bold strategies that will turn this plan into reality.

This work is long overdue. While there has been significant investment off campus, our core main-campus academic buildings, campus center, athletic facilities, and housing are outdated. Since the 1980s, there has been just one major State investment in the main campus, the renovation and expansion of the Claire T. Carney Library. Our students, faculty, staff, and the region deserve better.

Central to this plan is our commitment to honor the legacy of the university's original architect, the internationally renowned Paul Rudolph, while confronting our deferred maintenance challenge through the renovation and replacement of outdated facilities. The Carney Library project proved that we can combine Rudolph's vision with 21st century realities to create compelling learning, living, and discovery spaces. This will position the university to attract and retain student, faculty, and staff talent that will strengthen the regional economic and cultural ecosystem.

Every dollar we invest in the campus will be mission specific. The highlights include:

- Renovated and new academic facilities with flexible, collaborative, technology-rich, and engaging learning environments.
- Replacement of first-year housing to provide a compelling mix of living and learning options.
- An expanded campus center with improved student activity, services, and dining venues.
- Enhanced visitor experiences that will be more inviting to potential students and connect our university community to our neighbors.
- Expanded athletic and recreational facilities that will increase student participation and access for our community partners.
- Traffic flow improvements that integrate pedestrian, bicycle, and transit ways.
- Sustainability best practices related to energy use and green space.

This facilities and landscape Campus Master Plan will now become a component of our university strategic plan, which we will develop in the coming year. We have purposely made this plan flexible to accommodate opportunities that arise during the strategic planning process. I hope you share my belief that the vision presented on these pages is possible through collaboration, bold strategic thinking, and steadfast determination.

Best regards,

Robert E. Johnson, Ph.D.
Chancellor

II. Executive Summary

Introduction

This Campus Master Plan is a road map for the renovation and replacement of University of Massachusetts Dartmouth facilities and grounds to enhance teaching and learning, research, and student development. The plan considers projected growth in student enrollment and the technological and pedagogical changes in higher education.

UMass Dartmouth is one of five universities that comprise the University of Massachusetts system and the only Massachusetts research university, public or private, located south of Boston.

In 1960, the Commonwealth of Massachusetts merged the New Bedford Institute of Technology and the Bradford Durfee College of Technology in Fall River to establish the 710-acre Southeastern Massachusetts Technological Institute in Dartmouth, between New Bedford and Fall River. Designed by world-famous architect Paul Rudolph, then dean of Yale University's School of Art and Architecture, ground was broken in 1964. The campus is one of the few examples in the United States where a single architect designed an entire campus.

Inspired by Thomas Jefferson's plan at the University of Virginia, Rudolph sought to create a unified campus core. Organized around a central north-south oriented communal green space and campus lawn continued down to the Cedar Dell Pond, Rudolph created a dramatic vista. The center of campus where these two corridors merge is where the symbolic forms and functions of the campus are located: the library, amphitheater, and campanile. These major corridors, combined with the Ring Road, and a landscaped berm ring, established a strong physical organization around which the campus core would be built.

Today, UMass Dartmouth has approximately 2.1 million gross square feet of space on the Dartmouth campus, and serves nearly 9,000 students with 55 percent of the students living on campus. UMass Dartmouth has additional off-campus sites, including UMass Law in Dartmouth, the Center for Innovation and Entrepreneurship in Fall River, the College of Visual and Performing Arts in downtown New Bedford, and the School for Marine Science and Technology on New Bedford Harbor, as well as the Kaput Center for Research and Innovation in STEM Education, which is currently based in Fairhaven.

This Campus Master Plan seeks to address issues related to deferred maintenance; campus teaching, research and student life capacity; visitor and prospective student experience; and pedestrian, bicycle, and automobile traffic. The plan is guided by a set of principles, including the need to enhance academic facilities to meet 21st century needs and aspirations, reinforce a sense of campus community and engagement, connect different sections of the campus with each other, improve first impressions of the campus, and honor Rudolph's legacy.

Campanile & amphitheater at the campus core

Process

Initiated in conjunction with the Division of Capital Asset Management and Maintenance (DCAMM), this Campus Master Plan update was developed with extensive involvement and input from the campus community.

Information Gathering

The Campus Master Plan process commenced with an in-depth qualitative and quantitative analysis of the existing UMass Dartmouth campus. The design team examined prior campus studies, toured the campus, assessed the facilities and infrastructure, studied campus circulation systems, quantified space usage, documented the qualitative aspects of the buildings and grounds, and met with numerous focus groups representing faculty, students, and leadership.

Findings and Guiding Principles

The Campus Master Plan team presented the initial findings from the information gathering stage and solicited feedback from constituents in order to establish the Campus Master Plan guiding principles, which state intended outcomes of the Campus Master Plan.

Scenario Planning

The Campus Master Plan team developed and refined a series of build-out plan options that were informed by the Campus Master Plan guiding principles. Feedback from the Steering Committee and senior leadership helped differentiate a preferred scheme that could be refined to address key issues facing the campus and accommodate future needs.

Campus Master Plan Vision

The Campus Master Plan vision reconciled the ideas and feedback that were facilitated by the scenario planning workshops into a holistic build-out plan. This vision was presented to the Steering Committee and senior leadership to seek feedback and facilitate discussion of project priorities.

Tours, workshops, & town halls were held throughout the Campus Master Plan process.

Key Issues

With input from the campus community and analysis of the campus, four key issues were identified that affect the function, perception, and condition of the campus:

1. **Campus Capacity**
   The UMass Dartmouth campus was built out in a relatively short time as a commuter campus with a capped capacity. Current student enrollment (with plans for growth), a larger residential component, changes in pedagogical modalities, increases in the number graduate students and greater research activities, have pushed the campus to its capacity.

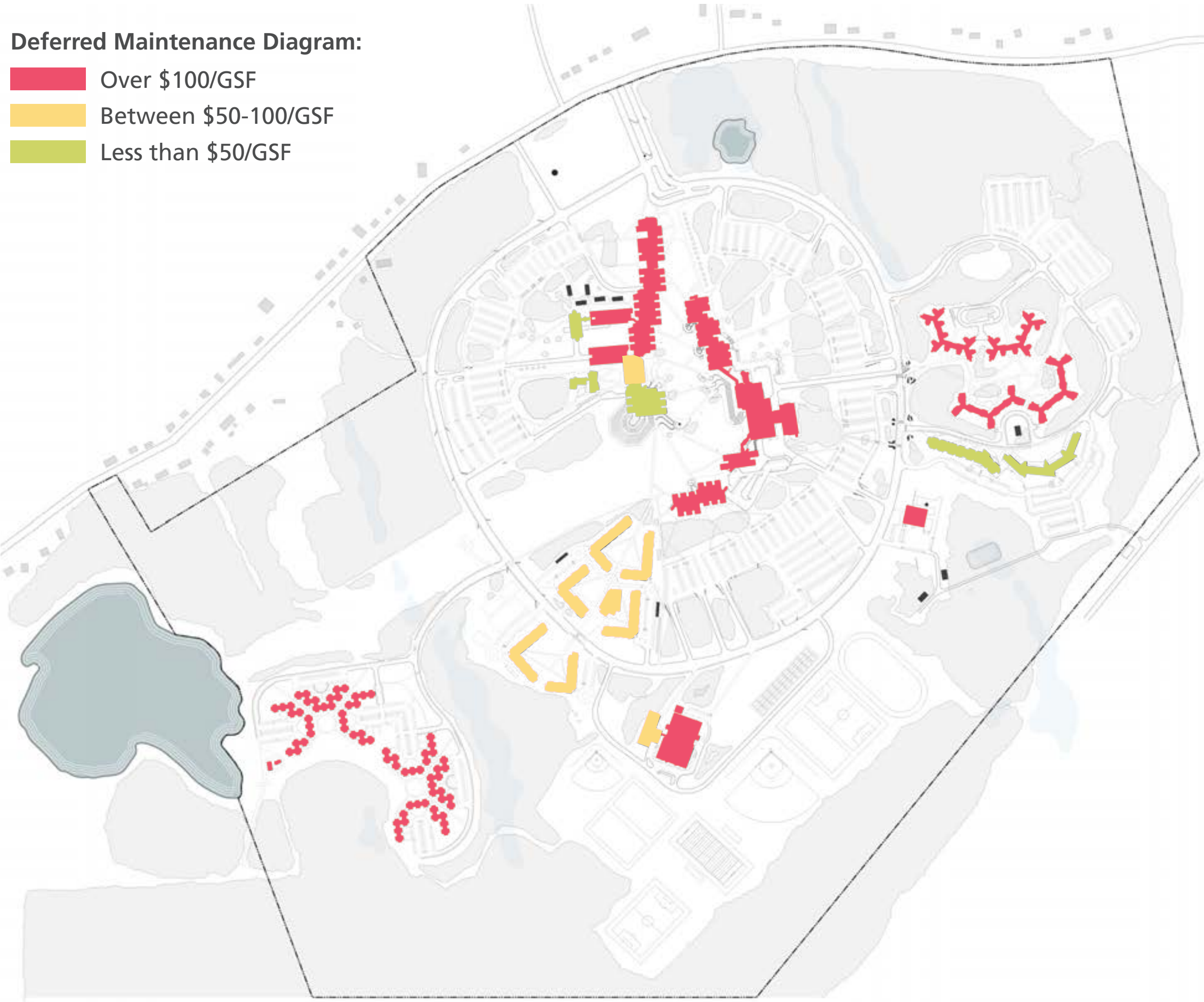
2. **Visitor / Admissions Experience**
   The visitor experience is compromised by confusing traffic patterns, difficulty determining the location of visitor parking, lack of clear wayfinding, an underwhelming Admissions Building, inadequate group meeting space, and an inability to see the best parts of the campus right away.

3. **Circulation/Transportation Issues**
   The campus circulation system suffers from clarity and safety issues, including an entrance drive that is offset from adjacent intersections, a ring road that lacks pedestrian and bicycle infrastructure, several points of automobile and pedestrian conflicts, a lack of wayfinding, a predominance of parking, and only one entrance/exit from campus.


Growth of student enrollment and changes in pedagogies provide new challenges on campus.


Existing Admissions Building


Existing vehicular entry comprises first impression.



4. Deferred Maintenance

All of the original Rudolph buildings are simultaneously experiencing serious performance deficiencies and are in need of significant renovation. Preserving and modernizing these buildings is crucial in maintaining and leveraging the Rudolph legacy. Sightlines has concluded that 53 percent of UMass Dartmouth facilities are 'High Risk – Life cycles of major building components are past due. Failures are possible.' The identified backlog for FY17 is $563.5 million, translating to almost $182/per square foot, and has continued to increase since 2008. In addition, the Cedar Dell residences and most of the first-year residence halls have exceeded their expected lifecycle.

Guiding Principles

During the Campus Master Plan process, a set of overarching guiding principles were developed that reflect the core values of the university and address the Campus Master Plan key issues.

The Campus Master Plan was initially conceived under the UMassDTransform2020 strategic plan, and the challenges and opportunities identified in that plan still face UMass Dartmouth as the university enters its next strategic planning process.

In September 2017, UMass Dartmouth Chancellor Robert E. Johnson began a listening tour involving small group conversations with about 30 internal and external constituent groups. The conversations solicited a variety of perspectives about UMass Dartmouth's optimal future state and encouraged possibility thinking. This will serve as the base to identify areas of strategic focus and chart a shared ambition for UMass Dartmouth's future.

The next strategic planning cycle will begin in Spring 2018, and will create the new strategic plan that will carry UMass Dartmouth to 2025.

Enhance Academic Facilities
As a tier one national research university, UMass Dartmouth must provide academic facilities that will meet the changing pedagogical and research needs of students and faculty.

Reinforce Campus Community
Provide spaces that support the daily life of students, faculty, and staff with adequate areas for collaboration, socialization, meetings, gatherings, dining, recreation, athletics, and indoor and outdoor activities.

Connect the Campus
Create physical connections across the campus, improve traffic flow and safety, link open spaces and campus edges, and maintain a compact campus with a blending of uses.

Improve First Impressions
Develop a student and visitor experience that is intuitive and shows what is best about the university.

Leverage and Interpret Rudolph's Legacy
Update the original Paul Rudolph buildings and grounds to meet the needs of today while being respectful of the original architecture, as was demonstrated by the award-winning renovation of the Claire T. Carney Library.

These guiding principles established the framework that the expansion and renovation of existing spaces would achieve.

Proposed Plan

The proposed plan is based upon the guiding principles, addresses the strategic initiatives of the university going forward, and builds upon architect Paul Rudolph's vision.

Enhance Academic Facilities
- New Interdisciplinary Science Building framing a new sciences/engineering quad
- Science / Engineering and Dion renovations
- Expanded LARTS building with up-to-date classrooms and collaboration space
- LARTS building renovation
- Expansion of Charlton College of Business
- Renovation of Foster Building for student services

Reinforce Campus Community
- Replacement of first-year and sophomore Living Learning Village
- New upperclassmen housing
- Expanded and improved Campus Center and Conference Center
- New campus dining venue
- Expanded athletics and recreation facility and improved fields

Connect the Campus
- South Lawn to Athletics and recreation
- Shift Ring Road and create East Lawn
- Improve Ring Road with pedestrian, bicycle, and transit accommodations

Improve First Impressions
- New entrance road
- New visitor center, auditorium lobby, and admissions drop-off
- Improved connections to the quad

Leverage and Interpret Rudolph's Legacy
- Renovations to existing Rudolph buildings to improve the learning environment
- Reintegration of collaboration spaces
- Second ring of quads, courtyards, and yards
- Improvements to the Great Lawn to accommodate comfort and universal access

Existing Campus Plan

Proposed Campus Plan

III. Observations

Campus History

In the late 1950s, the SouthCoast region of Massachusetts was enduring a period of economic stagnation and neglect by the state government. Governor Foster Furcolo sought to spark an economic revival in the area through the public higher education system, believing that a reinvigorated system could act as a catalyst for economic and cultural improvements. An enhanced and more robust public educational system was also a response to a growing post-war demand for a more educated workforce, which contributed to the expectation that there be universal access to higher education.

In a joint resolution in March of 1960, the New Bedford Institute of Technology and Bradford Durfee College of Technology located in Fall River were merged to form the Southeastern Massachusetts Technological Institute (SMTI). While both of these institutions were technology- and engineering-based, the planning and acceptance of this merger by the local communities in New Bedford and Fall River was influenced by enhancement and expansion of the academic offerings to include a robust liberal arts program. After final approval of the merger, the Board of Trustees of SMTI was tasked with the selection of a new site for the institution, which presented a rare opportunity for an institution in the process of creating an architectural identity. Located midway between New Bedford and Fall River, SMTI acquired a 710-acre parcel of land including farmland, meadows, and woodlands exemplifying the landscape of the SouthCoast.

The architectural firm of Desmond and Lord was retained by SMTI in 1961 to develop a comprehensive design for the new campus. Lacking the required experience and expertise to undertake an ambitious design at campus scale, Desmond and Lord turned to modernist architect, and then Dean of the Yale School of Architecture, Paul Rudolph to produce the design.

The 'tabla rasa' nature of the acquired site allowed considerable freedom for Rudolph's most complete and comprehensive expression of his ideas on architecture and urbanism. UMass Dartmouth was conceived as a campus for commuters due to the student population and the 'remote' location of the institution. To accommodate vehicular circulation, Rudolph defined the perimeter of campus with a Ring Road free of traffic signals to facilitate uninterrupted travel with central parking. Rudolph was very cognizant of pedestrians, and sought to create a distinct and separate experience once someone was within the campus core. A ring of landscaped berms lining the interior edge of the parking lots concealed the vehicular infrastructure from the inner core.

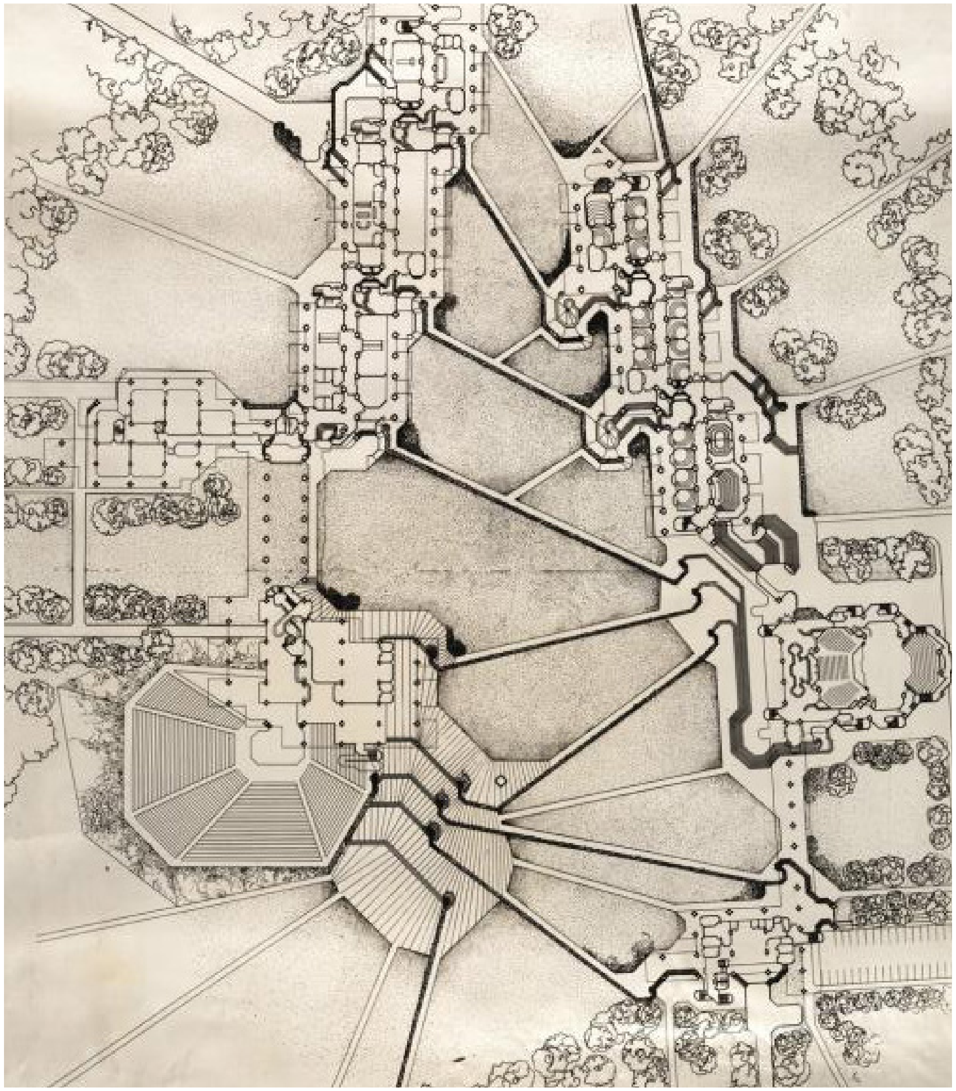
Site aerial of landscape prior to construction

Site aerial of Ring Road during construction

'Collective' rather than the 'Individual'

Inspired by Thomas Jefferson's plan at the University of Virginia at Charlottesville, Rudolph sought to create a 'unified' campus core that was organized around central elements. These organizing elements were a north-south oriented communal green space and a campus lawn that continued down to Cedar Dell Pond, creating a dramatic vista. The center of campus where these two corridors merge is where the symbolic forms and functions of the campus are located: the library, amphitheater, and campanile. These major corridors, the Ring Road, and the landscaped berm ring established a strong formal organization in which the campus core would be built around.

The major north-south corridor on the campus (Great Lawn) was terraced and negotiated a decrease in elevation moving towards the campanile. Diagonal pedestrian pathways crossed the Great Lawn at these terraced elevation changes that connected the atrium spaces located in the modulated Liberal Arts (LARTS) and Science and Engineering (SENG) buildings. These modulated academic buildings formed the edges of the Great Lawn and had a unified architectural character. These Rudolph academic buildings at UMass Dartmouth were characterized by their sculptural forms, cantilevered volumes, complex geometries, and brutalist material palette. Rudolph's material palette consisted of board-formed concrete, fluted concrete block, and expansive glass panes. The consistent use of these materials throughout the buildings on campus contributed to its unified feel.



Paul Rudolph's Campus Plan

While Rudolph's design received praise and accolades from the architectural community, the state government often critiqued his design as being too modern, extravagant, and a waste of taxpayer dollars. The Liberal Arts Building (LARTS) was completed in 1966 and was the sole academic building on campus until 1969. LARTS consolidated and housed most campus functions. However, weeks after the dedication of the LARTS building, bids came in for the SENG building and were over budget, which prompted the state to remove Rudolph from the project. With Rudolph removed from the project, the integrity of the Campus Master Plan vision was in jeopardy. However, the architects at Desmond and Lord whom had worked with Rudolph, remained dedicated and committed to carrying out the unified campus vision. This proved integral to shaping the campus' layout in what Rudolph called "the most complete expression of his ideas about architecture and planning."

1971 Campus Master Plan Update – Shurcliff, Merrill, and Footit

Rudolph's Campus Master Plan was rigorous and structured, forming edges of the Great Lawn as well as framing the Cedar Dell vista. In 1971, the landscape-planning firm of Shurcliff, Merrill, and Footit completed an update to Rudolph's Campus Master Plan that offered the first iteration of where academic and residential expansion could be sited. While the majority of the Campus Master Plan was never realized, it included some compelling ideas of how to both expand the campus and respect Rudolph's legacy.

The new Campus Master Plan team gravitated towards a few concepts in particular in regards to the Shurcliff update. One idea was to construct a second 'layer' of academic buildings to the west of the Science and Engineering buildings. This would introduce a new spatial typology on campus of smaller quads in the area between the existing Science and Engineering building and proposed academic expansion.

Additionally, these new plans maintained the integrity of the campus corridors and played off the module organization of the Rudolph academic buildings. Another compelling concept in the Campus Master Plan update was the organization and form of the east residence halls. The cellular layout of the dormitories formed the edges of court-like spaces, creating a public space that belonged to each building. A clear spatial hierarchy was defined between the more private space in front of each building and the more public collective space bounded by the grouping of dormitories.

2005 Campus Master Plan Update – Chan Krieger & Associates

The 2005 Campus Master Plan built upon some of the recommendations from the Shurcliff, Merrill and Footit plan by proposing a second layer of buildings west of the Science and Engineering buildings, creating a series of intimate courtyards that could be themed as arboretums or other learning landscapes. The new buildings were perpendicular to the Science and Engineering buildings creating sunny east-west outdoor spaces.

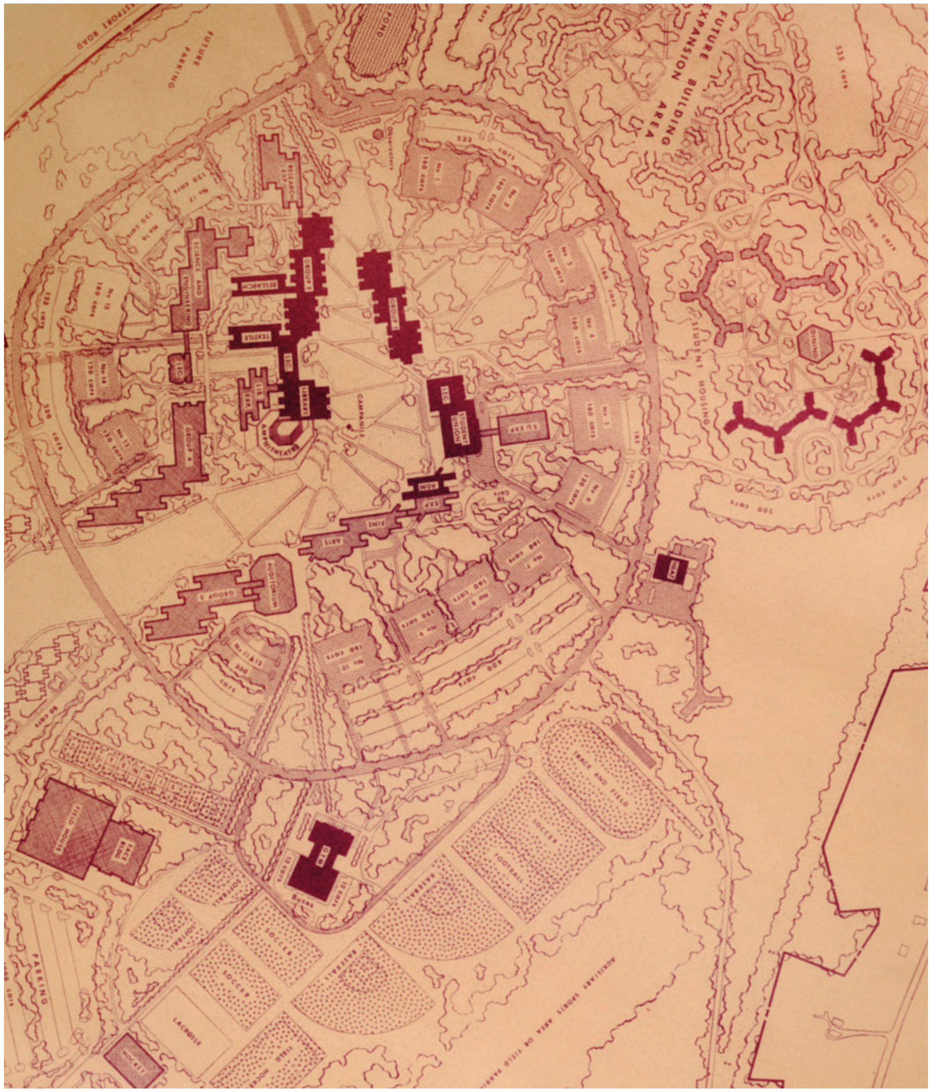
The plan proposed additions to the Auditorium that would provide needed back of house and front of house spaces. The Library renovation included glazing in the former open air passageway as a new library commons, which was incorporated into the renovation. New student housing was proposed on the east side of campus as well as the creation of what today is the Woodlands. Cedar Dell was to be removed and additional housing placed on that site.

Future building sites and a significant new open space were identified east of the Auditorium Building to build connectivity to the eastern housing cluster. The Tripp Center would be expanded with a new fieldhouse adjacent to the outdoor competition and recreational fields. Parking continued to expand primarily within the Ring Road.

The plan included an extensive assessment of the existing campus buildings, grounds, and infrastructure that highlighted both the challenges as well as the opportunities for renewal, such as converting the Library ground floor passageway into a commons as well as expanding usable space under the lecture halls with glass exterior walls. Other opportunities included upgrading the campus lighting, wayfinding systems, entrance drive and visitor experience, and new Ring Road pedestrian crossings to improve campus safety.

Overview of UMass Dartmouth

UMass Dartmouth is an accredited, four-year university that offers 55 undergraduate majors, 33 graduate programs, and 14 doctoral programs to almost 9,000 enrolled students. This critical mass of students has solidified UMass Dartmouth's academic impact throughout Massachusetts and beyond, as well as strengthening the cultural, economic, and social fabric of the region. UMass Dartmouth maintains research and a creative-based presence in Fall River and New Bedford, forging an 'Innovation Triangle' in the SouthCoast that produces knowledge and ideas that impact the region and the world.

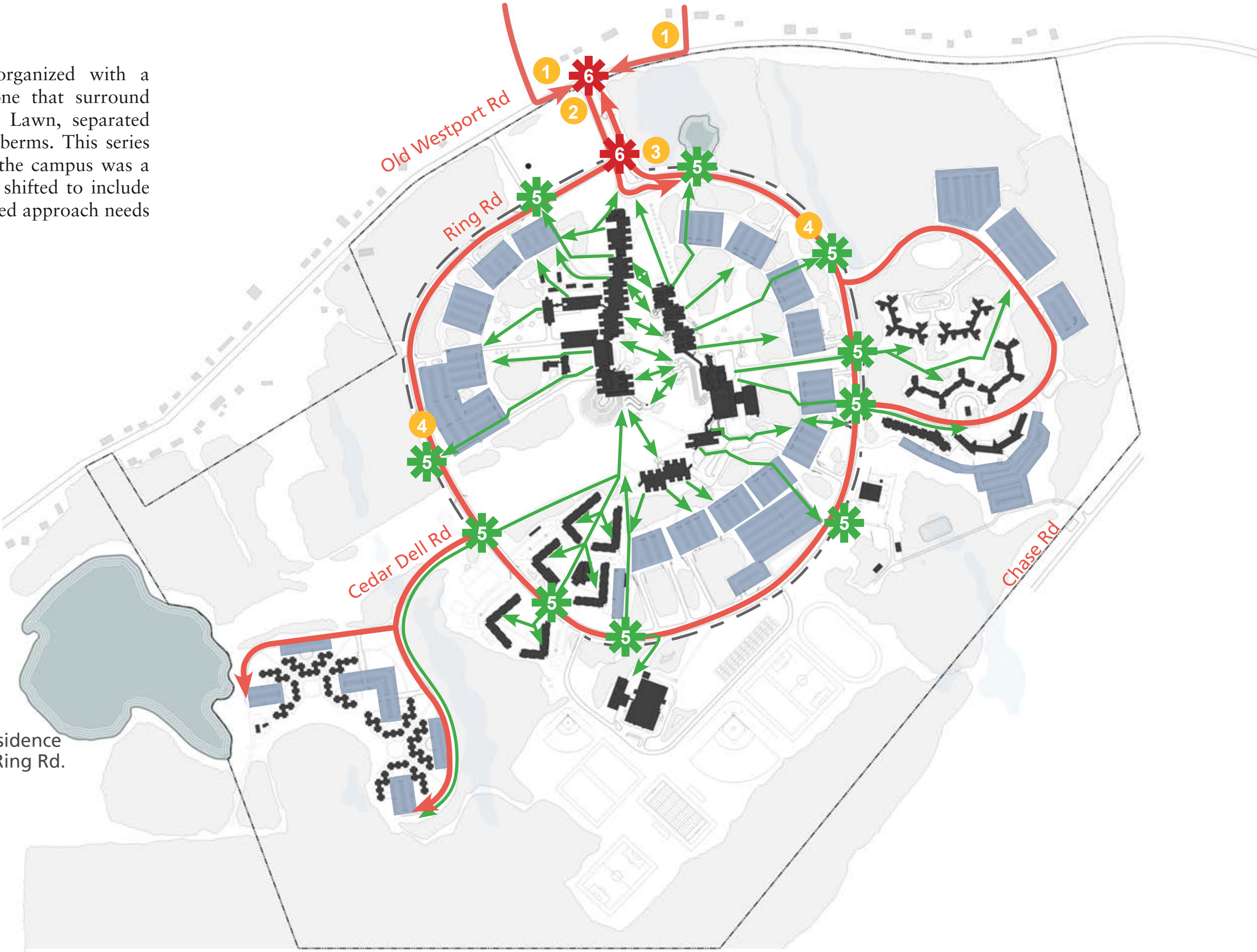


Shurcliff, Merrill, & Footit Campus Plan

Built Systems

Circulation/Transportation

The UMass Dartmouth campus is organized with a perimeter Ring Road and parking zone that surround the academic campus core and Great Lawn, separated by a buffer of natural woodlands and berms. This series of concentric rings worked well when the campus was a commuter campus. As the campus has shifted to include more residential communities, this layered approach needs to be adjusted in a few key areas.



Campus Circulation Diagram:

1 Entrance Locations
2 Campus Entrance
3 Ring Road Juncture
4 Ring Road Character
5 Pedestrian Conflicts at East Residence Halls, Cedar Dell, Athletics, & Ring Rd.
6 Vehicular Conflicts
Parking
Pedestrian Circulation
Vehicular Circulation
Parallel Parking

1. **The entrance location**
The main entrance to campus is on Old Westport Road in between Cross Road and Morton Avenue. The intersection offset from Cross Road is about 620 feet and the offset from Morton Avenue is about 350 feet. Both roads are used on a regular basis and both routes require several turning movements to enter into campus, backing up traffic and creating potential for automobile and pedestrian accidents. Ideally, the campus entrance would align with Cross Road as it is designed to accommodate the larger volume of traffic coming to the campus on a daily basis.

2. **Ring Road juncture**
The main entrance to campus is designed as a divided multilane road that is oversized for the amount of traffic coming into the campus and is out of character with most of the other roads in Dartmouth. As the entrance road connects with the Ring Road, there is an offset in the ring that is confusing and leads to more potential automobile conflicts. Ideally, the entrance Road would connect to the Ring Road in a very simple T intersection or rotary to ease traffic movement and simplify driver decision-making. Exiting the campus presents a problematic condition as well, as vehicles traveling eastbound on Ring Road have to cross two (2) three-lane roadways at an unsignalized intersection.

3. **Ring Road character**
The Ring Road is a two lane, two-way road with parallel parking on its outer edge. There are numerous curb cuts into the perimeter parking lots off the Ring Road. Due to the wide lanes and rural character of the road, drivers tend to drive relatively fast which increases the risk of vehicular and pedestrian accidents. In addition, there are no striped bike lanes or accommodations for pedestrians along the road, which leads to safety concerns. Ideally, the road would be narrowed, slowed, accommodate the volume of traffic needed to support the campus, as well as provide accommodations for bicycles and pedestrians to become a multimodal transportation loop for the campus.

4. **Pedestrian conflicts at East Residence Halls, Cedar Dell, and Athletics**
The Ring Road creates a perimeter around the academic core and separates the east residence halls, Cedar Dell, and athletics from the campus center. The result is several pedestrian and automobile conflict pinch points that slows the flow of traffic and potentially affects the safety of pedestrians. Ideally, the Ring Road traffic would either be calmed or rerouted to avoid these pedestrian auto conflicts.

5. **Wayfinding**
One of the beautiful attributes of the campus is the integration of the mature landscape. However, the landscape also conceals the core campus from view from the Ring Road making it difficult to understand where one is located on campus. Additionally, a visitor to the campus is faced with a confusing series of turns when entering the campus. There is a lack of sufficient direction and wayfinding, which creates a disorienting condition. Ideally, there would be a more intuitive wayfinding and signage system that would orient drivers to their location on campus.

6. **One entrance**
The main entrance drive off Old Westport Road is the only access point for the campus. There have been snow emergencies or other circumstances when it is necessary to move people off the campus relatively quickly, which is difficult with only one exit point. There may also be times where due to an accident on, or near, the entrance road, there is limited ability to exit the campus. Ideally, there would be at a minimum two exit points from the campus to the surrounding road network providing a relief valve to the singularity and congestion of the current condition.

7. **Parking**
The campus was initially conceived as a commuter campus and has 5,260 surface parking spaces today, which are more than is needed for the current campus population. In addition, the parking surrounds the academic core, which separates areas of campus outside of the Ring Road from the academic core. Ideally, some of these internal parking lots would be developed as building sites in order to improve connectivity on campus and would shift parking to the perimeter of the campus, connected with well-lit, comfortable walkways. The quantity of parking would need to be adjusted to remain in balance with the campus population. With the potential enrollment growth to about 10,500 students on the Dartmouth campus, the parking demand should be around 6,500 cars.

Visitor Experience

The ability to attract and recruit new students each year is crucial for a university in order to continue operations. Many times, these prospective students will make a campus visit and comparison-shop with other universities they are considering attending. First impressions are very important for these prospective students and their families and the university must do its best to show what's great about UMass Dartmouth and create an intuitive visitor experience. However, the visitor experience is compromised at several key points.

Entry Sequence Diagram:

- Offset Entrance
- Intersection of Entry & Ring Road
- First Impression of Campus Architecture
- Wayfinding
- Visitor Parking & Arrival Sequence
- Admissions & Welcome Center
- Vehicular Circulation
- Pedestrian Circulation

1. **The offset entrance from Cross Road to old Westport Road to the campus entrance**
   In order to enter the UMass Dartmouth campus, a visitor is forced to make two consecutive turns directly after one another. In addition to the safety issues discussed in the previous section, the quick turns can be tricky to navigate for a first-time visitor and lacks sufficient signage and wayfinding.

2. **The decision point where the entrance Road intersects with the Ring Road**
   Insufficient and ineffective wayfinding at this intersection creates a confusing decision for a visitor, as it is unclear which direction visitor parking and visitor programs such as Admissions and the welcome center are located.

3. **The view of the northern end of the Paul Rudolph buildings from the Ring Road**
   Currently, the entry sequence aligns with the north end of Dion, specifically the bunkerlike concrete lecture hall. This is an aesthetically unappealing first view of the campus that can be resolved by the strategic relocation of the entry road.

4. **Wayfinding to visitor parking and Admissions**
   The entry sequence currently lacks clear signage and wayfinding from the intersection of Ring Road/entry road intersection to the visitor parking lots.

5. **Arriving at Admissions**
   Admissions is a fluted concrete block appendage to the Auditorium Building that does not have visual presence from the visitor parking lot. Access to Admissions is confusing and unclear, showing another instance on campus where there is a lack of clear signage and wayfinding.

6. **The Admissions office and welcome center**
   Admissions and the Welcome Center are difficult to locate from visitor parking. This confusing sequence does not contribute to a positive first impression of the campus. Ideally, Admissions, welcome center, and visitor parking would be located adjacent to one another with a clear system of signage and wayfinding to direct visitors.

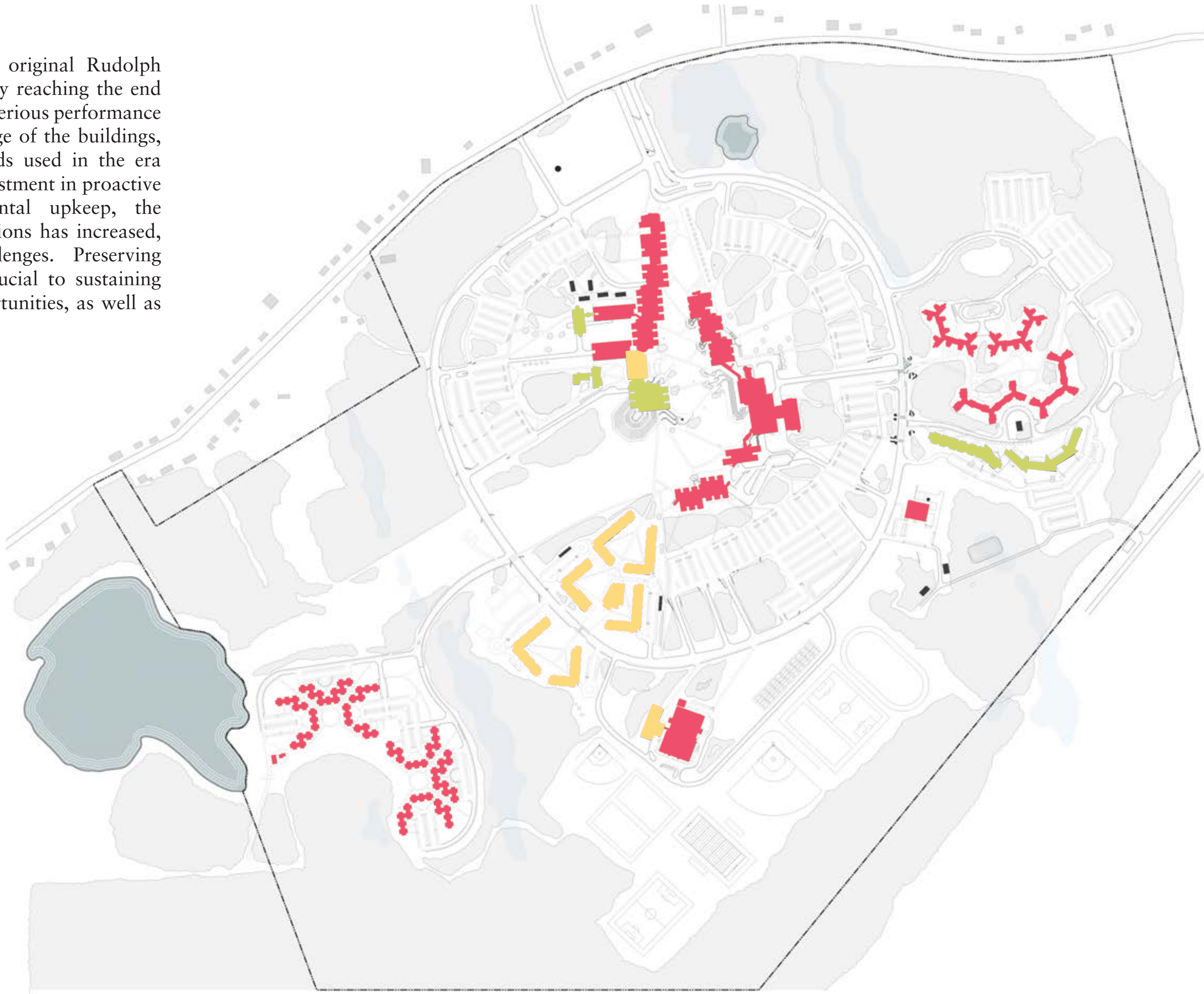
   Other visitors may be coming to campus to hear a lecture, attend a play, visit the gallery, or visit administrators. All of these visitor experiences are important to build connections with the greater community and support the university mission. All of these visitor experiences should be clear and intuitive, however many are not. Ideally, the entrance to the Auditorium, art gallery, and administrative offices would be visible and accessible from visitor parking near the entrance drive.

   During the workshops, participants brought up the idea of honoring the Paul Rudolph legacy by creating a museum that could be part of the visitor experience. It was also suggested that in the Admissions and welcome center displays could be created which highlight the core campus programs as well as satellite campus programs such as the Star Store Arts Campus, UMass Law, and SMAST. This Admissions/welcome center could also house a campus alumni center, celebrating and displaying the achievements of former Corsairs.

   The combination of the key touch points above does not create a positive impression of the university. All of these points can be addressed effectively by repositioning the entrance road experience, aligning an entrance drive that leads to visitor parking and the Admissions office, and improving the connection from Admissions to the core campus.

Deferred Maintenance

Another key issue is that all of the original Rudolph buildings on campus are simultaneously reaching the end of their useful life and are experiencing serious performance deficiencies. This is a product of the age of the buildings, the lower quality construction methods used in the era they were built in, and the minimal investment in proactive upkeep measures. Without incremental upkeep, the investment required to mitigate conditions has increased, creating deferred maintenance challenges. Preserving and modernizing these buildings is crucial to sustaining educational quality and research opportunities, as well as preserving the Rudolph legacy.



Deferred Maintenance Diagram:

- Over $100/GSF
- Between $50-100/GSF
- Less thank $50/GSF

In 2016, Sightlines (Facilities Asset Advisors) presented to UMass Dartmouth a comprehensive look at the campus' deferred maintenance and the amount of capital investment that would be needed to renovate and mitigate those conditions.

Accumulation of repairs needed to correct these building deficiencies requires asset reinvestment, which is a significant financial commitment. Asset reinvestment at UMass Dartmouth should be implemented on a phased basis in order to make these renovations financially feasible, offering the opportunity to take a more holistic approach to the building renovations. In addition to the phased mitigation, this Campus Master Plan proposes a larger investment in providing building upkeep to ensure proper performance throughout their useful life.

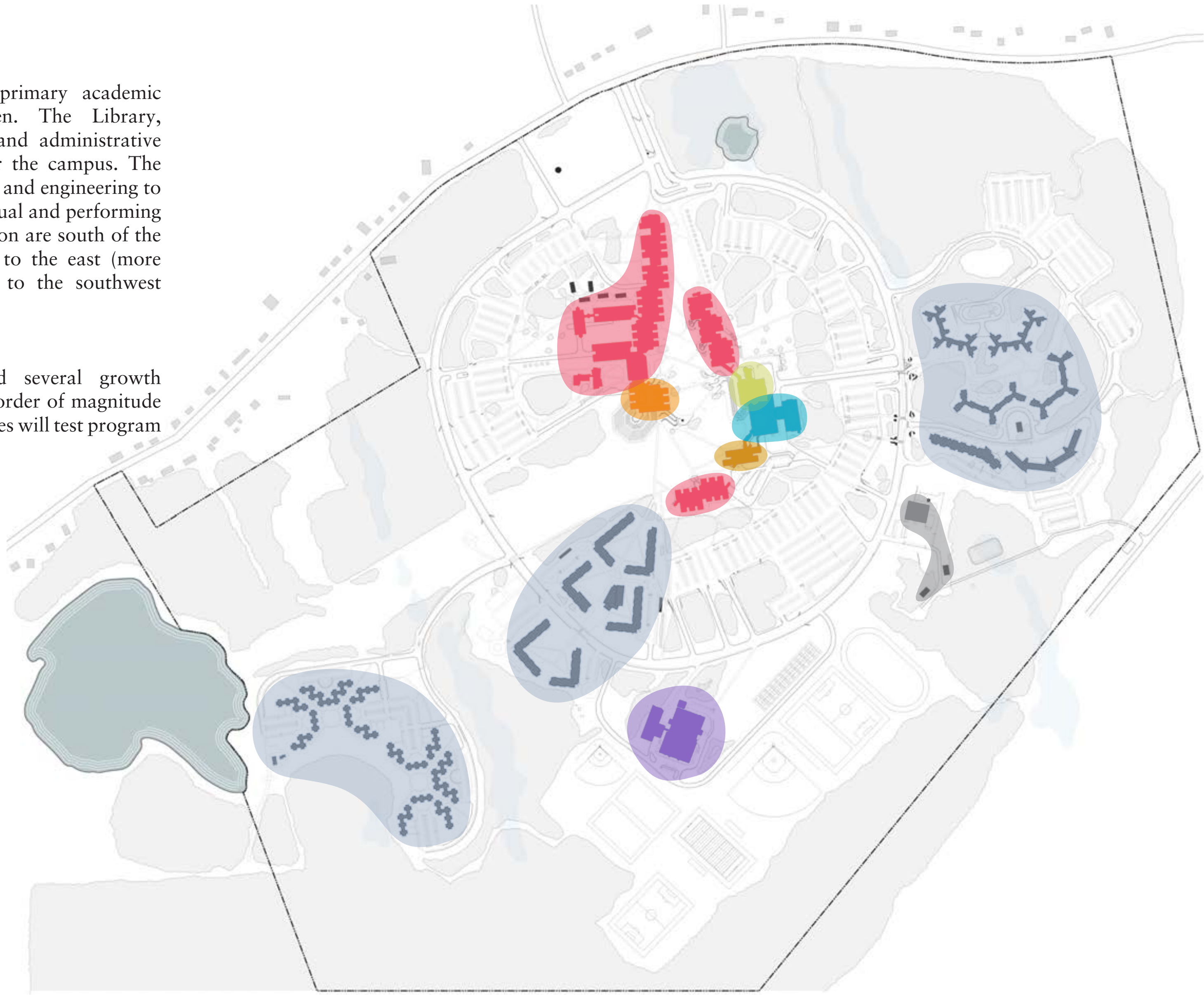
Aerial view of Library & Science and Engineering Building prior to the Claire T. Carney Library Renovation & Addition

Campus Organization

The campus is arranged with the primary academic buildings around the central green. The Library, Auditorium, Campus Center/Dining, and administrative offices are centrally located to anchor the campus. The academic core is organized with science and engineering to the west, liberal arts to the east, and visual and performing arts to the south. Athletics and recreation are south of the Ring Road. Residential is distributed to the east (more traditional and suite-type units) and to the southwest (apartment units).

Space Needs

The Campus Master Plan explored several growth projection scenarios to develop future order of magnitude space needs. Subsequent feasibility studies will test program fit and location.



Existing Building Use Diagram:

- Academic
- Library
- Administration
- Public Venues
- Student Life
- Housing
- Athletics/Rec
- Facilities/Maintenance

Academic and Office Space

The UMass Dartmouth campus was built out in a relatively short time as a commuter campus with a capped capacity. At nearly 9,000 students, more majors and colleges, and increased graduate students and research, the campus has reached its capacity.

Science and Engineering as well as Nursing are growing programs with inadequate facilities and no place to grow.

- Dion has two large tiered lecture halls that are steeply raked, which presents teaching difficulties.
- General use classrooms are in need of updating, including the redesign of most of the small-tiered classrooms.
- There is a lack of collaboration space across the campus.
- There is no swing space to allow taking academic or administrative buildings off-line to facilitate renovations.
- There are two research buildings on the campus that have some capacity remaining.
- As enrollment and departments have grown over the years, faculty and staff have had to share office space or move into spaces that were originally classrooms. Additional academic office space is needed across the campus.
- While the quantity of administrative office space is nearly adequate, it is difficult for visitors to access. Foster Administration would be an appropriate location for a "one-stop" student services center including tutoring and other student service space.

Housing

In 2016, a housing study was completed by Brailsford & Dunlavey. They reviewed the overall on-campus housing stock, available housing within the surrounding communities, and assessed projected demand for improved or replaced on-campus student housing.

The UMass Dartmouth campus has evolved from a purely commuter school at its founding to a residential campus that houses approximately 50 percent of its full-time undergraduate students as well as a small portion of the graduate and law students. The existing housing stock ranges from pod-type residence halls on the east side of campus built in the 1970s and 1980s to newer apartment buildings. Pine Dale, Oak Glen, and the Woodland apartments are relatively new and in good condition. The Woodlands provides apartments, traditional units are in Pine Dale, and semi-suite type units are in Oak Glen. Elmwood, Maple Ridge, Roberts, Chestnut, and the Cedar Dell apartments are all in poor condition and are candidates for replacement.

Dartmouth, Massachusetts has a somewhat limited supply of off-campus student housing, however New Bedford has more variety of housing available to students. In the interviews with students, it was felt that if adequate, modern, and new housing were available on campus, students would prefer to live on the Dartmouth campus.

The current unit type distribution is out of balance with the campus demographics - too many apartments and too few traditional, semi-suite, and suite units. With the removal of Cedar Dell, this will begin to be more in balance, but replacement beds are needed.

Student Life Spaces

- There is a lack of student-oriented spaces in the Campus Center.
- Dining is undersized to serve the current campus population, let alone any enrollment growth.
- Campus Health Services is currently located in one of the east village residence halls and is difficult to access. It will need to be relocated and right-sized.

Assembly and Exhibit Space

- The conference facilities are in what was intended as a residence hall commons and should be moved to a larger and more accessible location.
- The auditorium lacks an adequate lobby, pre-function space, and restrooms. The tiered balcony classrooms lack acoustical privacy and access to current technology and should be rethought.
- The College of Visual Arts Gallery is in the CVPA Building and difficult for visitors to find. Providing wayfinding signage to an accessible entrance would be ideal.

Athletics and Recreation

- Athletics is combined with recreation and lacks adequate facilities to serve both groups.
- A multi-sport fieldhouse with a 300M indoor track is needed, freeing Tripp Athletic Center for recreation.
- The campus lacks an ice sports facility. Ideally, it would have two sheets of ice with one as a competition hockey venue.
- Competition fields have been recently improved, but practice and recreation fields are insufficient.

Service and Support

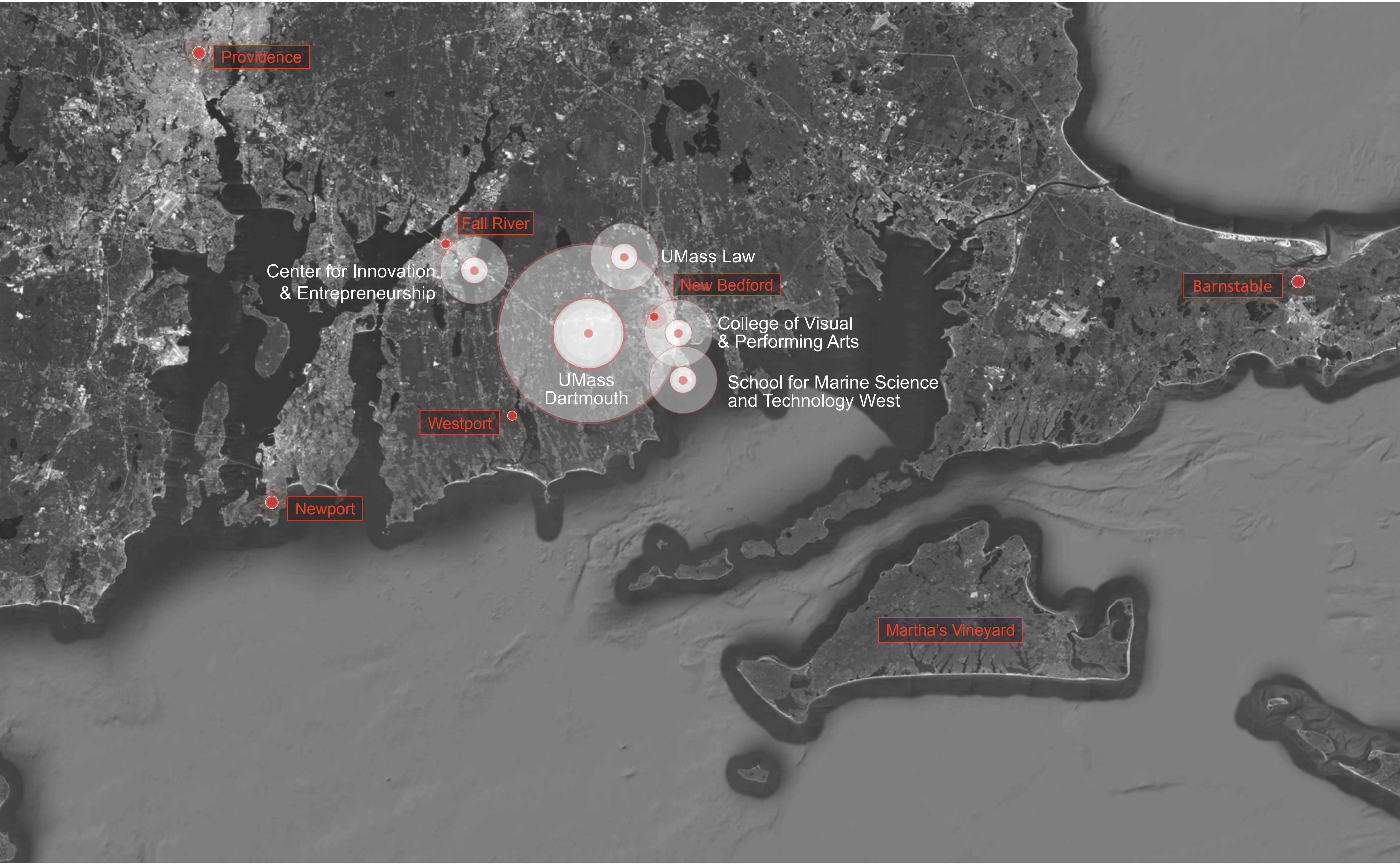
- The physical plant is undersized to serve any campus expansion.
- Campus security has outgrown their space and should relocate to the edge of campus.
- Maintenance shops are currently in a residence hall and should relocate to a more appropriate location.
- A centralized and secure hazardous materials building is needed in the sciences quadrant.

School of Law
UMass Law has projected significant growth and will outgrow its existing facilities within 10 years. The expansion potential of the existing site or moving the Law School to the Dartmouth campus should be studied.

School for Marine Science and Technology - SMAST
SMAST is an impressive research facility located in New Bedford, Massachusetts that provides world-class marine science research. With its recent building expansion, SMAST should be able to meet its needs over the next decade.

Center for Innovation and Entrepreneurship - CIE
The Center for Innovation and Entrepreneurship (CIE) is located in the South Coast Research and Technology Park in Fall River, in a 60,000 square foot state-of-the-art technology facility. The facility should meet the needs of the program for at least the next 10 years.

CVPA Star Store Arts Campus
The College of Visual and Performing Arts Star Store Arts Campus in downtown New Bedford is a major draw for fine arts students and has room for expansion. The facility should serve CVPA needs for at least the next 10 years.



Regional map of UMass Dartmouth campuses

Natural Systems

Ecological / Habitat Assessment

The campus is located between the Paskamanset River to the east and the Westport River to the west, both rivers empty into the Atlantic Ocean to the south. Large continuous wetlands feed these rivers adjacent to campus and serve important ecological functions to the regions watershed.

The Department of Fish and Game has designated areas on campus as Core Habitat and Critical Natural Landscape. Core Habitat and Critical Natural Landscape often overlap. Together they identify 2.1 million acres that are key to conserving the state's biodiversity with much of it unprotected from future development. Areas with this designation include habitats for rare, vulnerable, or uncommon mammal, bird, reptile, amphibian, fish, invertebrate, and plant species. As well as natural landscapes such as high-quality wetland, vernal pool, aquatic, and coastal habitats and intact forest ecosystems.

Natural Systems Diagram:

- Mixed Hardwood Forest
- Coniferous Forest
- Wooded Swamp Deciduous
- Wooded Swamp Mixed
- Wooded Swamp Coniferous
- Shrub Swamp
- Shallow Marsh Meadow
- Successional Meadow
- Maintained Lawn

Site Context

The general topography slopes down to the south and west towards two linear wetlands with the center of the campus serving as a slight ridge. These wetlands connect to the large wetland system to the south.

Key defining ecological features of campus are the old farm pond to the north of campus, Cedar Dell Pond to the south and the dense mixed forest perimeter. Within the forest perimeter are several wetlands that are classified as Wooded Swamps. Wooded Swamps are any wetland with an abundance of woody plant species. These sensitive areas contain a high biodiversity of plants and animals.

Just north of Cedar Dell Pond is an ecologically sensitive area designated as a Shallow Marsh Meadow. Shallow Marsh Meadows are often host to high plant diversity and high densities of buried seeds. In general, the forest, ponds, and wetlands serve as critical habitat for the regions fauna and serves as a stopover for migrating birds.

Wetlands Diagram:

Wetlands

Pond

Environmental Conditions

Wind Impact

The prevailing winds on site generally come from the south-west in the summer and the north-east in the winter. The existing building orientation is parallel to prevailing winds creating undesirable wind tunnel conditions in the winter. However, this orientation enhances cooling summer breezes off Cedar Dell Pond. The colonnade that runs north-south is the only exterior parallel circulation route along the SENG block. This exacerbates the impacts of wind by creating deep shade without buffering the north-east winds.

Solar Exposure

The Ring Road is generally defined by the forest perimeter on the outside and the fragmented forest parking buffer on the inside. The density of trees provides some shade along the Ring Road but in many cases the road is overexposed to the sun and contributes to an "urban heat island effect." Expansive parking lots contribute to heat island effect as well.

In the campus core, the buildings are oriented in a north-south direction. The low colonnade along the buildings provides deep shadows and a cool microclimate in the summer, but has a negative effect in the winter. Minimal tree planting in the campus core, as well as the residential areas, creates gathering spaces that are fully exposed and offer no thermal comfort during the warmer months.


Forested buffer and perimeter parking at Ring Road

Circulation

Pedestrian Circulation

Existing pedestrian circulation is defined by strong geometric spokes radiating from the parking lots to the campus core. Currently there is no safe pedestrian access from the surrounding community to the campus. The Ring Road has no sidewalk or pathways adjacent to it, nor any other traffic-calming measures, creating safety issues for pedestrians. Pedestrian and vehicle conflicts happen at multiple points along the Ring Road such as from the first year residence halls to the campus core at the Ring Road. Persons with disabilities face formidable obstacles when moving in a north south direction along the Great Lawn.

The east and west building blocks are both flanked by a walkway against the facade. As the building entries step with grade, stairs with ramps occur to mediate the grade difference. The existing stair and ramps do not meet current code standards and are considered barriers to accessibility. One of the biggest barriers to site accessibility is the approach from parking lots #3-#7 to the Great Lawn. The elevation difference is 10-12 feet and is navigated by a steep narrow stairway

Path legibility is an issue, there is no clear hierarchy to the current path system or visual cues to clearly establish building entries. In addition to not being code compliant, the walkway on the eastern side of SENG confines views making it difficult to determine building entries. There is no barrier-free circulation route that completely navigates the entire campus core. Navigating the campus for first-time visitors can be disorienting.

Ring Road

The current configuration of Ring Road allows for an approximate 40-50 foot right of way. There is parking along the Ring Road, but no sidewalk for pedestrians to safely walk to the campus core or residential areas. The wide-open character of the roadway allows vehicles to reach excessive speeds. This poses major health and safety risks to pedestrians.

Lack of pedestrian circulation at Ring Road

Pedestrian & vehicular intersections at Ring Road


View of Campanile from Great Lawn

Views and Vistas

Positive campus defining views are generally experienced from the Great Lawn towards Cedar Dell Pond. The view from the northeast corner of the campus core offers some of the best views of the existing architecture. Views from the Ring Road are generally of the surrounding forest and open parking lots. In many instances the existing architecture is not approached from the best angle making the architecture appear ominous instead of highlighting the depths and details of the façade.

Service and loading areas are located in prominent areas and in full view of pedestrians and vehicles, often with their paths intersecting. Expansive parking lots dominate the views from the Ring Road where the forest buffer is not continuous.

Open Space

The Great Lawn

This iconic space unites the east and west parts of campus. The Great Lawn landscapes suffers from legibility issues as well as accessibility issues. The building colonnades flanking the Great Lawn exacerbate the wind and cold during the winter months.

Forest Ring and Campus Pedestrian Connections

The campus core is defined by the buildings at the center, a forest ring between the buildings and the parking lot and the ring road. The forest ring contains many well established trees and enhances the idea of a campus in the woods. Some parts of the forest ring contain park like zones, of trees growing out of lawn, such as the northeast portion that create valuable campus character and should be preserved and enhanced. Other parts contain thick forest fragments. The dense understory of the forest ring poses a security and safety issue in some areas. The forest ring can make it difficult to visually navigate the campus because there is no pedestrian connection around the forest ring. Finally, service vehicles do not adhere to traveling only on the paved paths and instead drive over the landscape damaging the lawn and sometimes damaging pavement.

Pedestrian connections across Great Lawn

East Residence Halls

This area is defined by interesting geology and dense stands of trees. The glacial erratics serve as landmarks throughout this area. Unfortunately, the built landscape at the east residence halls is failing in multiple ways and needs a major overhaul to bring it with in the standards of accessibility and modern student life. Each building lacks a clear connection with each other, as well as the sophomore housing. Pathways in this area do not meet accessibility codes and are poorly aligned in relation to pedestrian desire lines. Inappropriate placement of site furnishings do not encourage student gathering. This Campus Master Plan calls for the demolition of first-year housing while preserving as much existing forest as possible.

Athletics and Recreation

Currently this area suffers from a lack of a clear connection to the rest of campus. There are no barrier-free pedestrian paths to access the game fields. Fields are currently accessed by a narrow roadway and informal foot paths. The existing fields experience drainage issues during times of heavy rain. A centrally located bus drop-off for visiting teams and spectators is sorely lacking. Ticketing for field events is difficult because a perimeter barrier and ticketing gates do not exist. This area also lacks adequate recreational areas for students. Intramural and pickup fields are lacking due to the current arrangement of fields and lack of adequate year-round play surfacing.


Existing East Residence Halls


Addition at Tripp Athletic Center

Residential Social Spaces
The existing residential areas on campus could be greatly improved with thoughtful landscape interventions. The residence halls in particular suffer from a lack of planning for plantings, furnishings, utility screening, and insufficient site lighting, grading, and pathway layout.

Arboretum
The open space formed by the Violette, Textile, and Research buildings has been previously known as the Arboretum. Spatial constraints such as the proximity of buildings and utilities do not make this an ideal location for a heavily planted area. An expansion to the Violette Building was added to the west. Although some site details successfully capture the historic landscape character such as the retaining walls, site circulation is a major issue. Currently, the Arboretum lacks a sense of place and purpose. There is no sense of entry or destination. There are no accessible paths leading into the space. Circulation in general is inhibited by service and loading drives. Maintenance vehicles have damaged the plaza and walkway adjacent to SENG. Large utilities including a generator and blank facades flank the area. There is a steep grade change that occurs at the southwest corner, disconnecting it from the adjacent spaces.


Existing Residential Social Spaces


Existing Arboretum

Mature Trees & Park Setting at Pedestrian Pathway

Existing Park Setting

The northeast area of the campus core represents an area of the original Campus Master Plan that has held up and matured over time. This area is defined by large stands of pine trees set in lawns with rolling topography and offer key defining views of the campus architecture.

Existing Forest and Forest Parking Buffer

The original Campus Master Plan developed a forest ring between the Ring Road and the parking lots. This successfully buffers the parking lots from the roadway. In some areas the planting buffer is not continuous and the parking lots are fully exposed. Invasive species pose a threat to the biological diversity of the forest. Currently, the existing configuration is seen as a barrier and the forest lacks a cohesive trail system that could engage the community.

Expansion Opportunities

Compact future development should be focused within the Ring Road to the south/southeast and northwest. The northeast section of campus containing the most park-like landscape should be preserved as much as possible to maintain the historical character of the original Campus Master Plan. It establishes the campus identity as a campus in the woods, and enhances first impressions for new visitors. New development outside the Ring Road should be focused around existing development. Development in the Athletics and Recreation area should take care not to expand into the surrounding forest.

Existing Berm & Forest Buffer to Remain Intact at Parking

IV. Campus Master Plan Vision

Guiding Principles

The proposed Campus Master Plan seeks to build upon the Paul Rudolph legacy, and greatly improve the student, faculty, staff, and visitor experience by enhancing traffic flow, developing needed facilities to meet the strategic initiatives, and addressing deferred maintenance through phased renovations.

The following guiding principles were created with input from the campus community. They reflect the essence of what the university is and aspires to be. This chapter explores the plan in more detail.

Build upon UMass Dartmouth's Strategic Priorities

In September 2017, UMass Dartmouth Chancellor Robert E. Johnson began a 45-day listening tour involving small group conversations with about 30 internal and external constituent groups. The conversations solicited a variety of perspectives about UMass Dartmouth's optimal future state and encouraged possibility thinking. This will serve as the base to identify areas of strategic focus and chart a shared ambition for UMass Dartmouth's future.

The next strategic planning cycle will begin in Spring 2018, and will create a strategic plan. The plan will address projected enrollment growth, develop flexible academic spaces that support interdisciplinary education, enhance research facilities, improve the student experience, foster connections to the community, and develop a sustainable infrastructure.

Enhance Academic Facilities

Meets the university's core mission by updating academic facilities. The leading priority of the plan is to provide modern, flexible, technology-rich instructional, lab, and collaboration spaces through thoughtful additions, shifts of uses, phasing, and renovations that address the needs of 21st-century learning.

Reinforce Campus Community

Provides spaces that support the daily life of students, faculty, and staff with adequate areas for collaboration, socialization, meetings, gatherings, dining, recreation, athletics, and indoor and outdoor activities.

Connect the Campus

Creates physical connections across the campus, improves traffic flow and safety, links open spaces and campus edges, and maintains a compact campus with a blending of uses.

Improve First Impressions

Establishes a student and visitor experience that is intuitive and displays the best of the university.

Leverage and Interpret Rudolph's Legacy

Meets the needs of today while being respectful of the original architecture, as was demonstrated by the award-winning renovation of the Claire T. Carney Library.

These guiding principles established the framework that the expansion and renovation of existing spaces would achieve.

Campus overlook at Claire T. Carney Library

Existing Campus Plan

Proposed Campus Plan

Campus Districts

The following section provides a tour of the campus by key initiative.

Improve First Impressions

The Campus Master Plan proposes relocating the entry road to align with Cross Road and wind through the existing woodlands in order to create a more visitor-friendly sequence, as well as displaying the beautiful SouthCoast woodlands setting to those entering campus. Leveraging the unique landscape elements will help improve first impressions of campus as it is a much more scenic and safe entry to the campus than the current configuration. The entry road is configured to avoid the 100’ setbacks associated with the wetlands that are located in that area of campus.

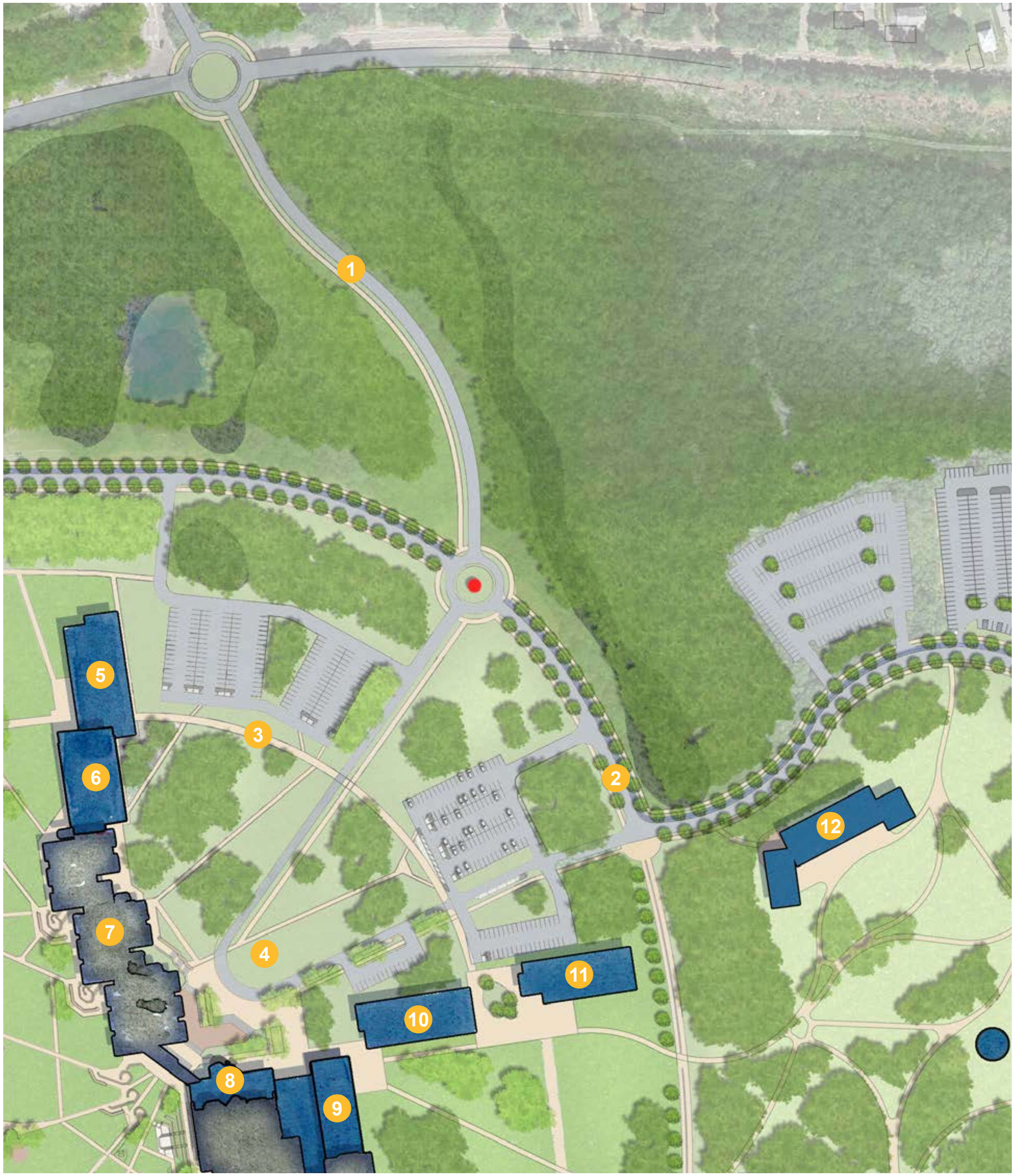
A traffic circle with clear wayfinding and signage is proposed at the intersection of the entry road and the Ring Road in order to clearly and deliberately identify the visitor sequence. Inside the Ring Road, the entry road continues on axis with the campanile as a way of orienting visitors with one of the campus’ iconic structures.

The entry sequence incorporates a drop-off plaza to accommodate both campus visitors as well as attendees of campus events/performances that may be going on. This plaza creates an entry destination that is absent in the current campus configuration.

A density of visitor-focused functions and parking is located around the entry road in order to create a clear and intuitive visitor experience. The functions that have been allocated to this part of campus include a new Admissions/Welcome Center that includes a lobby area for the Auditorium, and an Administration Building.

District Key Plan:

1 New Connections to Cross & Old Westport Roads
2 Improvements at Ring Road & Break at East Village
3 New Inner Pedestrian Ring
4 New Drop-Off & Parking
5 New LARTS Building
6 Expansion for New LARTS Classrooms
7 Renovation of LARTS Building
8 Expansion for Entry Lobby & Admissions
9 Expansion of Campus Center
10 New Alumni Hall Building
11 New Administration Building
12 New Law School Building



Expansion for Auditorium & Admissions/Welcome Center

Left: A new glass addition to the MacLean Campus Center will provide a welcoming first impression to the UMass Dartmouth Campus, while also providing an accessible entry to campus.

The Arrival Hub will be defined by a cascading terrace that honors the Rudolph legacy as well as provides a graceful accessible route to the Great Lawn. This space will be further defined by a higher level of landscape treatment. As visitors traverse the 10-12 feet from the vehicle drop-off area, they will experience sweeping views of the Great Lawn, the Campanile and the library beyond. To meet accessibility goals, a series of compliant ramps radiating out into the Great Lawn will lead visitors, students, faculty, and staff to the rest of the campus without having to navigate the existing stairs. This new entry sequence will provide an informative referential view that could help visitors and prospective students orient themselves within the campus.

Existing Admissions Building

Enhance the Academic Facilities

Sciences Quad
The new STEM education building is proposed to anchor the north end of a new sciences quad immediately west of the SENG buildings. Future buildings will define this outdoor room further creating a new mid-sized campus space, allowing for a semi-public open academic space for students to utilize. This space would form a link between atriums in the SENG expansion and the transformed Dion Atrium along with the continuous campus pedestrian loop.

Transformation of Existing Space
Guidelines for future expansion and growth of the UMass Dartmouth campus is an important objective of this updated Campus Master Plan. However, the transformation and renovation of existing space (the Rudolph buildings in particular) on campus to meet UMass Dartmouth's future goals is just as crucial.

District Key Plan:

1. New Nursing School
2. New STEM Building
3. New SENG Building
4. New Science Quad
5. New Chemical Storage Building
6. Renovation of Dion Building
7. Renovation to SENG Building
8. Violette Research Building
9. Textile Building
10. Charlton College of Business
11. Claire T. Carney Library

Right: The STEM and SENG buildings create a new campus quad, activated at the ground level through large openings and new glazing within the historic structure.

The existing academic buildings were designed so that the first and second floor contained instructional space of varying class size, with offices located on the third floor. Rudolph's sculptural building forms create a condition where the first, second, and third floor envelopes do not vertically align, and create a compressed covered exterior pedestrian pathway. Because the ground floor classrooms are set back, less natural light is able to filter into the classroom space.

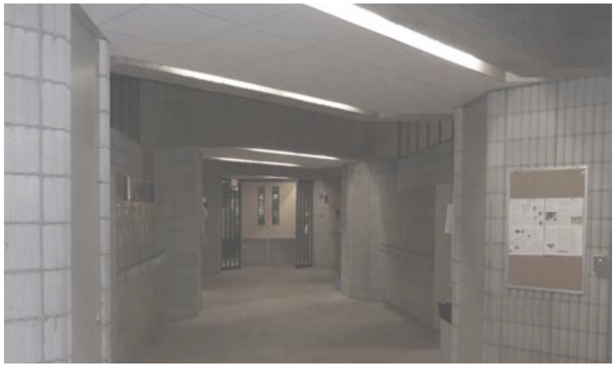
The existing classroom dimensions are conducive to 25-30 student classrooms, which is a class size in high demand. Relocating the ground floor envelope to align with the second floor above would allow the interior classroom partitions flexibility to relocate and widen the academic corridors to accommodate additional flexible student space, while maintaining the existing classroom proportions.

Relocating the envelope would also allow for increased natural light for ground floor classrooms, with a more active academic presence on the Great Lawn. This change would also infill a compressed pedestrian path that is currently routed underneath the second floor cantilever, and would facilitate a new accessible path on the great lawn that would have improved views of the campanile and Great Lawn.


Existing SENG Building

View of New STEM Building & Science Quad

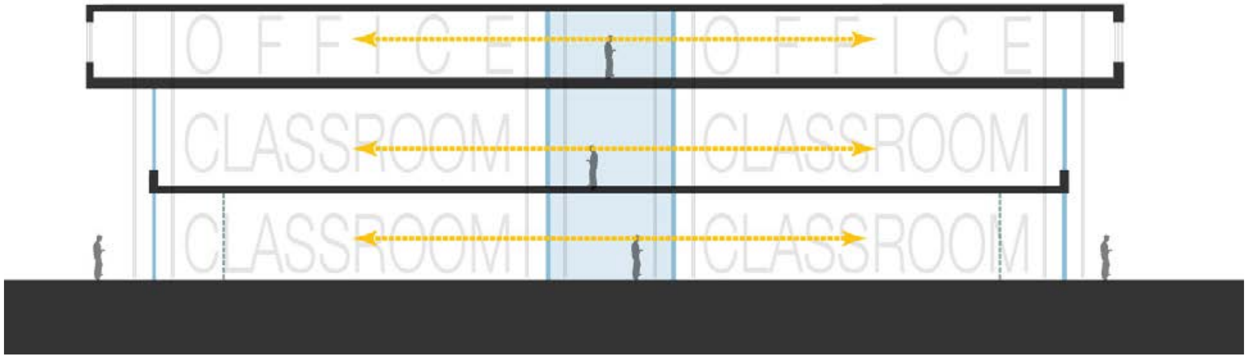

View of Transformed Corridor



Existing Building Corridor

Typical Building Section _ Existing conditions

Perkins Library Link at Duke University - precedent image of transparency between corridor and classrooms



Proposed Building Section - Includes glass at the interior corridor for increased transparency and a relocation of glass at the envelope for increased natural light and improved classroom proportion

Classroom | Corridor Transformation

Existing academic corridors present opportunities to be improved from both an experiential and programmatic standpoint. CVPA, LARTs, and SENG possess very similar layouts and architectural character, which allows for architectural recommendations to be implemented at each building.

The existing structural system in the Rudolph academic buildings is a robust one made up of concrete columns and piers arranged in 14' x 28' modules which a 45 degree cant that occurs in the corridor. Corridor partitions are constructed out of fluted concrete block, which prevents the filtering of natural light. Compounding this issue is the existing condition of lockers lining the academic hallways, which also decrease the overall width of the corridor and an increasingly compressed spatial condition. These corridor walls are not load bearing which would allow not only for their replacement with glass partitions of varying translucency, but for their relocation to better reconcile classroom sizes with the ideal number of students in each section. The fluted concrete block partitions dividing two individual classrooms also have the potential to be removed in order to create a classroom capable of accommodating larger classroom sizes. The specific needs of each college would facilitate what the ideal classroom size would be.

Academic space planning has tended towards incorporating an increased amount of informal breakout space outside of classrooms. In its current configuration, the academics corridors do not have sufficient width to accommodate these uses, especially with the existing lockers that are located in the corridors. Incorporating flexible student space would allow a heightened visual relationship between the classroom activity and the corridors.

Left: By replacing the existing interior walls with transparent glass partitions and improved lighting, the classrooms are more inviting and promote greater interdisciplinary activity.

Reinforce Campus Community

New Residence Halls, Dining, and Improved Student Center
As the demand for commuter parking within the concentric ring reduces with the increasing residential population, it allows for the native woodland to cross Ring Road, creating wooded bands. These wooded bands supplement the original stands of woodland. Bringing student housing inside the ring, and transitioning parking to the perimeter, is a necessary part of the transition from commuter planning to on-campus living.

While the timeline is undetermined, the existing first-year residence halls have been slated for demolition due to their existing disrepair. New mixed-use residence halls with an active ground floor of classrooms and collaborative spaces is proposed to be located along the "park ring" and proposed "pedestrian loop." This series of buildings can act as flex space for both academic and residential renovation and new construction by allowing additional class space and beds. This neighborhood provides an academic presence outside of the campus core, and links the once remote Pine Dale, Oak Glen, and Woodlands residential neighborhoods.

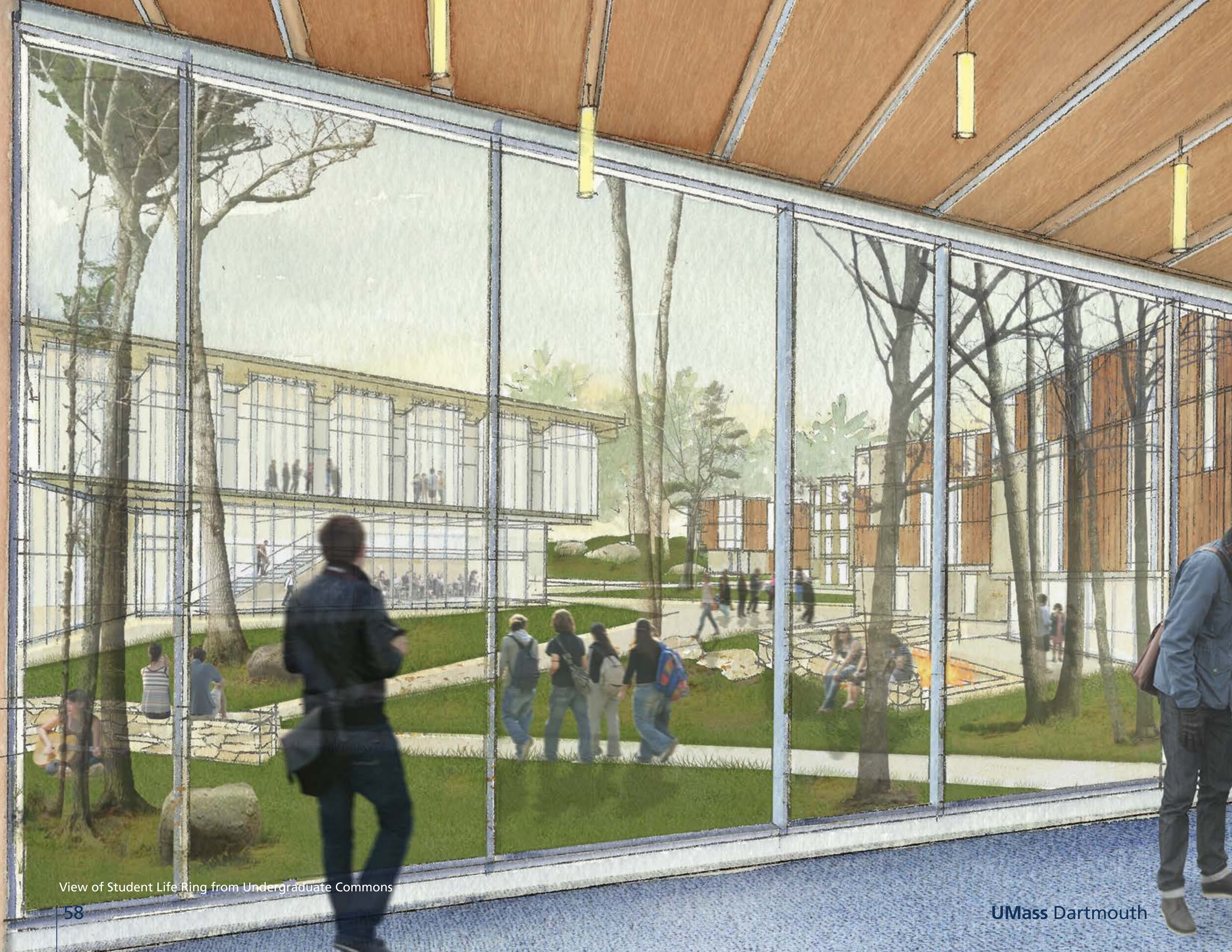
With the construction of the first-year commons and the additional new sophomore/junior commons, the quadrant south of CVPA and Foster provides the opportunity to create a new residential neighborhood set in the "woods" but connected to the core campus. A new woodland walk is created in the concentric pedestrian ring bordered by the new housing. Throughout the walk the ground level amenities of café, retail, study and lounge spaces, student organizations or seminar rooms, animate the residential village.

District Key Plan:

1. New Undergraduate Commons
2. New Undergraduate Housing
3. New Dining Hall
4. New Graduate Housing & Improvements to Pine Dale & Oak Glen Quads
5. Renovation & Expansion of Campus Center
6. Renovation of Foster Building
7. Expansion at CVPA
8. Renovation of CVPA
9. Expansion of Central Plant & Facilities

The arc-like trail incorporates a desired path from the existing Oak Glen, Pine Dale, and new sophomore/junior commons and commuter hub to the enclosed first-year commons that provides the western 'bookend' that continues to the Tripp Athletic Center. The woodland path and casual arrangement of housing buildings allows for strategic crossings as it connects back to the campus core providing direct paths to all major destinations such as student center/ dining, library, west and east group classrooms. This new residential enclave knits together the existing Woodlands Village and new sophomore/junior commons allowing for a rich mix of students from all classes along with academic and student life components. In our analysis, this quadrant is the only campus section that can accommodate the density of residential buildings required by the relocation of the first-year commons.

The site design strives to celebrate the idea of a campus in the woods. Buildings have been intentionally located to create a dynamic relationship with each other and to take full advantage of the existing stands of trees. The design envisions re-using existing boulders that were deposited by the receding glaciers on site to create a unique open space in the character of the native SouthCoast landscape.



View of Student Life Ring from Undergraduate Commons

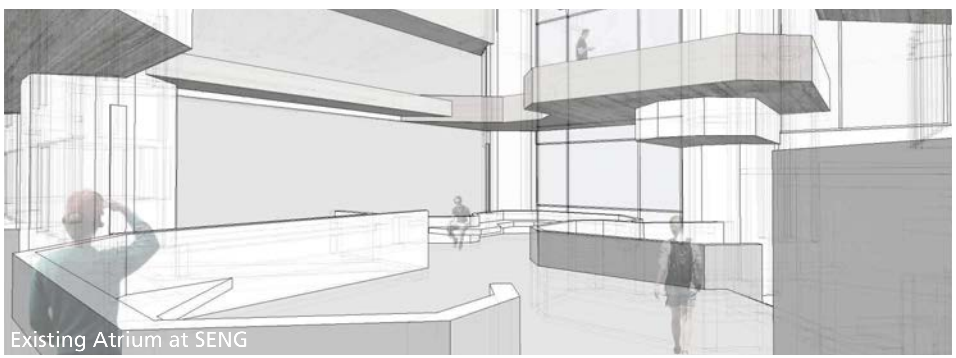
Left: Common spaces dispersed throughout the undergraduate village activate the ground level and provide a public view toward the Dining Hall.

The Commons

The new undergraduate village is flanked by the sophomore/junior commons, commuter hub, and first-year commons. These buildings serve as gateways into the village from the north and south. The sophomore/junior commons and commuter hub will serve as a transit center, allowing students and visitors to wait comfortably under cover for their bus out of town or around campus. The dining common is located at the nexus of the development. The dining common is strategically located to share the loading court of the existing dining hall adjacent to the student center. The service court will be screened using plant material and thoughtful architectural screening materials.

Existing Forest & Rock Outcroppings at Future Commons

Enclosed Collaborative Space at the Claire T. Carney Library Renovation


Existing Atrium at SENG

Improved Social | Gathering Spaces in Academic Buildings
Rudolph designed the interior spaces of the academic buildings to facilitate spontaneous human interaction and exchange. This was influenced by UMass Dartmouth's status as a predominantly commuter campus, where students would attend class and leave directly after. As the needs of the increasingly resident-based student experience continue to evolve, it is important that these existing social and gathering spaces be transformed to align with these campus principles. Increasingly residential populations on campus have allowed UMass Dartmouth to become a more full-service institution, with more campus activities and student involvement.

The recent renovation of Claire T. Carney Library (CTCL) has proven very successful in providing students with flexible and collaborative learning spaces that are adaptable to the evolving higher education institution pedagogy. This Campus Master Plan proposes the re-imagining of the existing atrium spaces, using the CTCL renovation as a guideline, to accommodate additional collaborative space distributed throughout campus to encourage interdisciplinary exchange.

One potential transformation would be to partially or fully enclose the cantilevered atrium trays with glass partitions to create acoustically separated spaces for smaller group meetings to occur. These enclosures would reference the existing Rudolph formal geometries, presenting the Rudolph legacy in a way that meets current academic and student needs.

Another high-impact transformation that could occur in LARTs and SENG atriums would be the removal of the existing second-level partition to create additional flexible furnished space located adjacent to the three-story-height space. Transforming these spaces to increase the amount of diverse collaborative space can help activate the atriums that were such integral and important spaces in Paul Rudolph's original Campus Master Plan. UMass Dartmouth is currently exploring this as a potential project in one of the existing LART's atriums.

The majority of buildings on campus have a monotonous and imposing color palette of fluted concrete block that is both the interior and exterior finish. Introducing colored surfaces into the atrium, corridor, and classroom spaces could help create a more vibrant atmosphere as well a cohesive interior system of way finding.

Right: Collaborative spaces can be created through the use of transparent enclosures within the existing sculptural volumes.

View of Transformed Atrium

Connect the Campus

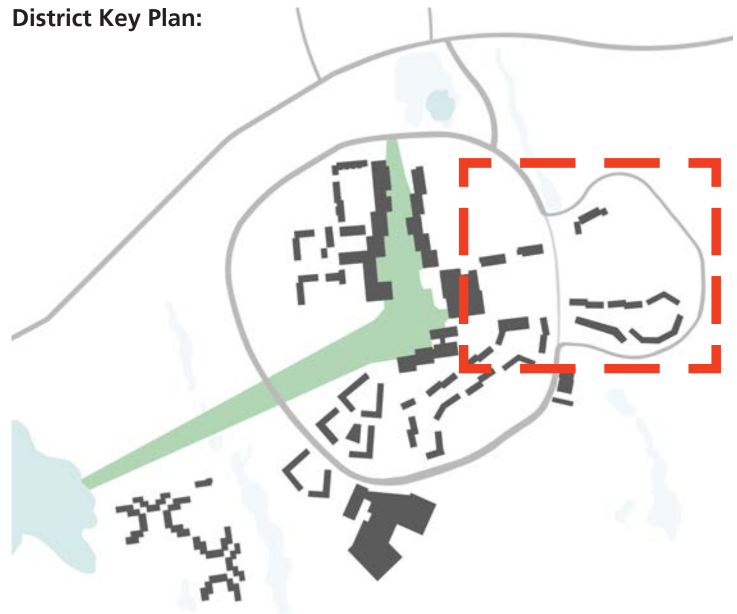
Universal Access

Reaching the academic core is currently a challenge due to grade changes and slopes of critical pathways. The site design has reimagined these connections by establishing accessible outdoor routes into the core. Alleviating this barrier will strengthen the connection between the “Student Life Ring” and academic core.

Currently, the residential housing on campus lacks composed outdoor spaces that allow for a wide range of student interaction. Building entries typically lack space for students to congregate. Most residential buildings have no indoor/outdoor connections at the ground level that make for dynamic social interaction.

The vision is to create a hierarchy of open space to encourage and support social interaction to build a strong sense of community amongst residents as well as commuters. This can be accomplished by creating a sequence of spaces and connections that are scaled as students walk from their classes to their housing.

District Key Plan:



1 New Law School Building
2 New Administration Building
3 New Alumni Hall Building
4 Student Union Expansion
5 New Undergraduate Housing & Commons
6 New Dining Hall
7 New Graduate Housing & Improvements to Pine Dale & Oak Glen Quads

View of Student Life Ring

Left: Pathways between residential structures provide dynamic, human-scaled pedestrian experience. The campus space is inspired by the natural woodlands and rock outcroppings, which is also reflected in the architectural materials.

A key feature of the land plan is the creation of a student life ring. This would serve as a main pedestrian travel way through the new residential neighborhood. This would connect with Woodland and Tripp Athletics to the south and the academic core to the north. The existing sophomore dorms Pine Dale and Oak Glen, currently feel orphaned from the campus core. The new student life ring would provide these resident halls a strong connection back to campus. The student life ring would be further activated by ground floor program space in the new residential buildings such as cafés, fitness centers, and live / learn classrooms. This “main street” concept would greatly improve the social fabric of UMass Dartmouth student life. Functionally, this wide path would also serve emergency vehicles as needed.

The proposed residential buildings have been placed to create semi-public open space that would support active and passive recreation for students, such as tossing the Frisbee or lounging on the grass. These medium-scaled outdoor spaces reinforce a neighborhood feeling.

These spaces are generally located at building entries and provide generously paved spaces so that students can congregate. These spaces are more private to the buildings they serve. These spaces might have a gas fire pit for students to sit by during a cold autumn night as well as outdoor table tennis and other space-activating elements. Striving to make these spaces usable throughout the school year will create a strong sense of community and improve the happiness and well-being of the student population.

View toward Campanile from Student Life Ring

Right: Bordered by the transformed Student Union and new Dining Hall, the East Lawn creates a pedestrian threshold between the Main Campus and East Village.

New East Lawn

This Campus Master Plan proposes removing a portion of the Ring Road that divides the existing first year residence halls and academic core. With daily vehicular circulation removed from this portion of campus, the space can be transformed into a new campus lawn that facilitates improved connectivity between residences and the academic core.

Existing East Lawn

View of East Lawn toward ew Dining Hall

Athletics and Recreation

Athletics facilities are currently disconnected from the campus core, lacking a visual presence. A new campus lawn serves as the connective fabric between the academic core and athletics. This transformation enhances the visitor tour experience, exposing the once concealed athletics complex. This new campus lawn also serves as a passive open space allowing for continuous circulation of the pedestrian loop.

District Key Plan:

1. New Undergraduate Housing
2. New Undergraduate Commons
3. Woodland Commons
4. Expansion of Fitness Center
5. Expansion & Renovation of Tripp Building
6. Improvements to Practice Fields & Big Backyard

View of Expansion to Tripp Athletic Center

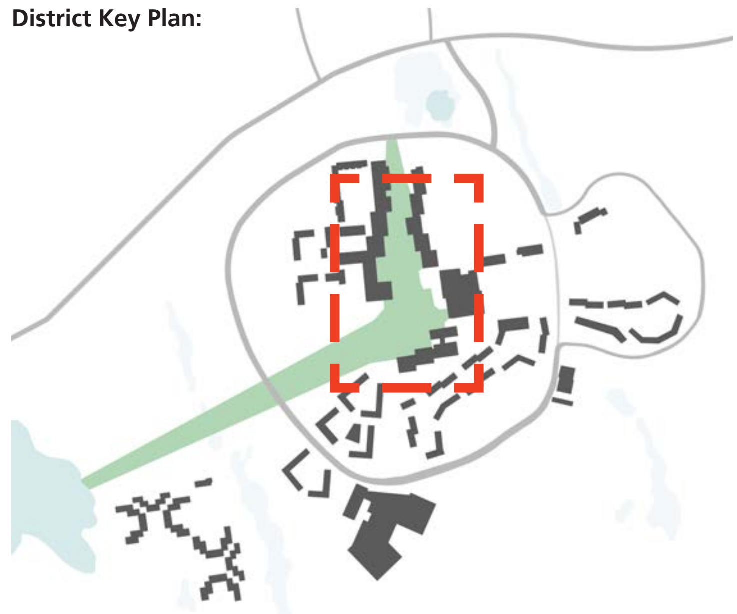
Left: The transformed Tripp Athletic Center includes a new entry, field house, and two ice rinks that create a welcoming approach through a wood and glass addition. An improved approach, vehicular drop-off area, and parking allow this venue to be used for a variety of athletic events for both students and the community.

Existing Tripp Athletics Center

Leverage and Interpret Rudolph's Legacy

Paul Rudolph's unique vision for the university unifies the campus but is in need of adaptation. As demonstrated by the renovation of the Claire T. Carney Library, the architectural legacy of Rudolph can be reinterpreted in a sensitive manner which increases transparency, adds collaboration spaces, and improves the educational environment. As mentioned under several of the guiding principles above, the plan addresses specific recommendations for improvements to the atriums by creating a mix of public, semi-public, and more private meeting spaces; expansion of the first floor classrooms to provide more space for flexible learning environments and visual connections to the outdoors and the interior corridors; creation of casual meeting and break-out spaces within the existing corridor systems that extends the learning environment outside the classroom; improvements to the Great Lawn for human comfort and universal access through improved walkways and gathering areas. While these recommendations address the existing buildings, the plan proposes the creation of a second tier of quads and courtyards that allow the academic facilities to expand meeting needed adjacencies and extending the ideals of the Rudolph planning principles.

District Key Plan:



Addition at Claire T. Carney Library

V. Implementation

Project Implementation

In order to realize the full vision for the UMass Dartmouth Campus, breakout project scopes are outlined and prioritized in the following categories:

Immediate Impact Projects
Completed: 0 - 1 Years

Near-term Projects
Design Begins: 0 - 3 Years
Construction Completed: 3 - 5 Years

Mid-term Projects
Design Begins: 5 - 7 Years
Construction Completed: 7 - 10 Years

Long-term Projects
Design Begins: 7+ Years
Construction Completed: 10+ Years

Aerial view of existing campus

Aerial view of proposed campus

Immediate Impact Projects

Completed: 0-1 Years

The Immediate Impact Projects will create a more welcoming first impression to the UMass Dartmouth campus for current and incoming students.

1a **Campus Beautification**

- Improvements to Entry Road
- Improvements to Campanile
- Improvements to Signage & Way finding

1b **Campus Arrival & Admissions:**

- Expansion for Entry Lobby & Admissions
- New Drop- Off & Parking
- New Inner Pedestrian Ring


1a
1b

Near-term Projects

Design Begins: 0-3 Years
Construction Completed: 3-5 Years

The Near-term Projects will impact the full student experience: additional state-of-the-art academic buildings, improved living/learning residences, and expanded extracurricular opportunities through a transformed Student Union and Athletic Center.

2a STEM & Science Quad
- New STEM Building
- New Science Quad
- New Chemical Storage Building

2b Campus Connections & Ring Road Improvements
- New Connections to Cross and Old Westport Roads
- New Egress to Chase Road
- Improvements at Ring Road & Break at East Village
- Improvements at East Village Road

2c Living/Learning Residences
- New Undergraduate Housing
- New Undergraduate Commons
- New Dining Hall
- Demolition of Roberts & Chestnut Housing
- New Graduate Housing & Improvements to Pine Dale & Oak Glen Quads

2d Athletics Complex
- Expansion at Tripp Building - New Entry, Field House, Ice Rinks
- New Athletics Drop-Off & Parking
- Improvements at Practice Fields & Big Backyard

2e Student Union
- Expansion to Campus Center
- Renovation of MacLean & Banquet Hall
- Improvements at East Lawn

2f LARTS Expansion
- Expansion for New LARTS Classrooms


2a
2b
2c
2c
2d
2e
2f

Mid-term Projects

Design Begins: 5-7 Years
Construction Completed: 7-10 Years

The Mid-term Projects improve upon the assets of the campus, from the renovations of historic structures to the preservation and improvements to landscape environments. Additionally, it provides the infrastructure for continued growth through parking and central plan expansions.

3a Cedar Dell Parking & Central Plant
- Demolition of Cedar Dell Housing
- New Cedar Dell Parking Lot
- New Campus Police Station
- Expansion of Central Plant & Facilities

3b Nature Walk & Observatory
- Demolition of Elmwood & Maple Ridge Housing
- New East Village Bike Trails & Nature Walk
- New Observatory

3c Alumni Hall & Administration
- New Alumni Hall Building
- New Administration Building

3d Tripp Center
- Renovation to Tripp Building
- Expansion of Fitness Center

3e Historic Structure Renovations
- Renovation of CVPA Building
- Renovation of Foster Building
- Renovation of Dion Building
- Renovation of LARTS Buildings
- Renovation of SENG Buildings

3f Campus Space Improvements
- Improvements for Accessibility to Great Lawn
- Improvements to Building Entries from Great Lawn
- Improvements at Cedar Dell Lawn
- New Lighting & Cover at Amphitheater
- Expansion for New LARTS Classrooms


3e
3e
3c
3b
3f
3e
3f
3a
3d
3a

Long-term Projects

Design Begins: 7+ Years
Construction Completed: 10+ Years

The Long-term Projects allow for the continued growth of UMass Dartmouth's academic programming, ensuring continued excellence in academics and student experience.

- 4a New LARTS Buildings
- 4b New SENG Buildings
- 4c New Nursing School Building
- 4d New Law School Building
- 4e Expansion at CVPA
- 4f Improvements to Woodland Commons


4a
4b
4c
4d
4e
4f

VI. Design Guidelines

Building Guidelines

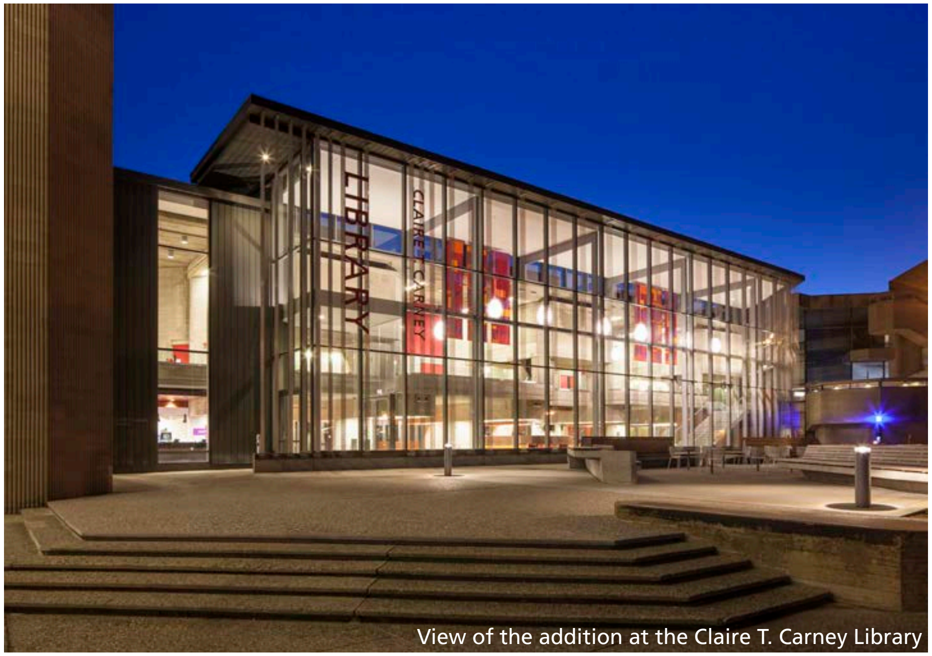

Historic image of Paul Rudolph unveiling the campus design

"I do not think it is generally recognized how different conceptually the SMTI campus is. That the whole of America, almost the whole of America, is based on the freestanding building in a plane of space, and that the space in between is simply there. It has no use, no real meaning. And that is a tragedy because the European example is the exact opposite. It took many buildings, built over great length of time, and by placement formed a greater whole, a social whole if you will. And we haven't got the hang of it. But I would insist that the basic thinking at SMTI it is the exact opposite. I don't mean stylistically, which it may or may not be but — well, it is different of course, but that is not the real point. The real point is that the buildings are connected to form a greater whole, and that whole is a social entity, and that entity is not yet fully developed."

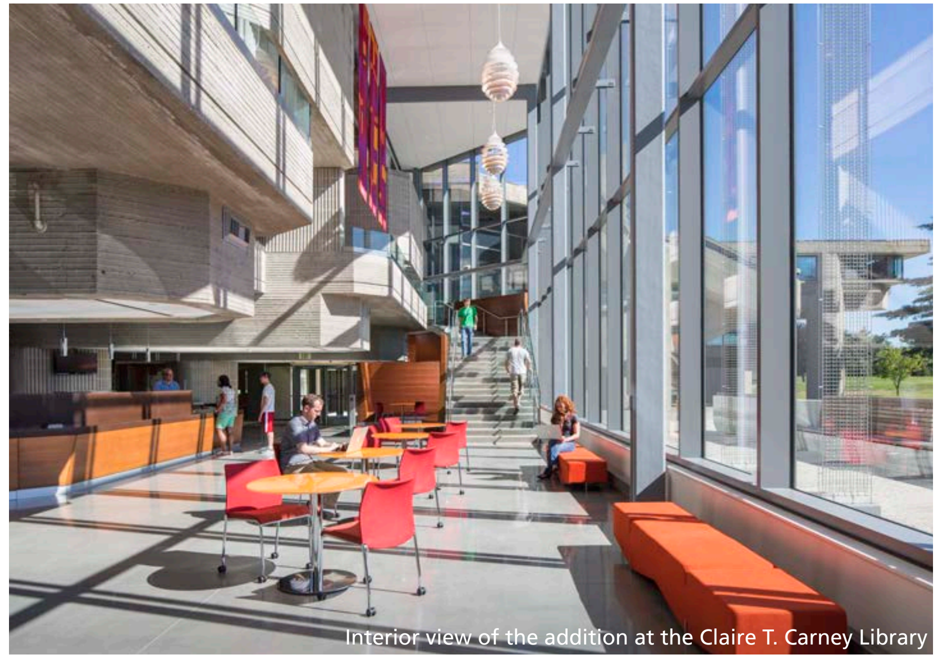
-Paul Rudolph

Paul Rudolph envisioned a campus that was unified, collegiate in scale, organized around academic, and student life zones, and ordered yet not formal. His plan embraced the land, vegetation, natural drainage patterns, and clear circulation patterns. The limited materials palette, strong sculptural forms, and use of color have created a unique educational environment that should be built upon in a sensitive and coherent manner, yet not be copied which may diminish the power of the original buildings. These precepts are the starting point for all new additions or modifications to the campus as outlined in these design guidelines.

One of the guiding principles of this plan is to honor the Paul Rudolph legacy. This campus is unique and must be thoughtfully considered in both renovation schemes as well as in the introduction of new buildings and landscapes. The design guidelines are organized around three sections: Renovation of the Rudolph Buildings, New Buildings, and Landscape.



View of the addition at the Claire T. Carney Library



Interior view of the addition at the Claire T. Carney Library

Renovations and Additions to Paul Rudolph Buildings

As demonstrated by the renovation of the Claire T. Carney Library, it is entirely possible to honor the Paul Rudolph legacy while refreshing buildings. The renovation transformed a rather opaque building into one that is transparent, flexible, and sustainable. With the introduction of vibrant colors and appropriate fixtures, the library is now a focal point on campus.

Before

Transparency and Orientation

Exterior Transparency:
The selective removal of exterior walls and the insertion of glass opened up the building to receive more natural light while giving users both inside and outside of the building an orientation to the campus.

Before

Transformed corridor at an existing building

Transformed atrium at an existing building

Interior Transparency:
Many of the interior walls are concrete block, which makes the corridors dark and disorienting. Selective walls or portions of walls can be removed to allow more natural light to penetrate the corridors, but also allow for more of a collaborative environment with views into and out of the classrooms, labs, and offices. The placement of the walls may allow for seating and collaboration space within the corridors creating a third place.

Before

Atriums:
The atriums are the connective tissue between the Paul Rudolph buildings. He considered these spaces as "Happenings" spaces that create spontaneous and serendipitous connections across the campus community. The multiple level changes made the space very interesting, but have proven to be challenging for those with physical challenges. There is an opportunity to rethink these spaces to create accessible, comfortable, and acoustically isolated collaboration spaces that can restore their intended functions of connections and gathering.

Before

Browsing Area at the Claire T. Carney Library

Color, Fixtures, and Furnishings

Color:
While generally Rudolph chose monochromatic and muted color palettes, the introduction of vibrant color as demonstrated in the Library can have a great effect when played against the primarily concrete building. The color must be used judiciously in select areas such as floors, upholstery in built-in seating, furnishings, elevator cabs, and painted accent walls. The color palette has its origins in 1960s and 1970s color schemes, which are appropriate given when these buildings were constructed.

Fixtures and Furniture:
The selection of furnishings and fixtures can also refresh the Rudolph legacy. Modern and energy efficient light fixtures that harken back to the time period can become another level of design within the building. New lighting placement can highlight the salient features of the textural and sculptural nature of Rudolph's work. Modern furnishings in vibrant colors can also contribute to the unified look and feel of the campus.

Flexibility + Technology:
Instructional pedagogy and technology has transformed the way universities function since the time these buildings were built. Integrating more wireless technology can be challenging with predominately concrete buildings, but access to technology must be ubiquitous across the campus. Classrooms with tiered seating must be accessible and flexible for different instructional styles including collaborative work. While keeping some of the original small, tiered classrooms in LARTS, many of them, for example should be leveled and expanded to create a more flexible, active learning environment. The steep lecture hall in Dion is another opportunity to rethink the large lecture format as a collaborative learning room by reducing the steepness of the room with broader tiers and improved handicapped access. Office environments can benefit from a mix of collaborative spaces and private offices supported by telephone rooms and small conference rooms.


Claire T. Carney Library


New Residential Village

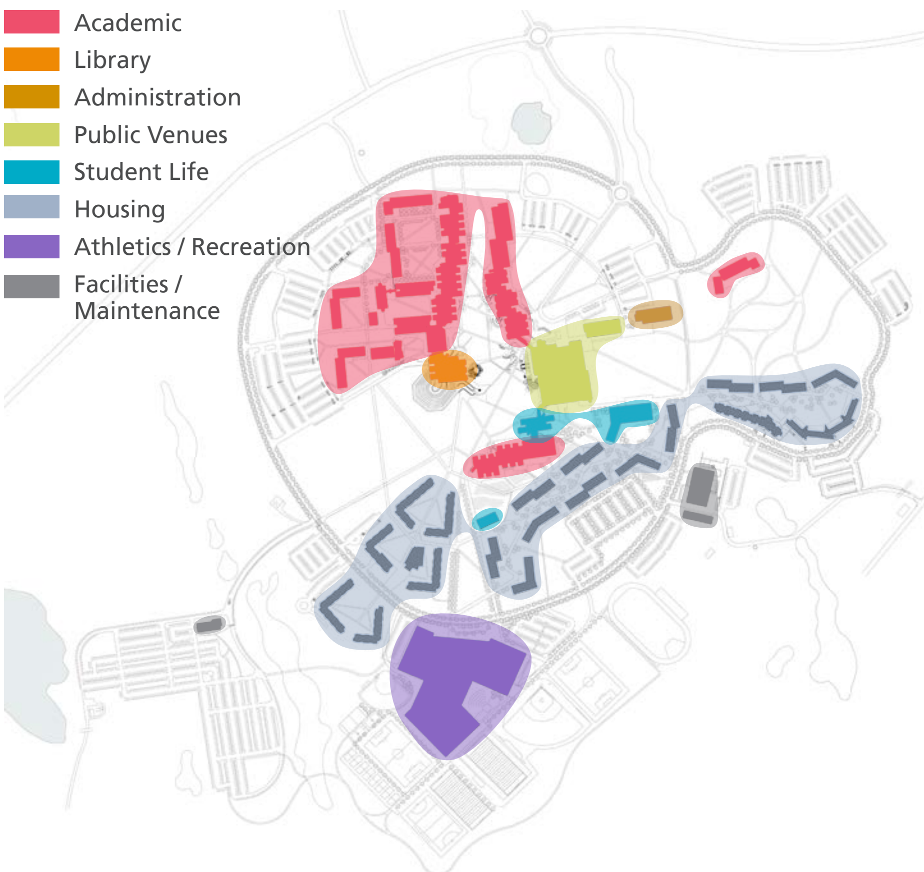
Additions

Additions to the Rudolph buildings beyond the building facades should be sympathetic to Rudolph's design. Incorporating transparency, appropriate linkages to the existing atriums and use of natural materials are encouraged. Facades should build upon the regulating lines of the architecturally significant portions of the original buildings, paying specific attention to massing, void, and proportion.

New Buildings

New buildings on the UMass Dartmouth campus should honor the legacy of Paul Rudolph in a careful and sensitive manner but be careful not to copy the original buildings. The original Rudolph buildings should continue to stand alone as the hero buildings of the campus. Any new additions or stand-alone buildings should be significant, well designed and crafted, and expressive but defer to the scale of the original buildings.

Proposed Building Use Diagram:



Open Spaces Diagram:

Building Typologies

Campuses buildings have a mix of different uses ranging from academic, student life, residence halls, and athletics and recreation. The architectural expression of the buildings should reflect their use and create appropriate forms, materials, fenestration patterns, massing, and scale in keeping with the overall campus character. Care should be taken to maintain a human scale throughout.

Defining Edges of Open Spaces

Paul Rudolph's buildings around the Great Lawn defined an informal series of open spaces. New buildings should be placed to expand on this open space structure in key areas, which are expanded upon in the landscape section of these guidelines. In particular the student life ring, (2) the lawn to the Athletics zone, (3) the East Lawn, (4) the campus entry quadrant, (5) Sciences Quad, and (6) East Village nature area.

New STEM Building

New East Lawn at Student Union

Massing and Scale

Paul Rudolph's buildings are quite sculptural with bold columns, overhangs, and expressive massing. New buildings should not attempt to copy these traits, but be sensitive to them through massing, size, height, placement, roof, levels of transparency, fenestration patterns, and materials.

Paul Rudolph's buildings are generally three to four stories tall with relatively low floor-to-floor dimensions. Most buildings range from 33 feet to 50 feet above grade. New buildings are limited to 50 feet above grade due to firefighting equipment limitations. In addition to safety, the goal is to make sure the buildings are nestled within the woodland and be no taller than most of the mature trees.

Façade Composition and Proportion

Rudolph's buildings have a clear base, middle, and top giving them clarity of order. New buildings should use this principle through materials, levels of transparency, and expression of functional relationships within the building. Monolithic building facades should be avoided. Expressions of floor levels are another method to give vertical definition and ordering of building facades. The goal is to develop a nuanced architecture that is sympathetic to the ordering principles of the contemporary campus.

Paul Rudolph's buildings have a strong vertical orientation with the repeated column bays topped with a strong horizontal cantilevered cap. This system of verticals supporting a cap can be another ordering principle in façade composition.

Rooftop screens at Claire T. Carney Library

Roof Forms

All roofs on campus should be flat. Where it is possible to view a roof from within a building, green roofs should be considered to beautify the campus experience as well as address localized storm water management.

Rooftop equipment should be screened with perforated metal screens with a zinc or grey finish. The height of the mechanical equipment should be minimized as much as possible and the mechanical equipment screens should conceal the equipment from view from the ground.

New Admissions Building

Building Materials

Paul Rudolph used a material palette of fluted concrete block, board formed concrete, and glass in his unified composition of UMass Dartmouth's Campus. The buildings are very sculptural, but are showing their age as the concrete has spalled, rebar is exposed, and glass panels have broken. Prospective students and visitors to the campus have consistently observed that this material palette is intimidating and uninviting, which needs to be addressed in order to improve first impressions of the campus.

It is recommended that the architectural material and color palette be expanded to help improve student and visitor perceptions of campus. While strategic use of concrete in buildings is encouraged, this design team does not advocate mimicking the original buildings materials, nor does it recommend painting over existing concrete surfaces.


New Undergraduate Housing

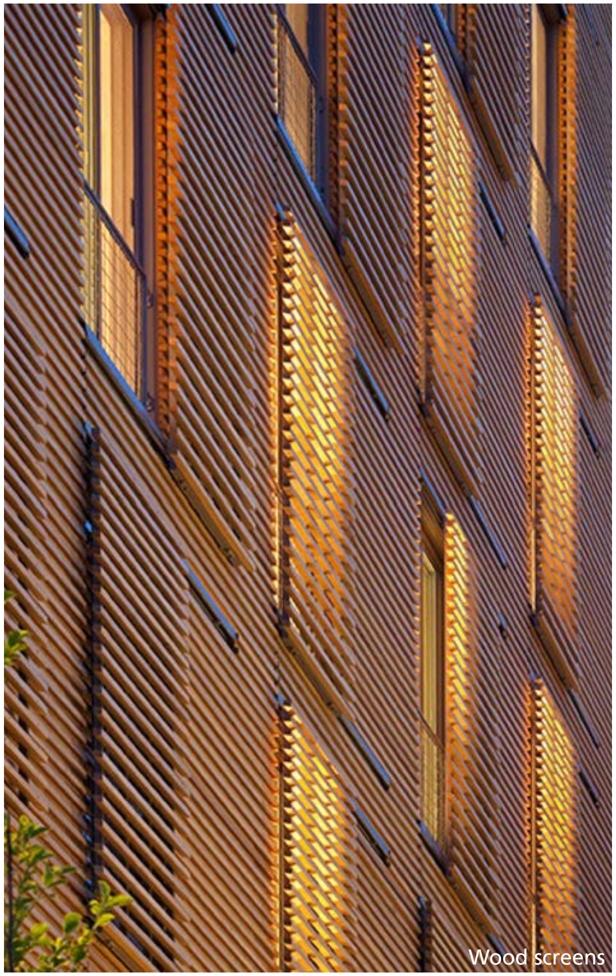
Transformation Materials

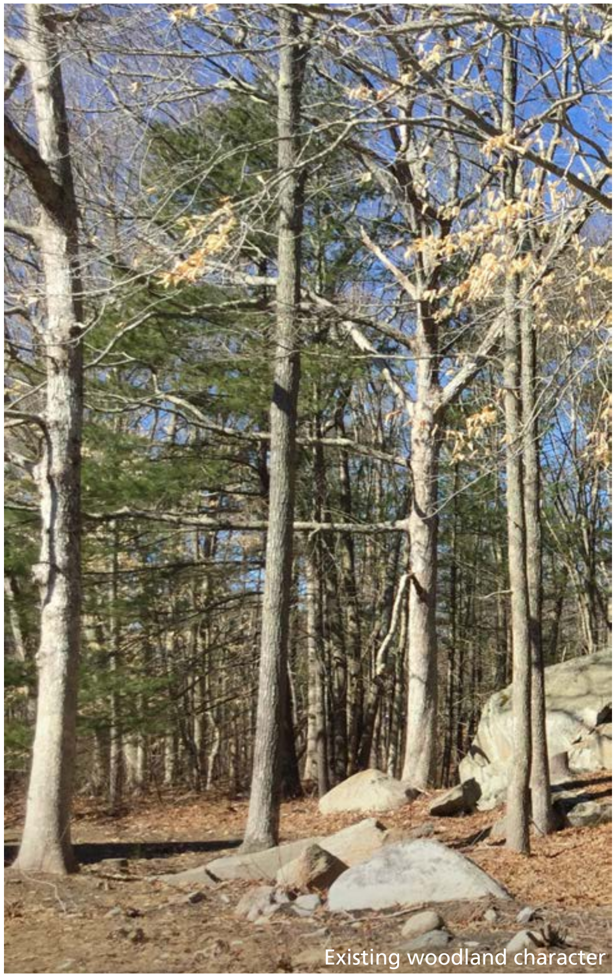
The renovation of the Claire T. Carney Library is an example of a successful transformation that both preserved the Rudolph character of the building while also creating a vibrant and light filled environment through the introduction of color and glass. This palette is one that can be utilized in the renovation of existing Rudolph buildings, providing a sensitive transformation that provides a contemporary palette to soften the appearance of the brutalist architecture to students and visitors.

The introduction of graphics and a vibrant color palette is one strategy that broke up the continuous expanses of fluted concrete block, board formed concrete, and glass. Not only can this be an aesthetically interesting strategy, but also one that can also help improve wayfinding within the continuous LARTS and SENG buildings that share a nearly identical interior character. Associating certain colors with each module of the LARTS and SENG buildings can help distinguish sections from one another, making it easier for new students to navigate their way through the Rudolph buildings. The UMass Dartmouth marketing department has created a secondary color palette that should be incorporated into interior finishes. Vibrant, warm colors should be the main color, to complement the brutalist background. Variations of the secondary palette can be used as secondary and tertiary colors within the respective college or building.

To give individual colleges identity, layers of primary, secondary, and tertiary colors can be used. For example, if a college has all cold colors, a warm color could be used that is complimentary to the college colors as the main color, with the college colors as accent. If the college has warm colors, complimentary cool colors as accent. For example, Nursing should be a warm vibrant color that compliments PMS 3125 teal.


TAKTL concrete paneling


Wood screens


Existing woodland character

Park Ring and Transformation of Architectural Character

Nestled within the park belt, the new undergraduate residence halls present an opportunity to introduce new forms and materials than those used in the academic core due to their unique setting and location on a new campus circulation route. While concrete may be introduced into the material palette for these new buildings, it is recommended that wood be introduced to help 'warm' the material palette, but also to enhance the character of the beautifully preserved 'park belt' in the academic core.

Embracing Woodlands

The existing SouthCoast woodlands character is an asset that should be embraced and enhanced on the campus. This can be accomplished through strategic plantings, landscaping, and manicuring. It is recommended that future buildings located within the wooded park belt introduce wood into the material palette as way of enhancing the woodland character and presenting a warmer building exterior to the campus. This material can help preserve the character of the SouthCoast woodland landscape.

Materials
The range of materials on campus is predominated by concrete on buildings, paving, walls, and furnishings.


Auditorium step & pathway improvements celebrate views across campus

Buildings:
The buildings are articulated in exposed concrete, inside and out, on floors and walls, combining several flat and striated finish patterns.

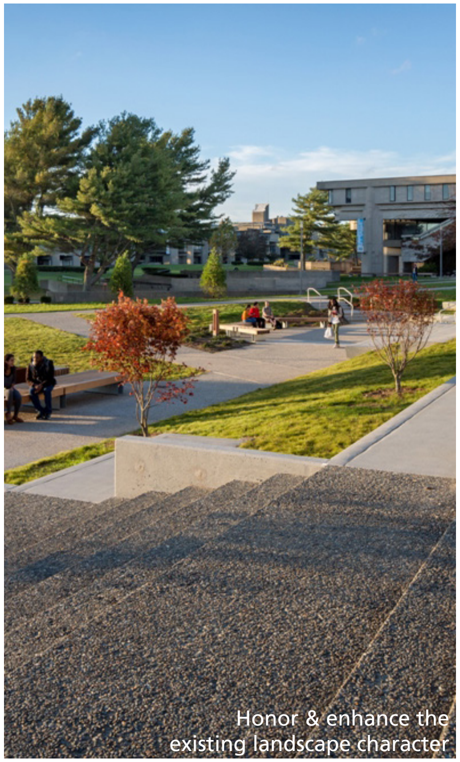
Paving:
There two types of existing paving materials: bituminous concrete, and exposed aggregate concrete. Bituminous concrete is used at all roads, parking, and most pathways outside of the central core. Exposed aggregate paving is used on all pathways, steps and plazas within the central core, as well as throughout the buildings, unifying the indoor and outdoor spaces. Over the years the concrete has achieved a warm patina. At many locations the original exposed aggregate has been patched up with a slightly different concrete mix. Curbing at the vehicular areas is conventional, consisting of mostly vertical granite and occasionally rolled bituminous concrete.

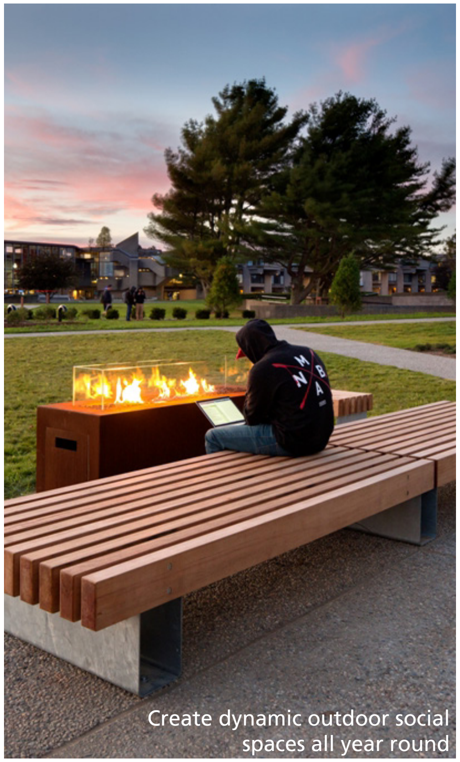
Steps:
Steps are consistently concrete with exposed aggregate finish. Most have prominent nosings that create a nice shadow line; however there were many instances of broken or patched up nosings. Throughout the campus, the steps typically have a wide profile with a shallow riser of 4” to 4 1/2” - which is too low for comfortable walking or sitting.

Site Walls:
Site walls within the campus core are made of exposed concrete with various striation patterns. At the campus entry, a series of dry-laid stone walls recall a pastoral New England image in contrast to the campus modern architecture style.

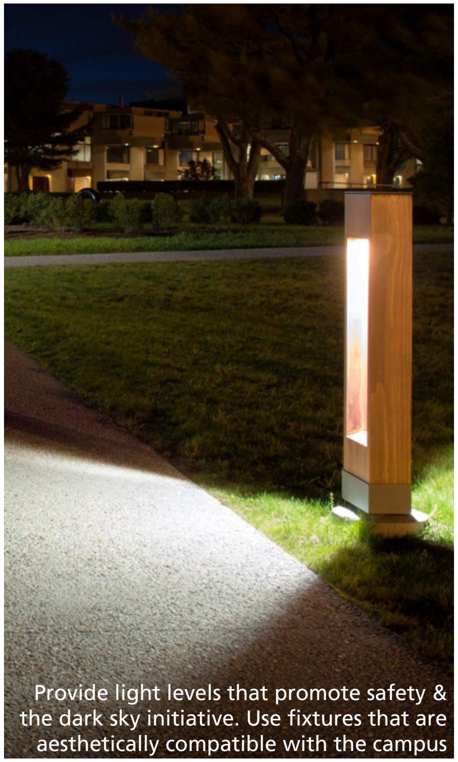
The limited materials palette on one hand unifies the campus but on the other does not distinguish between general and “special” areas, indoor and outdoor spaces, and creates a monotonous spatial experience.

As a general guideline, the exposed aggregate should continue to be used on walks within the campus core. Special places, however, such as the Campus Center Plaza and the Library Plaza, could introduce different paving materials such as concrete pavers, granite, and different finishes for cast-in-place concrete. For maintenance of the existing exposed-aggregate paving, a specific technical specification should be used as a standard for all repairs. The specified concrete mix should be developed to match the existing paving as much as possible, and should prescribe the exact material mix, source, color and additives. Outside of the campus core, bituminous concrete should be used consistently at existing pedestrian walks and the trails through the woods. Major pedestrian routes, such as those between residential areas and the campus core, should be paved with special paving and furnished with matching benches, trash receptacles, and light fixtures.


Honor & enhance the existing landscape character


Create dynamic outdoor social spaces all year round


Use artistic landscape lighting to create destinations & landmarks


Provide light levels that promote safety & the dark sky initiative. Use fixtures that are aesthetically compatible with the campus

Material Recommendations

All hardscape materials will be selected to compliment the architectural materials of the building while creating an updated modern campus feel. Maintenance, durability, and cost are other key factors that will be considered during the material selection process. Paving shall be designed in a hierarchical fashion to designate major and minor walkways. The use of specialized paving at gathering areas will contain patterning to increase the spatial character. Site furnishings such as benches, trash receptacles, and bike racks will be located throughout to accent gathering areas and desire lines. Colorful flexible seating near buildings will allow for a greater range of uses by students and faculty.

Finally, the overall lighting strategy will be to focus dramatic lighting at key entry points while applying the Dark Sky Initiative to the rest of the site. Another goal would be to use minimum lighting levels based on the usage of the site after dark. The use of cut off fixtures that limit light trespass will help towards that goal, while maintaining adequate lighting levels for a sense of security. Sections of main campus in academic and campus life quadrangles/clusters have lighting obligations that flow with the campus's activity. Light levels may vary across campus due to amount and times of activity. Flexibility in providing adequate light levels in active areas of campus is key.

Pedestrian pole lighting, which produces light pollution, will be kept to a minimum and should only be used where a higher level of illumination is required.

Site Context and Ecology

Cedar Dell Pond's water elevation is dropping over time. This issue is multifactorial and will require a big picture look at the overall campus hydrology. Future campus development should keep this issue in mind when making changes to the existing flows of water on campus. The university should take a proactive approach through research and investigation. Factors that could be influencing water-level dropping are encroachment of invasive species along the perimeter and slowly filling in the pond, excess sediment load raising the bottom of the pond elevation, campus development altering overall watershed flows to the pond, drought conditions resulting in loss of groundwater.

By limiting the impact of development on ecologically sensitive areas and using a holistic approach to the campus watershed these measures will work to ensure that the health of these ecosystems can be improved over time with thoughtful landscape infrastructure and intervention.

Landscape Sustainability

As the campus population grows so will the pace of development. Care should be taken to reduce negative impacts on existing ecological systems as well as the health, safety and welfare of the campus community through thoughtful design and planning. The university should consider adopting a systematic comprehensive set of guidelines such as the Sustainable Sites Initiative (SITES) to define and measure performance of the landscape.

The Sustainable Sites Initiative™ (SITES™) is a program based on the understanding that land is a crucial component of the built environment and can be planned, designed, developed, and maintained to avoid, mitigate, and even reverse these detrimental impacts. Sustainable landscapes create ecologically resilient communities better able to withstand and recover from episodic floods, droughts, wildfires, and other catastrophic events. They benefit the environment, property owners, and local and regional communities and economies.

In contrast to buildings, built landscapes and green infrastructure have the capacity to protect and even regenerate natural systems, thereby increasing the ecosystem services they provide. These services are the beneficial functions of healthy ecosystems such as sequestering carbon, filtering air and water, and regulating climate. Source - SITES v2 Rating System

In the short term, immediate steps can be taken to increase sustainability on campus. These measures can be applied by the Facilities Department in its approach to operations and maintenance of the campus landscape in coordination with a knowledgeable site manager. Included are recommendations for short term sustainability goals some of which might already be in practice.

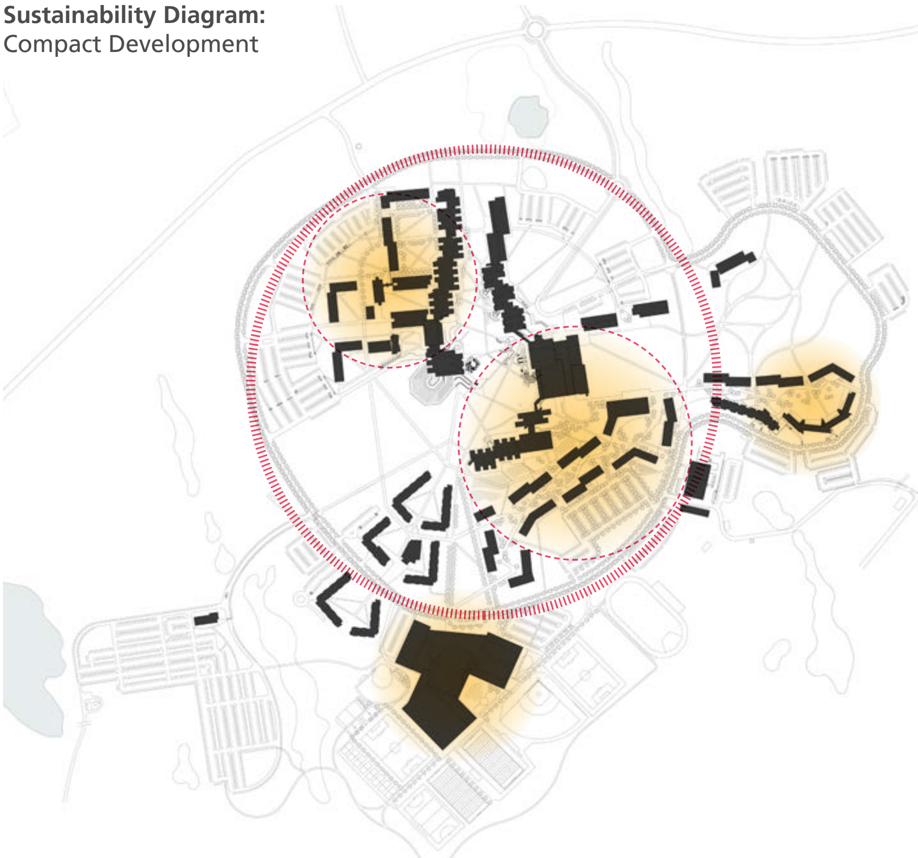
Recent native planting installation & invasive species removal at Farm Pond

Operations and Maintenance:

A comprehensive plan for sustainable site maintenance should be developed to help guide staff and establish sustainable priorities. The university should consider recycling all organic matter by creating on or off site composting. This involves collecting excess vegetation generated during site maintenance to a composting facility on or off site that is then turned into usable horticultural soil. Other waste reduction opportunities to be investigated would be the reduction of food waste. Developing a food waste composting program should be considered to help reduce outgoing waste.

Minimizing pesticide and fertilizer use on the great lawn would help improve water quality and reduce the impact on beneficial insects. Other achievable goals would be to reduce outdoor energy consumption by using high efficiency light fixtures. Energy consumption can be reduced further by minimizing mowable lawn area.

Sustainability Diagram:
Compact Development



Encourage compact development within the Ring Road.

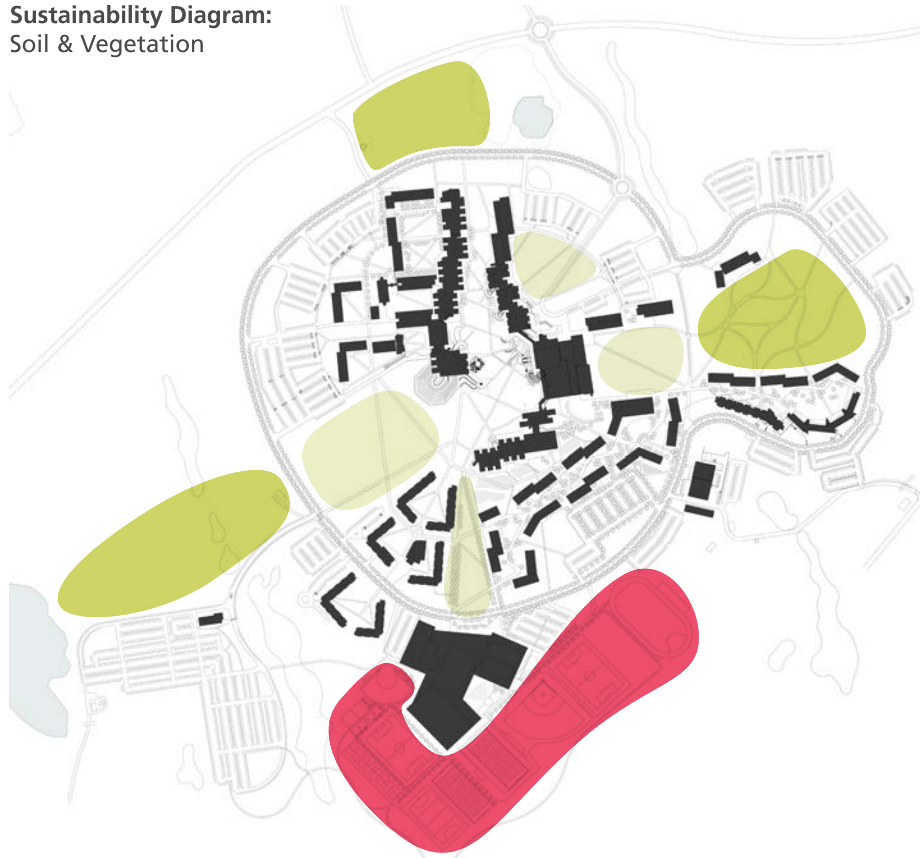
Focus new development outside the Ring Road around existing development.

Density within Ring Road focused in the south east and north west.

Long Term Sustainability Goals:

- Limit development footprint
- Conserve aquatic ecosystems
- Conserve habitats
- Locate projects within existing developed areas
- Increase connections to multi-modal transit networks designed around areas which have more activity. Focus on improved pedestrian, bicycle, and transit pathways.
- Improve accessible connections
- Create comfortable outdoor spaces

Sustainability Diagram:
Soil & Vegetation



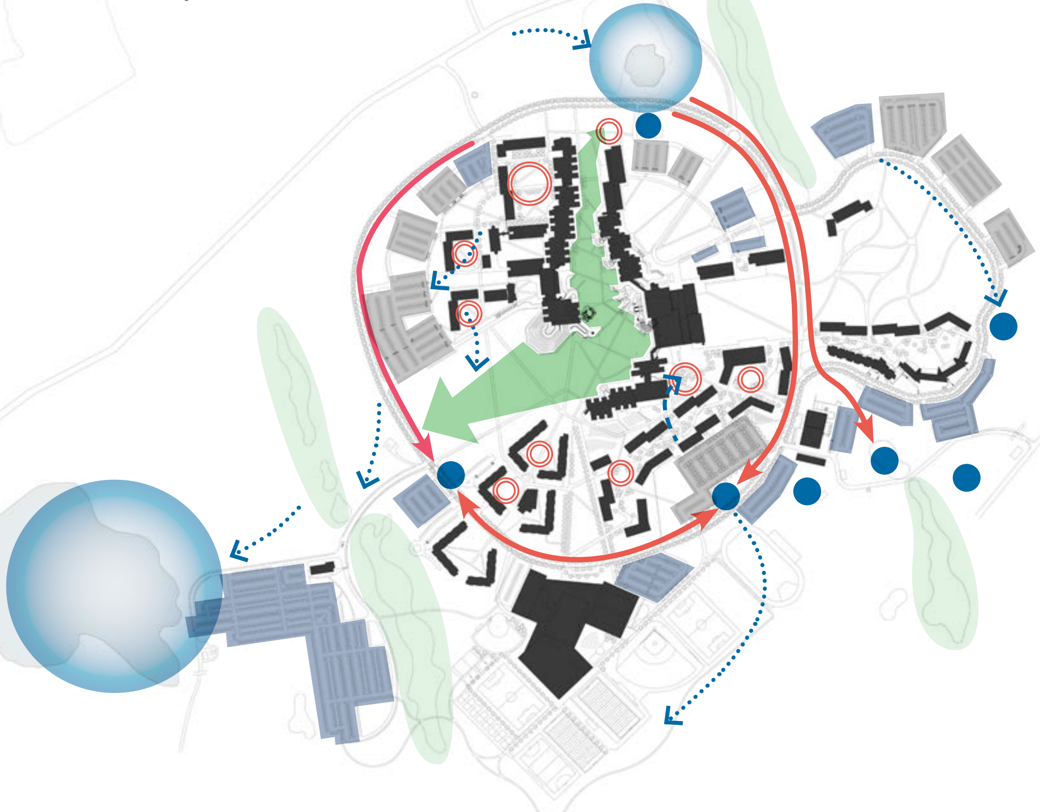
Meadow - establish a single annual mow schedule

Low Mow Area - limited seasonal maintenance, no fertilizer use

Athletics - Limit pesticide and fertilizer use

Soil + Vegetation:
The ring of dense woodland is a unique campus-defining element that should be preserved and enhanced. The woodland contains vegetation that stores an abundance of carbon that moderates the climate around campus. Equally important are the soils that filter and purify storm water as it seeps into the aquifers. Development should minimize any encroachment into the outer woodland ring. It is recommended that the university designate Vegetation and Soil Protection Zones to prioritize this area as preservation.

Sustainability Diagram:
Water Systems



Pond Ecosystem- conserve and restore

Woodland Swamp Ecosystem- conserve and maintain

Retention Area- enhance existing

Future Rain Gardens- filter roof runoff based on future building expansion

Bioswale- enhance roadway drainage channel, remove lawn & replace with biodiverse plant species

Overland Drainage Flow

Impervious Surfaces- reduce to provide precipitation infiltration

New Parking Lots - low impact development practices to mimic natural systems and increase stormwater infiltration

Great Lawn - reduce maintenance

Invasive plants are a threat to the biological diversity of the woodland. An assessment plan should be performed that creates recommendations and guidelines in the control and management of invasive plants. Early detection and prevention are the best lines of defense. Resources such as the UMass Extension Services offer various programs to educate members of the landscape maintenance community. Managing and controlling invasive plants will increase biodiversity and limit risk from insects and diseases.

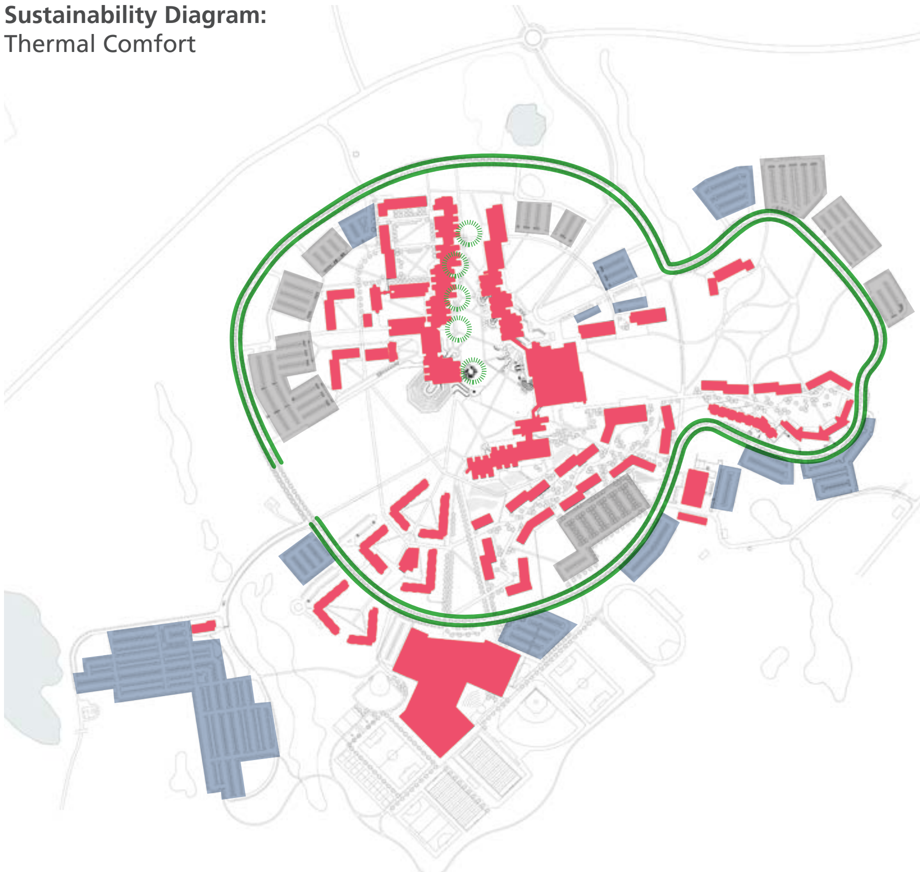
For new landscape construction, conserving and restoring native plants should be a priority. Healthy soils excavated for construction shall be stored on site using methods to ensure structure and usability is maintained. Imported soils from greenfield sites should not be allowed.

Water:
A major goal of this category is to manage precipitation by increasing filtration and infiltration without negatively affecting natural ecological flows or natural groundwater replenishment rates and volumes. Strategies that can be implemented on campus include modifying the existing drainage channels and retention ponds by including biodiverse plant species and healthy soils. This would reduce the need to mow the drainage channels except for once a year in the late fall or early winter to keep the bioswales in a meadow stage of succession. The campus already does a good job at reducing outdoor water use. Only temporary irrigation should be considered when trying to establish new plants.

New building construction should include rain gardens to receive roof stormwater. These gardens can serve as an educational tool for the campus. A rain garden is a planted depression that allows rainwater runoff from impervious urban areas, like roofs, driveways, walkways, parking lots, and compacted lawn areas, the opportunity to be absorbed into the ground. This reduces rain runoff by allowing stormwater to soak into the ground (as opposed to flowing into storm drains and surface waters which causes erosion, water pollution, flooding, and diminished groundwater). They should be designed for specific soils and climates. The purpose of a rain garden is to improve water quality in nearby bodies of water and to ensure that rainwater becomes available for plants as groundwater rather than being sent through stormwater drains straight out to sea. Rain gardens can cut down on the amount of pollution reaching creeks and streams by up to 30 percent.

The campus wetland resources include two ponds and a series of woodland swamps. In discussion with the university it was noted that the elevation of Cedar Dell Pond has been steadily dropping due to a recent construction project. An investigation should be done to locate and remedy the source of this problem. Dredging years of sediment loading in the ponds as well as removal of invasive species is recommended to restore the performance of these aquatic ecosystems. An assessment and management plan of the woodland swamp should be developed to monitor and remove invasive species to prevent the filling in of the wetland.

Sustainability Diagram:
Thermal Comfort



Shade Trees - provide close to ring road

High-Reflectance Rooftops - establish sr value of 64-82, use paving materials with an sr value of 0.33

Existing Impervious Pavement - replace with pervious pavement over time and increase the amount of shade trees in existing parking areas

New Parking Areas - provide shade trees and adequate soil mass to establish 50% shade coverage over a fifteen year period.

New Trees - plant at existing building entries to help buffer prevailing winds

Thermal Comfort:
Creating environmentally comfortable landscape spaces is the major goal of this category. This achieved by strategically planting trees to provide shade as well as buffer prevailing winds such as in parking lots and at building entries. Trees can also successfully minimize building energy by shading facades with high solar exposure. Tree planting at building entrances along the SENG block of buildings will help buffer prevailing winds. Using light-colored pavement and roofing materials will minimize solar heat gain. The additive effect of these measures will reduce the urban heat island effect making the spaces more comfortable.

Material Selection:
For new landscape construction, the following measures should be considered to ensure that sustainable materials are being used:

- Use sustainable wood species
- Maintain on-site structures and paving as much as possible
- Design for adaptability and disassembly
- Reuse salvaged materials and plants
- Use recycled content materials
- Use regional materials
- Support sustainability in materials manufacturing

Human Health and Well Being:

- Protect and maintain culturally important campus places
- Provide optimum accessibility, safety, and wayfinding
- Promote equitable use
- Support mental restoration
- Support physical activity

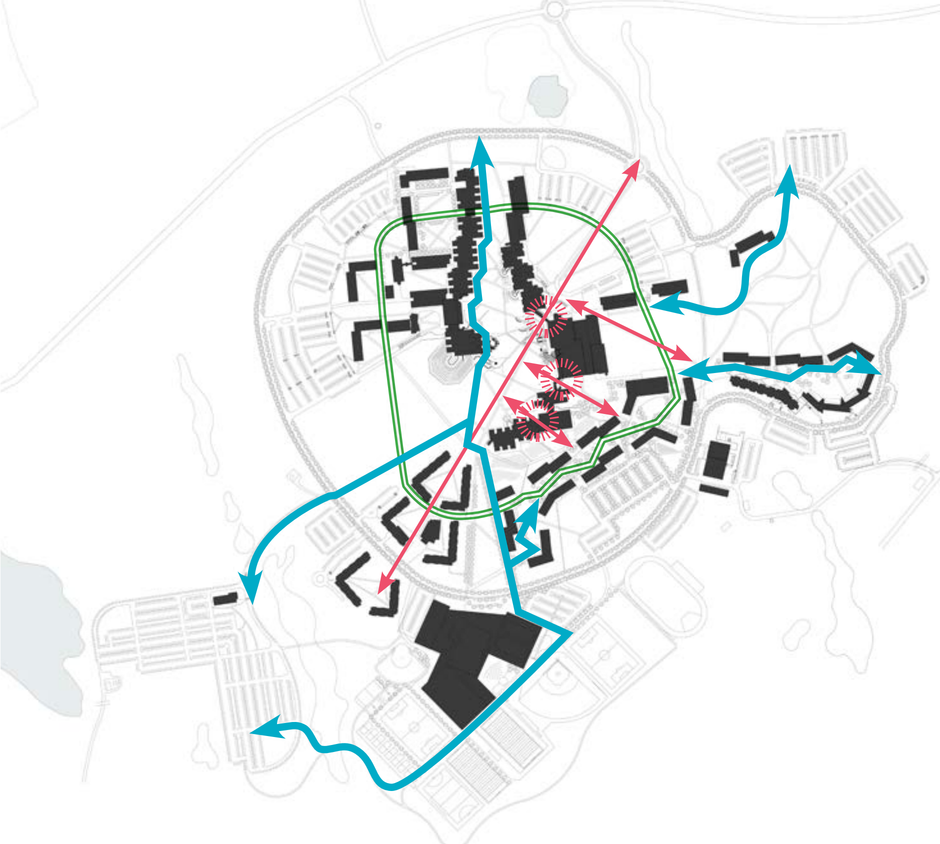
Support Social connection:

- Provide on-campus food production
- Reduce light pollution
- Support the local economy

Construction:

- Communicate and verify sustainable construction practices
- Control and retain construction pollutants
- Restore soils disturbed during construction
- Divert construction and demolition materials from disposal
- Divert usable vegetation, rocks, and soil from disposal
- Protect air quality

Proposed Accessibility Diagram:



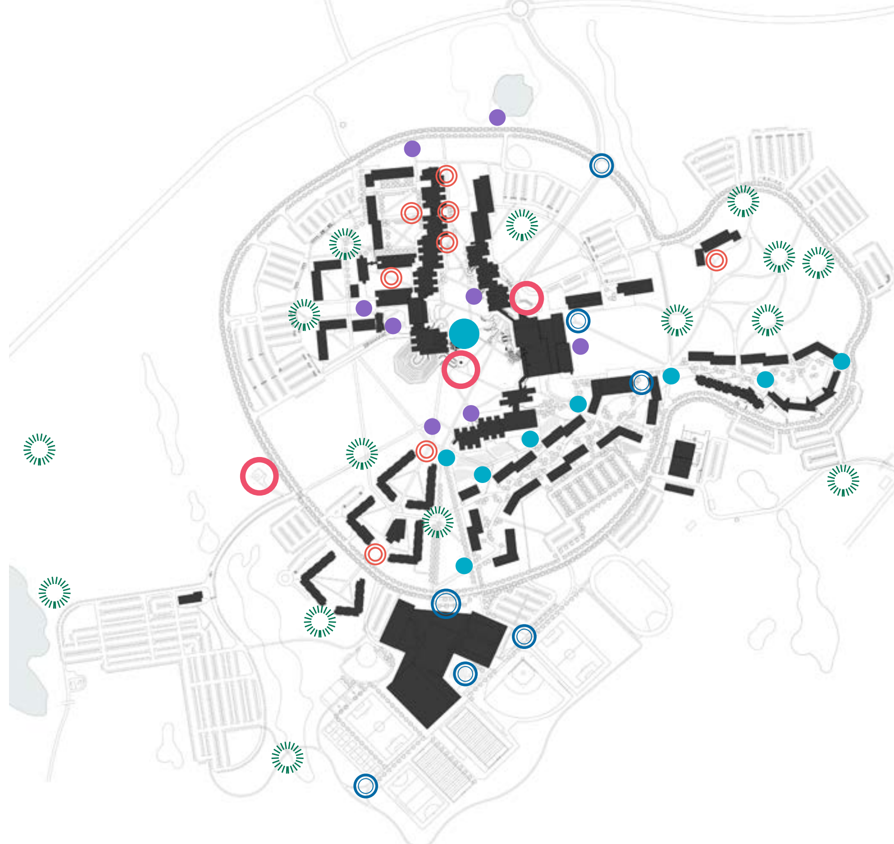
Major Proposed Accessible Route - 2-5% maximum slope

Proposed Accessible Grade Transition

Direct Accessible Campus Core Paths

New Pedestrian Ring

Proposed Public Art Diagram:



Campus Landmarks

Experiential

Existing Sculpture

Nodal Focal Points

Memorial

Student Art

Accessibility

Develop a pedestrian circulation strategy that creates a safe barrier-free environment, honors the iconic original pathway geometries and provides a unified hierarchy of paths that account for desire lines across campus. Enhance multimodal access to the campus by providing safe pedestrian and bicycle routes from the campus core to off campus destinations to the north by changing the location of campus main entry. Changes to Ring Road will eliminate the pedestrian and vehicular conflict by diverting Ring Road around the east residence hall group, creating better pedestrian connectivity between residences and campus core.

Currently there is no clear destination for visitors, by establishing a clear arrival hub for visitors will help mitigate campus legibility issues. Other measures to enhance path legibility would be to provide clear accessible paths of travel to destinations throughout campus and to improve existing building entry points with upgraded, architecture, public art and tree planting. Improving the axial relationships between the campus core to the eastern residences and south to the Athletics area will help further connect these parts of campus.

Implementing a pedestrian path ring that circulates around the entire campus core in between the parking lots and existing buildings will offer pedestrians clear access around the campus.

"Smart Road" section view

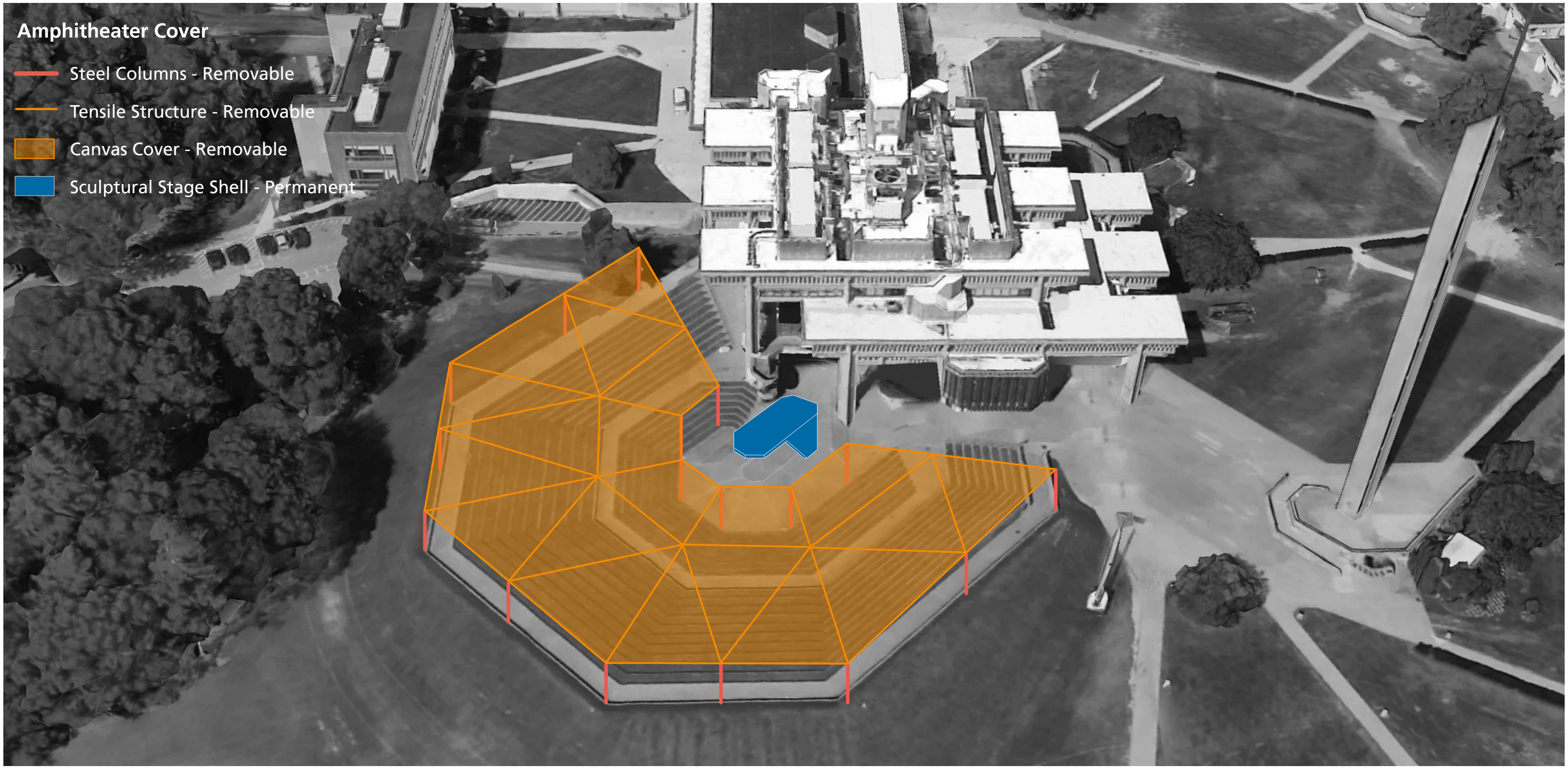
Ring Road

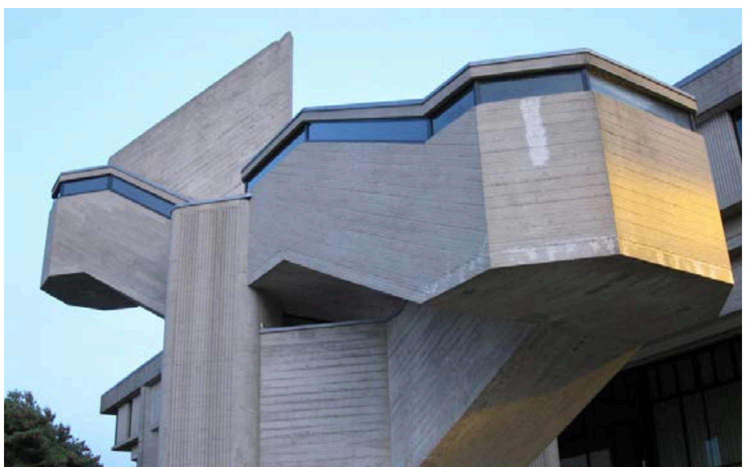
Develop a "Smart Road" approach that addresses three major goals:

- Walkability – Establish designated bicycle and pedestrian circulation to dramatically improve non-vehicular connectivity on campus.
- Sustainable Streets – Develop the existing swales to be a part of an overall landscape infrastructure system that holistically addresses stormwater and from a sustainability point of view. This would involve naturalizing the drainage swale to help filter stormwater before it enters the ecosystem. Improving roadway lighting that uses innovative technology such as LED's and that responds in real time to peak usage. This lighting system could also use the proposed campus solar grid to be powered. Shade tree planting should be planted on both side of the road to reduce the urban heat island effect as well as serving as a visual cue to slow traffic down.
- Slow vehicular traffic – Reduce the width of vehicular travel lanes to deter excessive speeds.

Views and Vistas

Improve views around campus by preserving and enhancing Rudolph's vision of grand views and vistas. No development should encroach on the grand views to Cedar Dell Pond from the Great Lawn. Axial views to and from the campus core to the East and South residential groupings should be established by some limited tree clearing and appropriate future building locations. The park-like views from the northeast section of campus towards the LARTS building should be preserved as this represents one of the most iconic glimpses of campus.





The shell is a permanent structure that fully covers the stage area, referencing Paul Rudolph's sculptural concrete volumes

The cover at the amphitheater seating is a removable tensile canvas, stretched across a lightweight steel structure

Open Space

The Great Lawn:

The Great Lawn is a campus defining element that should be preserved and expanded upon to define building entrances and enhance the ground plane experience at building entrances. This can be achieved through the location of appropriate tree planting, public art and site furnishings.

Amphitheater:

The amphitheater is the signature campus landform, which sits at the foot of the campanile and the Claire T. Carney Library. It hosts many university events, such as festivals and commencement celebrations. In order to achieve the protection from inclement weather without compromising the unique quality of landscape or adjacent historic structures, care must be taken to reference Rudolph's scale and form. The only permanent structure should occur at the stage area, which should optimize views from all sides and reference Paul Rudolph's sculptural geometric forms. The cover at the seating should be a temporary, tensile structure that follows the grade of the landscape, remaining deferential to the Claire T. Carney Library.

Student Life Ring and Campus Pedestrian Connections:

Establish a wide main path that allows pedestrians to continuously circumnavigate the campus. This connection would allow pedestrians to move easily from the student life ring north to the LARTS expansion and would serve as a campus defining landscape feature. This path derives its geometry from the ring road that the campus is circumscribed in. Provide a path with enough width to accommodate service vehicles in order to prevent vehicular travel on lawn and landscape. Selective removal of trees and understory in the forest fragments within the forest ring should be considered to strengthen visual connections with key parts of campus for safety and wayfinding.

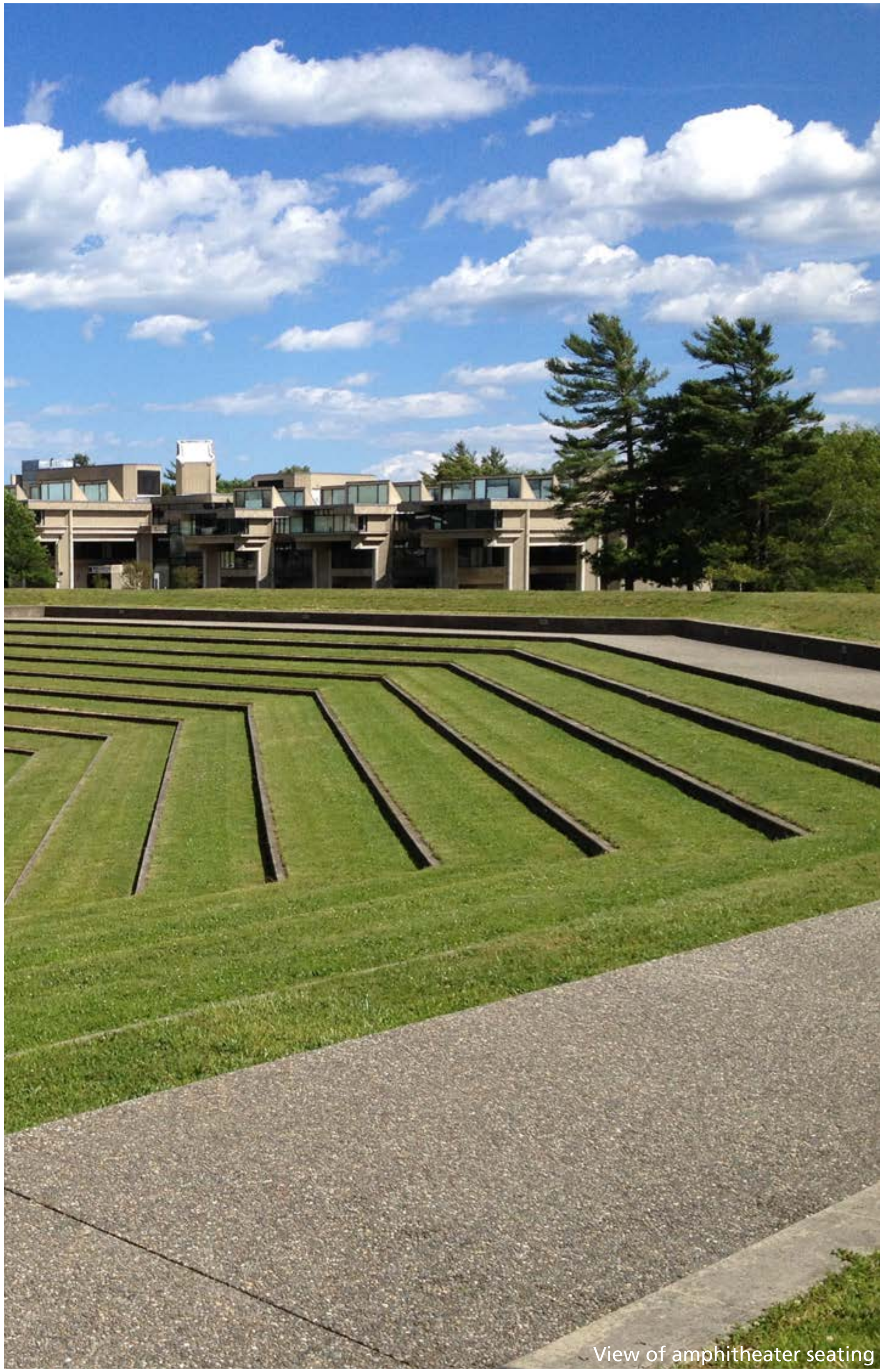
East Residence Halls:

A complete reorganization of this section of campus will introduce graduate housing in this area to create an enclave for more mature students. A strong spatial relationship will be created between the existing Pine Dale and Oak Glen dorms. A central pedestrian spine will connect students to the campus core without conflicting with vehicular traffic.
In the short term, after demolition of the existing buildings, a path system will be established to offer clear connections from the commuter parking lots to the north with the rest of campus. This path system will have the look and feel of nature trails with safe lighting levels and accessible pavement surfacing.

Residential Social Spaces:

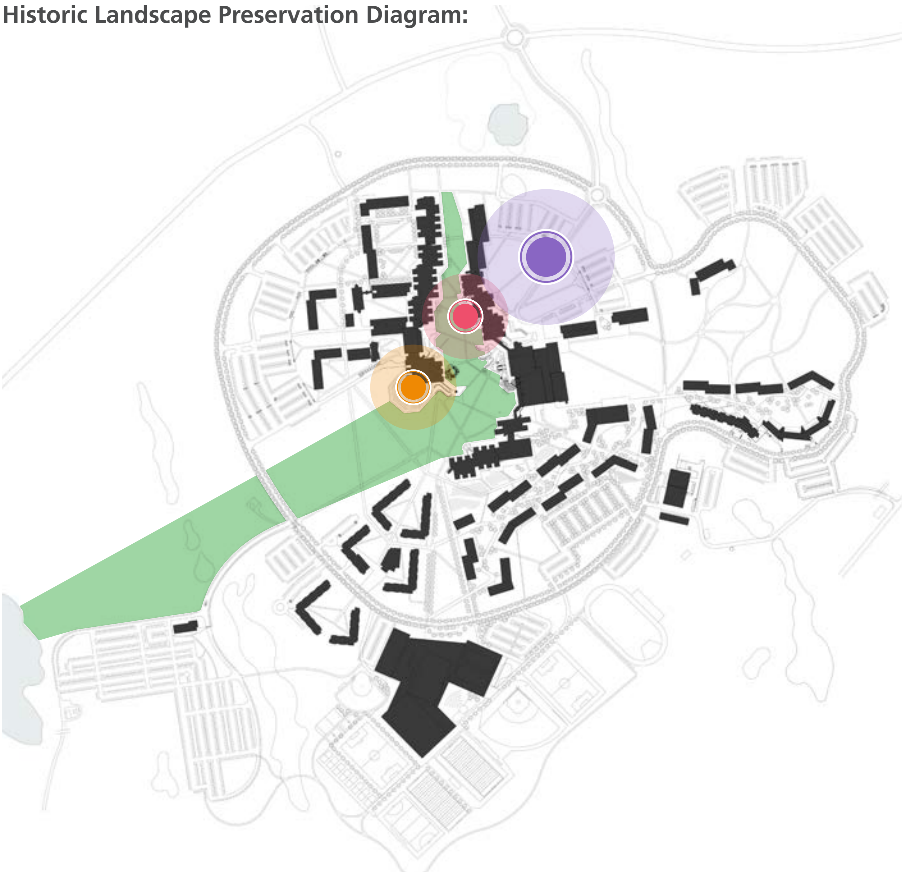
Treat each residence hall individually with thoughtful design guidelines in place to create a meaningful and memorable experience for students. Outdoor student gathering areas should be improved upon at the residence halls to encourage interaction and a sense of place. A balance of passive and active recreation should be enhanced by planning for a range of activities such as beach volleyball, flexible lawn space, and outdoor study areas.

Pathways should be wide enough to accommodate service vehicles but service vehicles should be limited to certain paths to reduce landscape disturbance as seen throughout campus. Landscape spaces should provide quality site furnishing and arranged to encourage dynamic outdoor social interaction.



View of amphitheater seating

Historic Landscape Preservation Diagram:



Park Settings
These areas are defined by large tree stands with rolling topography and offer key defining views of the campus architecture. These areas should be preserved as much as possible and should be developed as a last resort when considering campus expansion. This character should be expanded on where possible.

Iconic Landscapes
The nautilus seating areas, the LARTS eastern facade cascading stair and the signature '6' shaped gathering areas should be rehabilitated and upgraded with care.

Iconic Landmarks
The Campanile and Amphitheater are campus defining landmarks that should be preserved.

Great Lawn
The Great Lawn is a campus defining element that should be preserved and expanded upon to define building entrances and enhance the ground plane experience at building entrances.

Athletics and Recreation:
It is envisioned that this area will become a bustling hive of student activity. Part of this vision is to realize a "big back yard" for students to enjoy a range of recreational activities year round. Reorganizing and adding play fields with synthetic turf, courts, lighting and pathways will enrich the student experience.

Generating revenue from athletic events is a goal of this plan. Adding ticketing booths at pedestrian entry points and perimeter fencing will allow this to be realized. A "Main Street" like concourse is imagined along the length of the playing fields to allow for clear and safe pedestrian access as well as allowing room for vendors such as food trucks to provide services on event days.

A 150-180 car parking lot adjacent to the hockey rink shall serve the facility during non-event days and the expanded parking at Cedar Dell would be used for event parking. A series of accessible paths through the woods would allow for easy access between Cedar Dell and Athletics. The improved main entrance of Athletics would have a main entry plaza with space for bus and car drop-off.

Arboretum:
The current Arboretum space at Violette has the potential to be transformed into a research quad by improving circulation and providing landscape improvements. Thoughtful screening of the utilities with architectural elements could dramatically improve the visual character of the space. Landscape improvements such as lighting, outdoor seating, and new pavement should be made to the walkway and small plaza adjacent to SENG. Consider modifications to buildings such as adding windows to facades to increase visibility to the exterior.

The idea of an Arboretum should be expanded campus wide and not only in this location. The benefits of establishing a campus arboretum falls into roughly three categories:

- Research – Allow for research which promotes sustainable land management and conservation of plant biodiversity and natural resources.
- Education – The opportunities for educational range from identification of plants and ecological systems, botany and photography.
- Outreach – Strengthen the town and gown relationship by fostering citizen engagement through tours and events for the public.

Existing Park Setting:
Preserve and protect this area as much as possible. Consider development in this area only as a last resort when considering campus expansion. Expand this landscape character to other parts of campus. This portion of campus can contribute greatly to the proposed entry sequence, creating a unique and geographically specific experience for visitors, students, and prospective students.

Managed Forest and Forest Parking Buffer:
Establish a management plan for the campus forest. This plan would involve managing invasive plant species and improving the overall ecosystem health. Habitat preservation and identification should also be investigated to determine the most sensitive areas of campus.

Creating a forest trail system would provide passive recreation opportunities such as hiking, fishing and paddle boat access to the entire community. The campus could also serve to establish a link to the South Coast Bikeway system that is planned to pass through the area.


Campus Arboretum Community Outreach

VII. Acknowledgements

Acknowledgements

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EXHIBIT B
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The University of Massachusetts - Dartmouth FY17 ROPA Final Presentation

February 2018

Presenters: Emily Morris and Adam St. Denis

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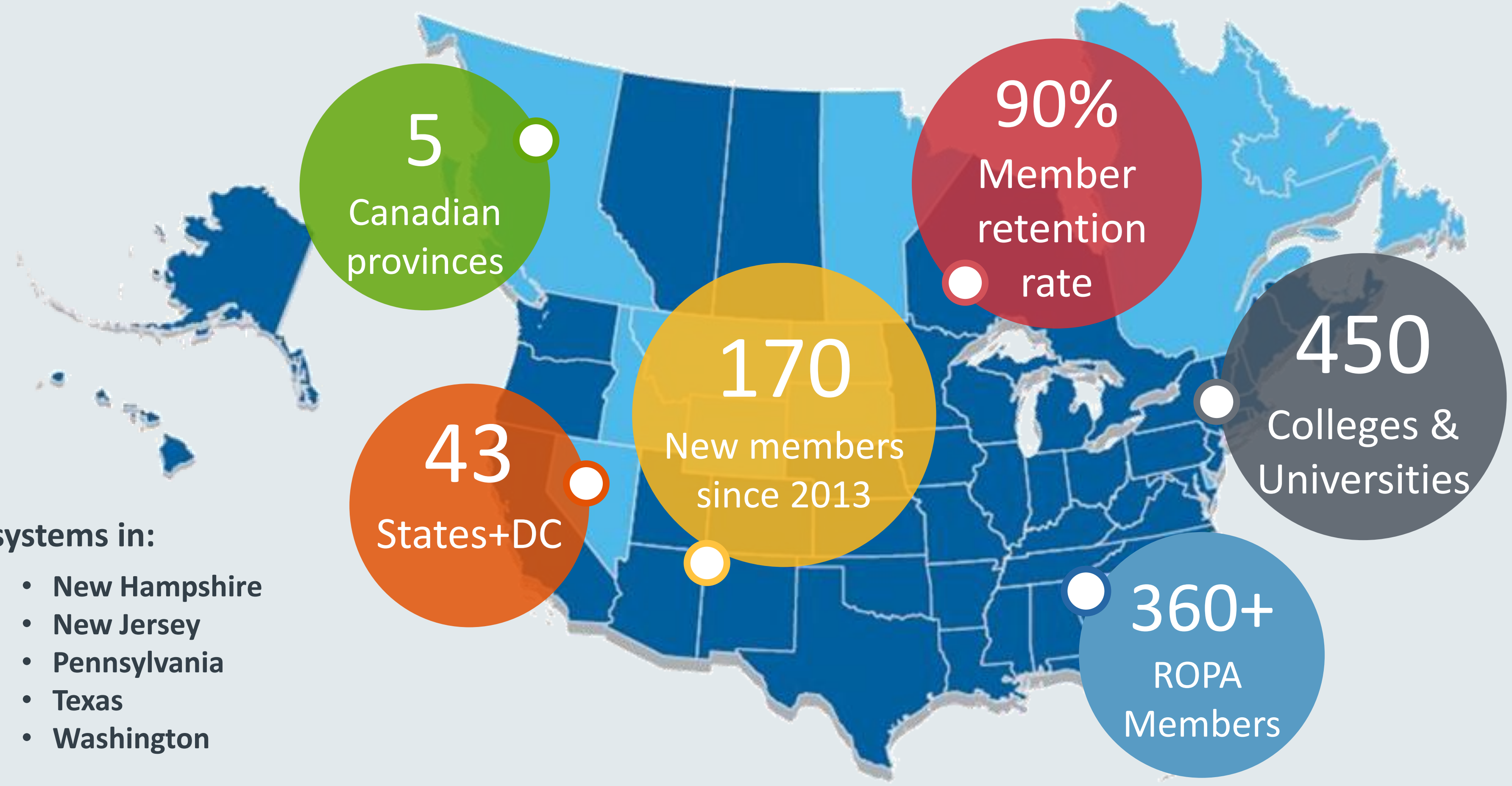
Sightlines by the numbers

Robust membership includes colleges, universities, consortiums, and state systems



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- Florida
- Hawaii
- Maine
- Massachusetts
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- Mississippi
- Missouri
- Nebraska
- Ohio
- New Hampshire
- New Jersey
- Pennsylvania
- Texas
- Washington

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Vocabulary for facilities measurement, benchmarking & analysis

Annual Stewardship

The annual investment needed to ensure buildings will properly perform and reach their useful life ***"Keep-Up Costs".***

Asset Reinvestment

The accumulation of repair and modernization needs and the definition of resource capacity to correct them ***"Catch-Up Costs"***

Operational Effectiveness

The effectiveness of the facilities operating budget, staffing, supervision, and energy management.

Service

The measure of service process, the maintenance quality of space and systems, and the customers opinion of service delivery.

Asset Value Change (Annual Stewardship ↔ Asset Reinvestment)

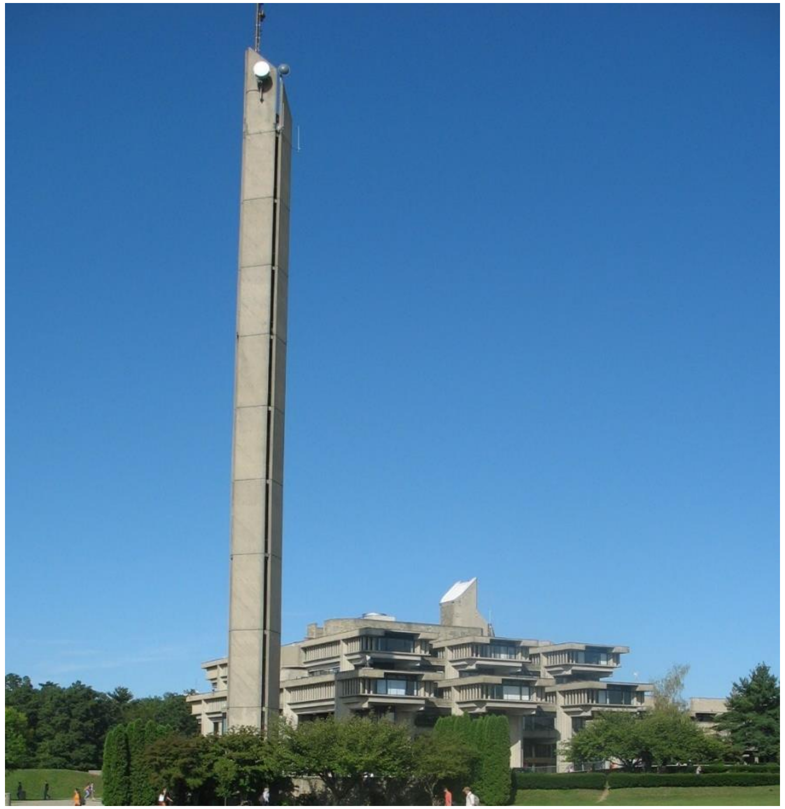
Operations Success (Operational Effectiveness ↔ Service)

Integrated campus stewardship

- Campus footprint is growing over time. Growth is more heavily weighted at the offsite locations.
- Despite new construction and renovations campus is aging with 54% of space over 25 years old.
- UMass Dartmouth's capital investment is increasing over time but not meeting the Sightlines' Annual Investment target.
- A high backlog of need exists on campus. A large portion of this need is coming due in the next three years and in the highest risk areas.
- Key academic and residential facilities are in need of major renovations.
- Facilities operating resources are comparable to peers. Energy costs and consumption are decreasing.

Peer Institutions for Benchmarking

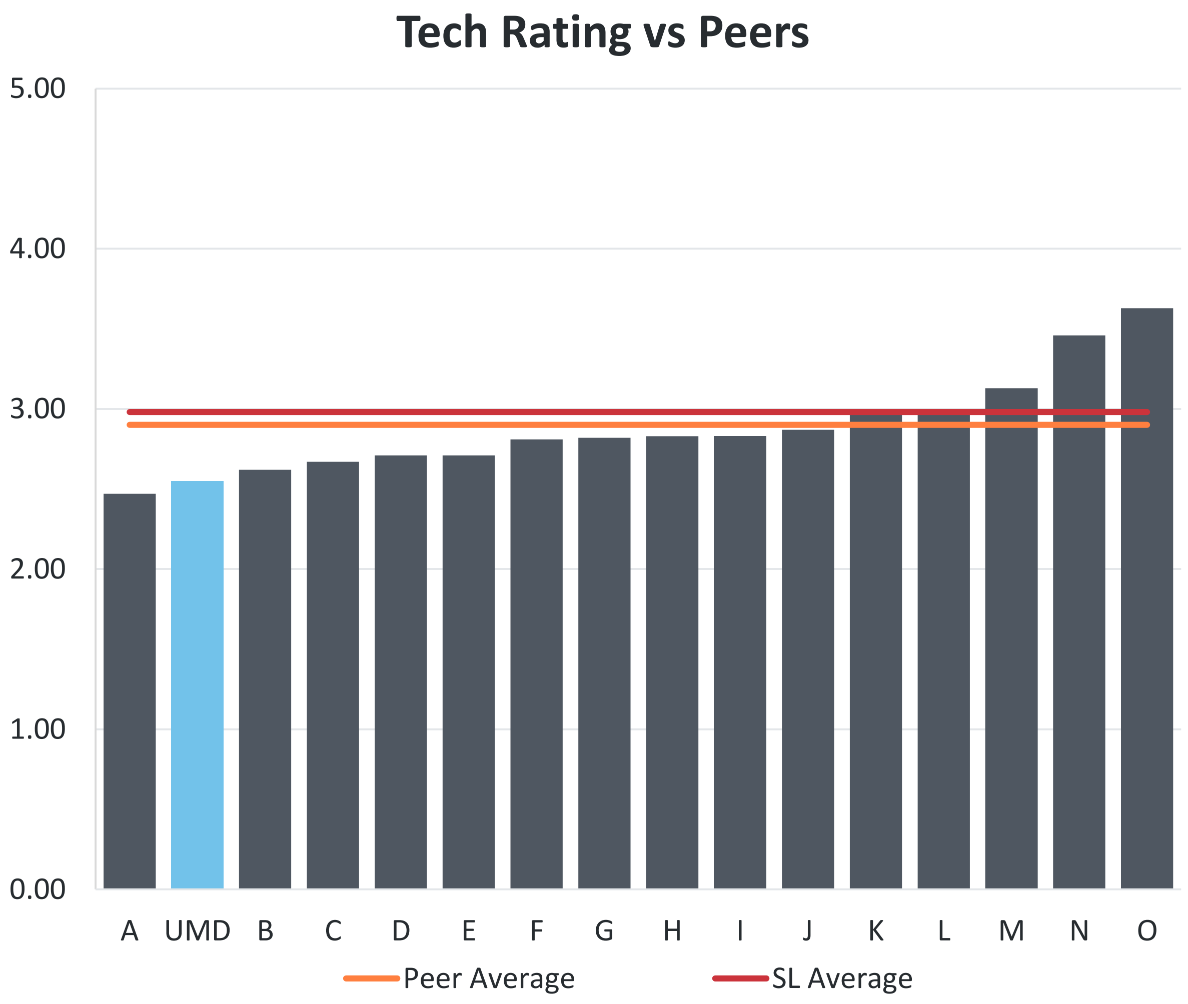
FY2017 Peer Group	Location
Bridgewater State University	Bridgewater, MA
Bristol Community College	Fall River, MA
Edinboro University of PA	Edinboro, PA
Fitchburg State University	Fitchburg, MA
Keene State College	Keene, NH
Plymouth State University	Plymouth, NH
Shippensburg University of PA	Shippensburg, PA
Slippery Rock University of PA	Slippery Rock, PA
University of Hartford	Hartford, CT
University of Massachusetts - Amherst	Amherst, MA
University of Massachusetts - Boston	Boston, MA
University of Massachusetts - Lowell	Lowell, MA
West Chester University of PA	West Chester, PA
Westfield State University	Westfield, MA

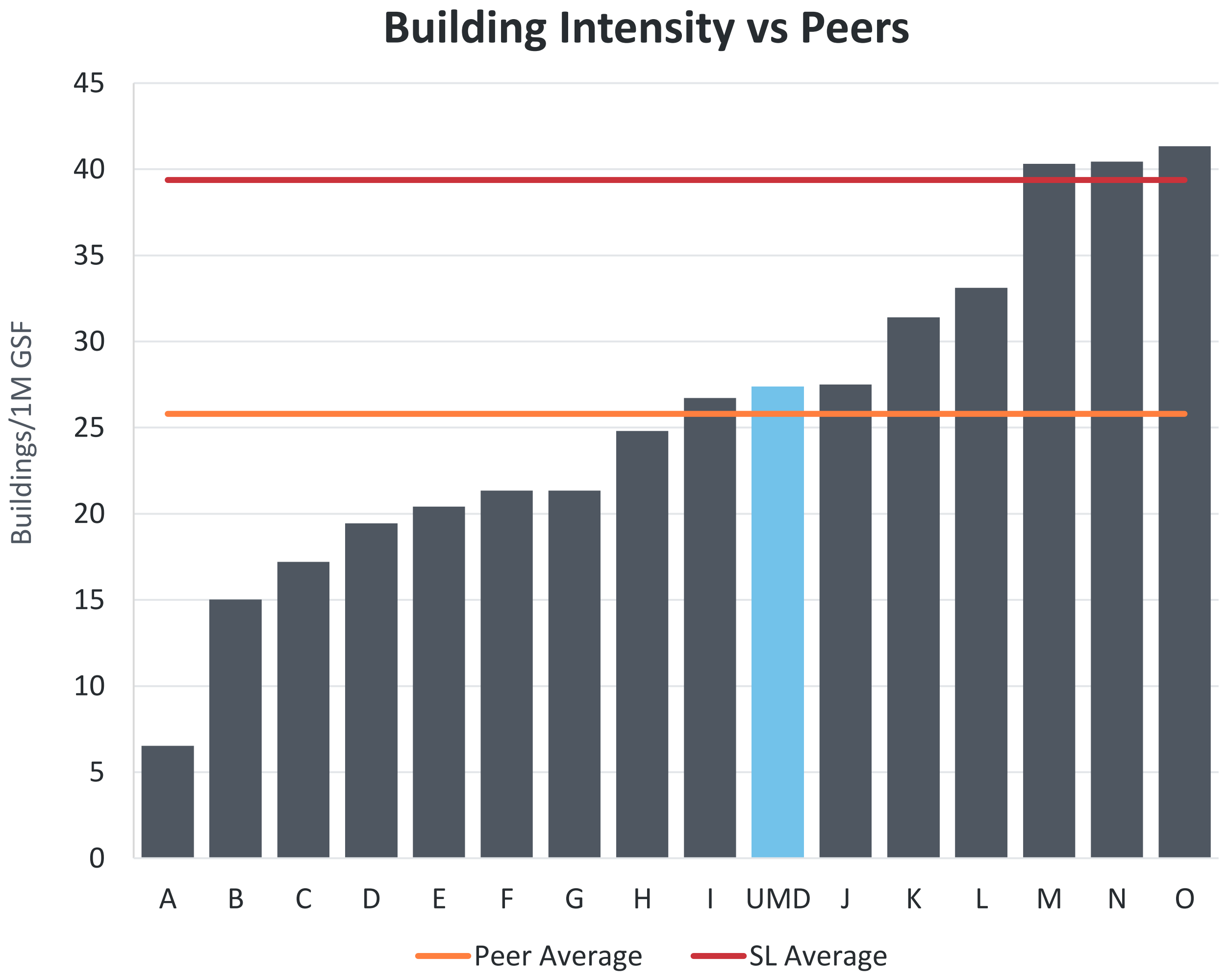


Comparative Considerations

Size, technical complexity, region, geographic location, and setting are all factors included in the selection of peer institutions

Technical Complexity and Building Intensity





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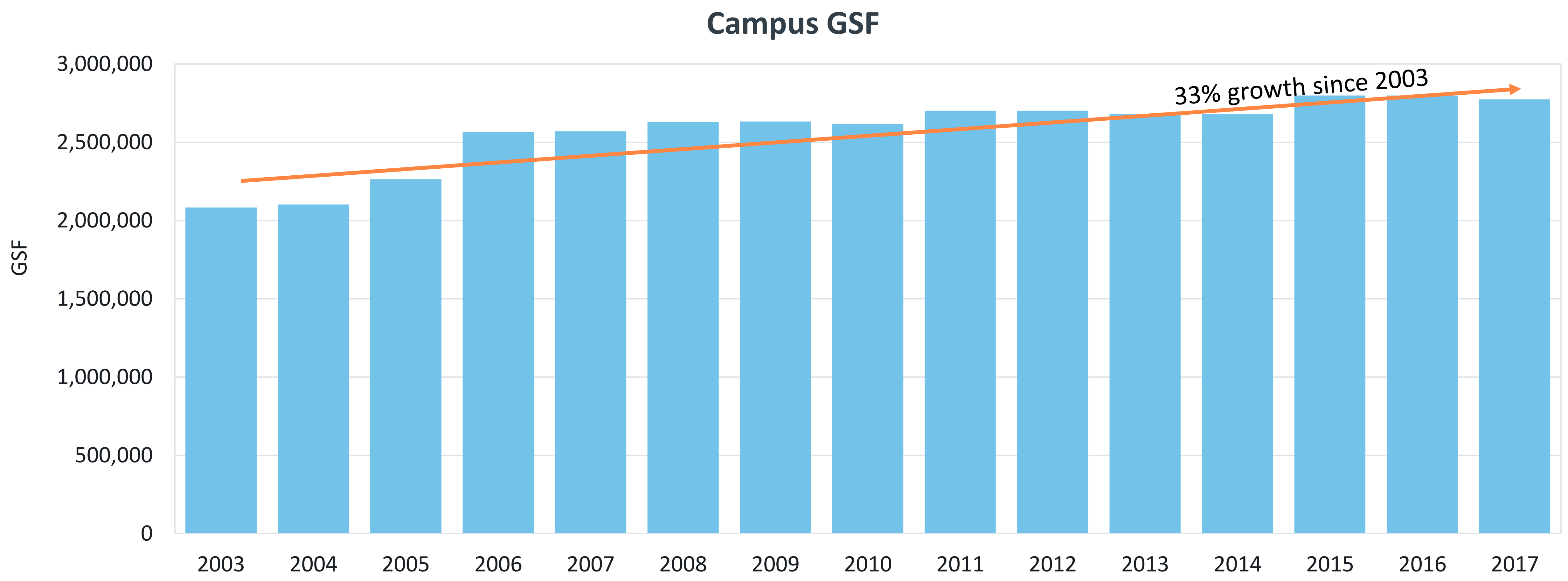
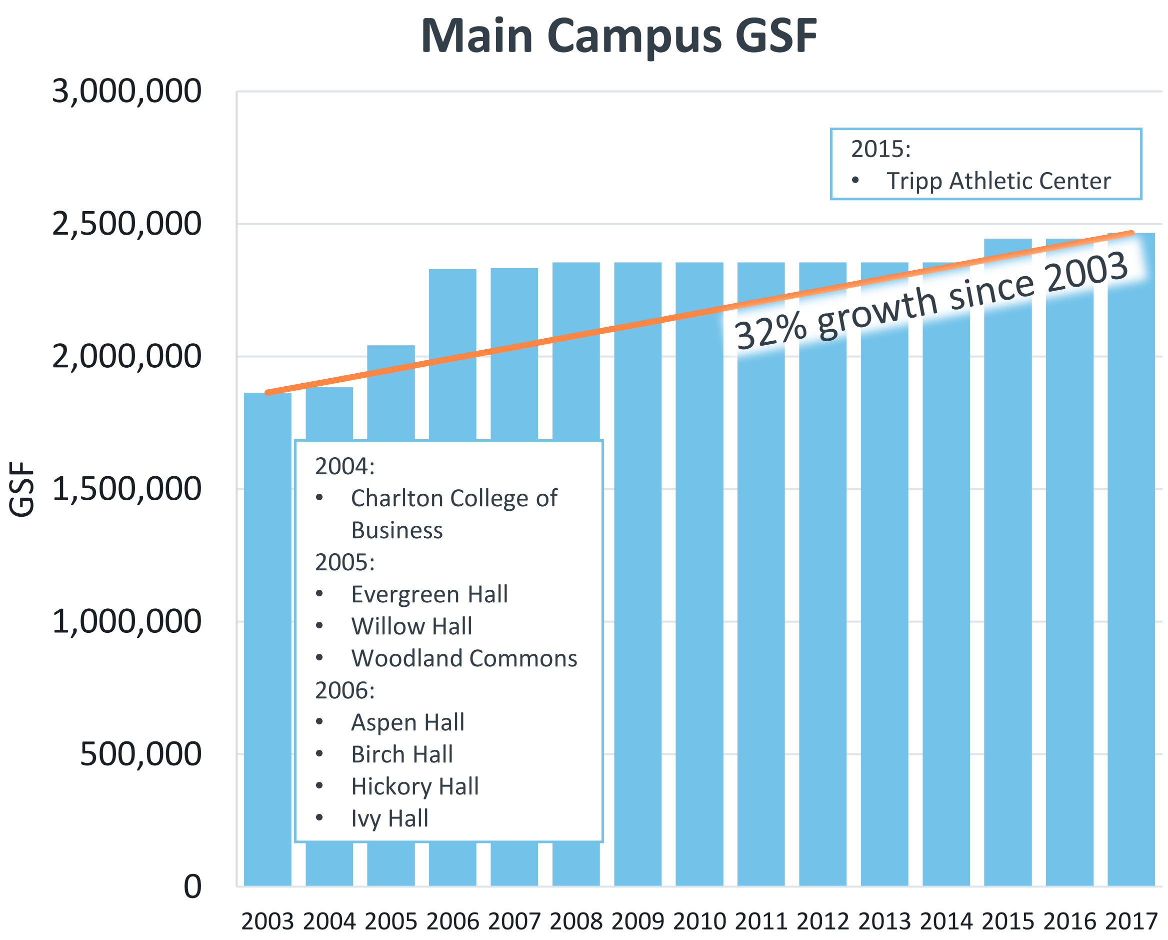
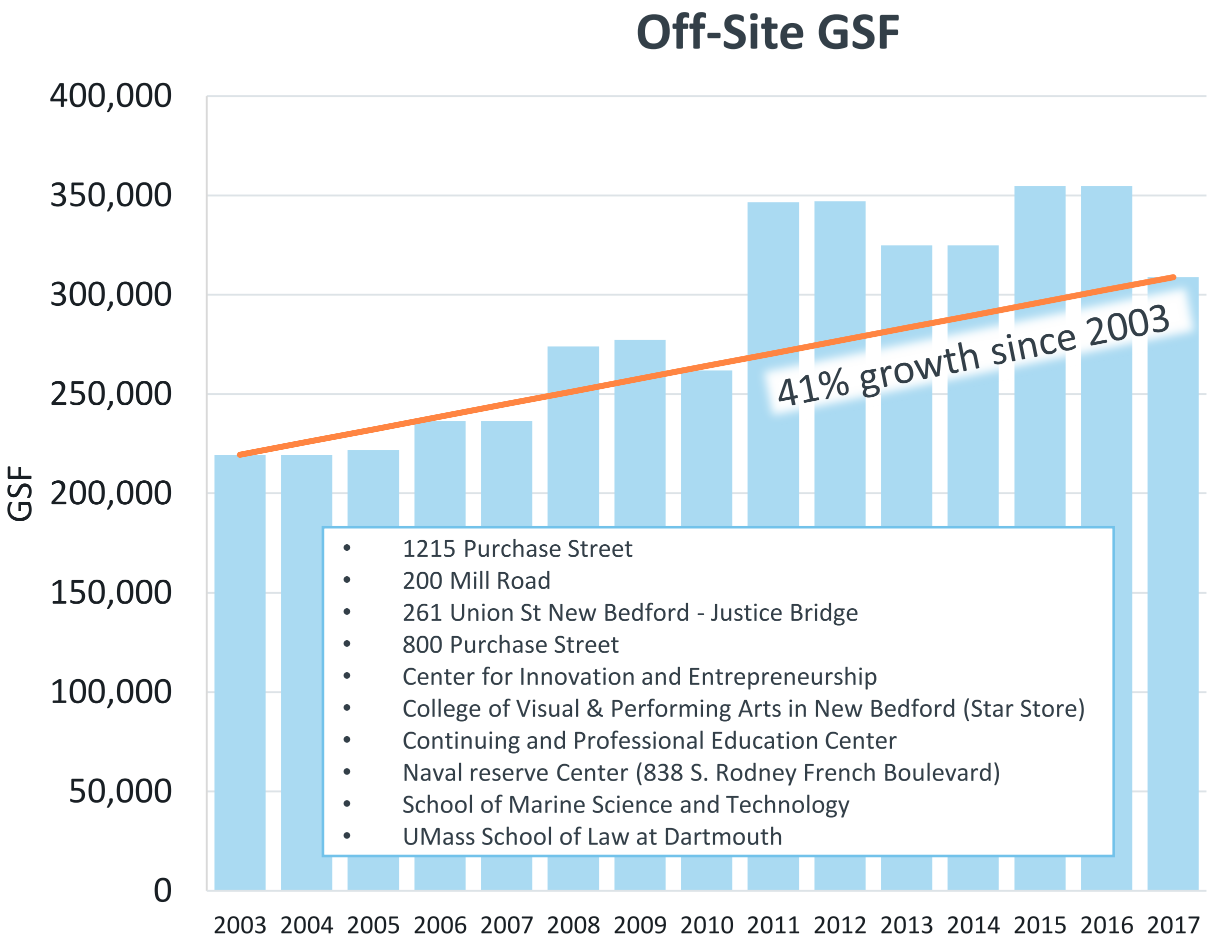
Campus GSF Growing Over Time



Campus Grows Faster at Off-Site Facilities

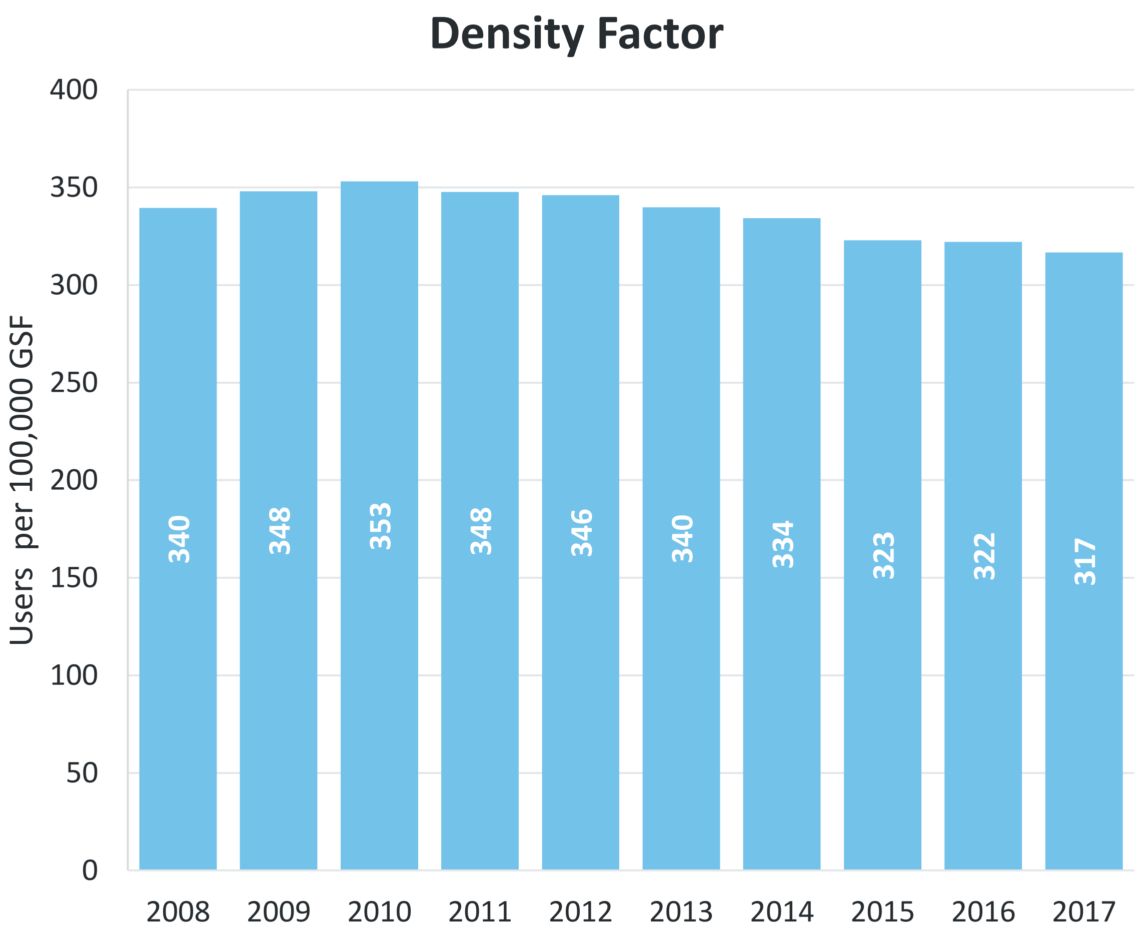
Off-site space out-grows main campus by 9% historically

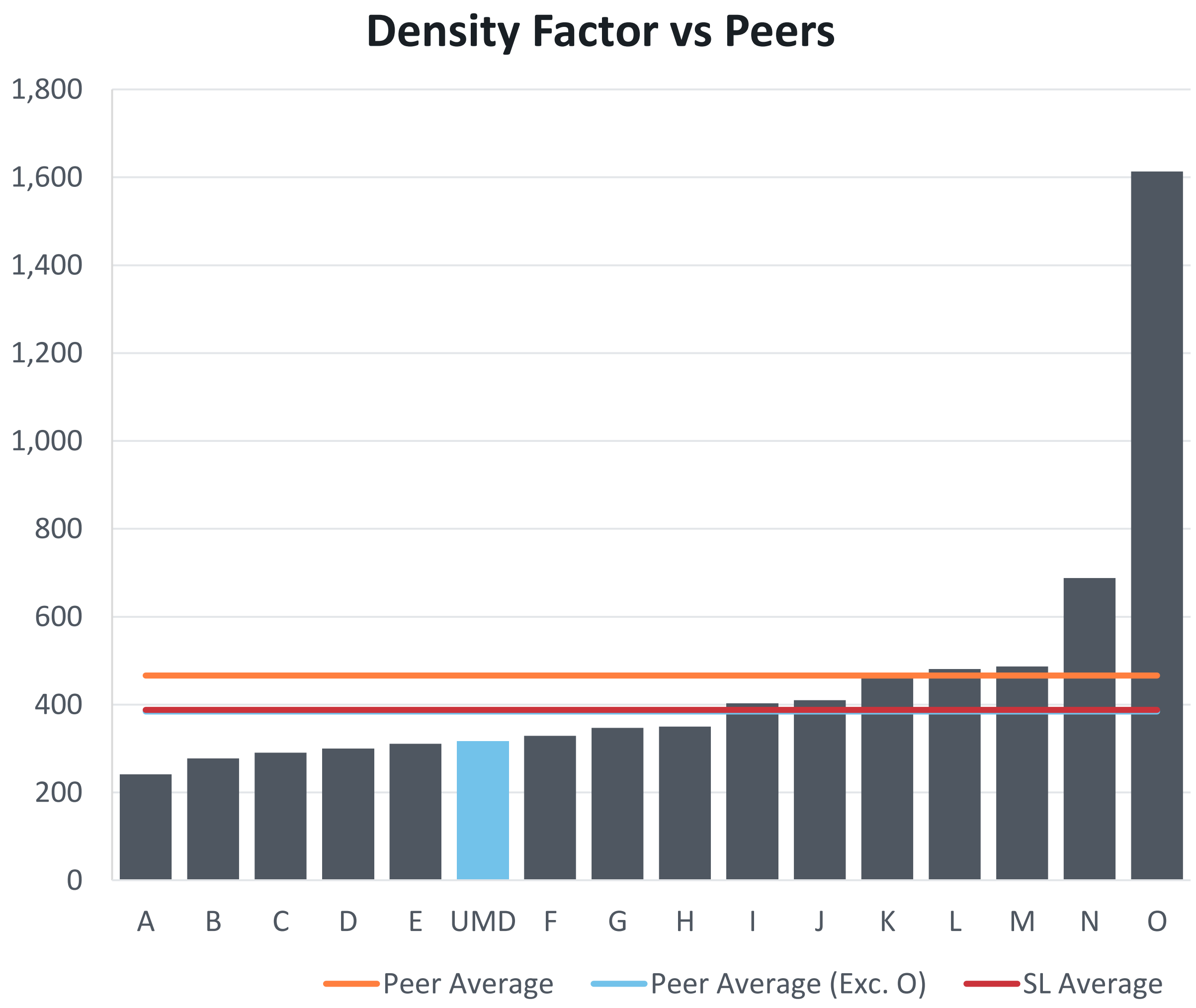




GSF Growth Leads to Less Dense Campus

UMass Dartmouth is less busy than peers





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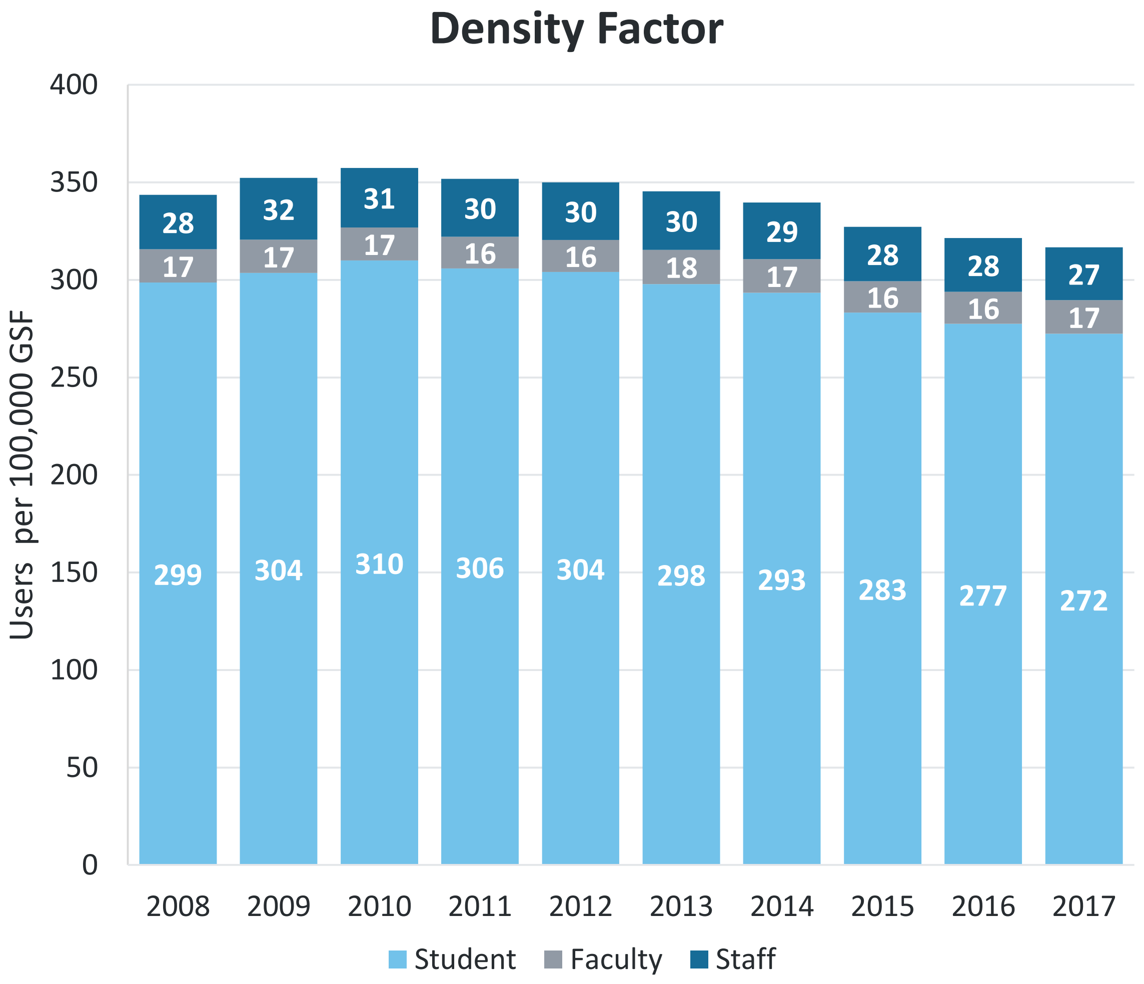

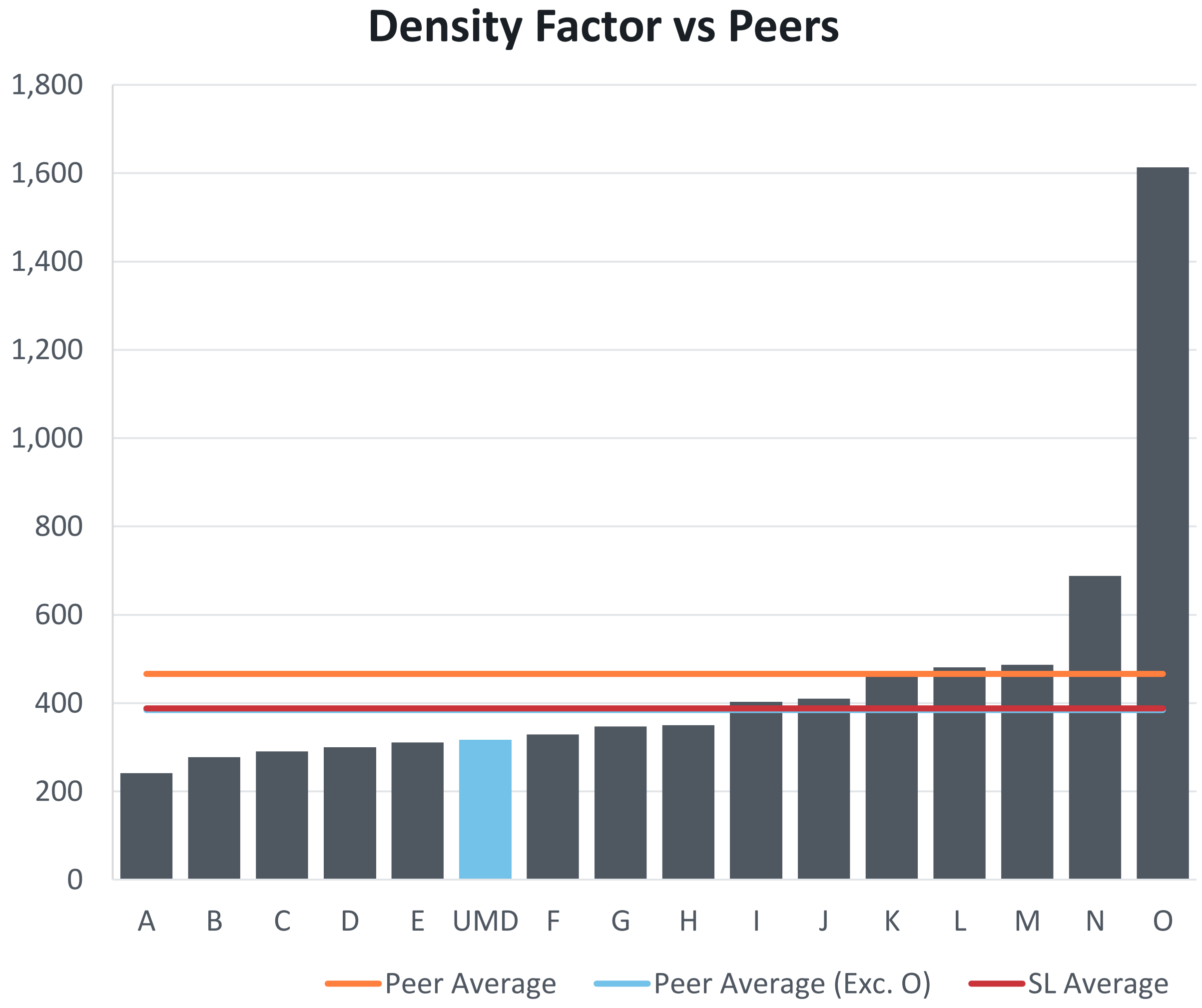

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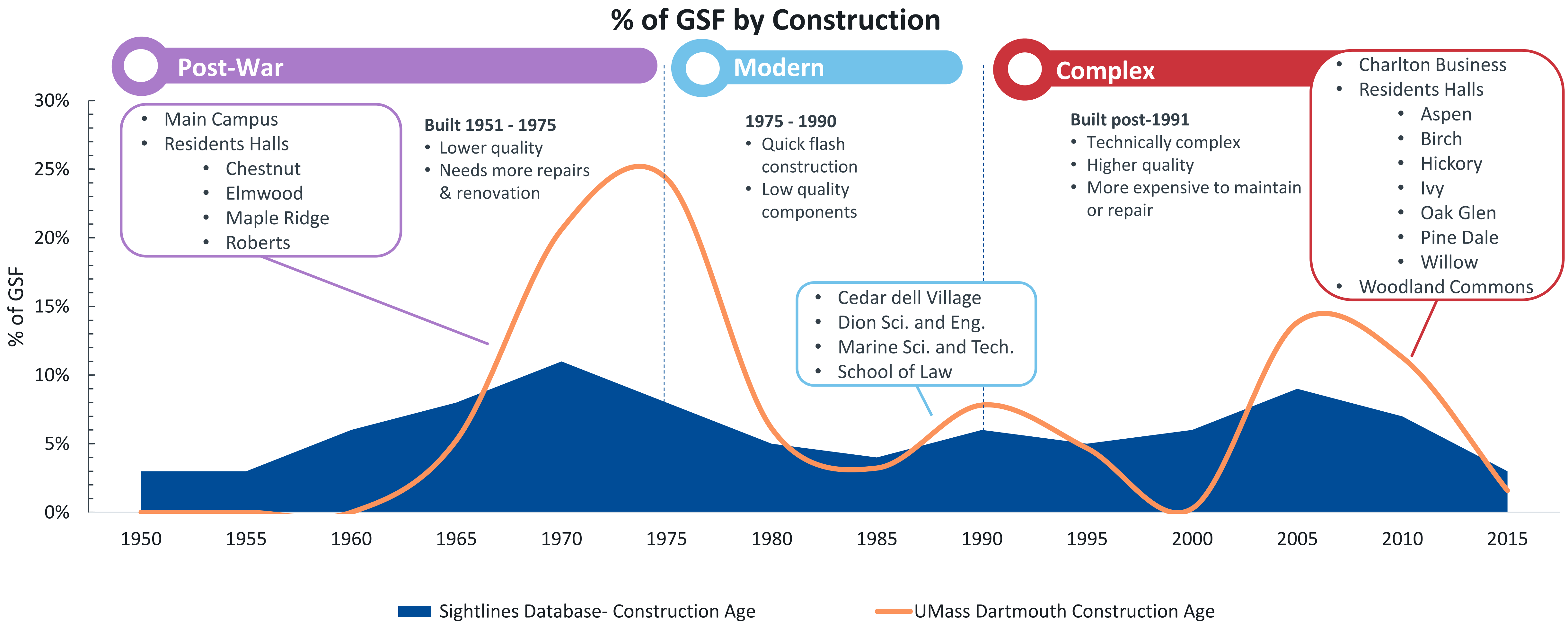
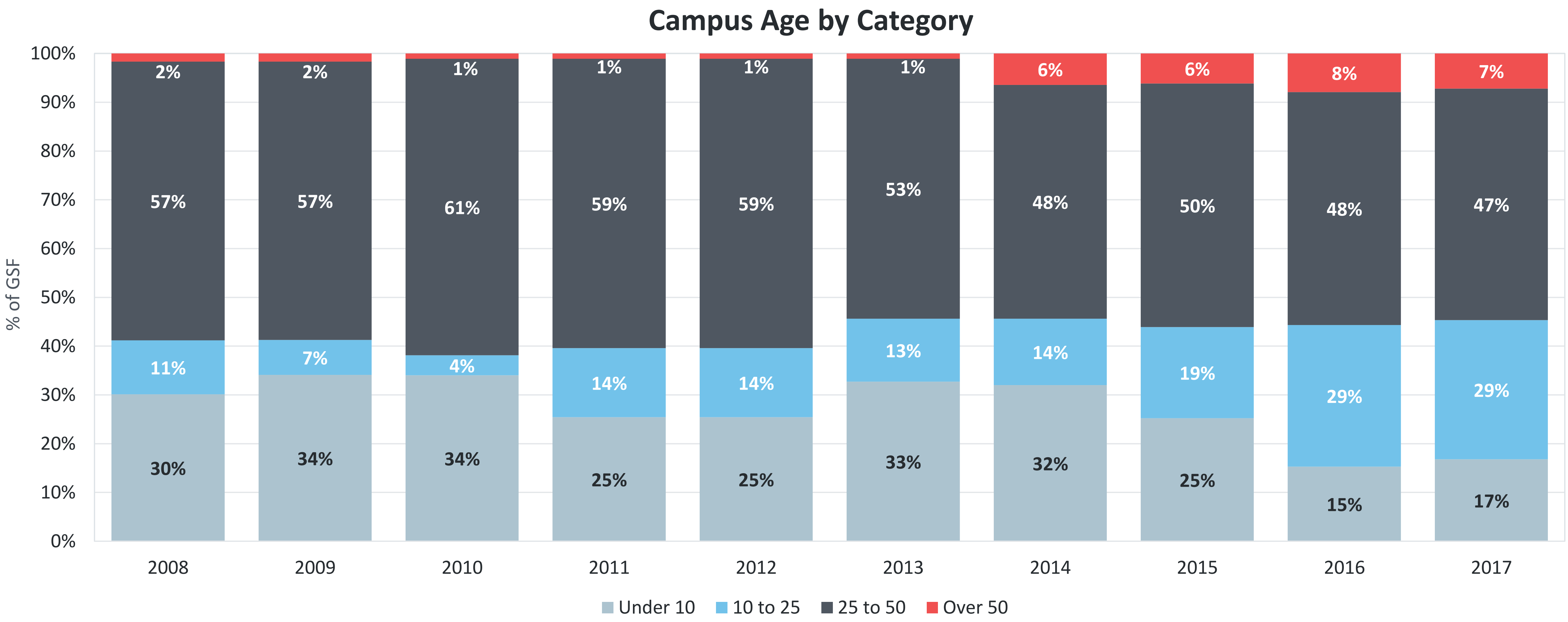
Putting Your Campus Building Age In Context



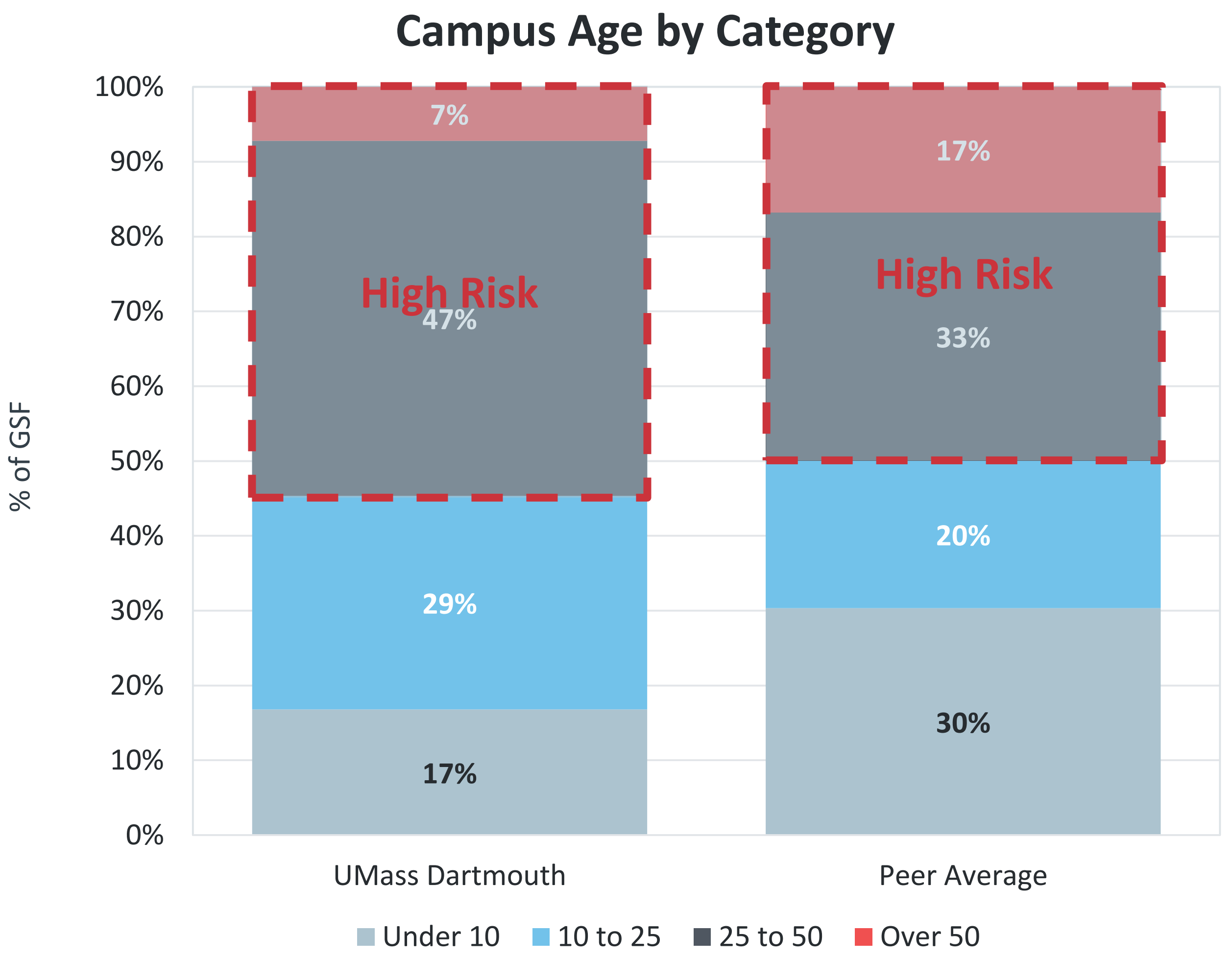
Campus Continues to Age

Percentage of campus over 25 years old consistent over time



Peer Campus' Age More Evenly Distributed

Balanced profile amortizes risk



Buildings Over 50

Life cycles of major building components are past due. Failures are possible. Core modernization cycles are missed.

Highest risk

Buildings 25 to 50

Major envelope and mechanical life cycles come due. Functional obsolescence prevalent.

Higher Risk

Buildings 10 to 25

Short life-cycle needs; primarily space renewal.

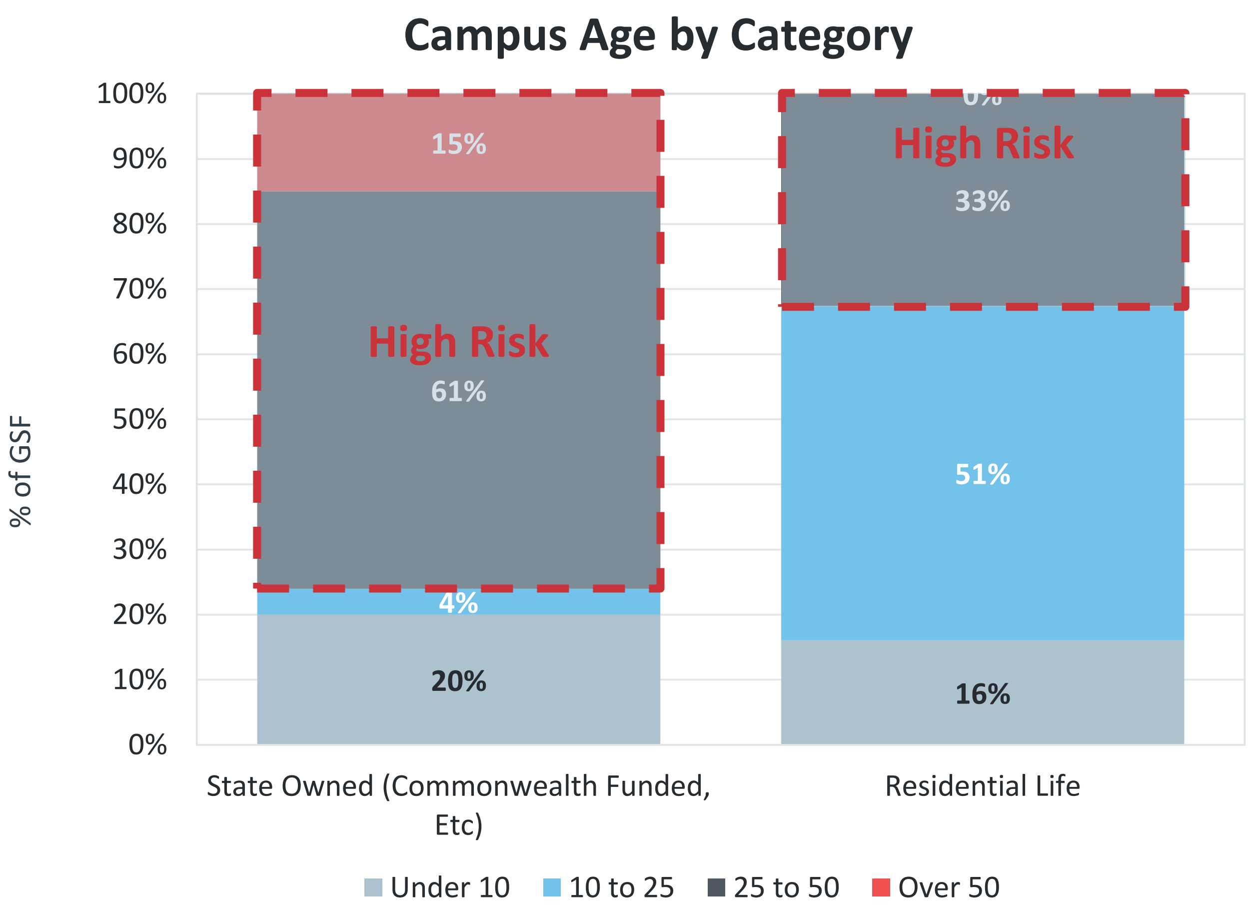
Medium Risk

Buildings Under 10

Little work. "Honeymoon" period.

Low Risk

Commonwealth Facilities are Highest Risk Buildings



Average Weighted Age: 36.2 | 22.3

Buildings Over 50

Life cycles of major building components are past due. Failures are possible. Core modernization cycles are missed.

Highest risk

Buildings 25 to 50

Major envelope and mechanical life cycles come due. Functional obsolescence prevalent.

Higher Risk

Buildings 10 to 25

Short life-cycle needs; primarily space renewal.

Medium Risk

Buildings Under 10

Little work. “Honeymoon” period.

Low Risk

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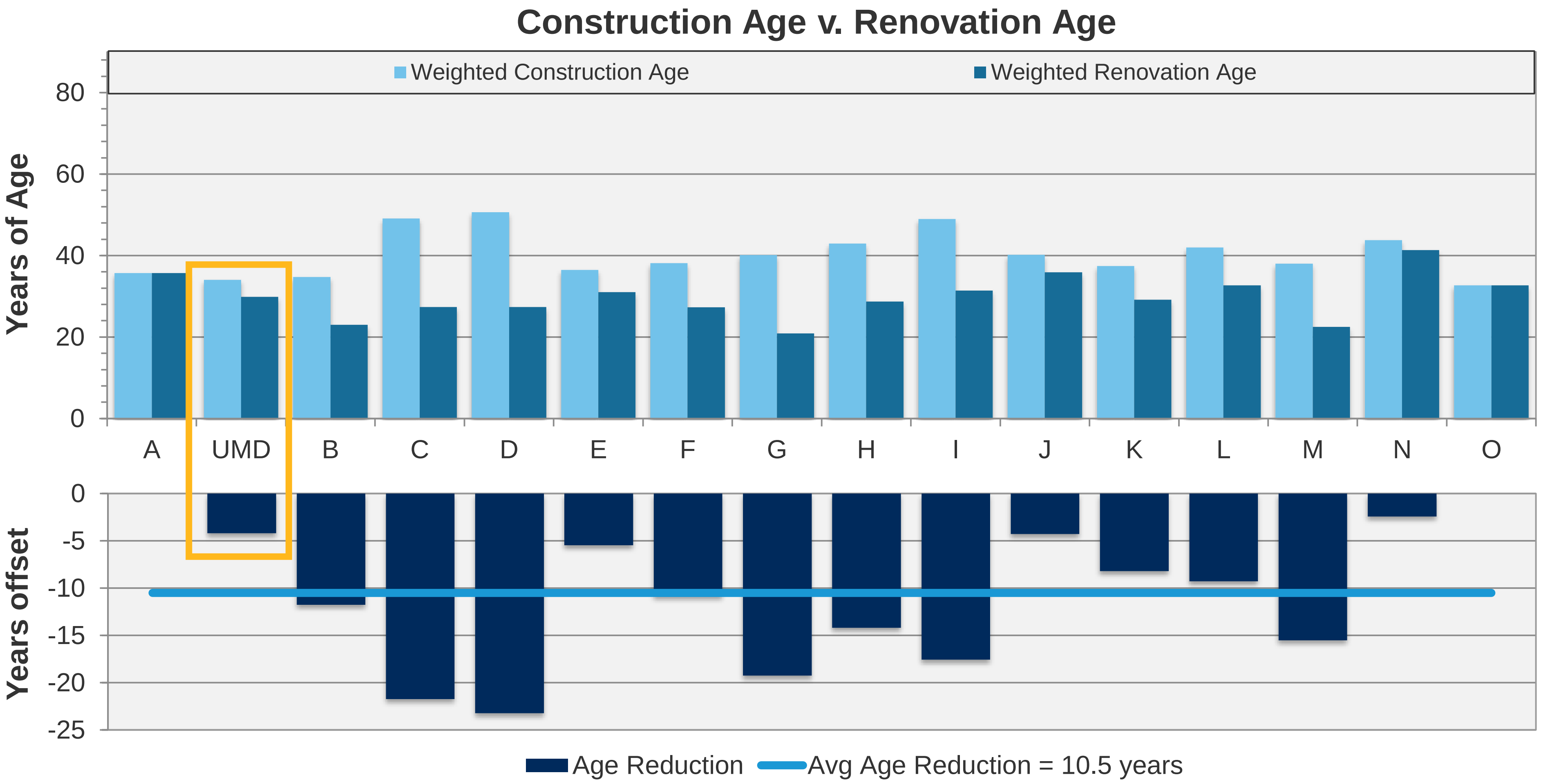
Renovations Aid in Resetting the Clock

UMass Dartmouth renovated less space than peers



- UMass Dartmouth offsets campus age by 4 years through renovations.
- UMass Dartmouth has completed less lifecycle resetting renovations than peer institutions
- UMass Dartmouth's strategy is to focus more on new construction than renovations
- Renovations help older spaces operate younger than their true construction age.

Major Renovations:
- Cedar dell Village: 2008/2009
- Charlton College of Business: 2017 (with addition)
- Fitness Center: 2013
- Library: 2013

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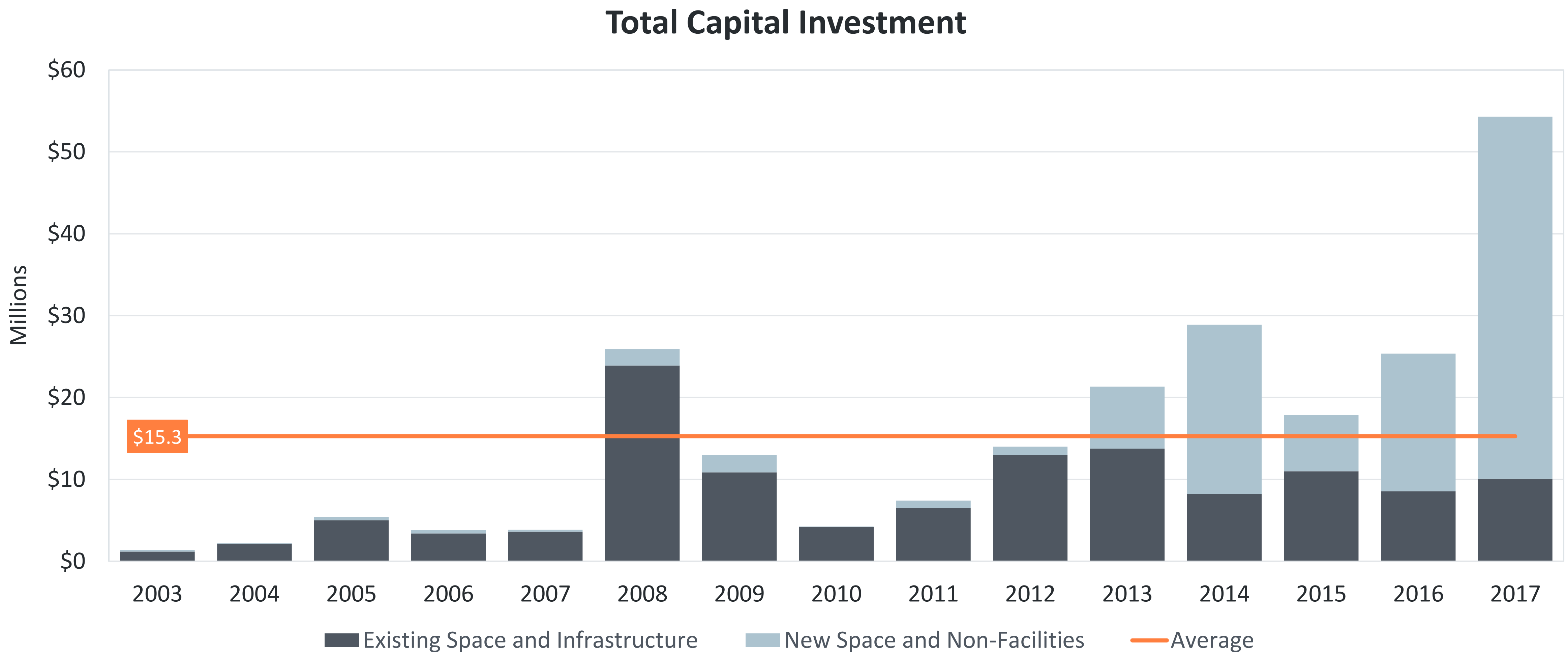
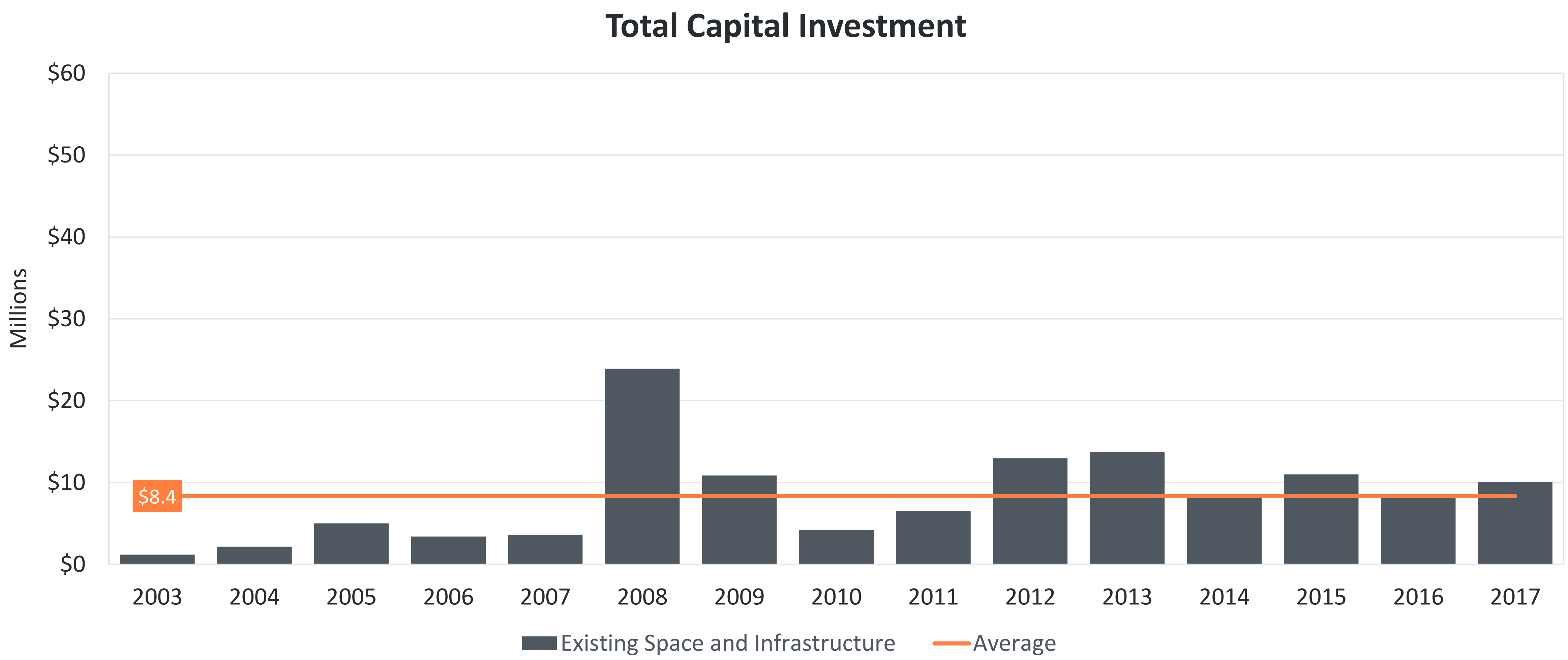
Capital Investment Profile

Capital Investment Focuses on New Space In Recent Years

Total investment growing over time



Investment Into Existing Space Averages $8.4M



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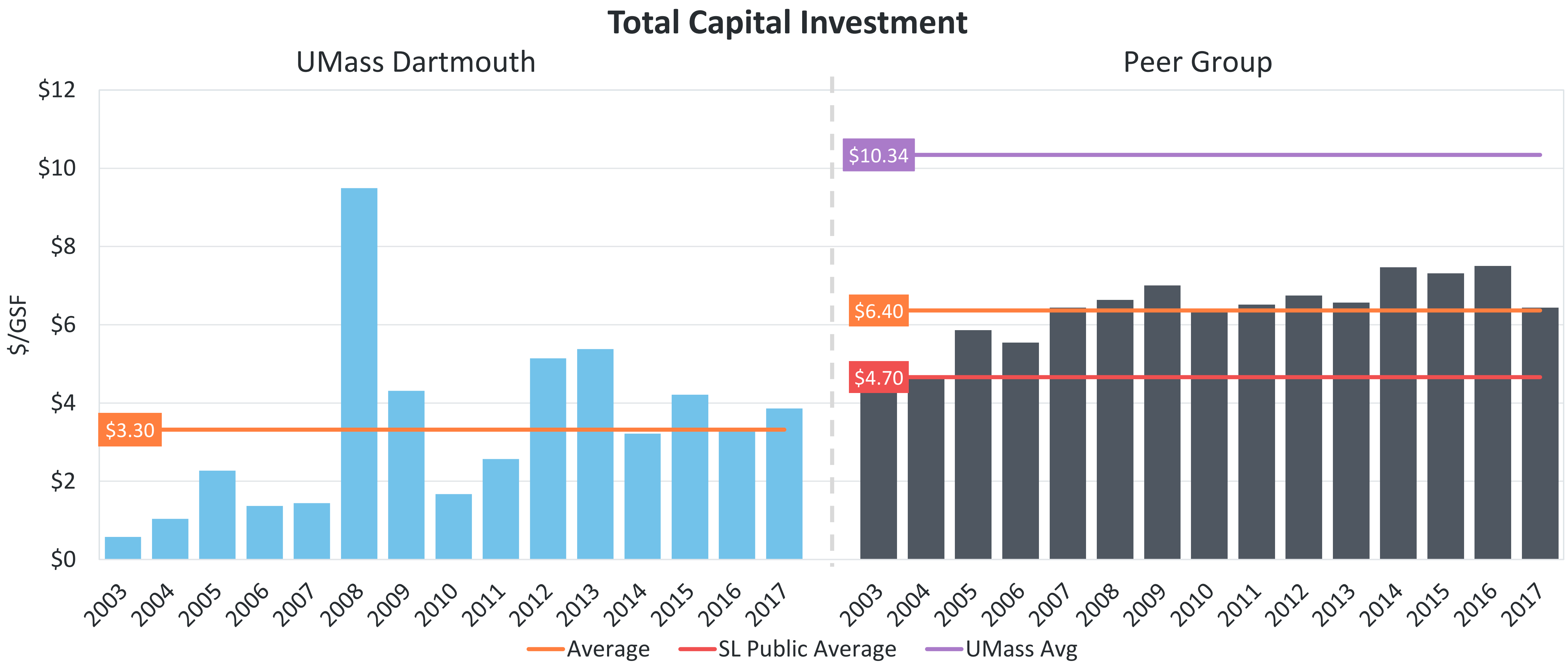
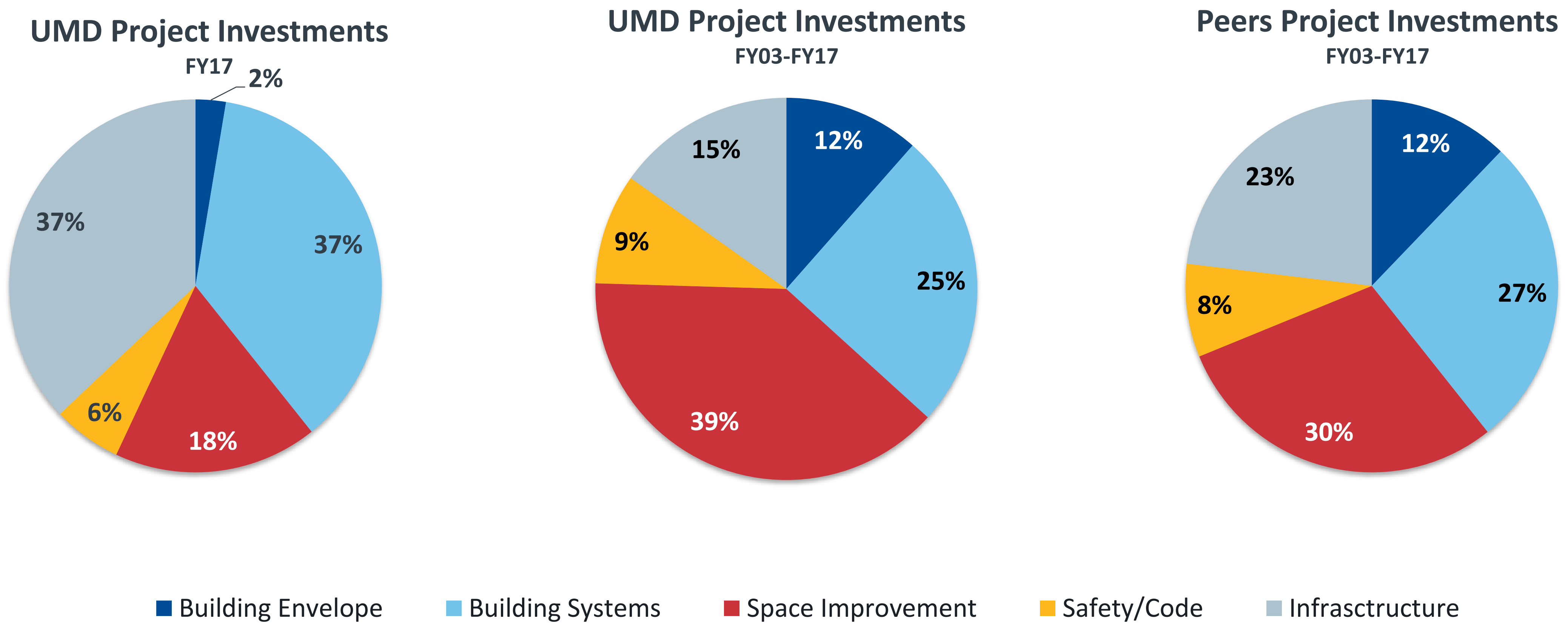
UMass Dartmouth Investing Less than Peers

An additional $8.4M needed to reach the peer average



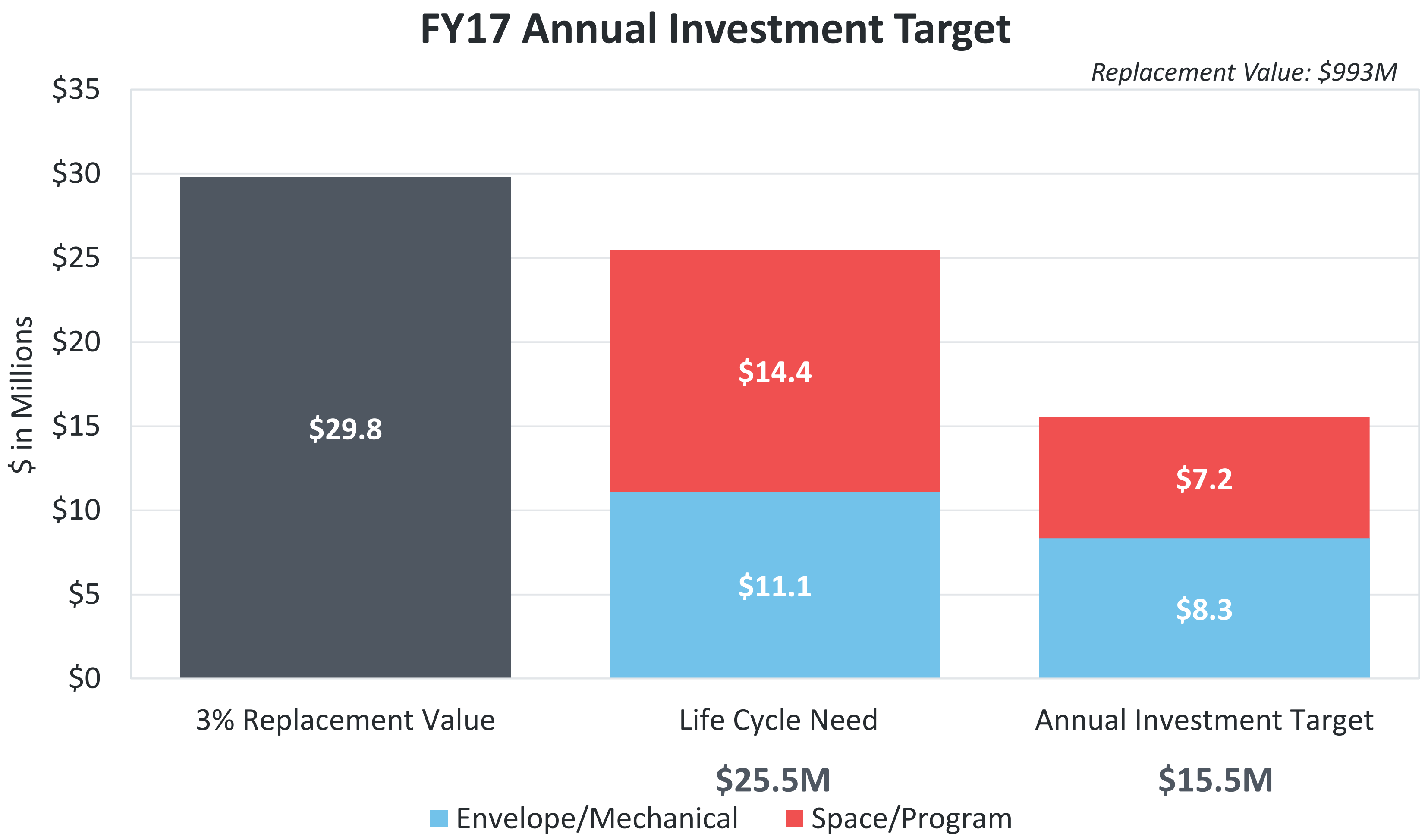
Focusing on Building Systems in FY2017

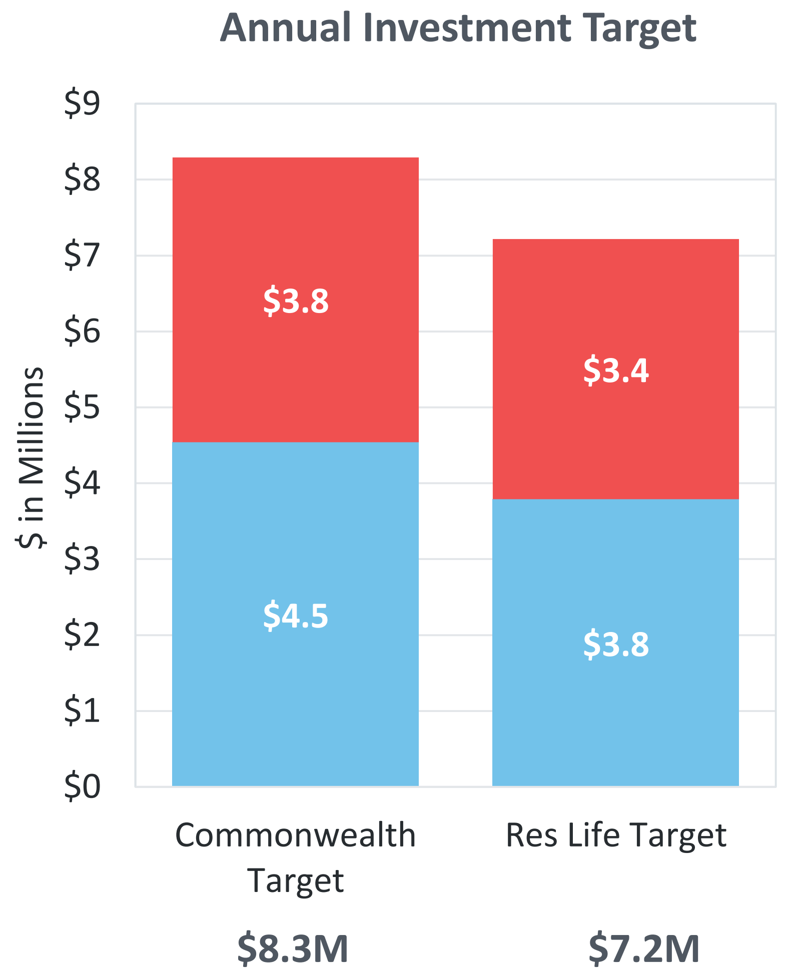
MEP investments reduce risk on campus



Defining An Annual Investment Target

What investment should UMass Dartmouth be making to keep steady state?





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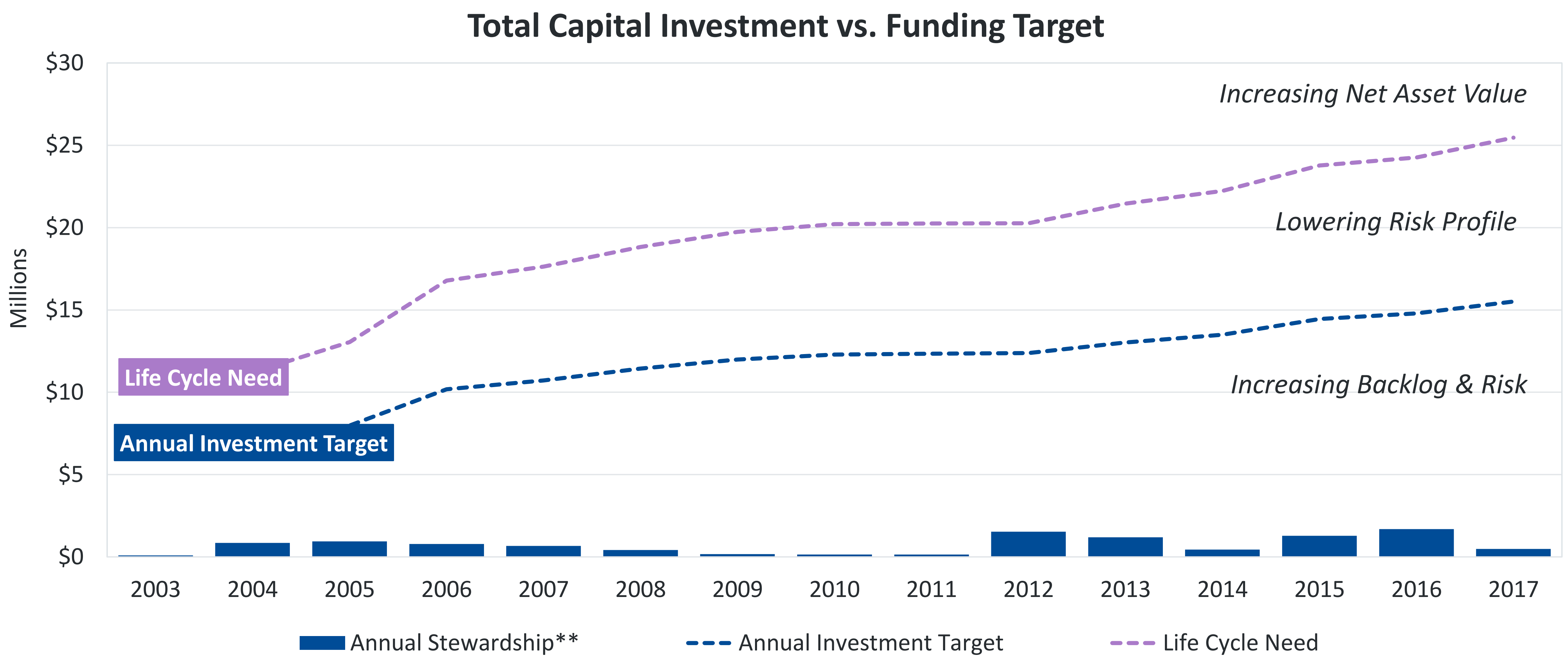
Lack of Recurring Capital Limits Stewardship of Campus



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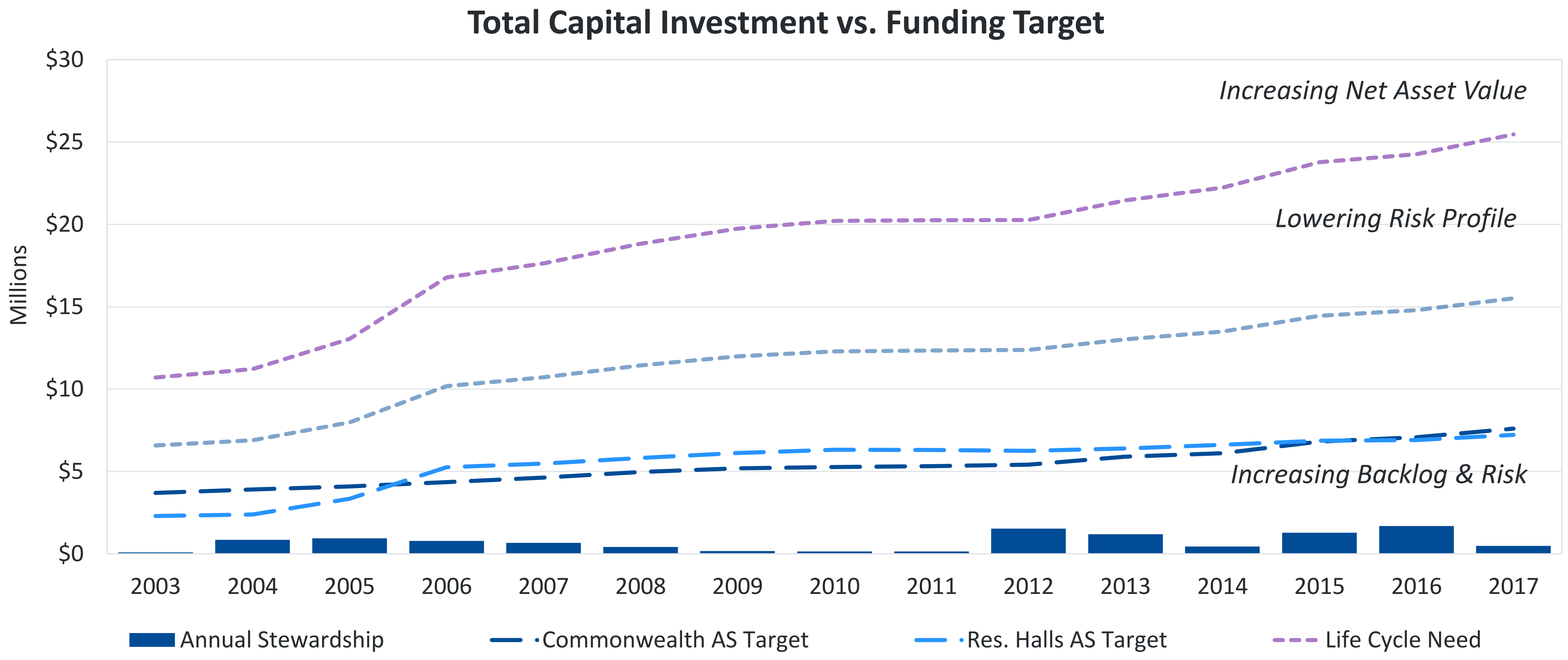
**Excludes Infrastructure spending*
*** Annual Stewardship is capital dollars funded locally by the university as well as planned maintenance funding*

Dividing Annual Stewardship Target by Funding

Investments do not meet target levels

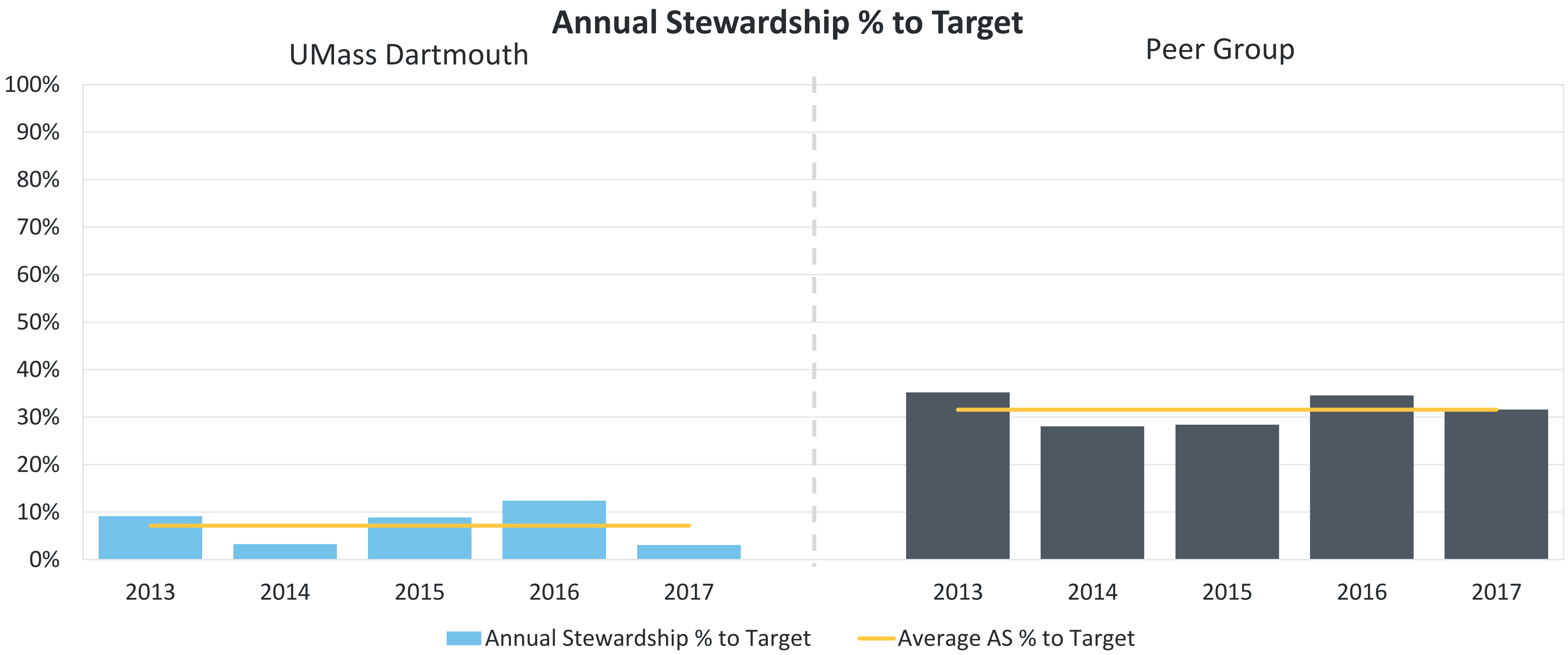


**Excludes Infrastructure spending*

*** Annual Stewardship is capital dollars funded locally by the university as well as planned maintenance funding*

UMass Annual Stewardship Weaker than Peers

Increasing recurring capital would allow more planned action against deferred maintenance



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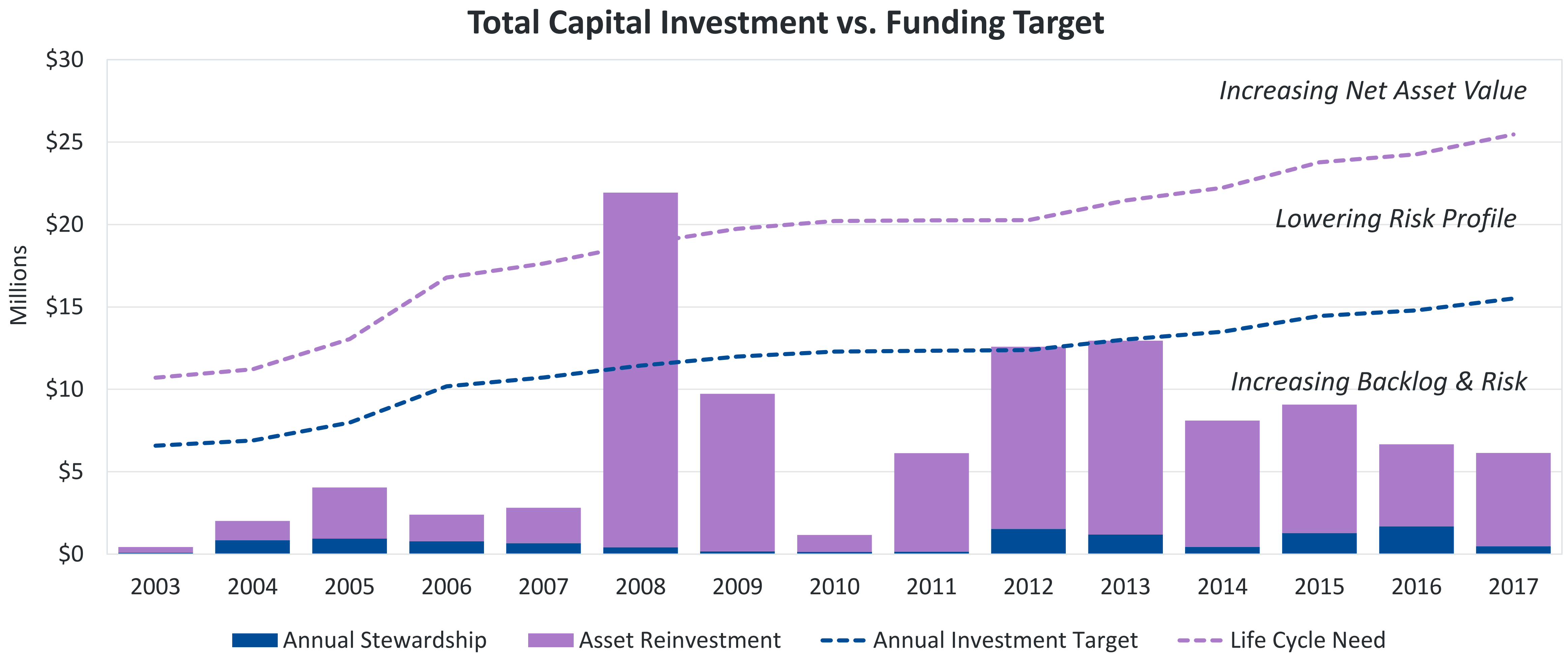
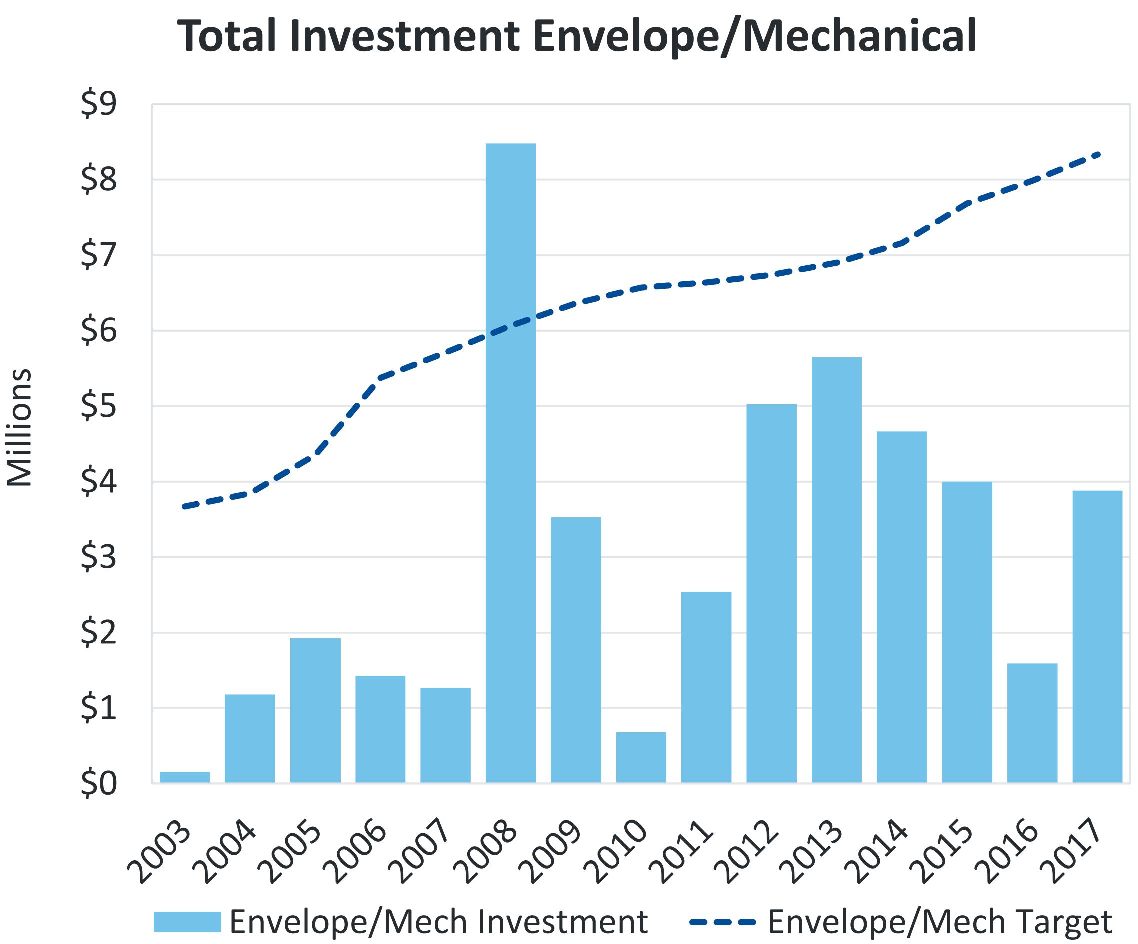
Increases In Capital Investment Reduces Deferral

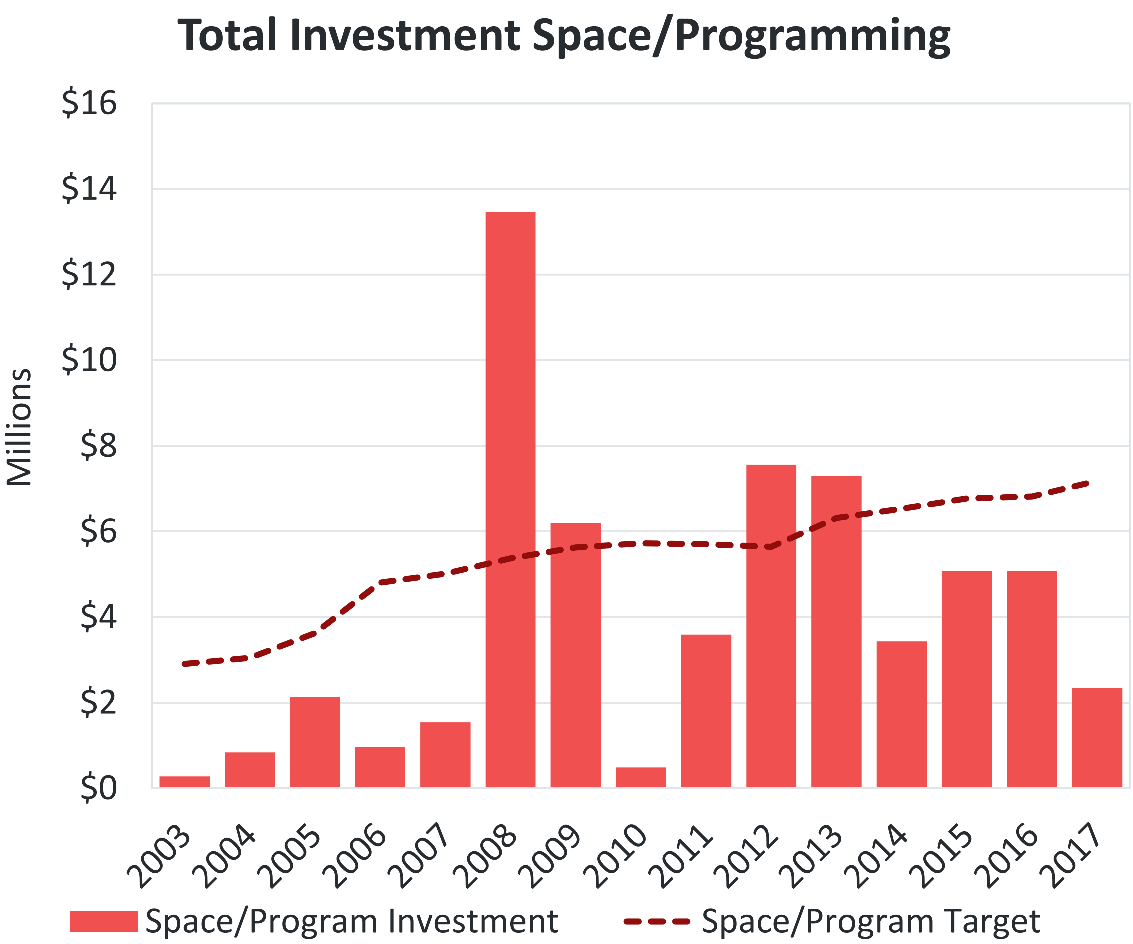


**Excludes Infrastructure spending*
*** Annual Stewardship is capital dollars funded locally by the university as well as planned maintenance funding*

Investment Type Misaligned to Targets

Envelope/Mechanical spending below target consistently





Note: Chart excludes investment into grounds and utility infrastructure

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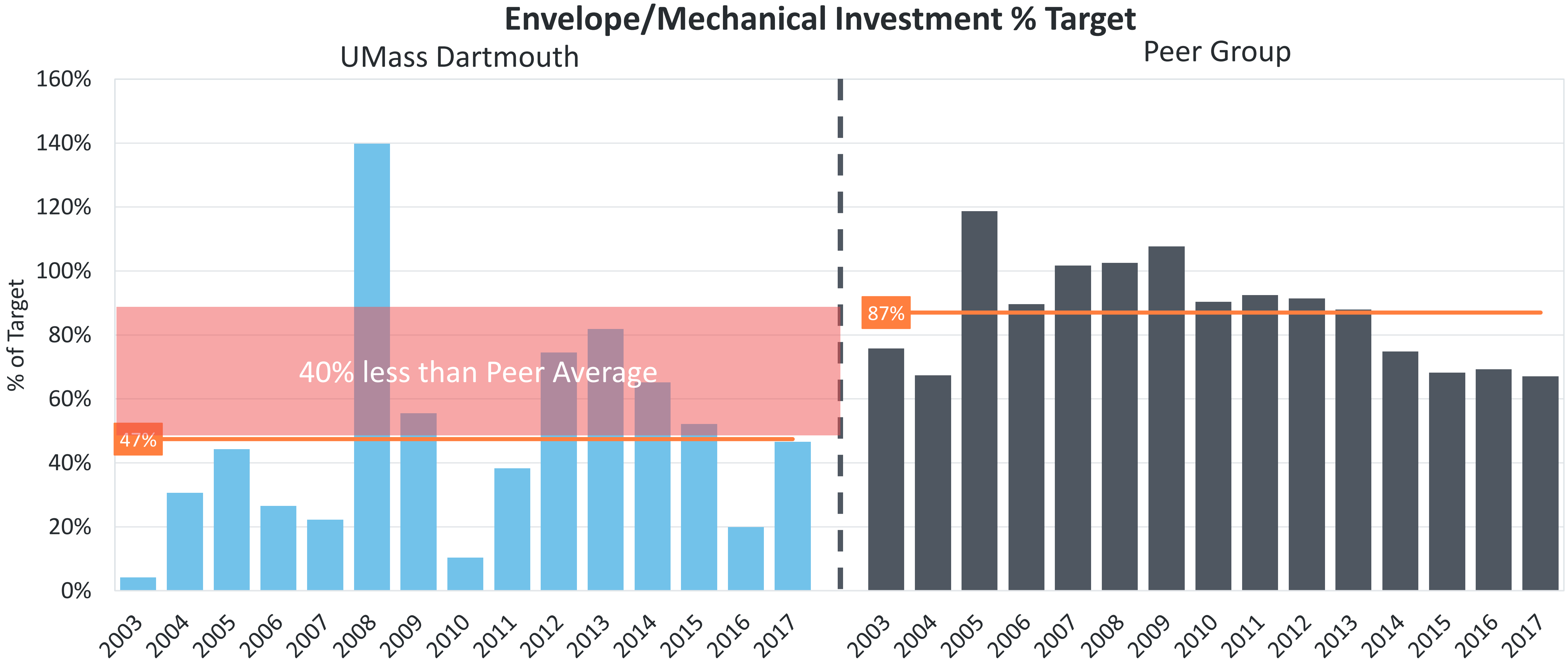
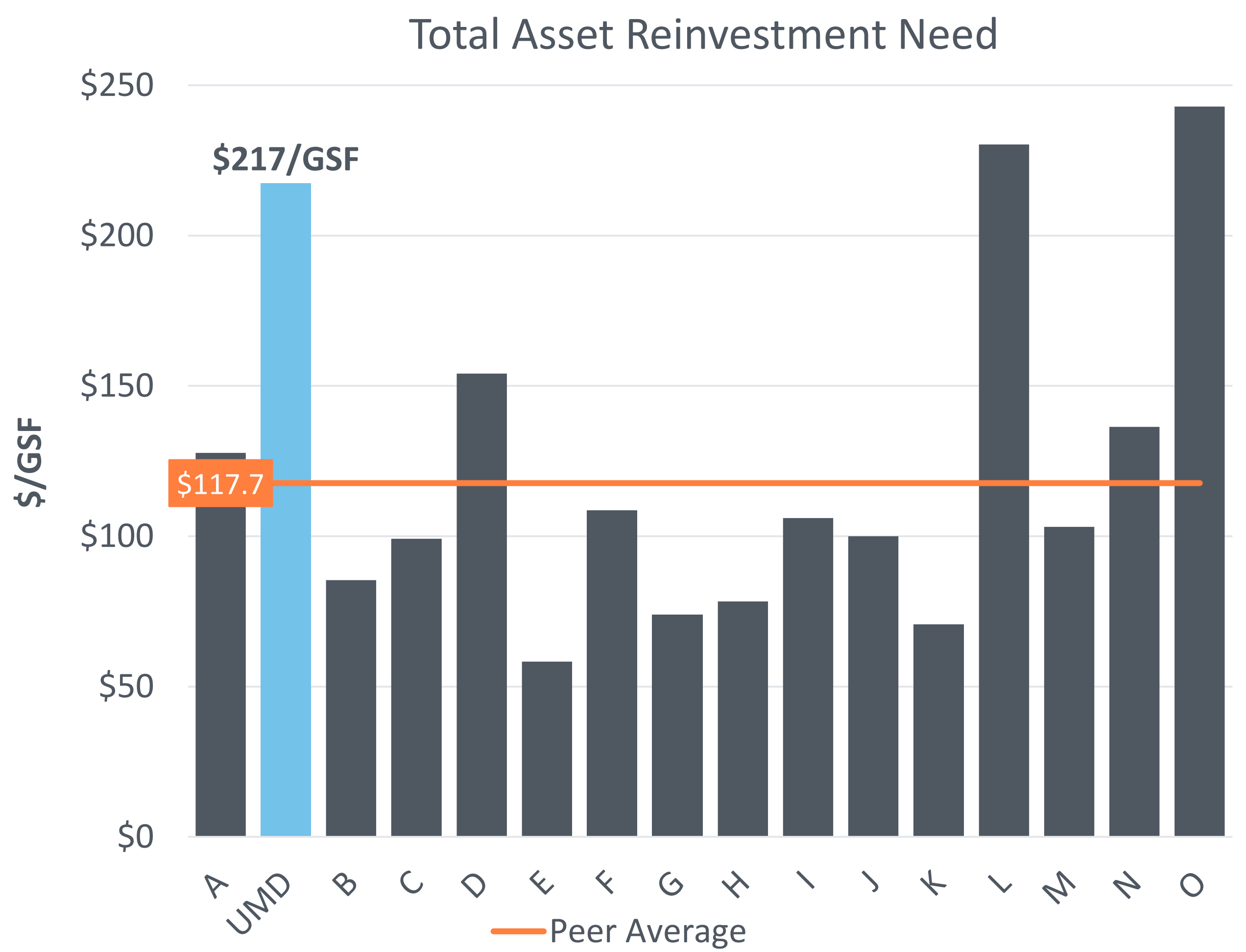
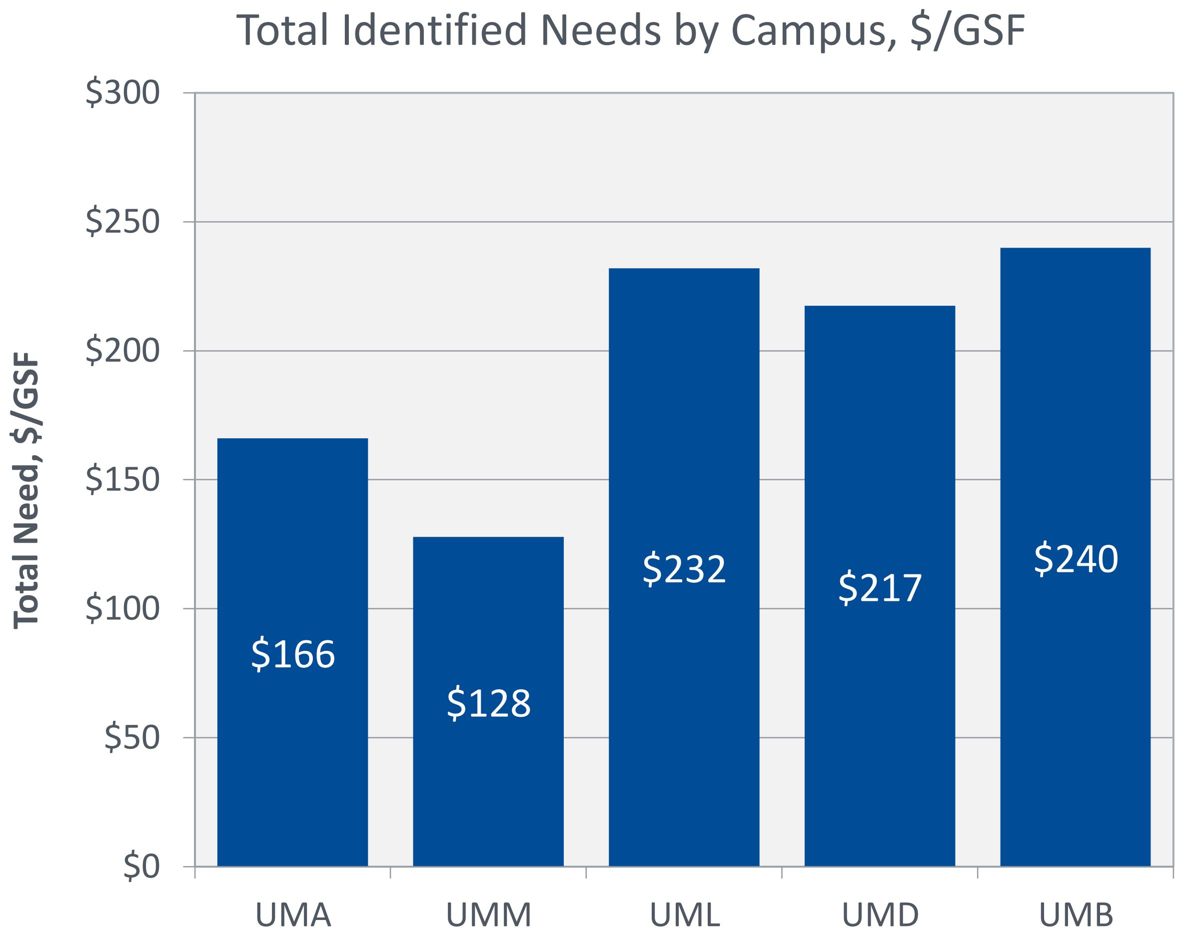
Investment Type Misaligned to Targets

Envelope/Mechanical spending below peers consistently



Asset Reinvestment Backlog Higher than Peers





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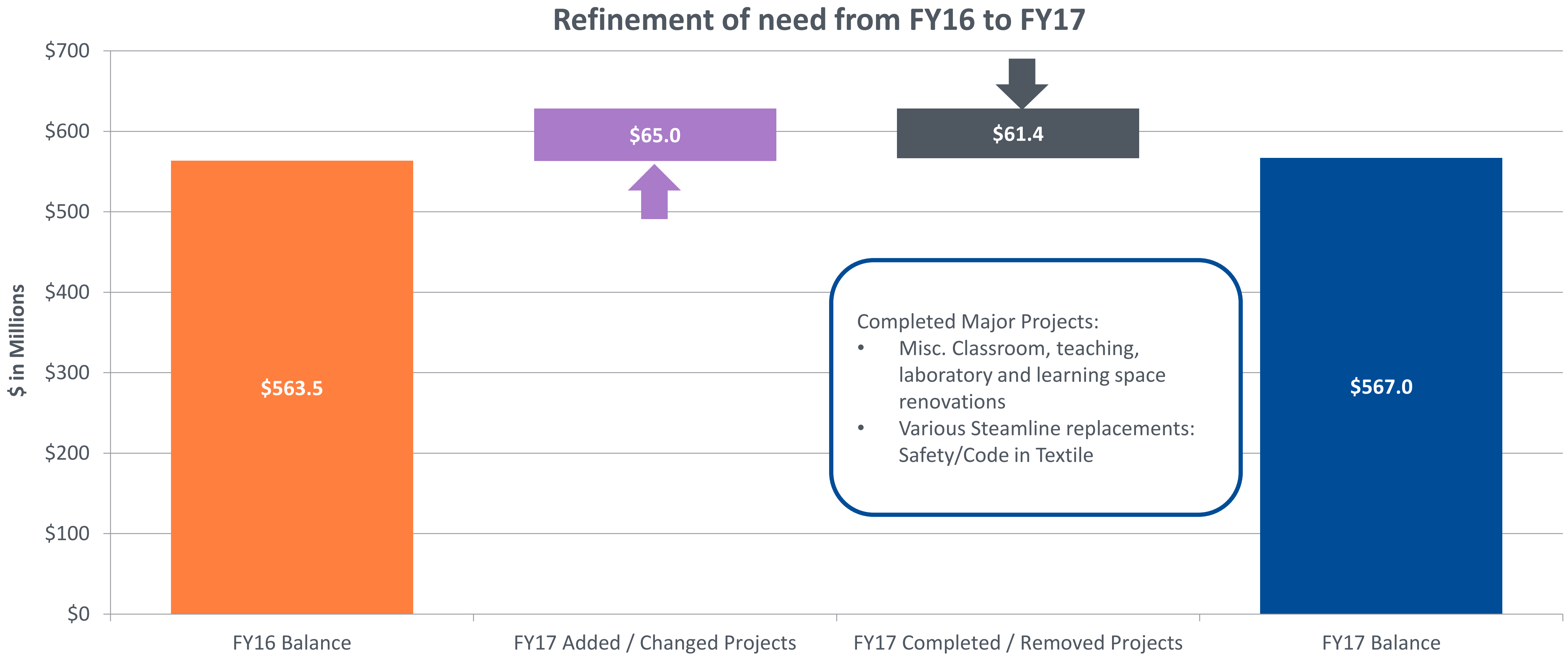
Building Portfolio Analysis

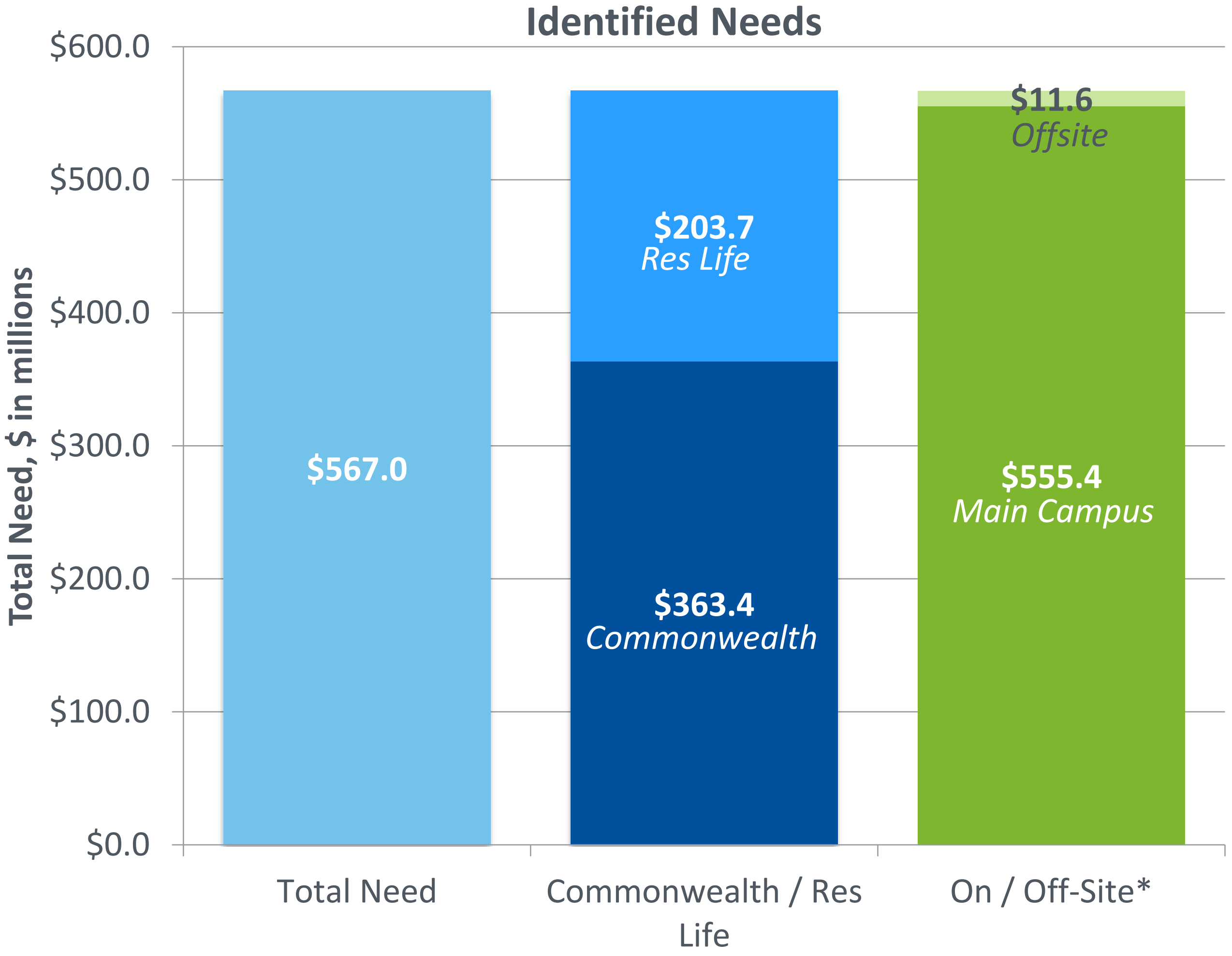
Overall BPS Update from FY16 to FY17

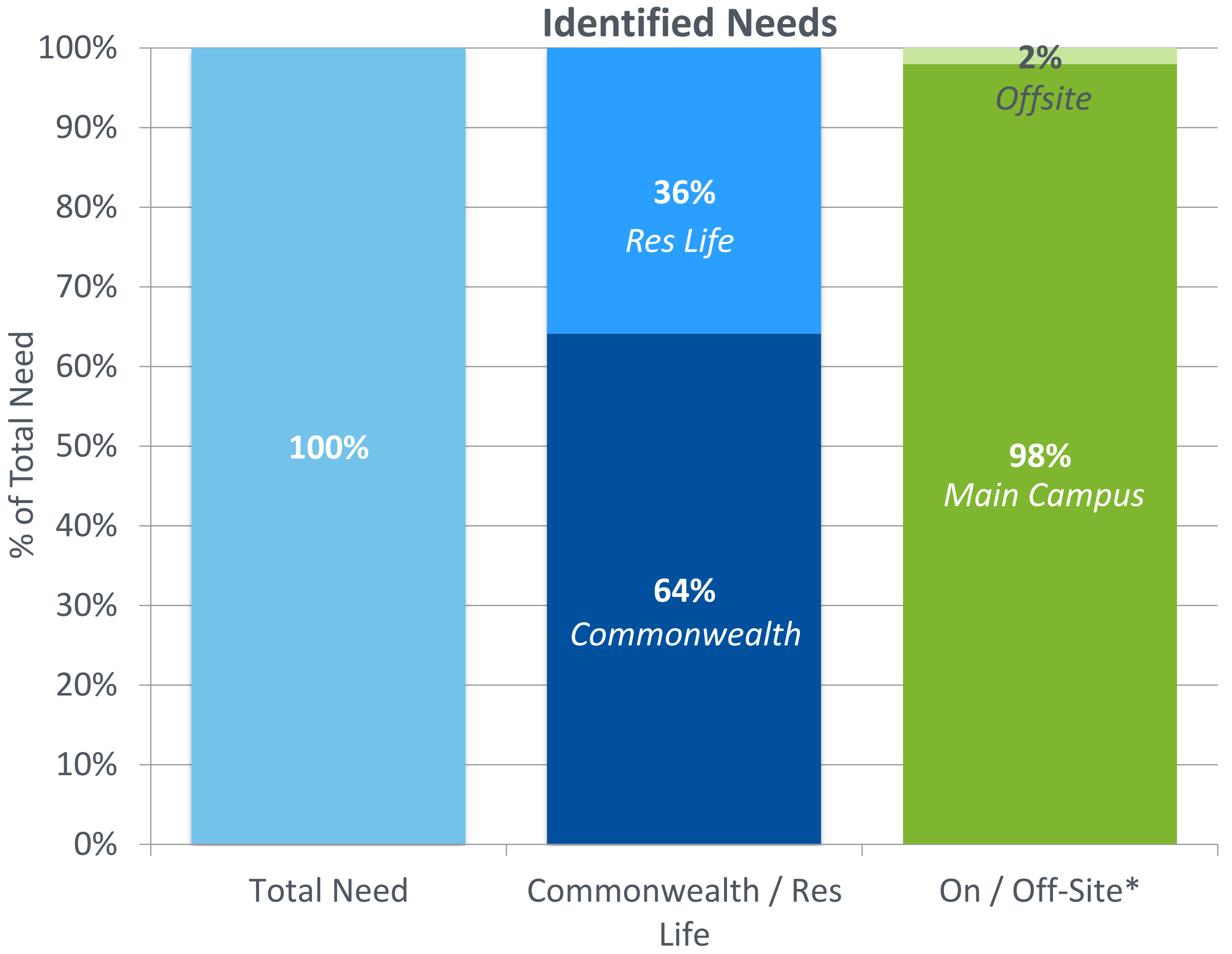
Continued assessment of campus needs and conditions increases data accuracy



Identified Needs by Funding Group and Location

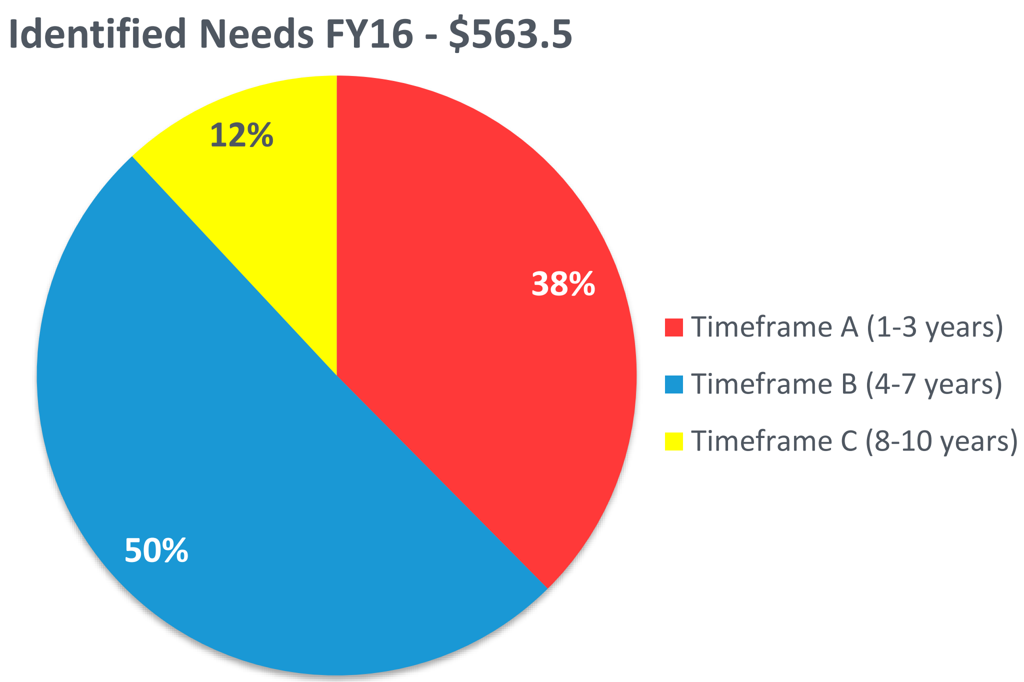
Most needs fall within Commonwealth funded space on the main campus

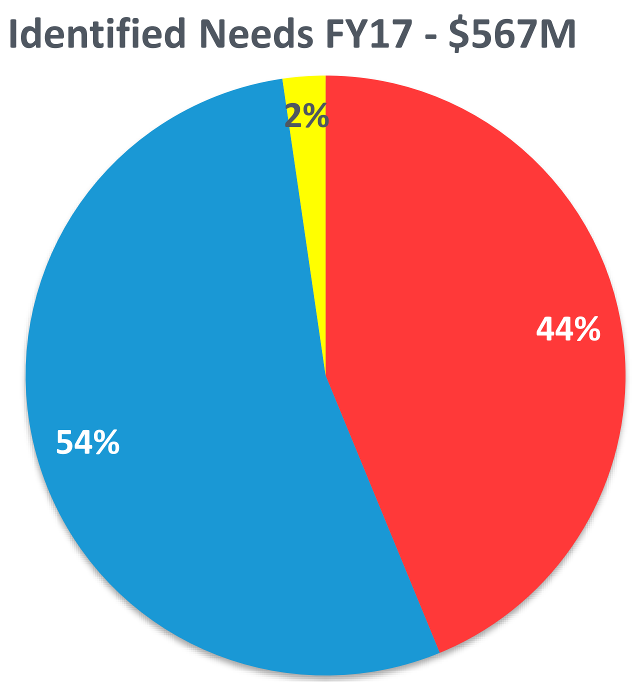




Off-Site Facilities: 200 Mill Road, 261 Union St New Bedford - Justice Bridge, 800 Purchase Street, Center for Innovation and Entrepreneurship, College of Visual & Performing Arts in New Bedford, School of Marine Science and Technology, UMass School of Law at Dartmouth

Need Becomes Higher Priority from FY16 to FY17





Timeframes

- **A Timeframe**: Projects due or coming due within the next one to three years
- **B Timeframe**: Projects coming due within the next four to seven years
- **C Timeframe:** Projects coming due within the next eight to ten years. Outside of ten years is considered "X" timeframe and outside of the scope of work for Building Portfolio Solutions

**Recent BPS experience includes Qualified data through July 2016*

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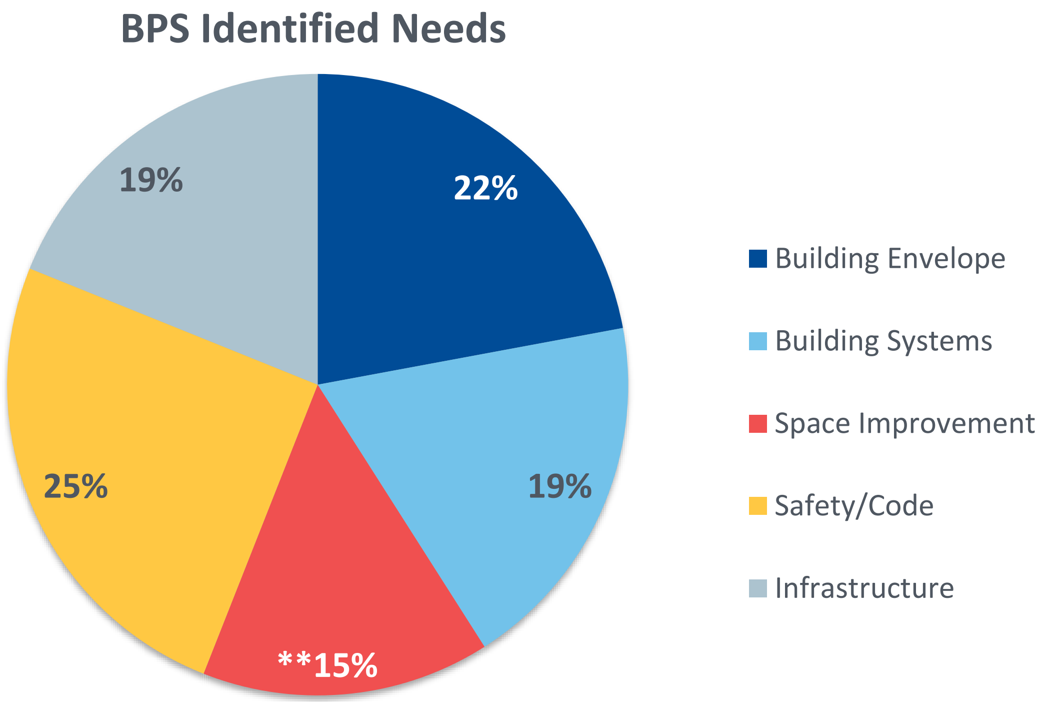
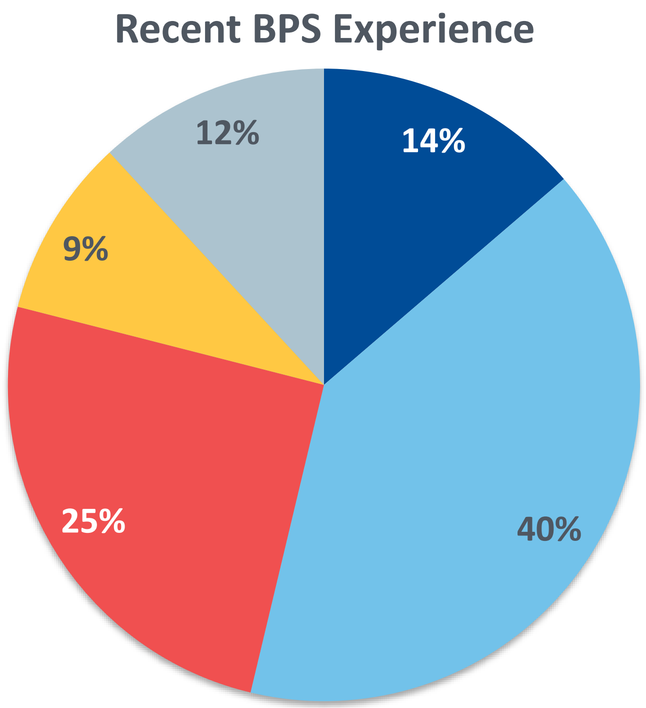
Identified Needs by System

Timeframes A, B, & C only – excluding new construction





Major Safety Code Projects:

- Campus Wide: Security Installation Project: $7M
- Campus Wide: ADA Renovations Immediate Needs: $2.2M
- Tripp Athletic Center: addition of sprinklers: $1.7M
- Tripp Athletic Center: upgrades to fire alarm reporting system: $1.5M
- Center for Visual and Performing Arts -Group VI: $1.2M

- **Building Envelope**: Exterior shell components that are exposed to the outdoors
- **Building Systems**: Mechanical equipment and components
- **Infrastructure**: Includes grounds and utility needs
- **Space Improvement**: Interior shell and cosmetic improvements
- **Safety/Code**: Code compliance and accessibility needs

***Additional $22.4M renovation need excluded from "Space Improvement"*

**Recent BPS experience includes Qualified data through July 2016*

Buildings by Portfolio

Administrative
Athletic Center Heating Plant
Chase Road Center
Foster Administration
Public Safety/Steam Plant

Academic
Center for Visual and Performing Arts - Group VI
College of Visual & Performing Arts in New Bedford (Star Store)
Charlton College of Business
Lecture Halls
Main Auditorium
UMass School of Law at Dartmouth

Science Research
Center for Innovation (Formerly ATMC)
Dion
School of Marine Science and Technology (706 Rodney French Blvd.)
Science and Engineering - Group II
Textile
Violette
VRAD (Research)

Freshman Experience
Auditorium Annex
Chestnut Hall
Elmwood Hall
Fitness Center
Liberal Arts- Group 1
Library
MacLean Campus Center
Maple Ridge Hall
Residents' Dining Hall
Roberts Hall
Tripp Athletic Center

Residence Hall/Student Life
Aspen Hall
Birch Hall
Cedar dell Village South A-1 – A-7
Cedar dell Village West 8 - 14
Evergreen Hall
Health Services Modular Unit
Hickory Hall
Ivy Hall
Oak Glen Hall
Pine Dale Hall
Woodland Commons
Willow Hall

Portfolio Structure

- **A, B, C Timeframe Need** — $897.9M
  - **Grounds and Infrastructure** — $67.4M
  - **New Construction** — $330.9M
  - **Building Needs** — $499.6M, $180.1/GSF
    - **Academic** — $36.7M, $132.5/GSF
    - **Administrative** — $16.0M, $207/GSF
    - **Campus Projects** — $17.6M
    - **Freshman Experience** — $171.0M, $182.8/GSF
    - **Residence Hall / Student Life** — $124.5M, $143.1/GSF
    - **Science Research** — $132.9M, $279.9/GSF

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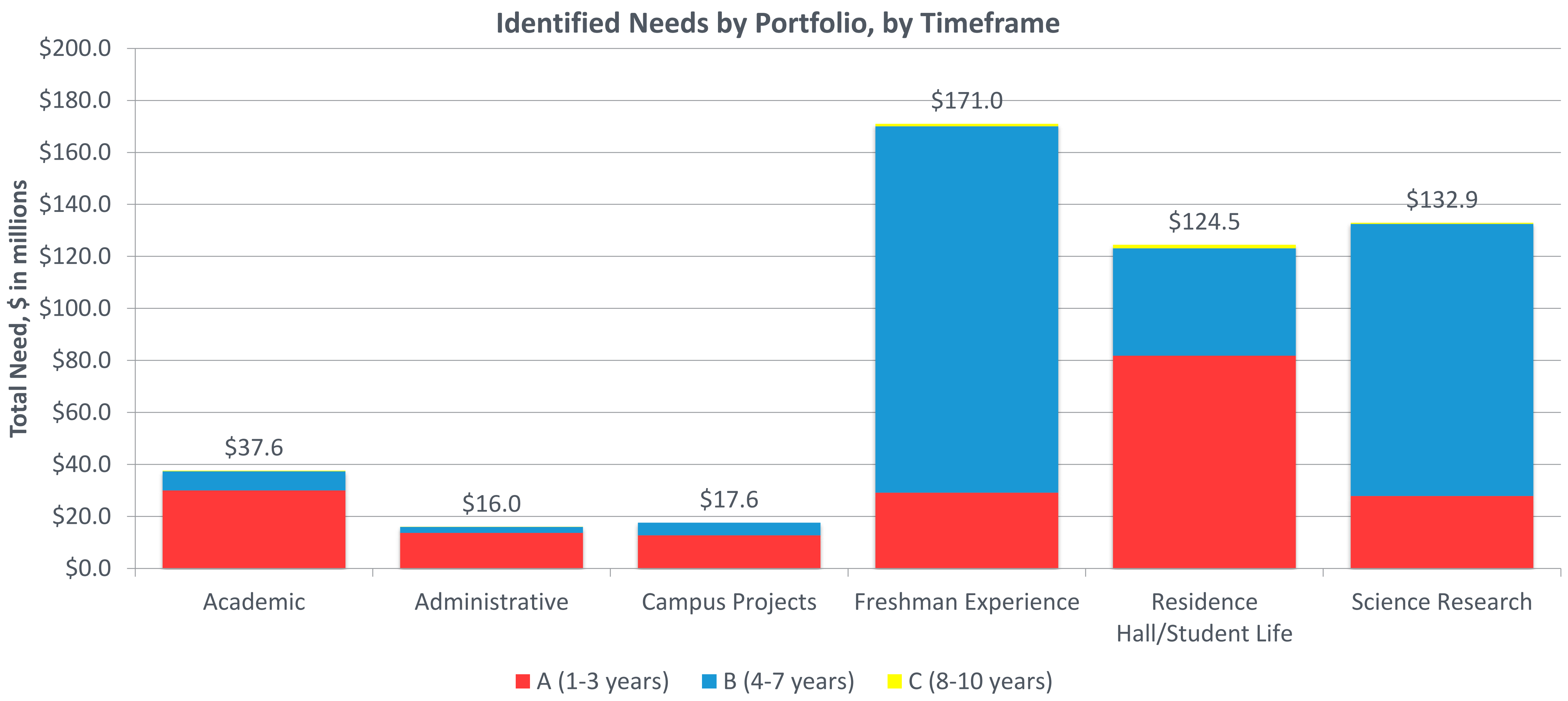
Residence/Student Life With Highest Priority Need



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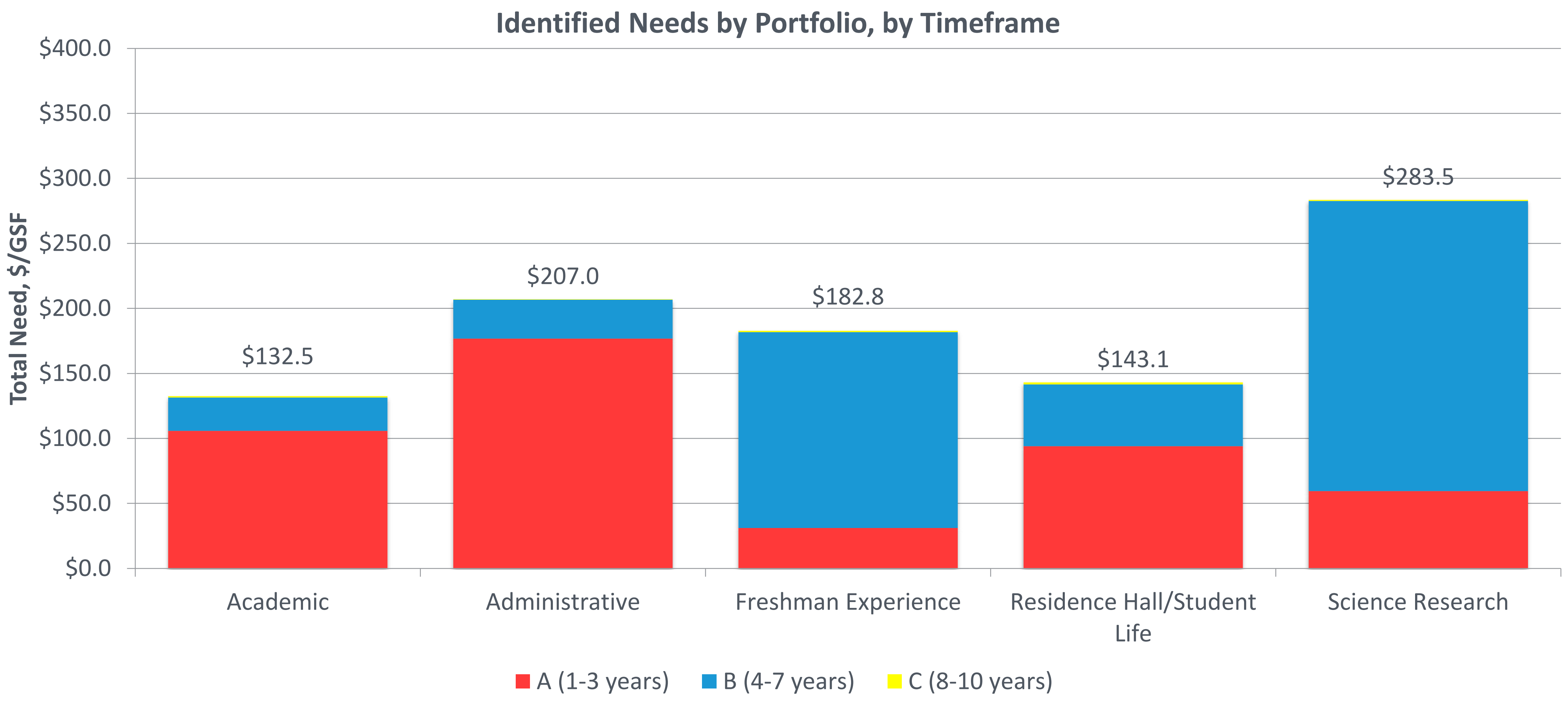
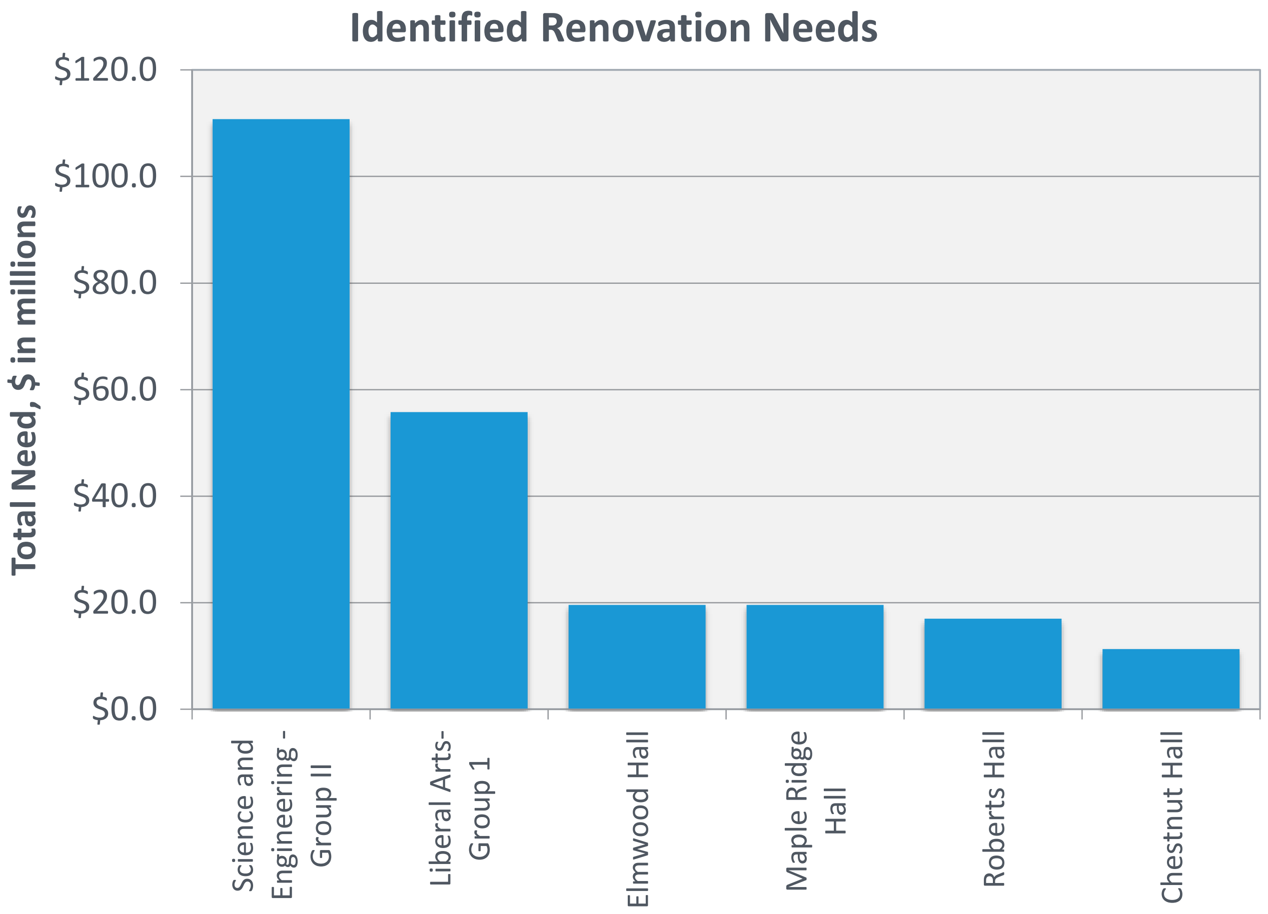
Science Research Driven by SENG Renovation



Strategic Renovations on Campus



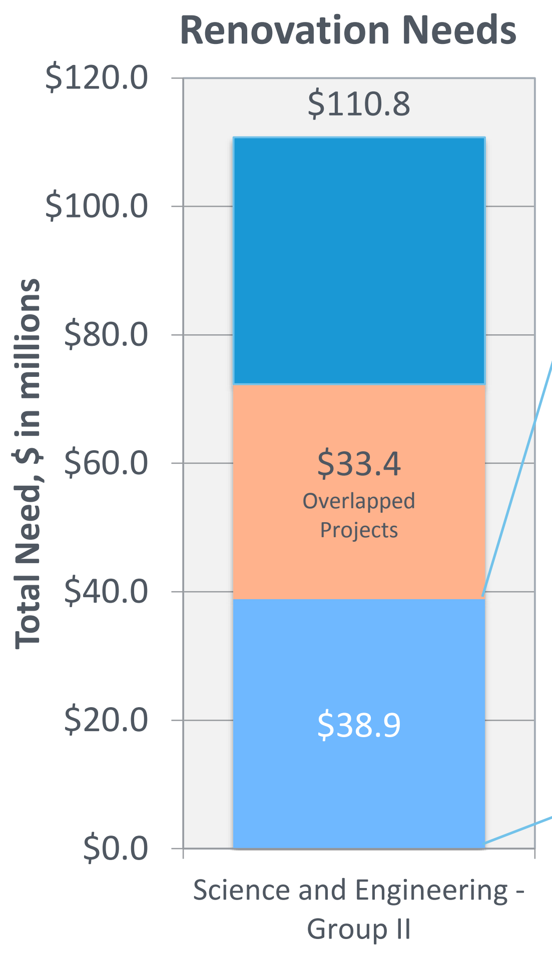
Building Renovations	
Science and Engineering - Group II	$110.8M
Liberal Arts- Group 1	$55.8M
Chestnut Hall	$18.8M
Elmwood Hall	$19.6M
Maple Ridge Hall	$19.6M
Roberts Hall	$17M

- *Systemic repairs will escalate and be more costly in the long term if renovations are not planned in the next 4-7 years.*

- *Key systems and envelope work in Science and Engineering and Liberal Arts are reliability need and risk failures.*

**Includes Building Need Only*

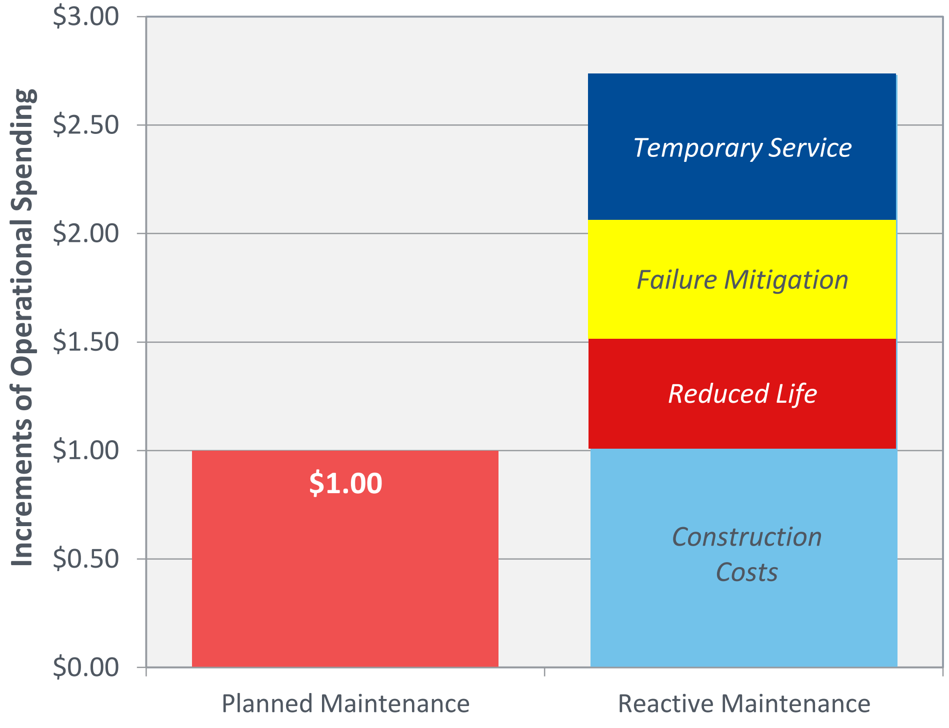
Science and Engineering - Group II



Capital Project Submission for State Funding Critical Infrastructure	
Envelope Upgrade	$13,013,869
Replace Chiller Water and Heating Plant	$5,561,628
Fire Protection & Smoke Exhaust	$5,523,677
ADA & MAAB Accessibility Upgrades	$6,825,597
HVAC System Upgrades	$7,958,387
Total ECC	**$38,883,158**

Opportunity for Cost Avoidance:

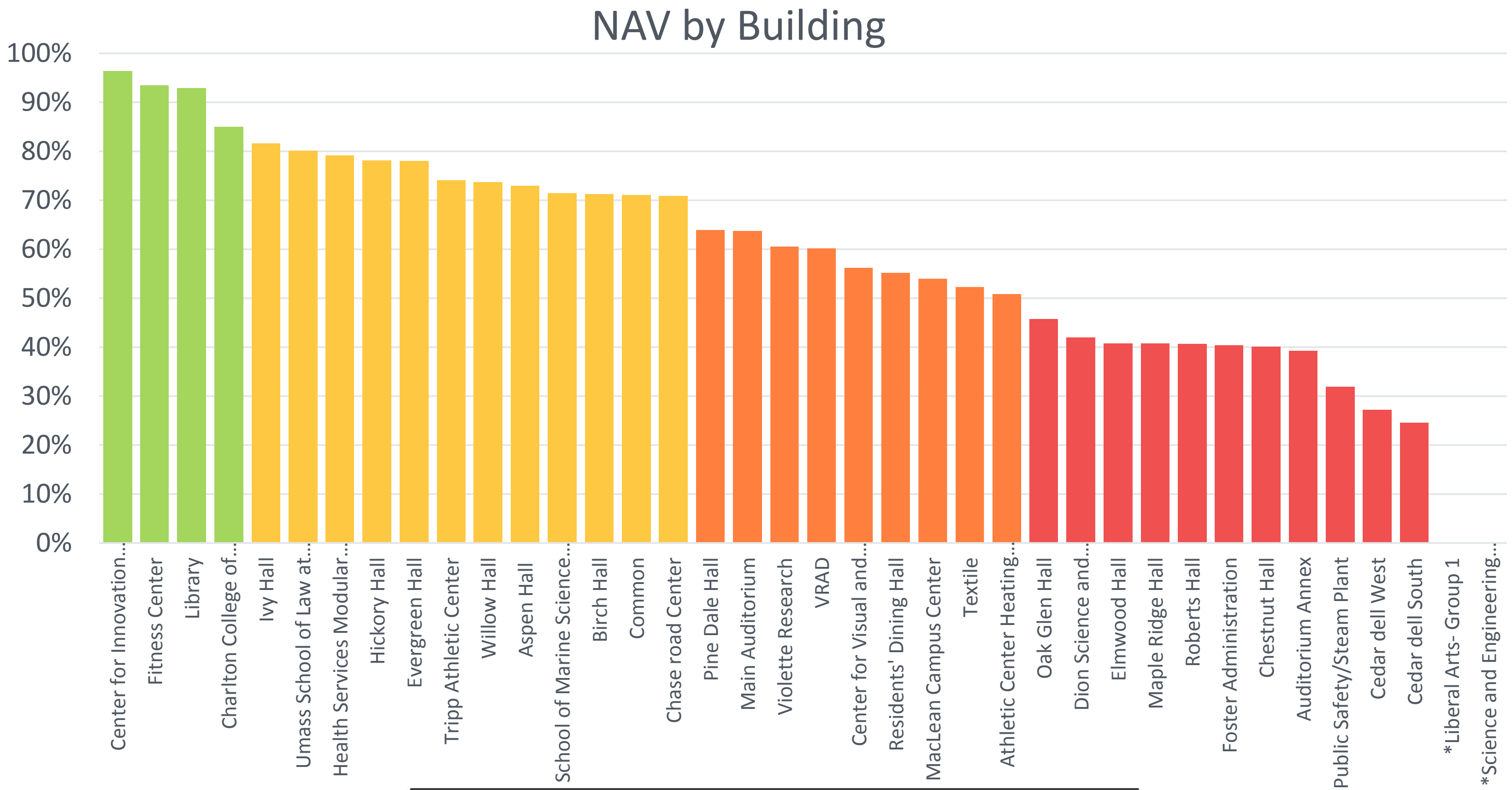
Invest $1.00 in Planned Maintenance now
OR
Spend $2.73 in reactive maintenance later*



**Data from Ozanne Analytics – research of Sightlines database of work orders comparing costs of corrective and emergency work orders to planned and preventative work orders*

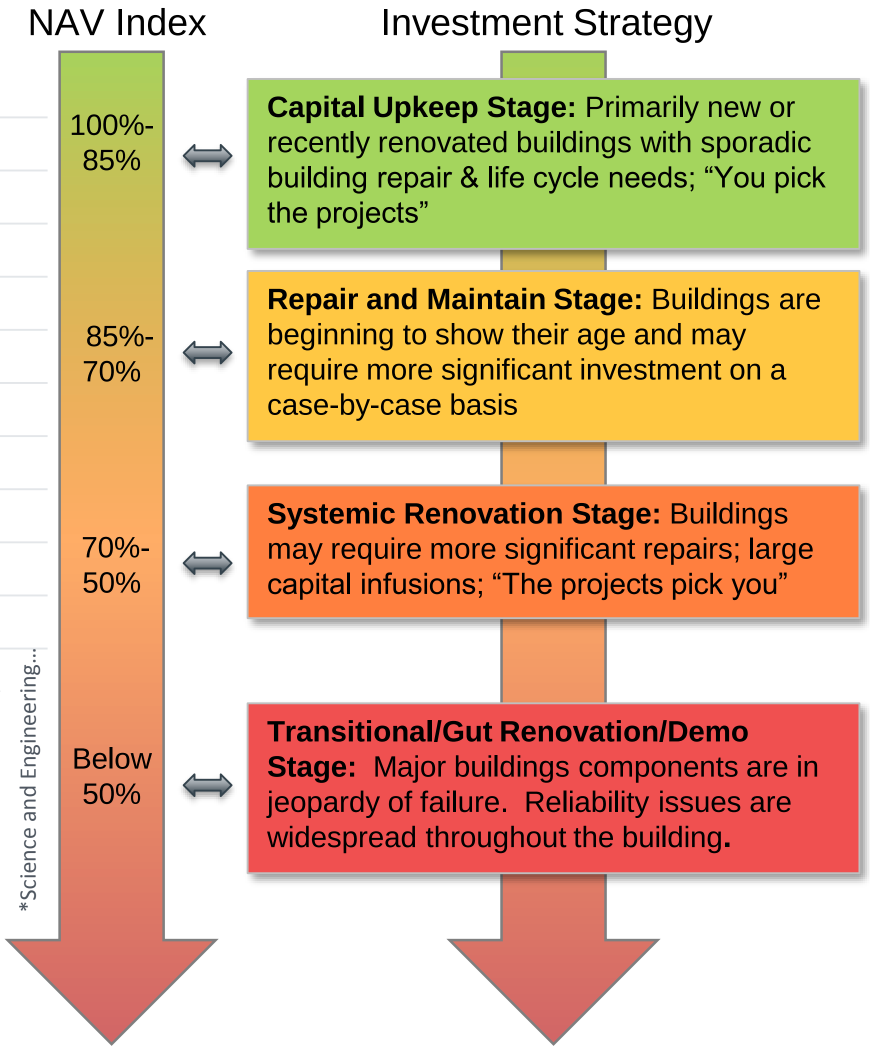
Net Asset Value by Building

Campus NAV average 50%

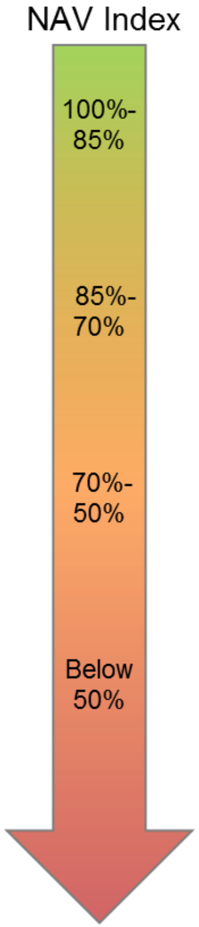


Net Asset Value = $\frac{\text{Replacement Value – Backlog}}{\text{Replacement Value}}$

**NAV less than 0%*



Campus by NAV



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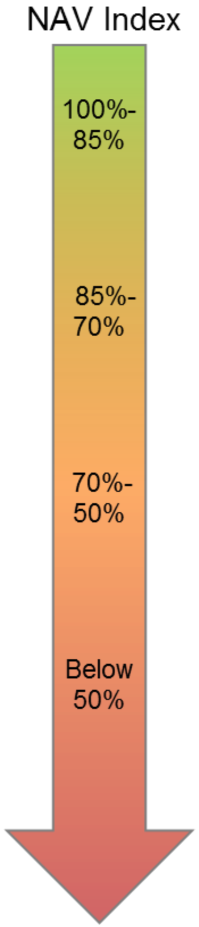
Capital Upkeep	Repair and Maintain	Systemic Renovation	Transitional / Gut Renovation

Campus by NAV



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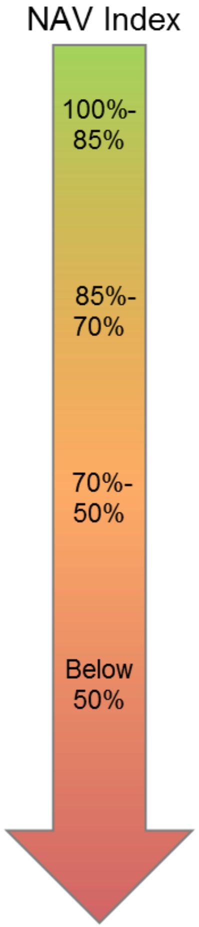
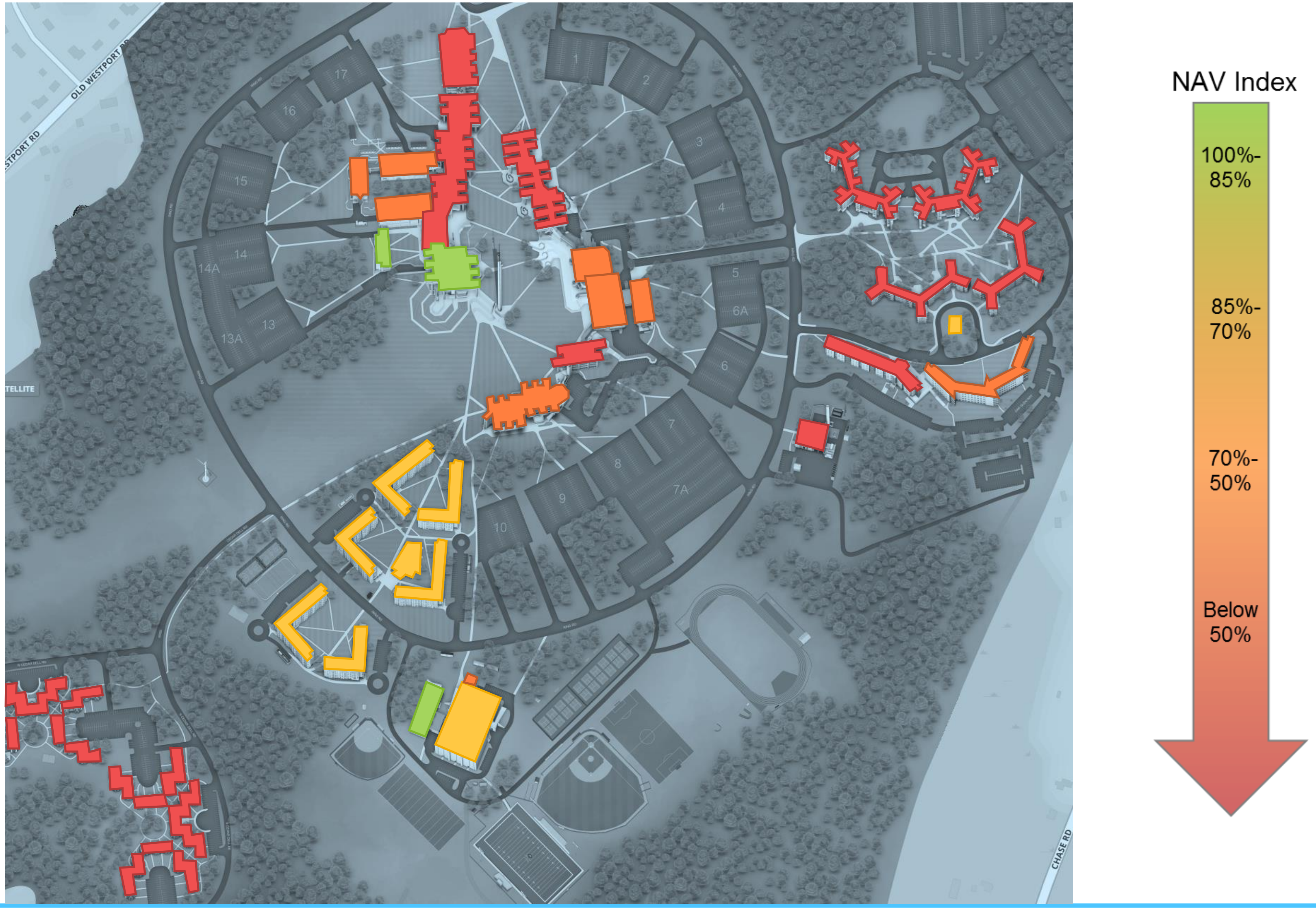
Capital Upkeep	Repair and Maintain	Systemic Renovation	Transitional / Gut Renovation

Campus by NAV



Capital Upkeep	Repair and Maintain	Systemic Renovation	Transitional / Gut Renovation

Campus by NAV



Capital Upkeep	Repair and Maintain	Systemic Renovation	Transitional / Gut Renovation

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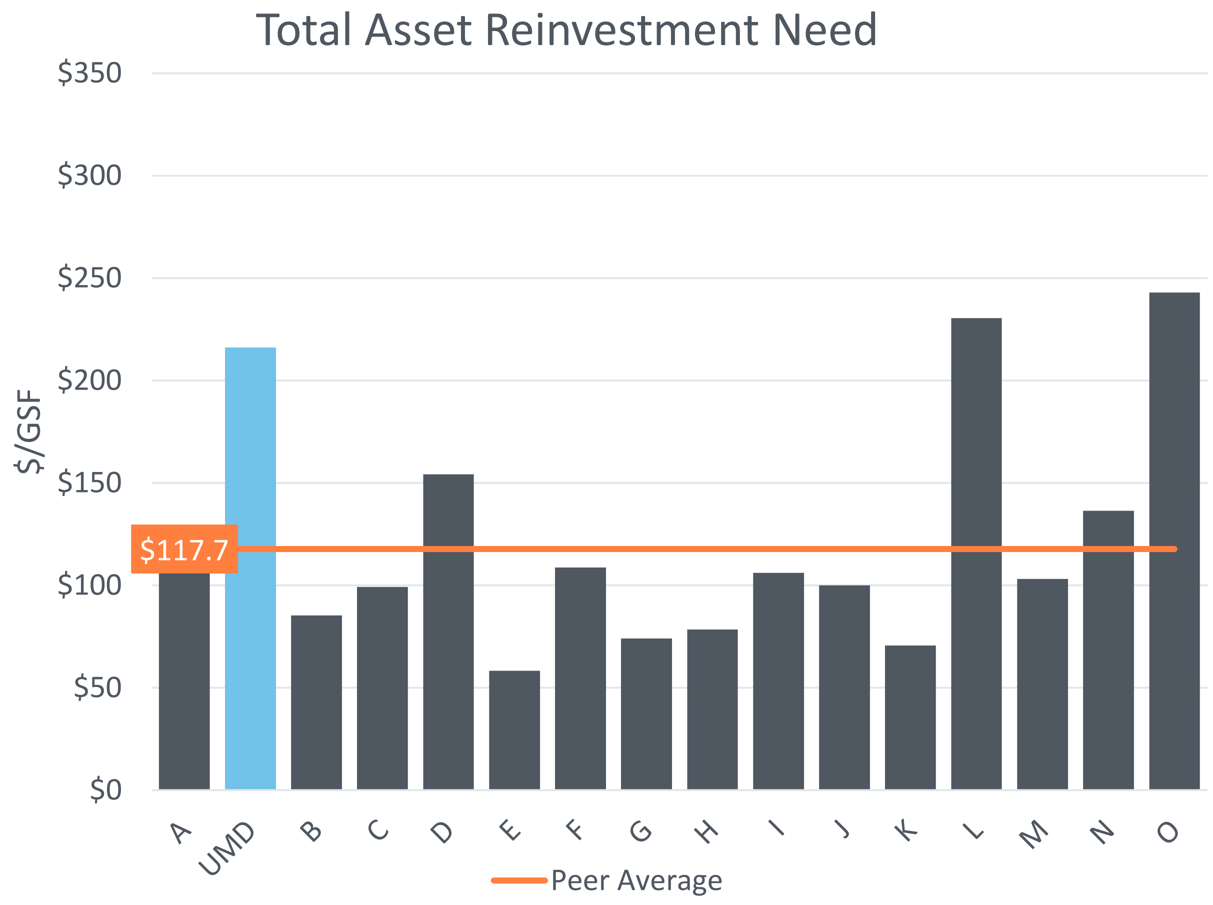
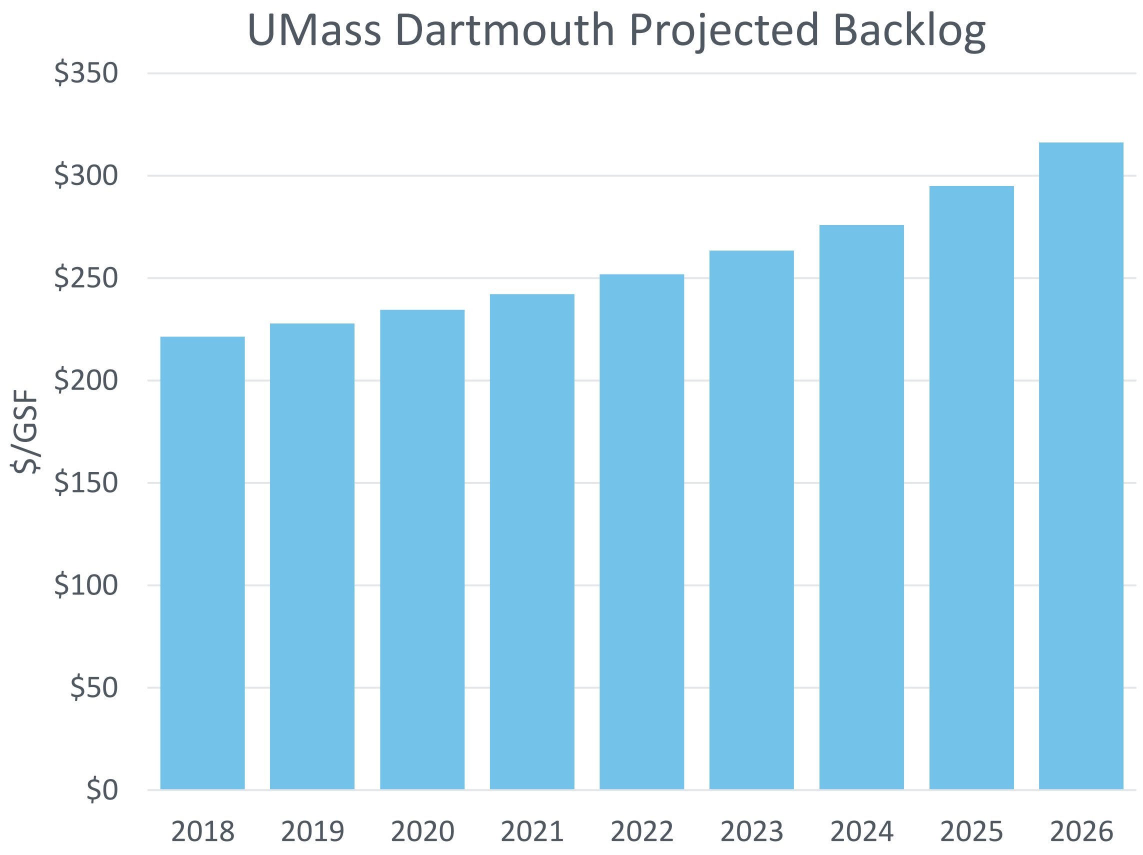
Stewarding $15.5M Annually (AS Target)

Backlog increases to $316/GSF from $217/GSF





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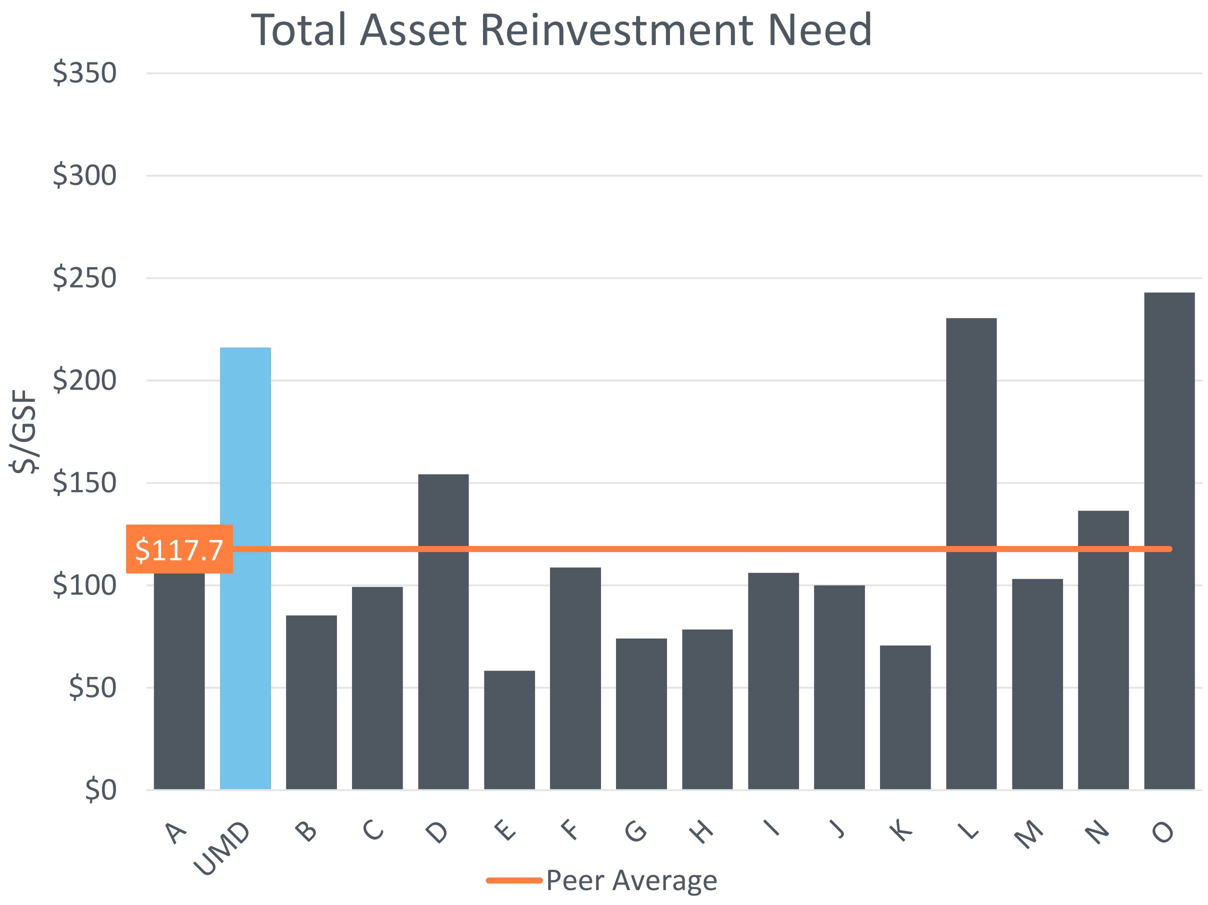
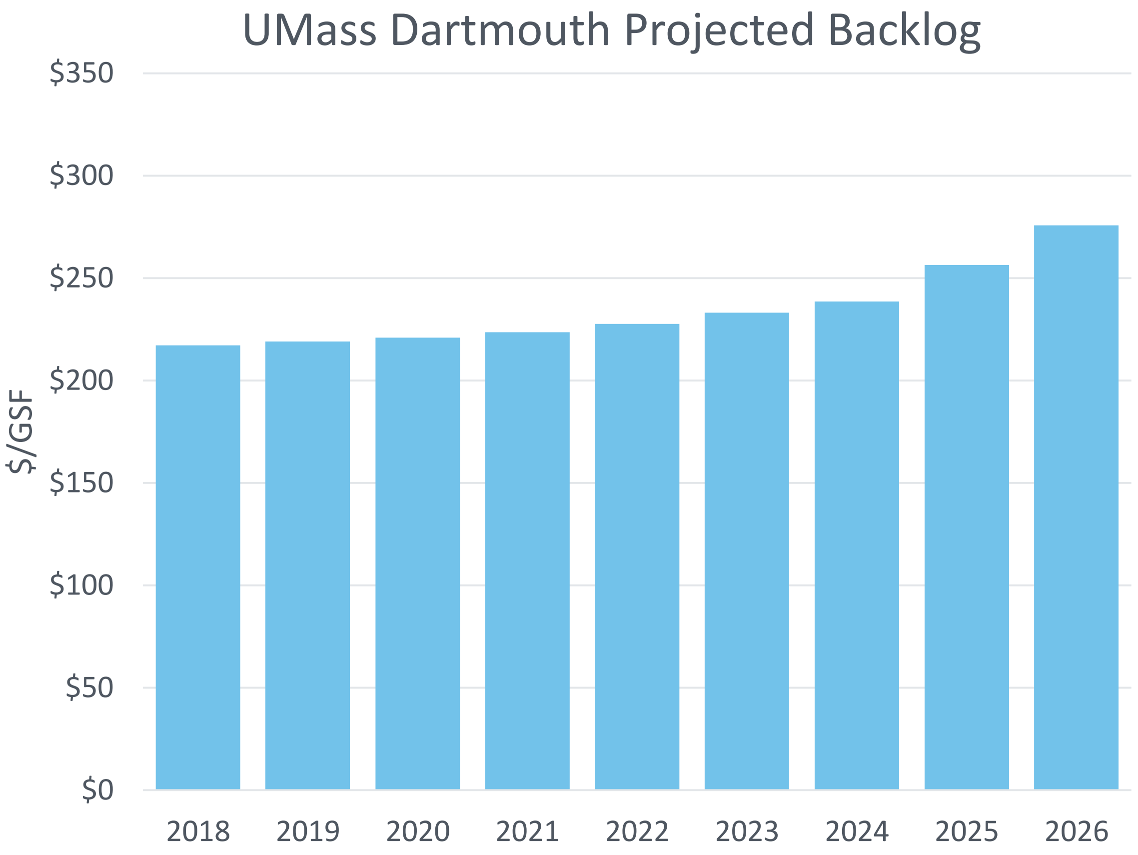
Stewarding $15.5M Annually + $10.1M (Life Cycle Need)

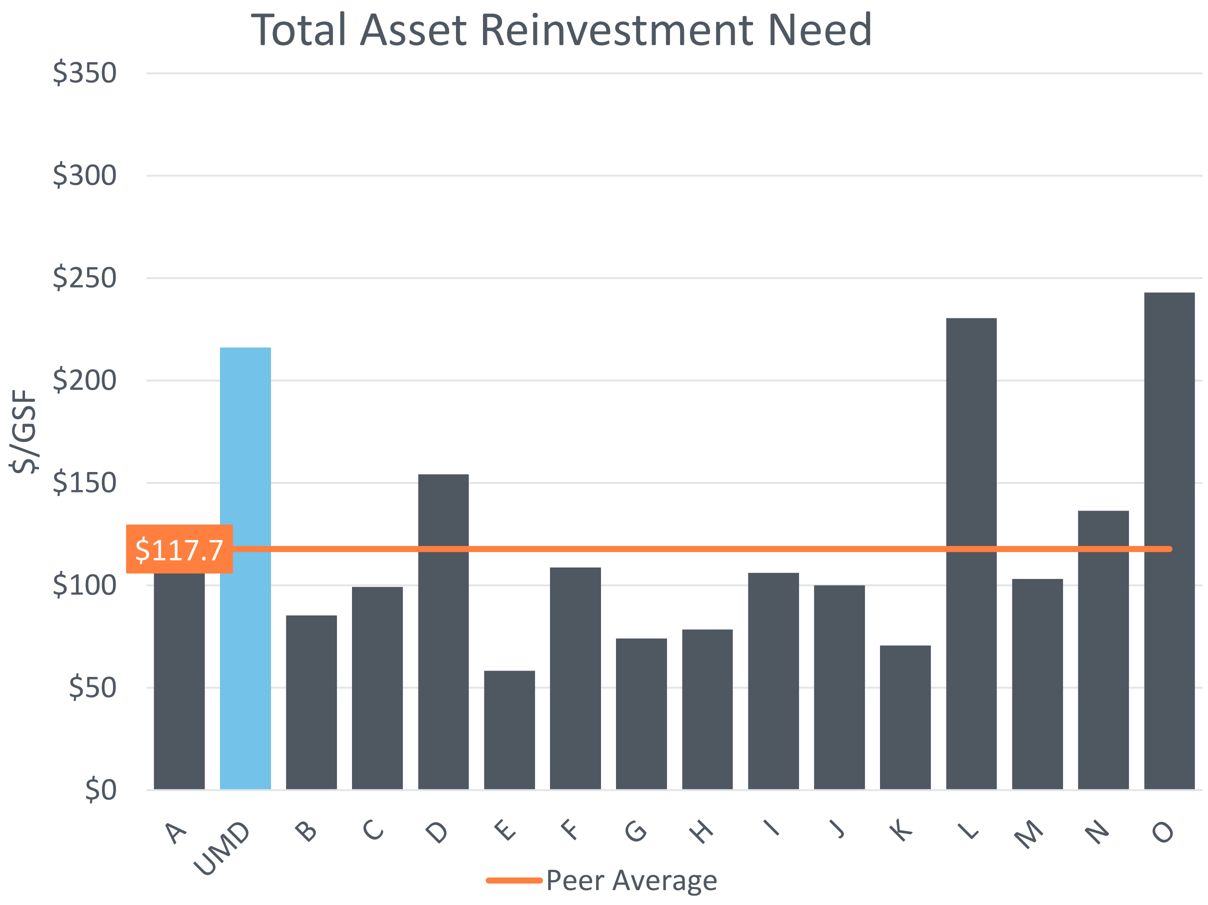
Backlog increases to $276/GSF from $217/GSF

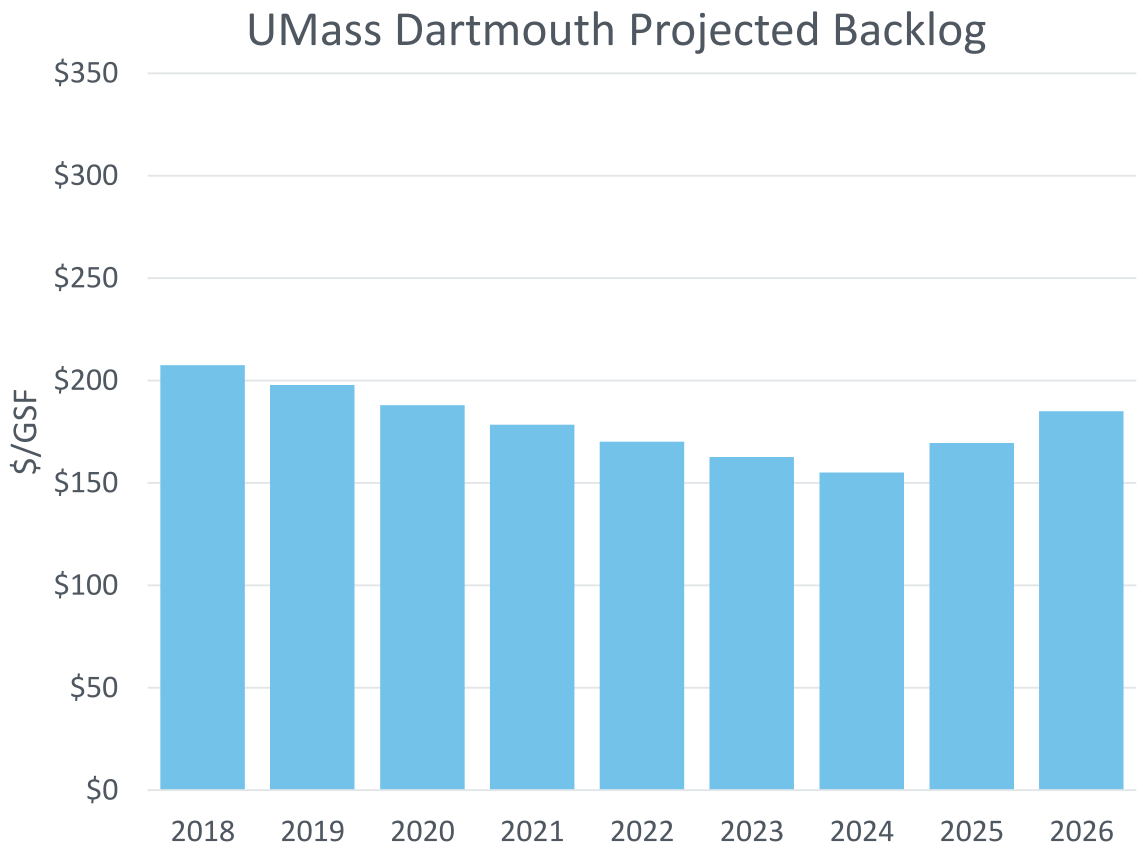




Stewarding $15.5M + $41.2M (BPS Total Need Over 10 Years)

Backlog decreases to $184/GSF from $217/GSF





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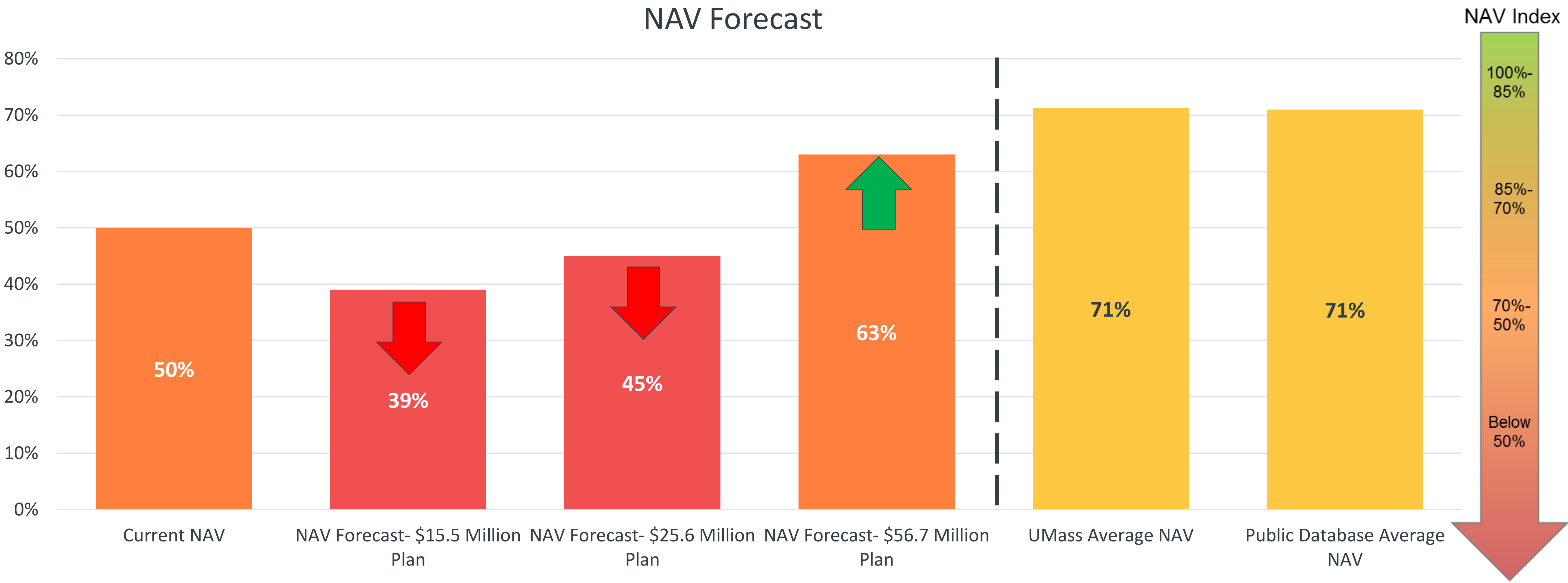
Summary of Funding Scenarios

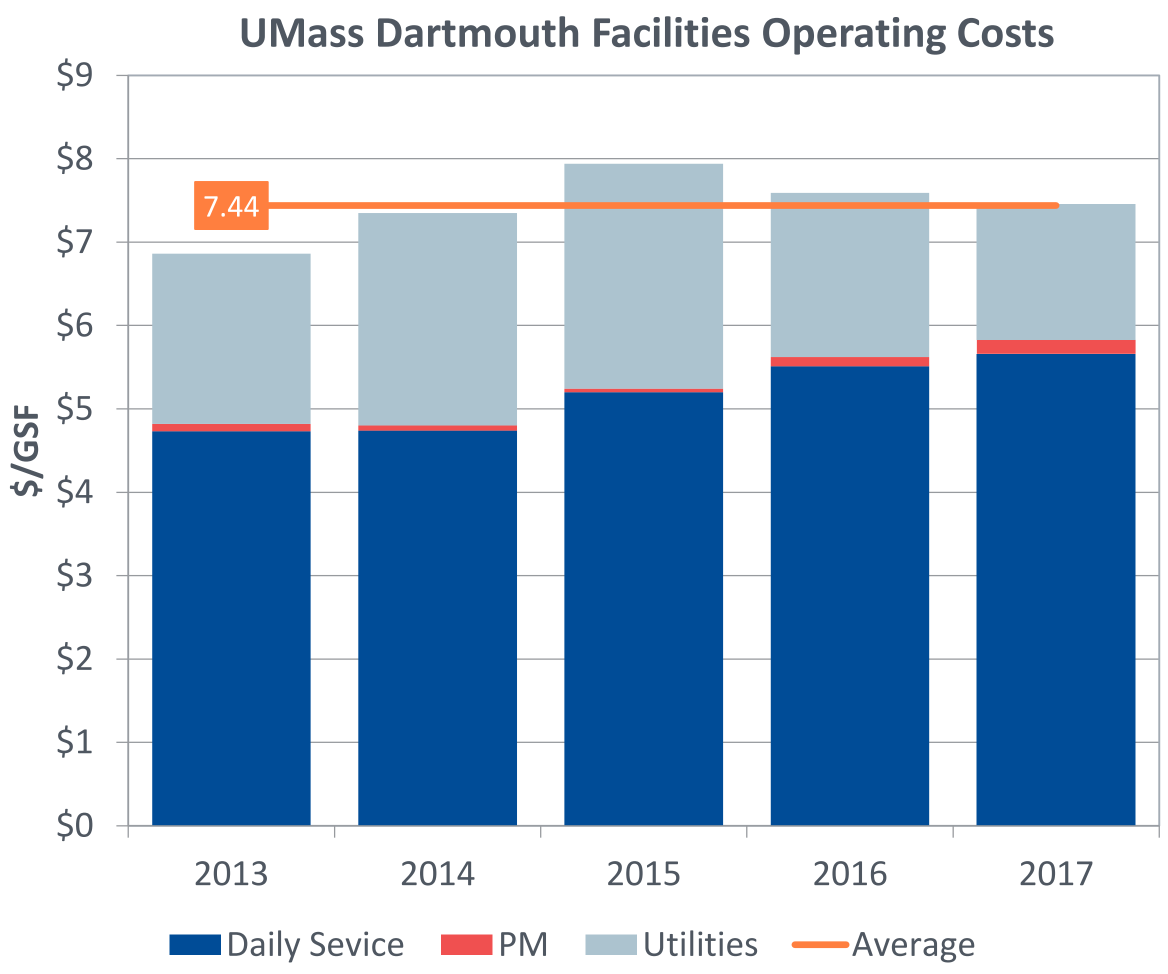
$56.7 Million Investment increases NAV to 63%

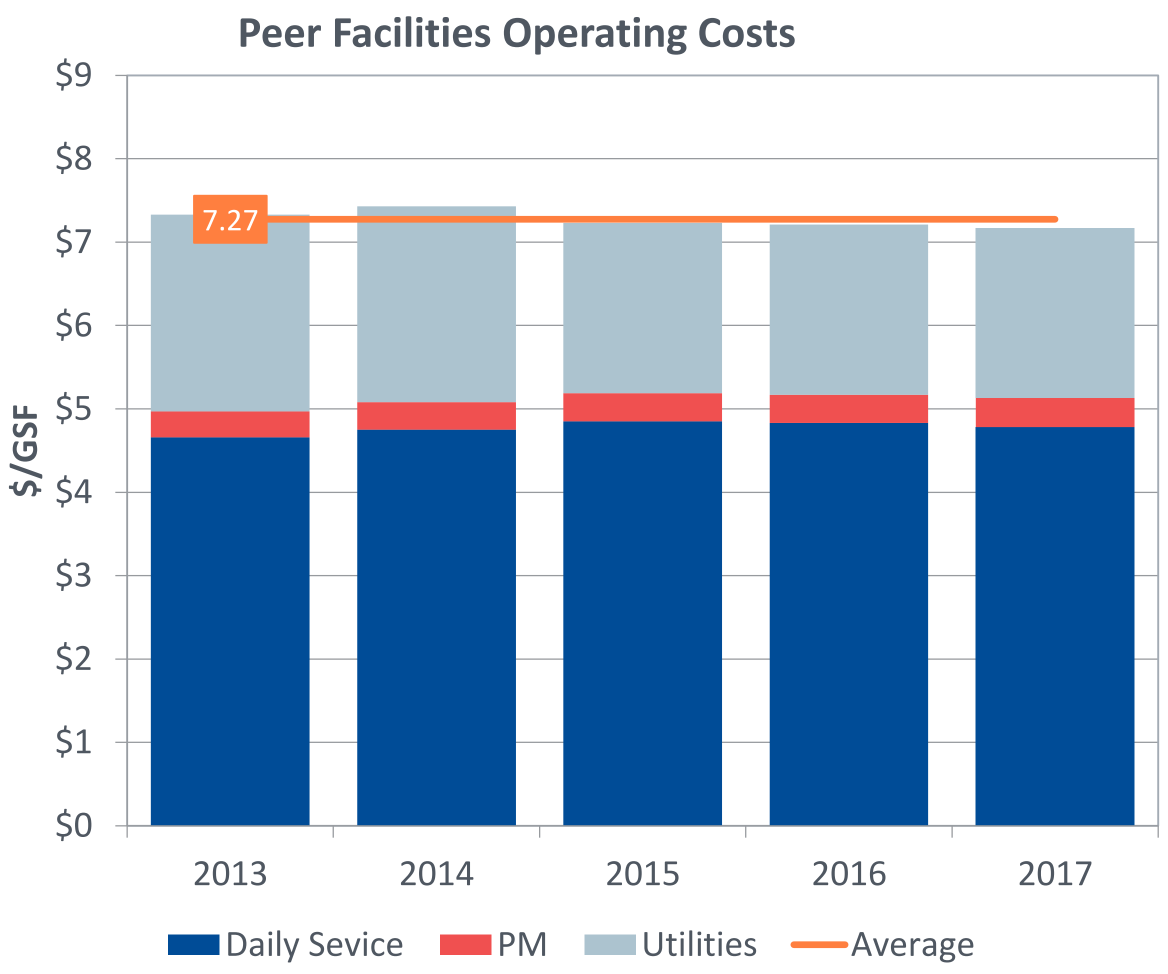


Operations

Operating Costs at Peer Levels

FY17 saw Dartmouth's highest PM investment and lowest utility cost on a $/GSF basis





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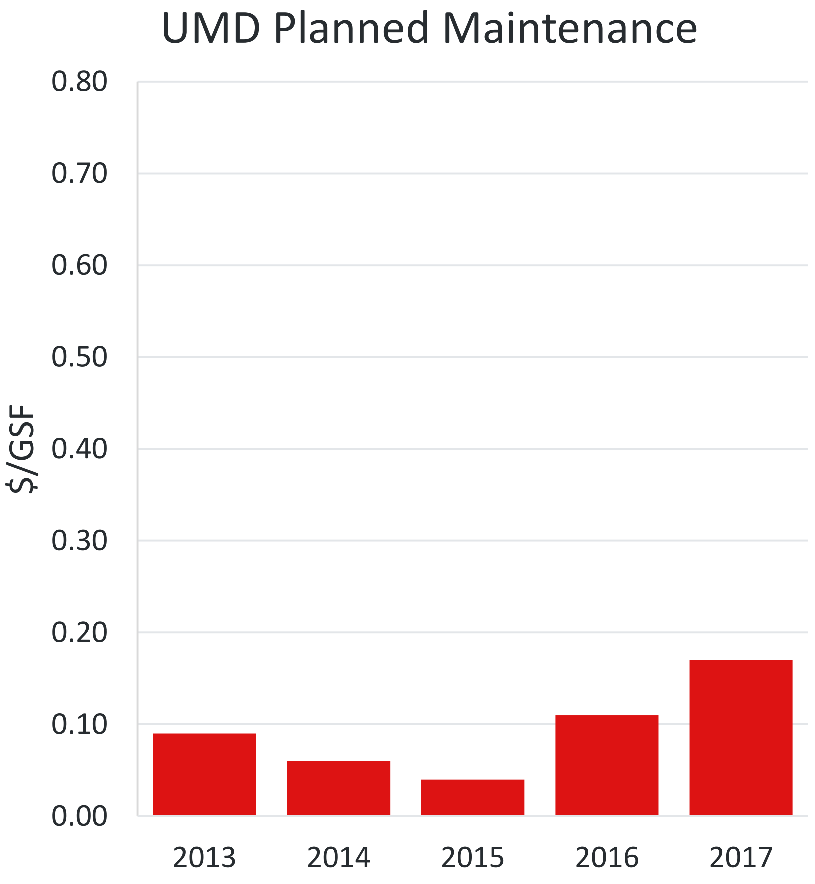
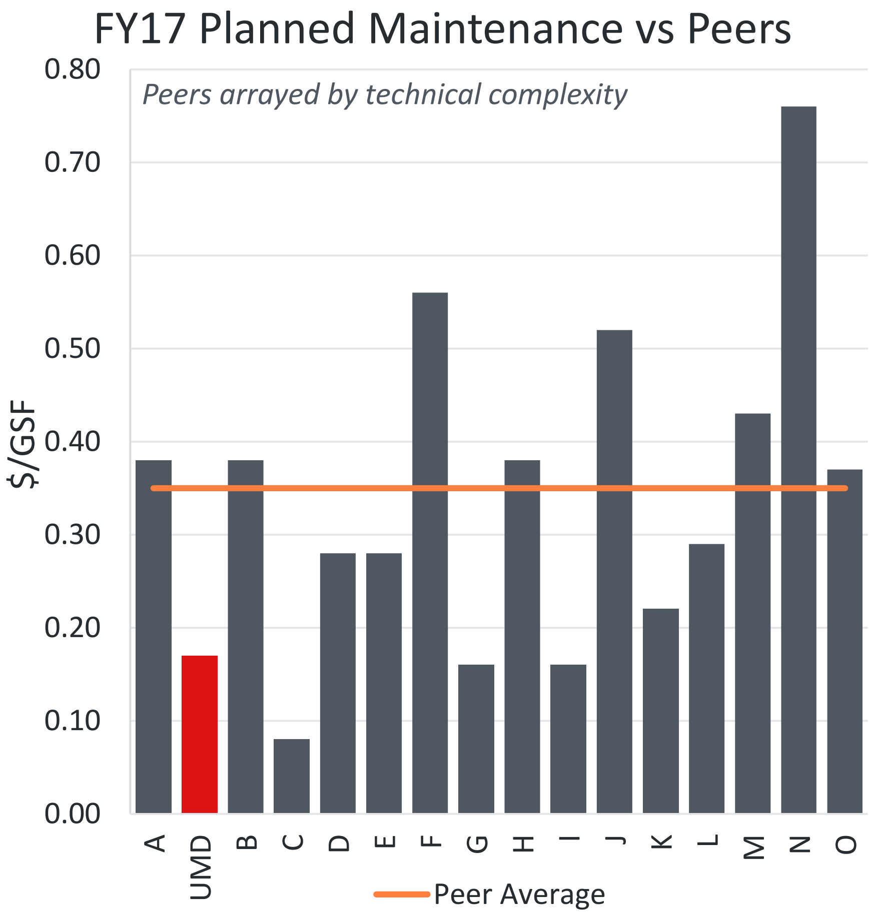
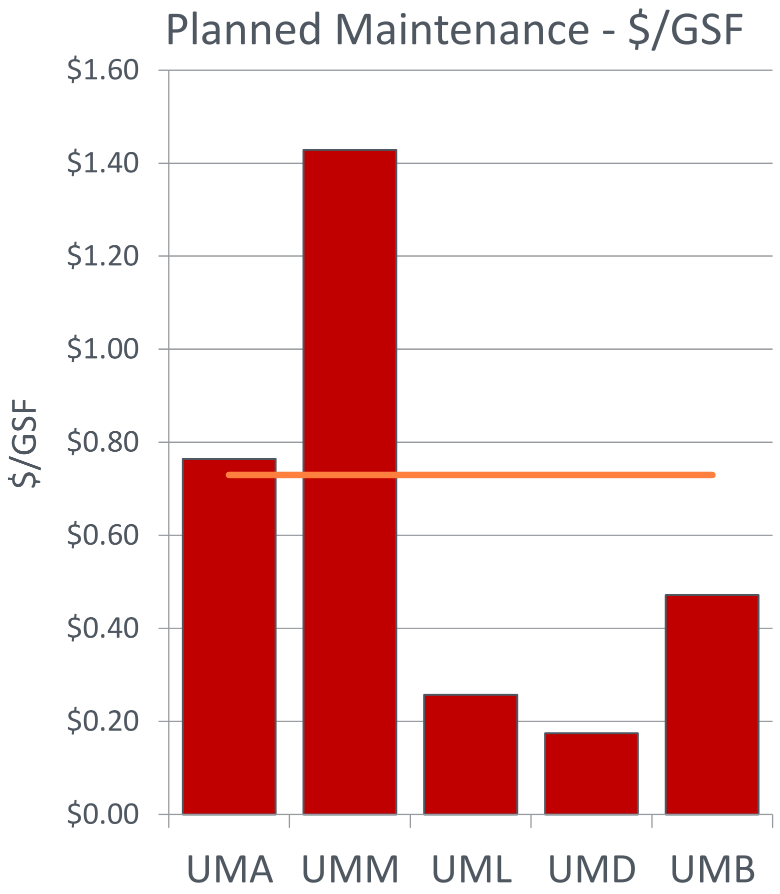
PM Funding Growing Since FY15; Lowest of UMass System

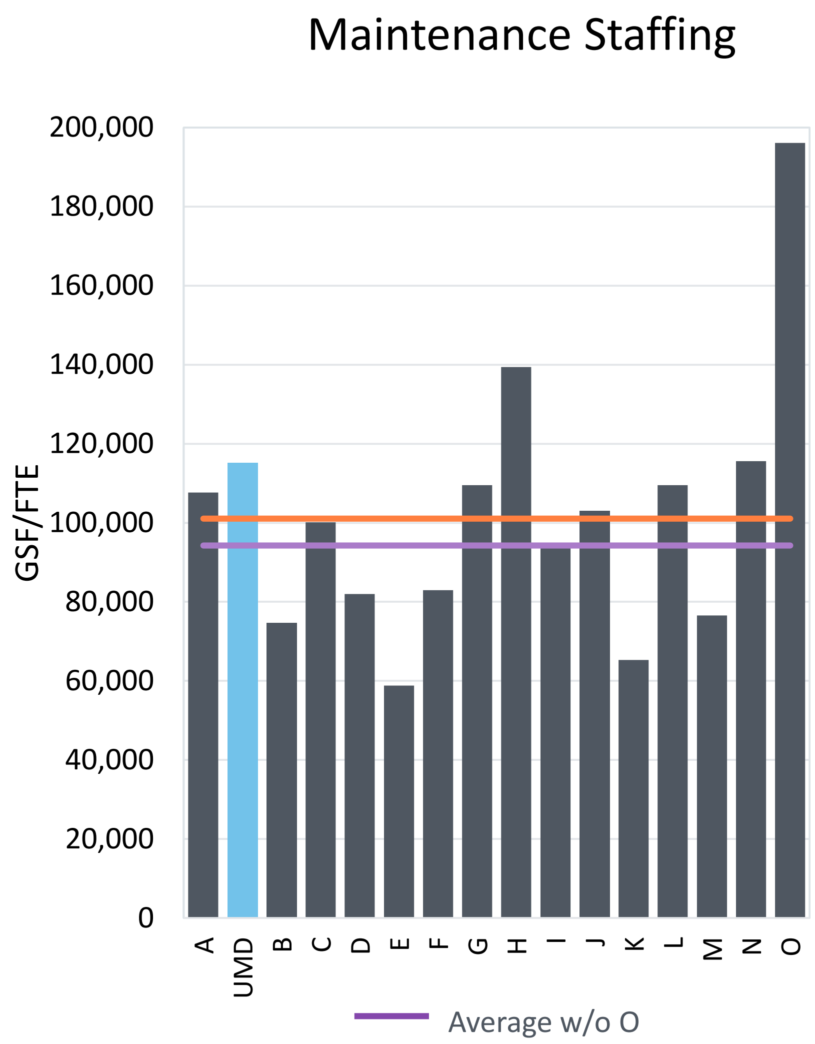
Proactive work extends the life cycle of campus assets

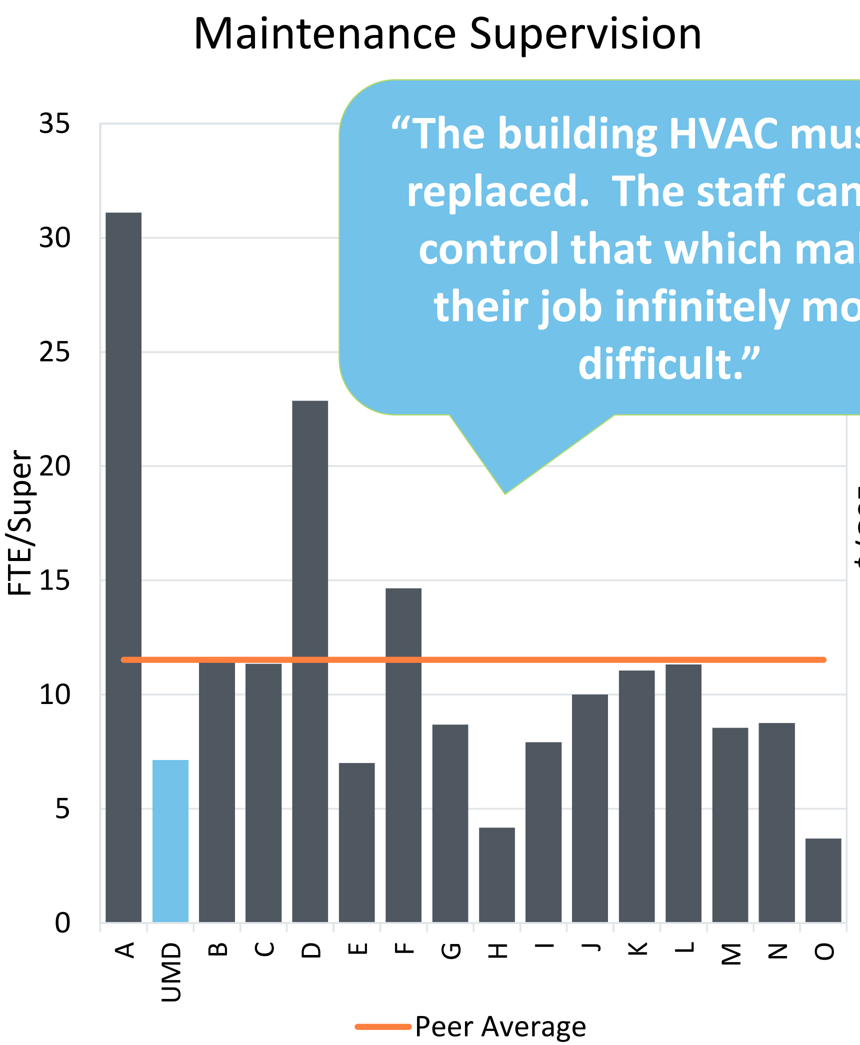




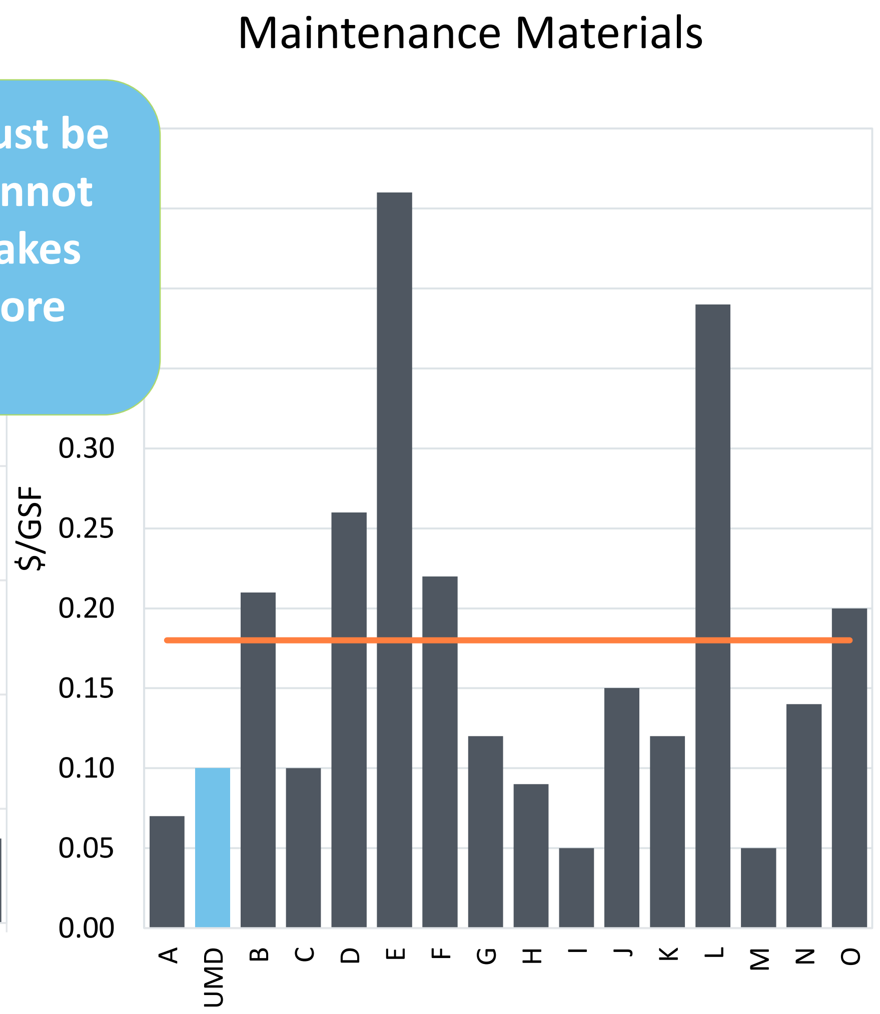


High coverage, closer supervision, less material spend than peers





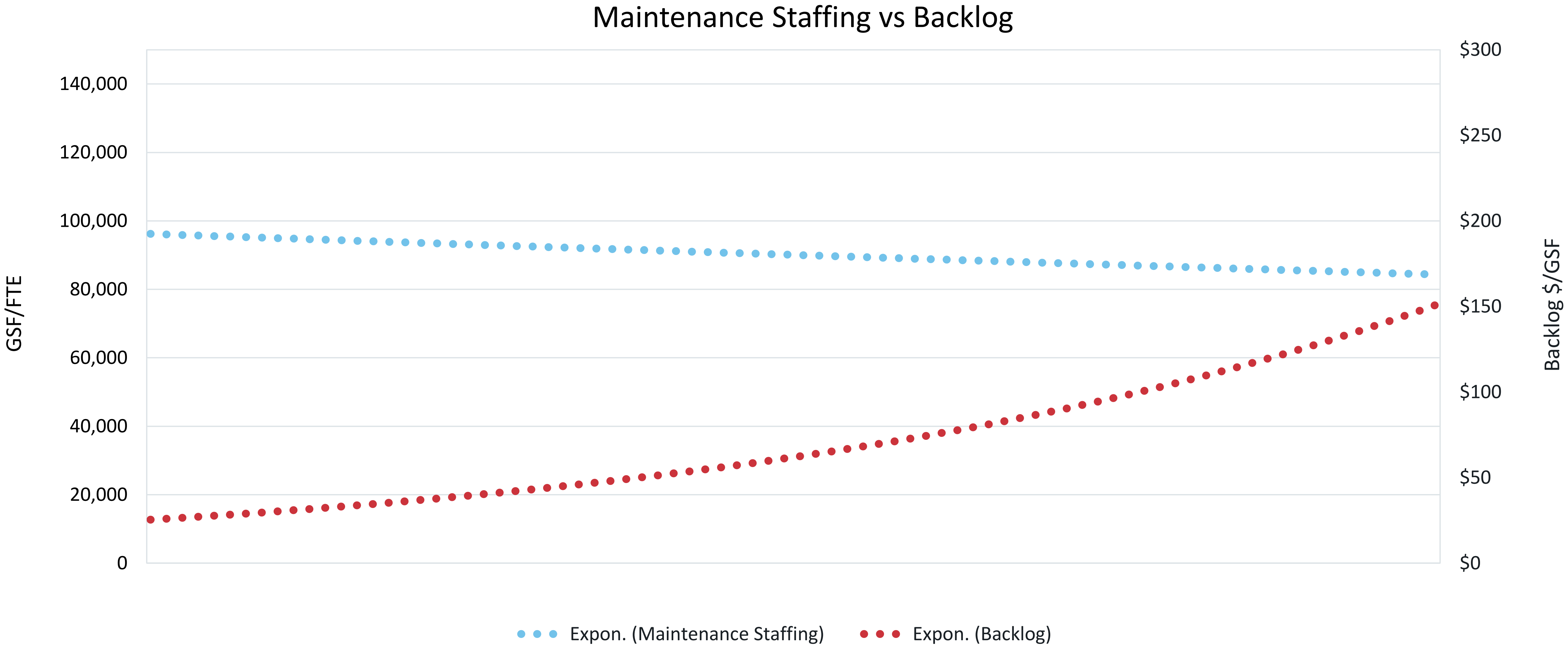
"The building HVAC must be replaced. The staff cannot control that which makes their job infinitely more difficult."



Peers arrayed by technical complexity

Maintenance Coverage Decreases as Backlog $/GSF Grows

Trending for Sightlines Public Institution Database



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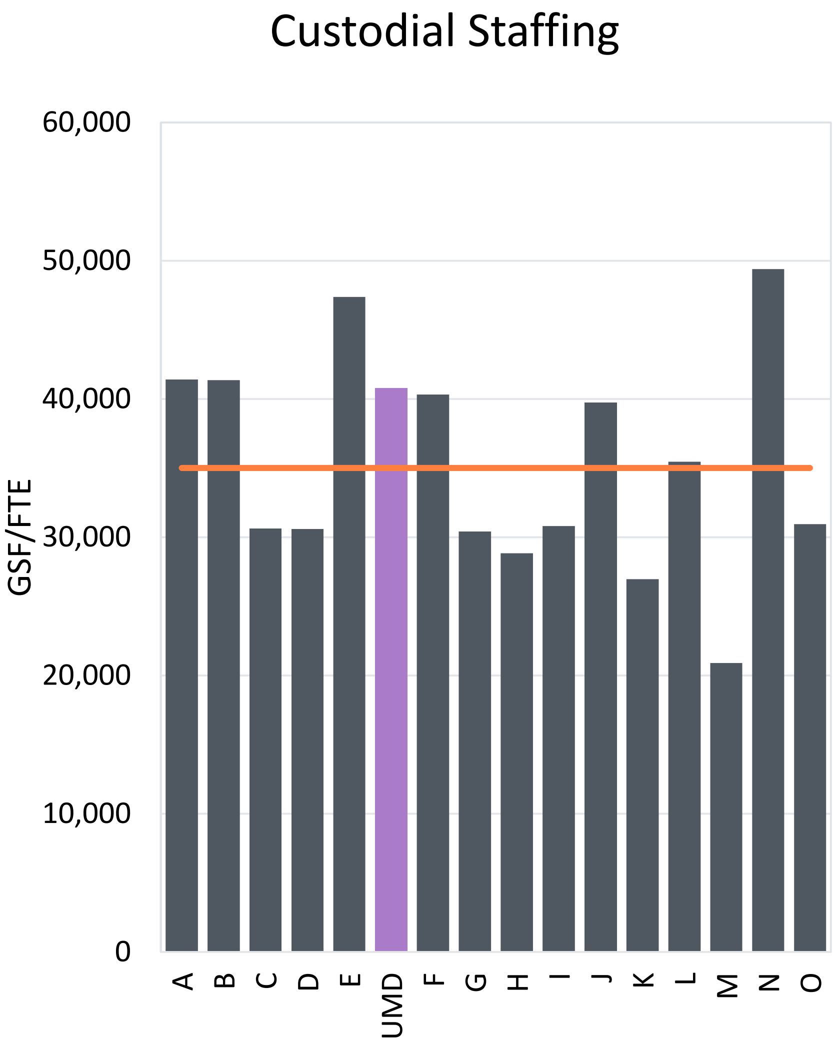
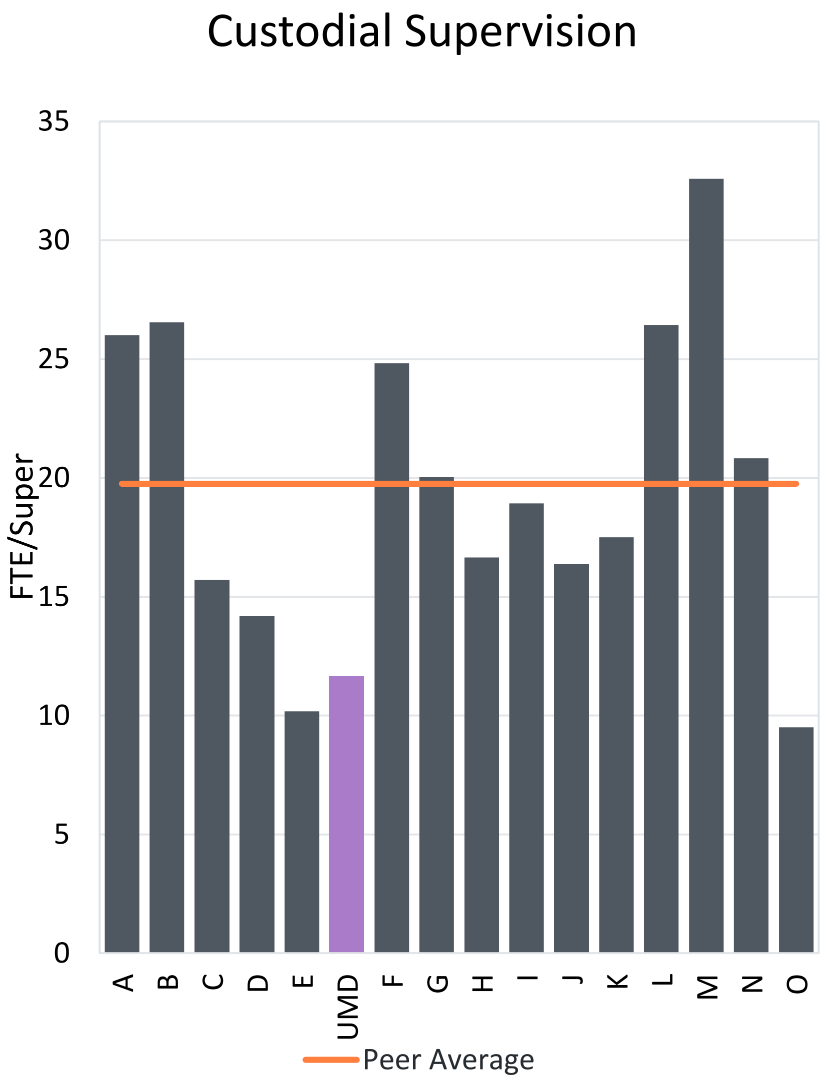
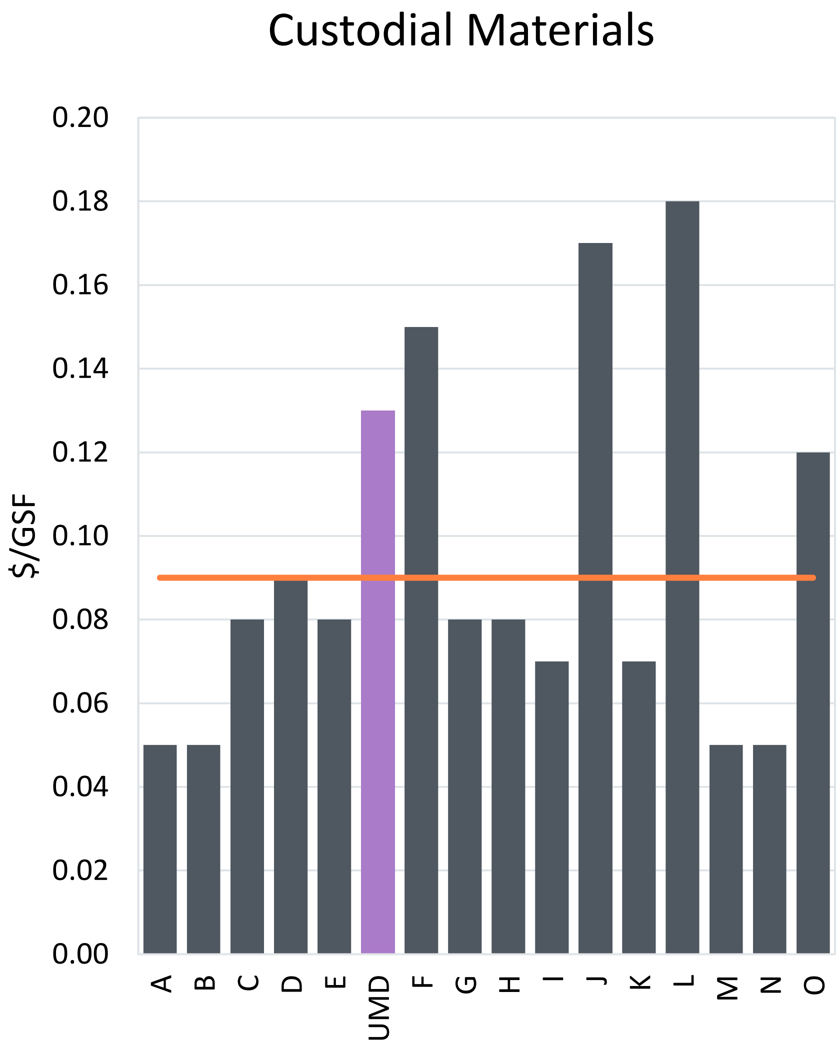
Less Custodial Staff with Higher Supervision and More Material Spend

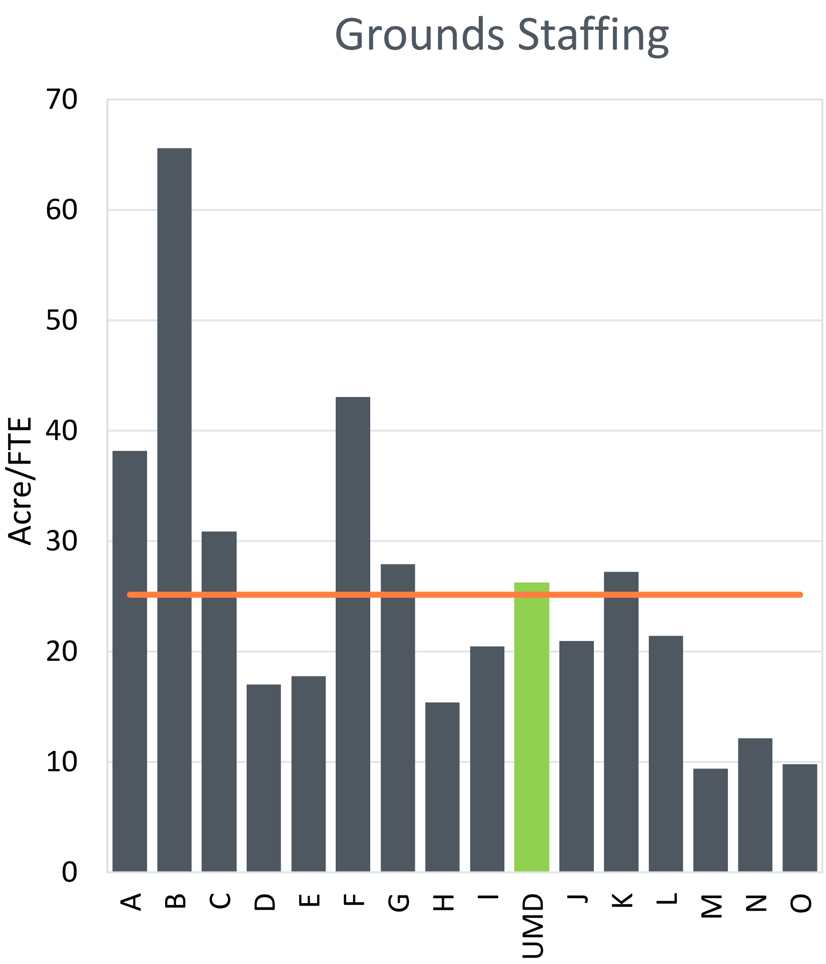


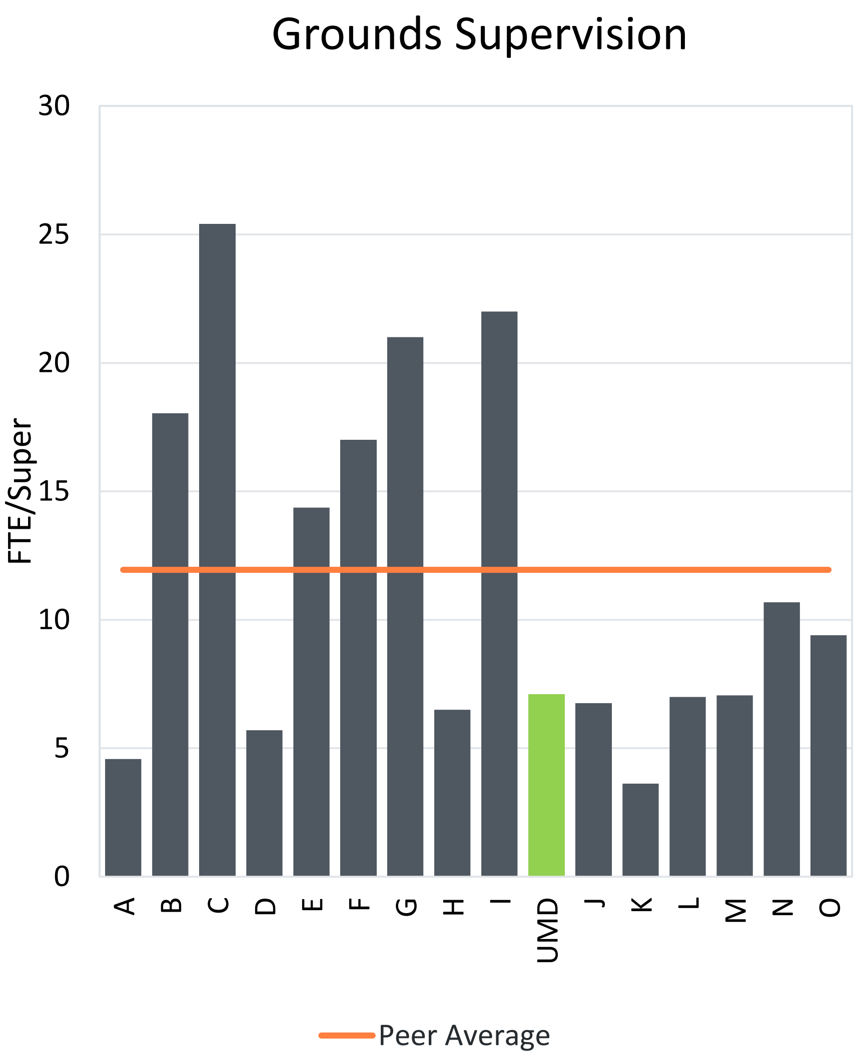


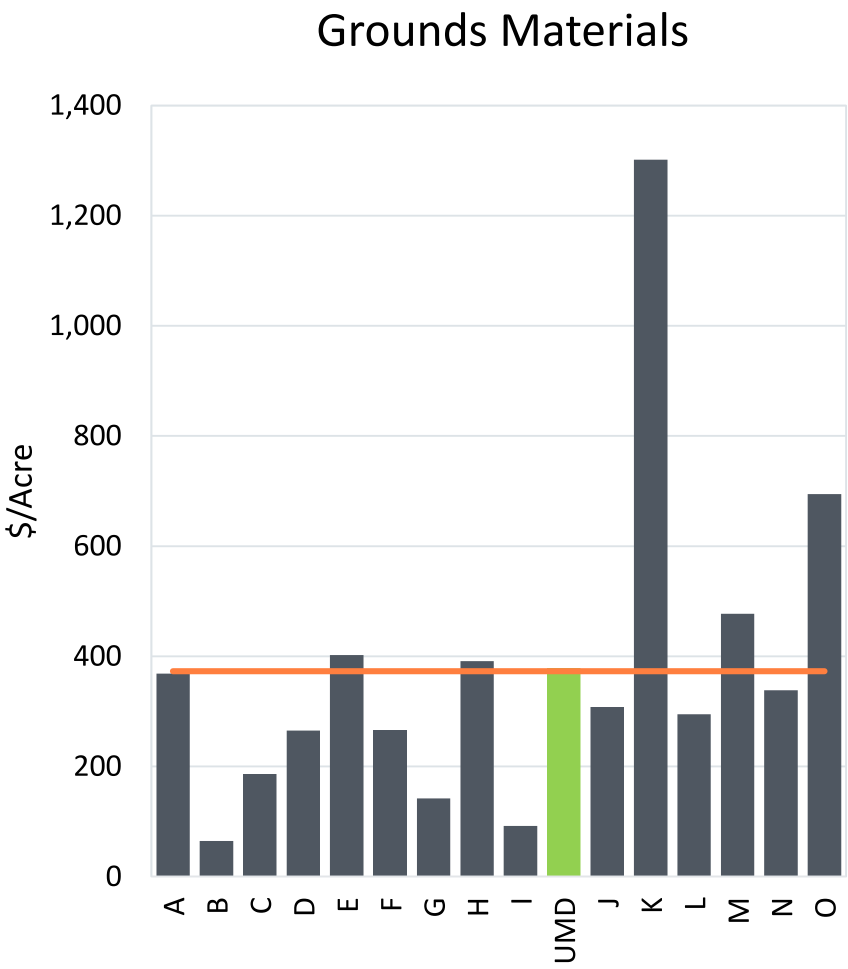


Peers arrayed by density factor

Grounds Coverage Similar to Peers, More Supervision







Peers arrayed by grounds intensity

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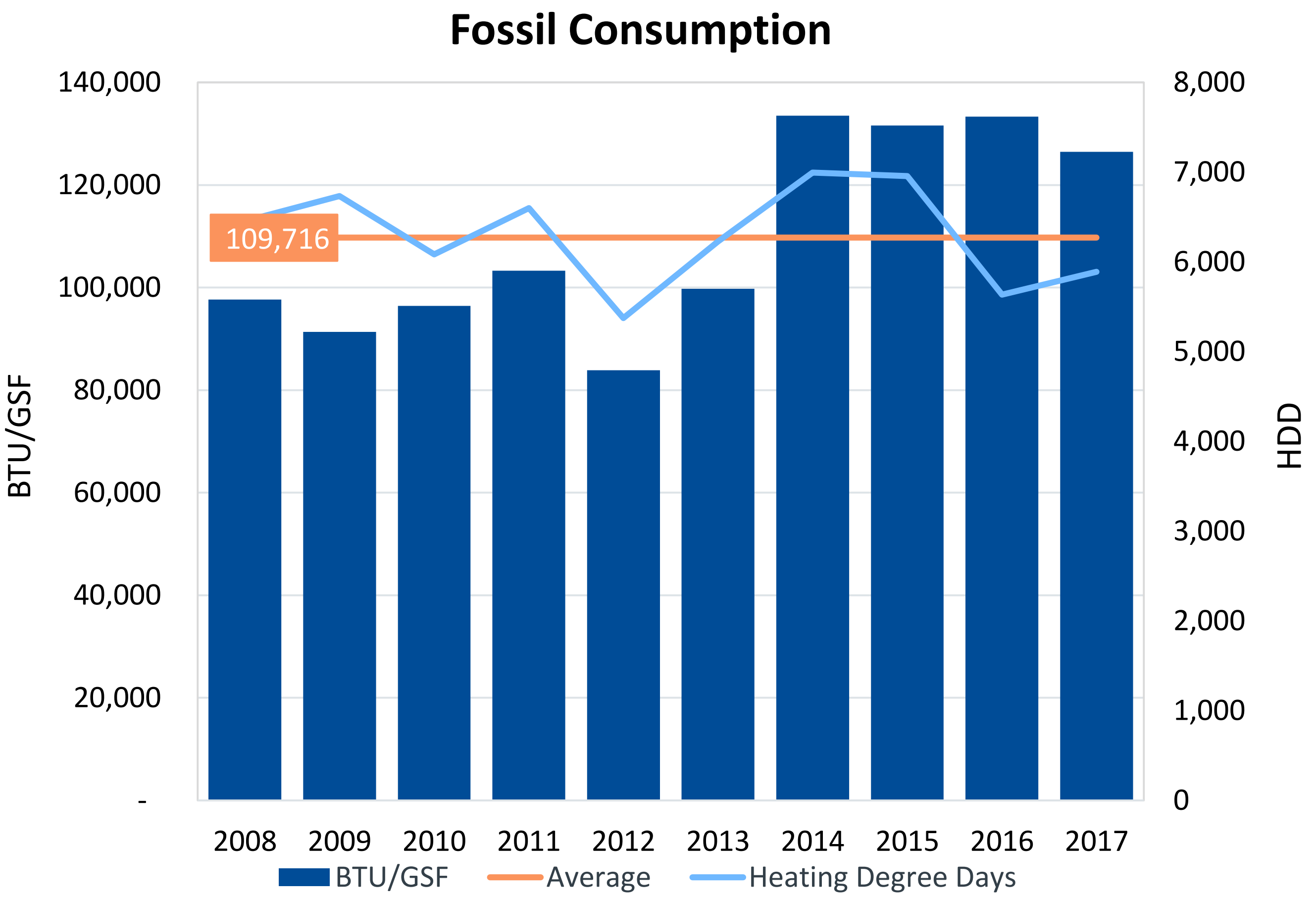
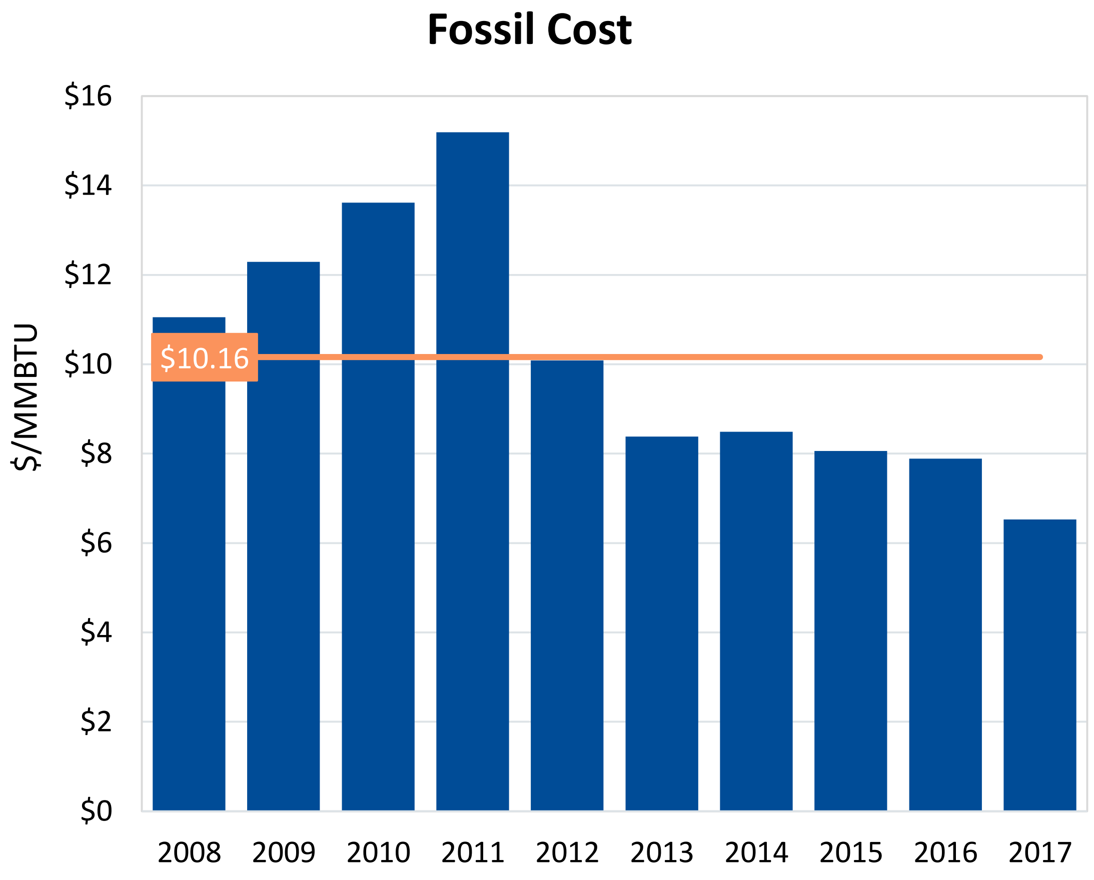
Reduced Consumption and Unit Price in FY17

UMD consumed less despite HDD; Infrastructure and System investment drives efficiencies





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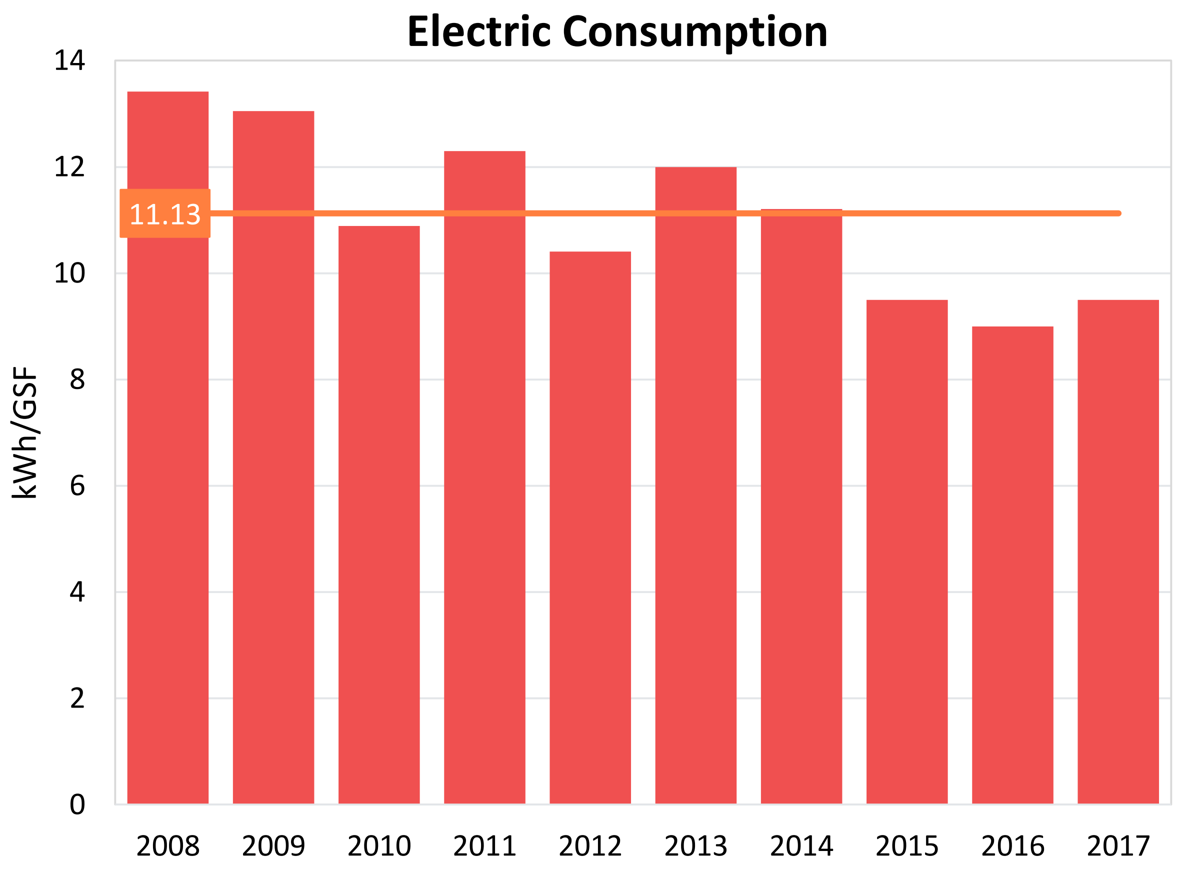
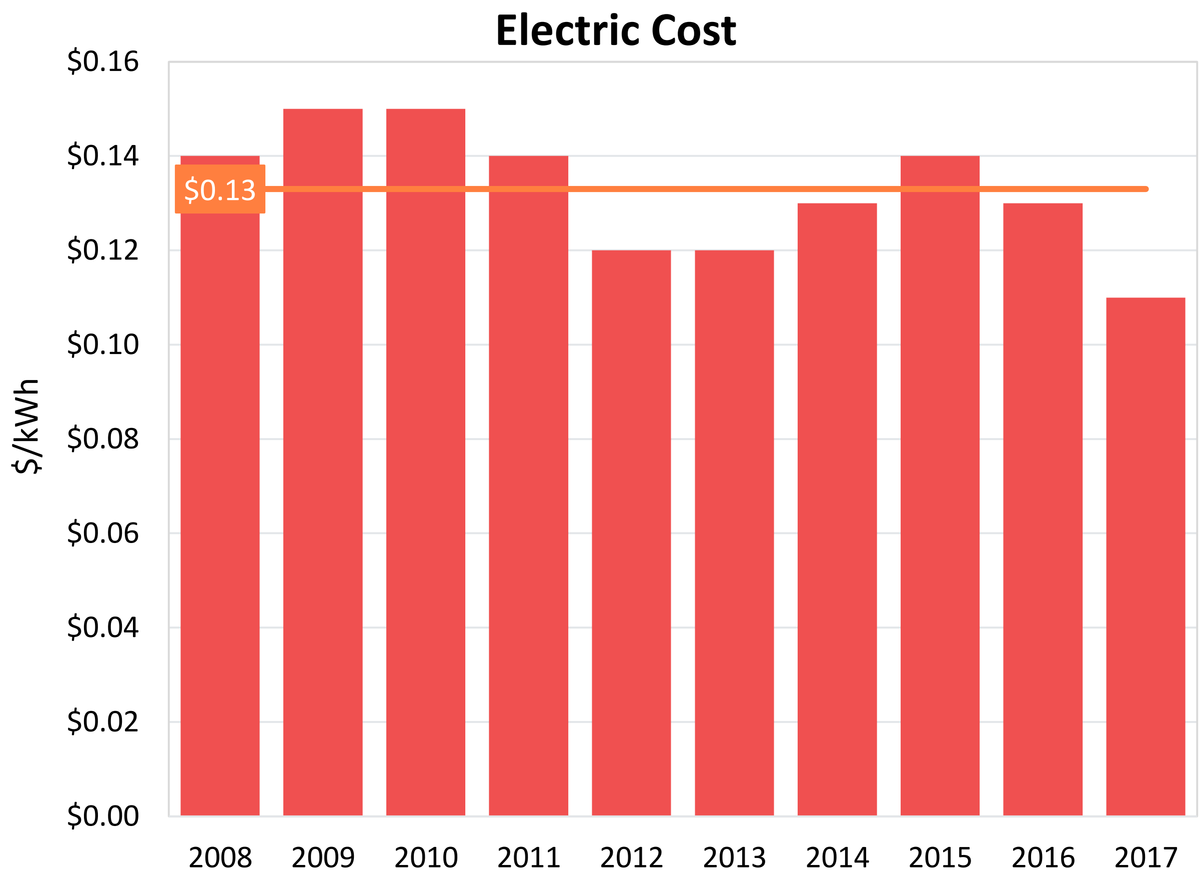
Consumption Sees Slight Increase and Lower Costs

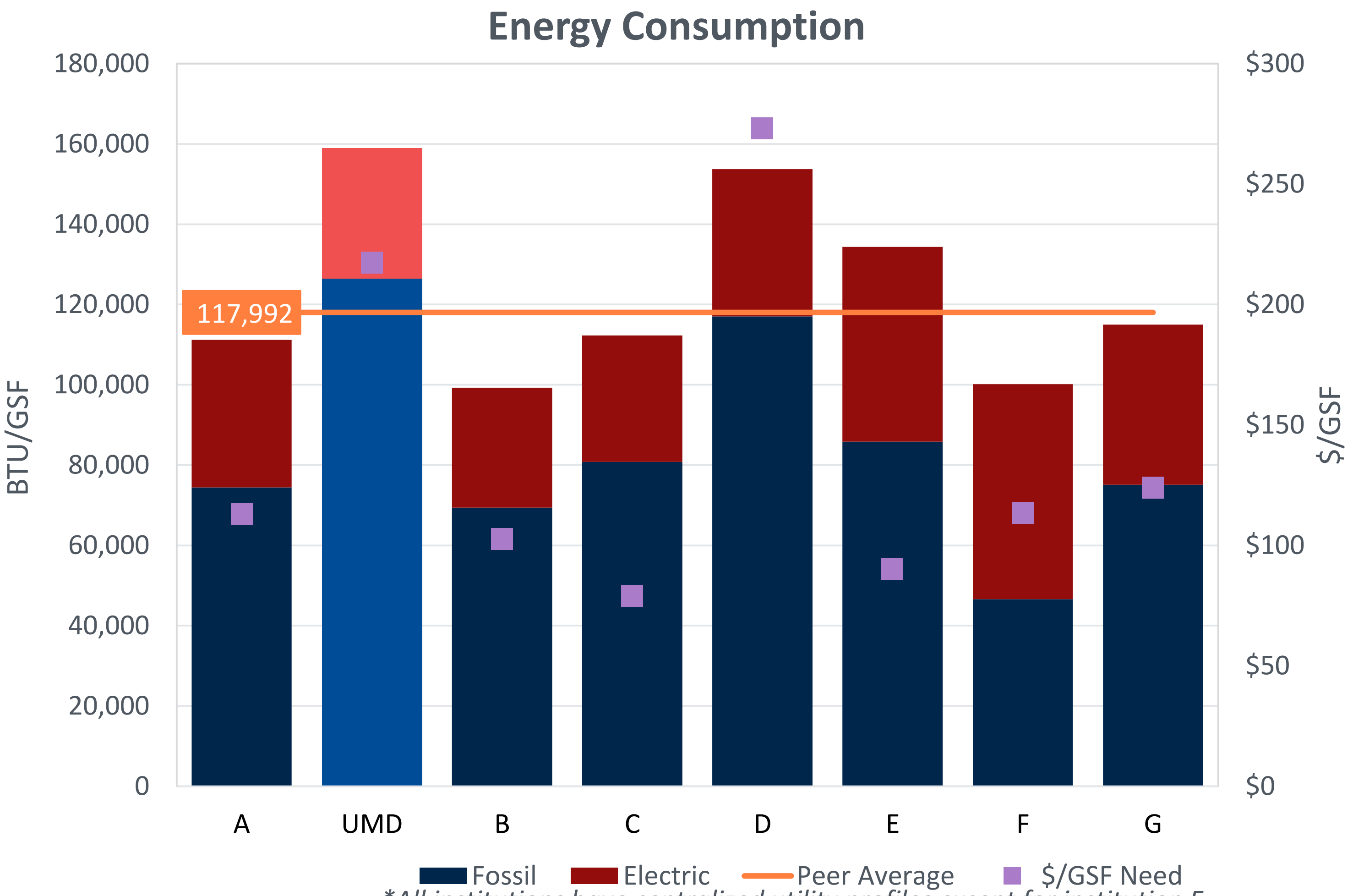
While increasing slightly in FY17, Electric consumption decreases over the past ten years



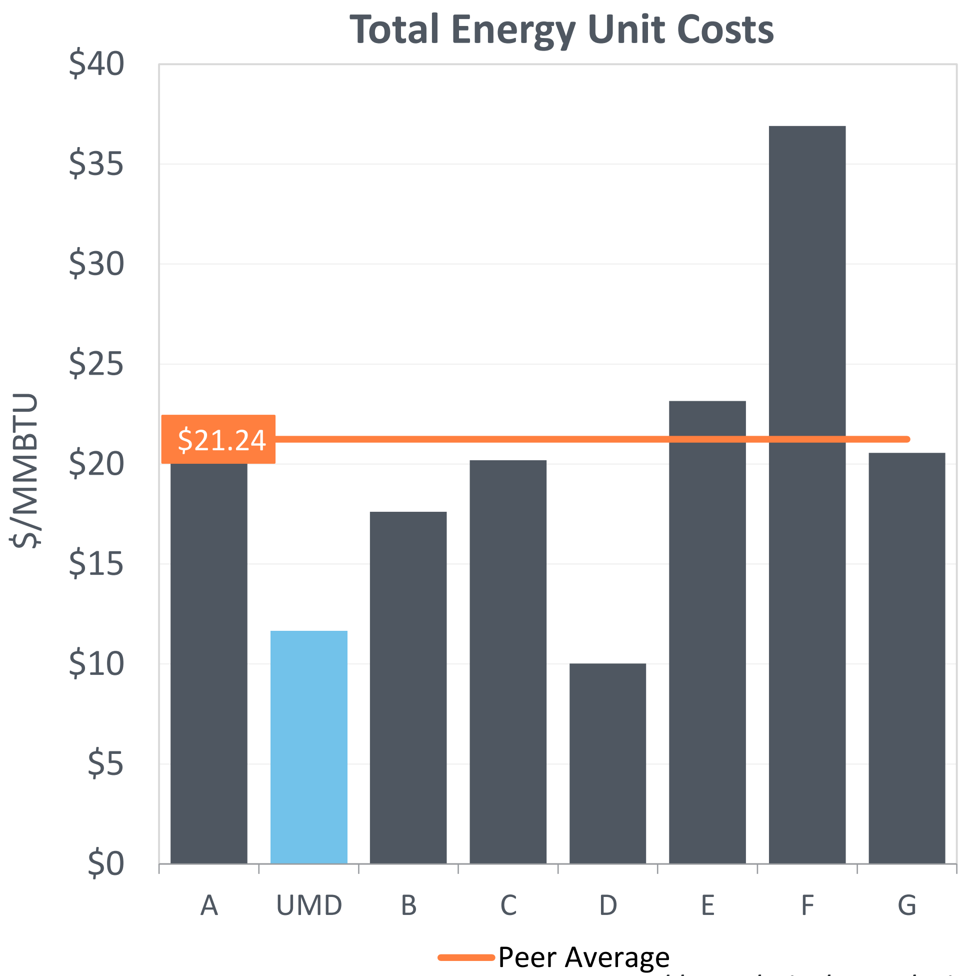


Energy Consumption Higher than Peers, Similar Costs

Higher backlog aligns with higher consumption



**All institutions have centralized utility profiles except for institution F*



Peers arrayed by technical complexity

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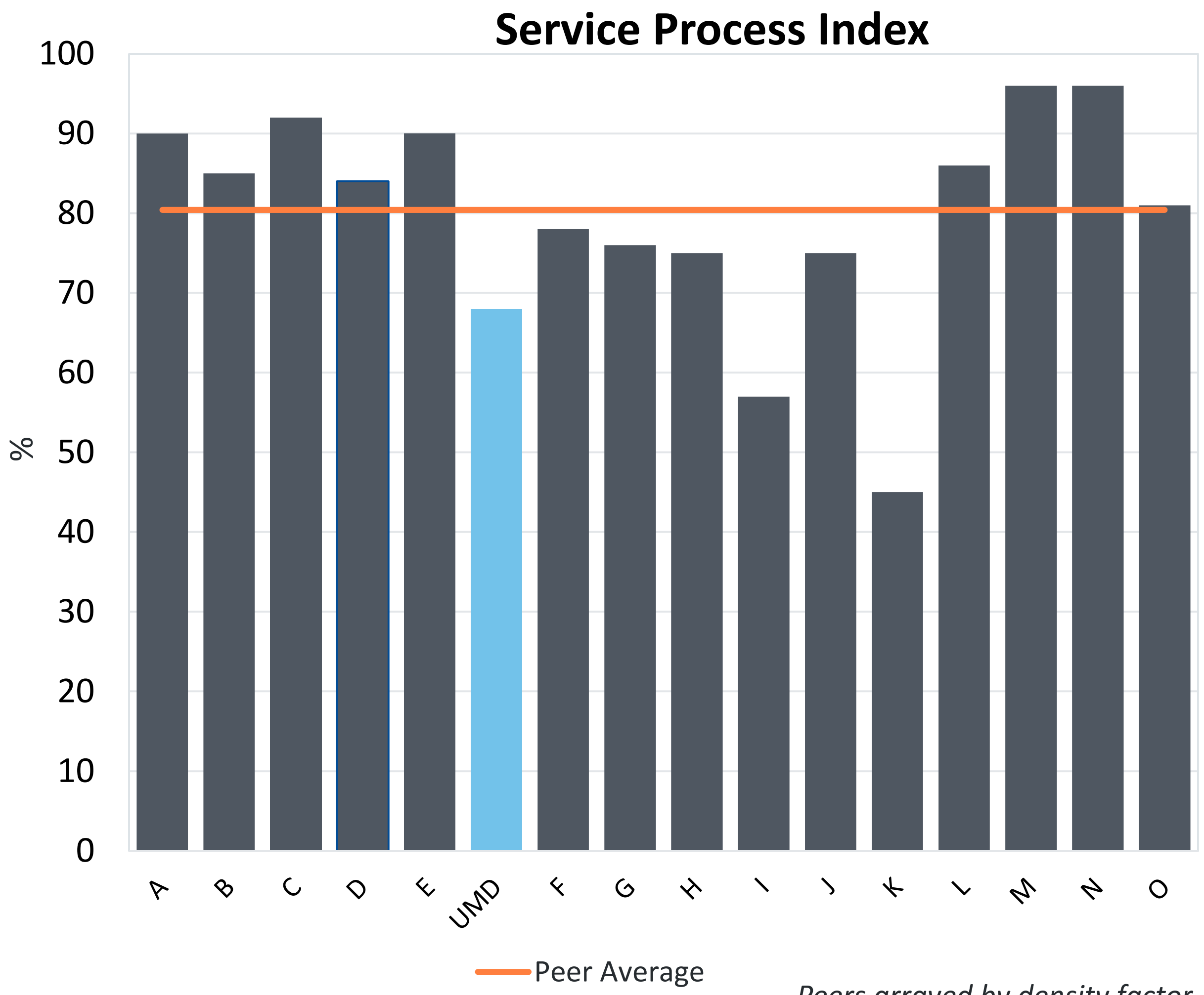
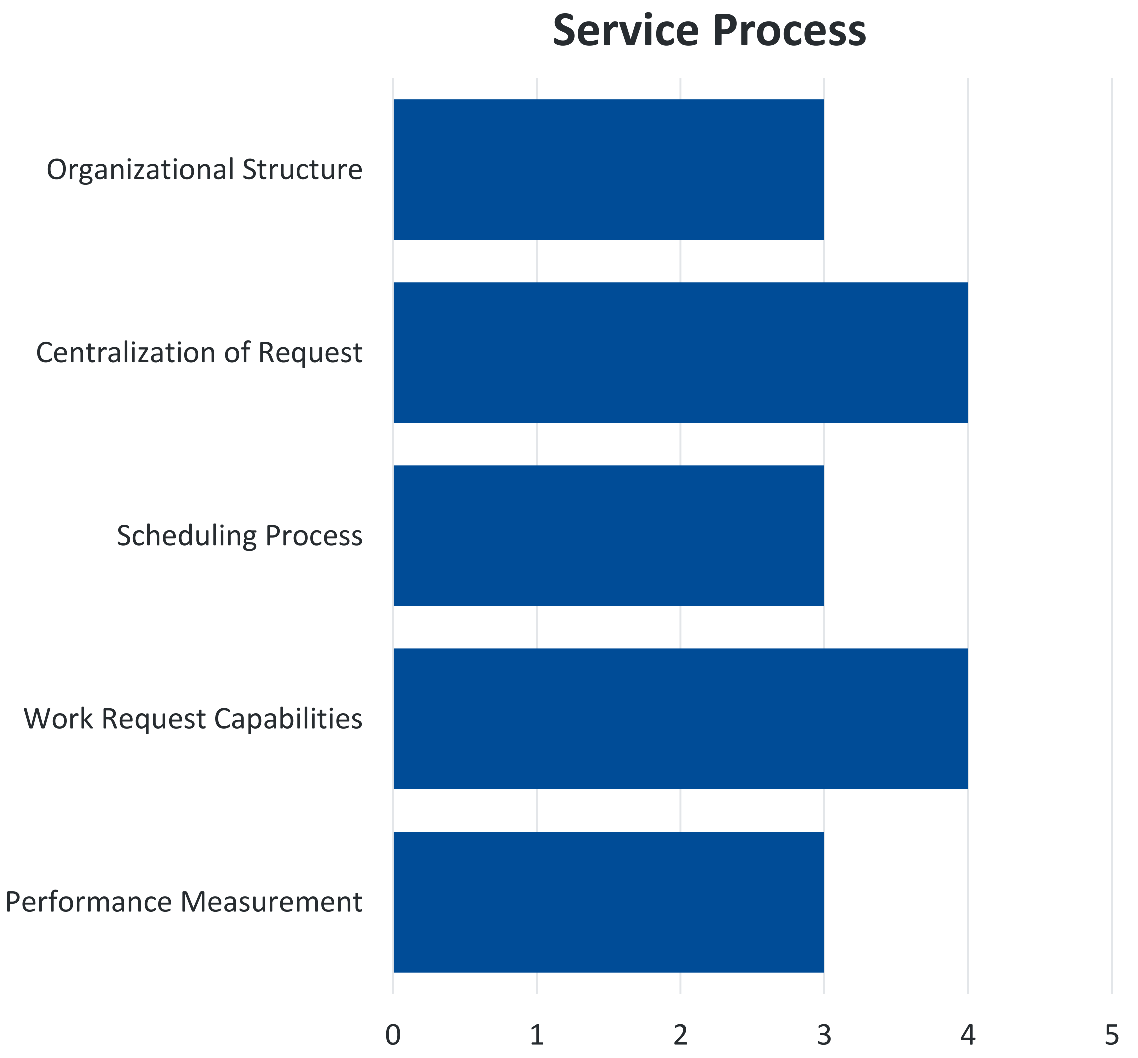
**UMD Energy Peer Group: Brandeis University, Connecticut College, Emerson College, Fitchburg State University, University of Rhode Island, Wellesley College, Wesleyan University*

Opportunities with the Work Order System

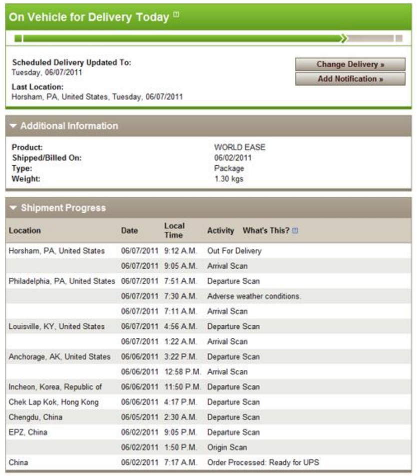


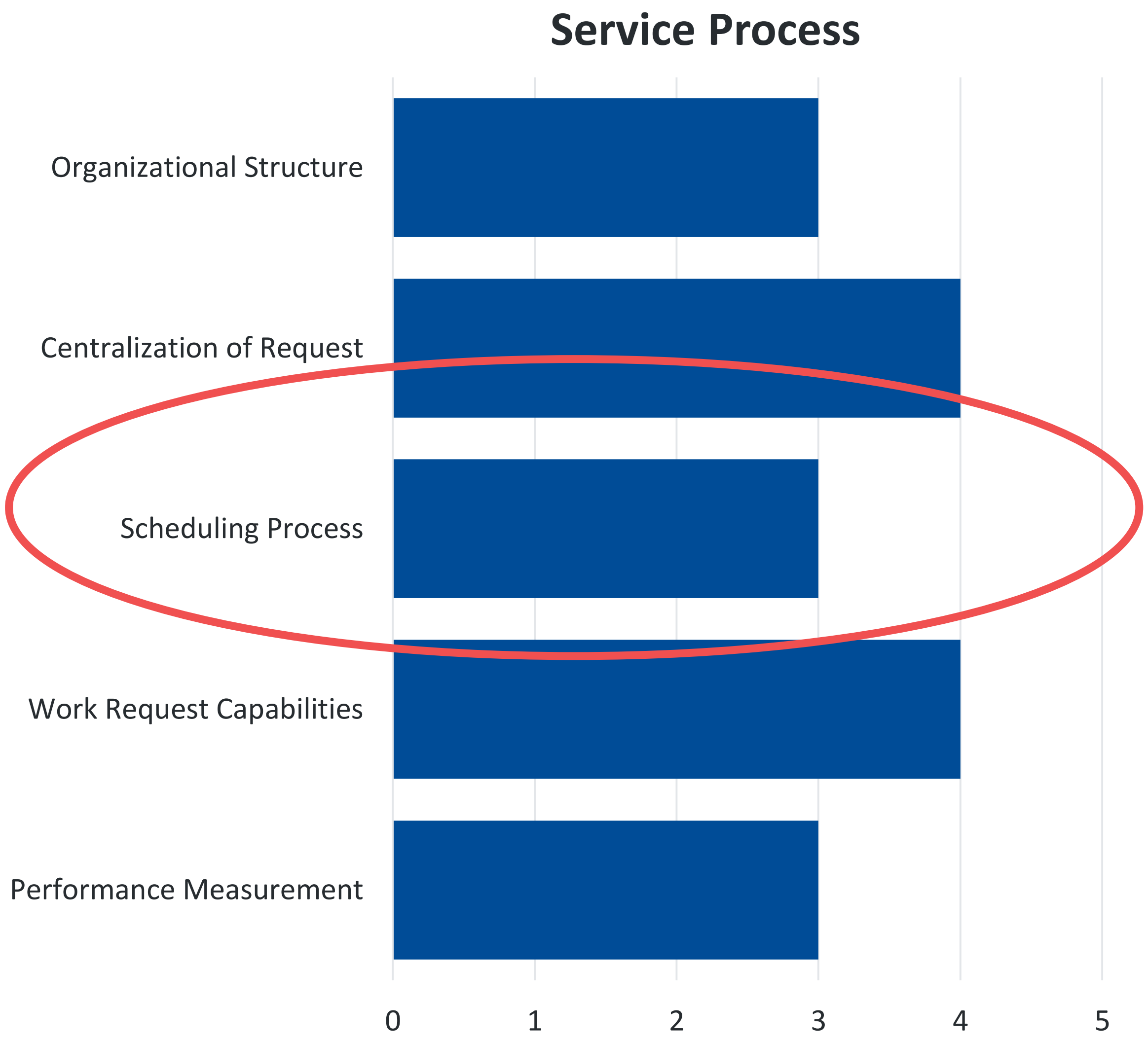
Peers arrayed by density factor



Opportunities with the Work Order System

Work Order System - Scheduling Process
Schedules are communicated to the customer
Changes in the schedule are communicated to the customer
Customers can access the current status of work requests through a web-based system
Changes to work request status are communicated to customer
Customer satisfaction is surveyed after work request is completed





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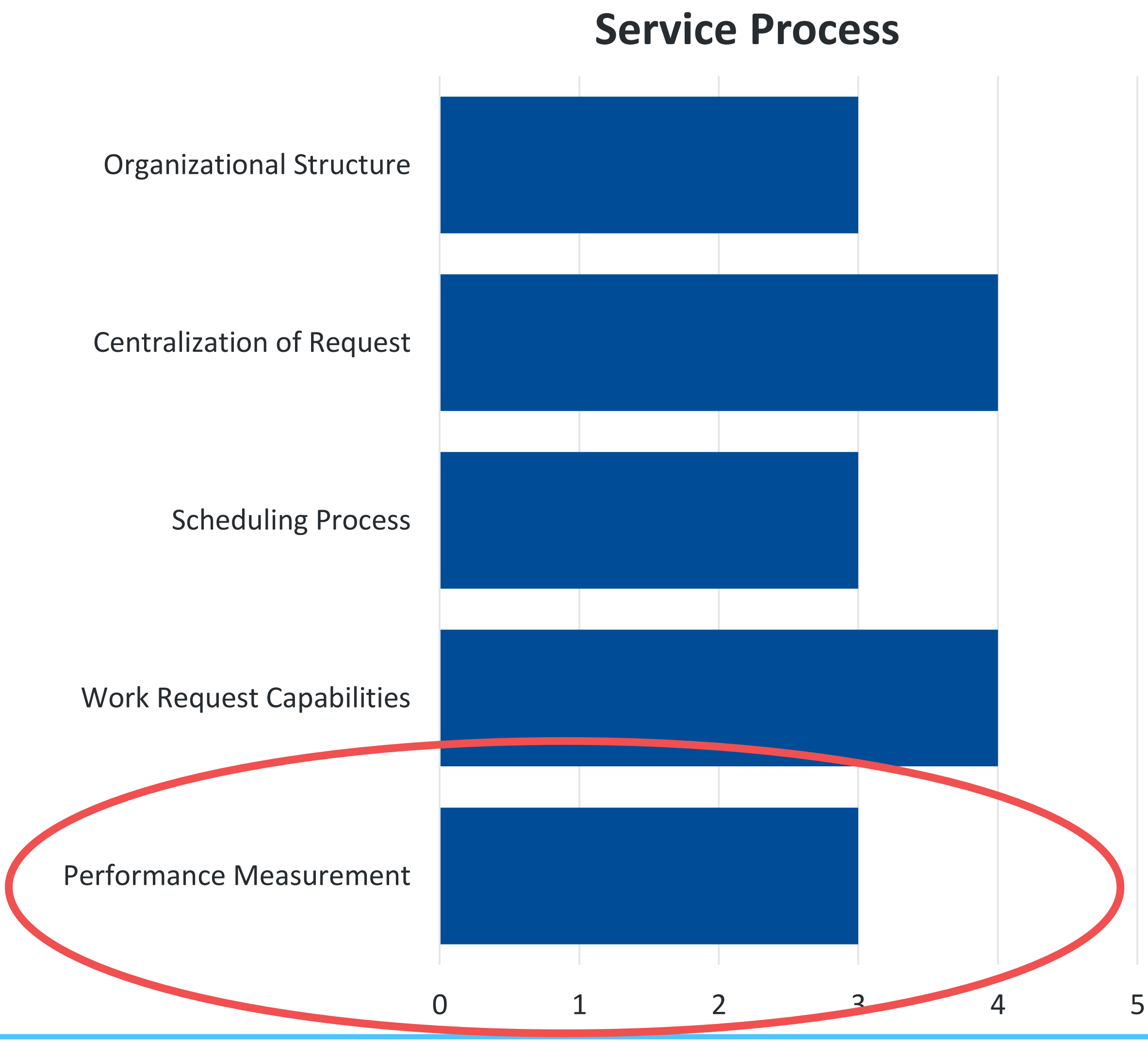
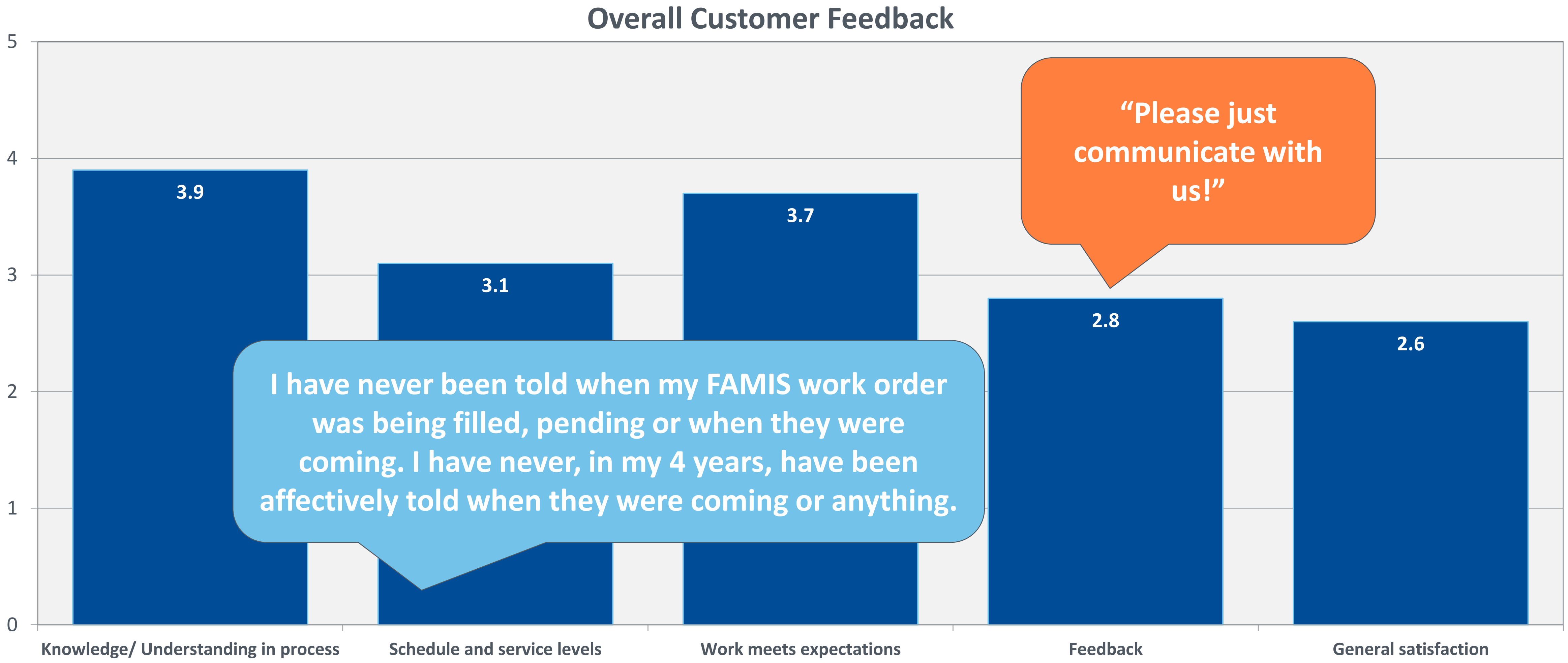
Opportunities with the Work Order System

Performance Measurement
Service desk personnel are adequately trained to run reports and manage system
Reports are regularly run for age of work requests (days from open to closed)
Reports are regularly run for time to complete work requests (labor hours)
Reports are regularly run for costs to complete work by work type
Reports are regularly run for costs to complete work by location
Reports are regularly run for costs to complete work by craft/trade
Findings from reports are used to support project list generation
Reports are run for customer feedback and satisfaction
Backlog of work requests is updated and re-prioritized



Customer Satisfaction Survey



Concluding Comments

- Age of campus and lack of consistent capital investment drives backlog of need over $200/GSF.
- Large infusions of capital in buildings flagged with high risk, high need will drastically reduce the overall campus need and risk. Given the need, the strategy should be major building renovations, not systemic repairs.
- Establish a recurring Facilities Fund. Start at peer levels, funding at 30% of the Sightlines Annual Target at $4.65M and grow to meet 100% of target.
- Continue to grow Planned Maintenance through Facilities' operational resources.
- As supervision levels align with peers through attrition, replace those positions with additional working staff.
- Update and education campus on work order schedules. Continue to monitor customer expectations through the Sightlines Customer Satisfaction Survey.

Questions and Discussion

EXHIBIT C
COMPETITIVE ENERGY SERVICES – RENEWABLE ENERGY CREDIT ASSESSMENT

COMPETITIVE ENERGY SERVICES

MEMORANDUM

Energy Master Plan Appendix

TO:	University of Massachusetts Dartmouth
FROM:	Competitive Energy Services
DATE:	December 23, 2020

Executive Summary

Competitive Energy Services ("CES") is supporting the University of Massachusetts Dartmouth ("UMD") in developing an Energy Master Plan to decarbonize campus operations and to achieve Carbon Neutrality. UMD has retained Ramboll to study energy production and distribution solutions for UMD to reduce greenhouse gas emissions associated with the campus' onsite fossil fuel consumption, so-called Scope 1 emissions, and options to reduce emissions associated with the campus' electricity purchases, so-called Scope 2 emissions, in order to meet the Commonwealth's emissions targets for state agencies in Executive Order 484. In addition, as a signatory of the American College & University Presidential Climate Commitment ("ACUPCC"), UMD has committed to achieving Carbon Neutrality by 2050. To do so UMD will need to achieve net zero emissions from all direct and indirect campus emissions sources.

This memorandum identifies and compares UMD's options to 1) acquire and retire supplemental Renewable Energy Credits ("RECs") from renewable electricity generation sources so that UMD can offset 100% of the campus' Scope 2 emissions and 2) to acquire and retire carbon offsets from emissions mitigation projects so that UMD can offset 100% of the campus' remaining emissions from Scope 1 and Scope 3 sources. Together, these two procurement actions will enable UMD to claim Carbon Neutrality and meet its ACUPCC goal. Procuring supplemental RECs to eliminate the campus' Scope 2 emissions also helps UMD make progress towards meeting the emissions reduction targets set forth in Executive Order 484.

UMD has two options to acquire and retire supplemental RECs – (1) UMD can purchase RECs from existing generators through spot purchases or under short-term contracts and/or (2) UMD can purchase RECs from new generation projects under one or more long-term agreements. These options have varying cost, additionality, geographic, and contracting characteristics that require careful consideration. UMD's options to acquire carbon offsets similarly have a range of costs depending on offset projects' additionality and location.

CES estimates that UMD's costs to purchase and retire supplemental RECs in sufficient quantity to eliminate the campus' Scope 2 emissions by 2030 could range from $12,000 per year to $480,000 per year, with the higher end of the range providing full additionality and better geographic proximity to campus. To acquire carbon offsets in a sufficient quantity to fully offset the campus' remaining Scope 1 and Scope 3 emissions, and therefore to achieve UMD's aspirational target of Carbon Neutrality by 2030, CES recommends UMD assumes a preliminary budget of $122,000 per year in addition to the cost for supplemental RECs.

Renewable Electricity Procurement

Campus Electricity Use and Sources Through 2040

To estimate future electricity use on the UMD campus we have used Ramboll's projections developed in the Energy Master Plan's Reference Case and Alternative Case. Ramboll's Alternative Case includes the phased conversion of the campus' energy infrastructure from the existing steam-based system to new district low-temperature hot water and chilled water systems with a large-scale borehole thermal energy storage system.

Ramboll's projection of campus electricity use in the Alternative Case between 2020 and 2040 is shown in Figure 1. As a result of the electrification of campus heating, total electricity use on campus is expected to increase by approximately 50% from current levels once the infrastructure conversion is completed in 2035. This timeline aligns with the end of UMD's 20-year contractual arrangement and debt service for its central heating plant's combined heat and power ("CHP") system installed in 2015. As Ramboll notes in the study, the final implementation timeline of the Alternative Case may change depending on funding availability, UMD's approach to the final years of the CHP's contract, and system design and construction requirements. Based on the extensive excavation and construction work that would be required to implement the Alternative Case, it is unlikely that campus electricity loads are significantly impacted by the conversion until at least 2030.

Figure 1 Campus Electricity Use: 2020 – 2040

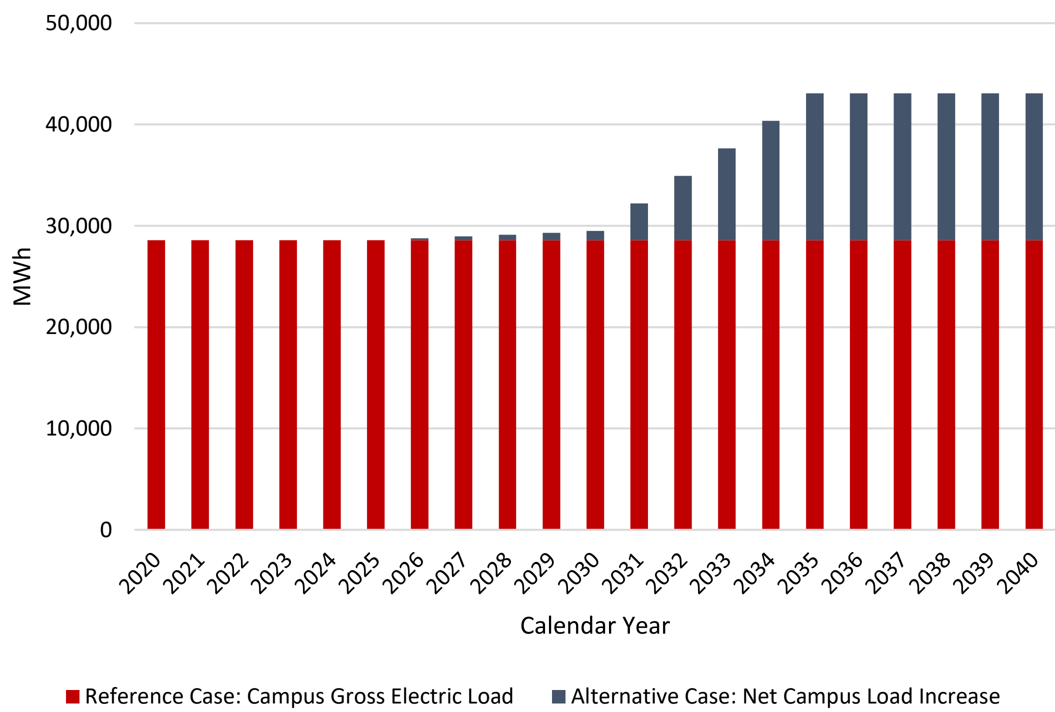
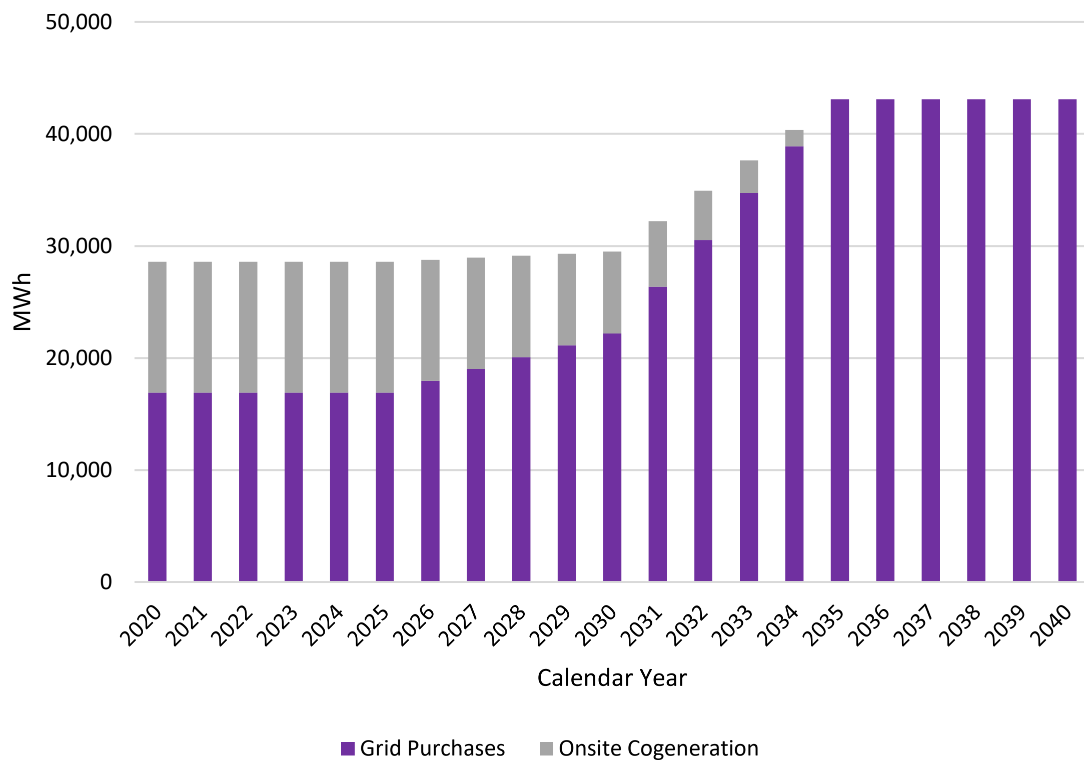


Figure 2 shows where UMD's electricity is forecasted to come from over the next 20 years. Today, roughly 40% of the electricity used on campus is generated by the CHP's electric cogeneration system. In the

Alternative Case, onsite cogeneration (shown in the gray bars in Figure 2) from the CHP system is phased down between 2025 and 2035, resulting in virtually all of the electricity used on campus being purchased from the grid (shown in the purple bars in Figure 2) beyond 2035. The exception will be electricity generated by several existing rooftop solar systems on campus buildings. The annual generation from these existing systems is small and is not shown in Figure 2.

Figure 2 Campus Electricity Sources: 2020 – 2040



Emissions Accounting & REC Volumes

A REC is a tradeable certificate that represents the environmental attributes of one megawatt-hour ("MWh") of electricity generated by a renewable energy source.[1] One REC is produced for each MWh of renewable electricity generated. By purchasing and retiring (i.e., not reselling) a REC, UMD can offset its Scope 2 emissions associated with electricity purchased and imported from the grid. We expect the Energy Master Plan will call for UMD's Scope 2 emissions to be offset in their entirety by 2030 to advance progress towards meetings the emissions reduction targets included in Executive Order 484.

Scope 2 emissions are offset one-for-one – that is, a REC must be retired for each MWh of grid electricity and onsite solar generation UMD purchases. While a REC must be purchased and retired on UMD's behalf

[1] It is important to note that UMD's purchase of RECs provides no physical delivery to UMD of the electricity generated associated with those RECs. Therefore, REC purchases have no impact on its decisions regarding how UMD chooses to procure its electricity supply.

to offset its Scope 2 emissions, the actual purchaser does not have to be UMD. In fact, most of the RECs that will need to be retired by UMD in the coming decades will be acquired and retired by UMD's retail electricity supplier pursuant to the supplier's obligations under Massachusetts' Renewable Portfolio Standard ("RPS") law and regulations. The RPS requires that all suppliers serving retail load in the Commonwealth meet their supply obligations by purchasing a certain percentage of electricity from renewable energy generators. Retail electricity suppliers do this by purchasing and retiring RECs in exactly the same way that UMD would do, but for the actions of the supplier.

We refer to these RECs retired by UMD's retail supplier as compliance RECs. Compliance RECs are not cheap. UMD is currently paying roughly $450,000 per year to its supplier to satisfy the RPS. In 2020, the cumulative RPS obligation is 27% of retail sales[2]. With the addition of the Clean Energy Standard Expansion[3] ("CES-E"), the cumulative RPS obligation will increase to 49% in 2021 and will subsequently increase by an average two percentage points a year until it reaches approximately 80% in 2040 and 100% in 2050.[4] These compliance obligations are presented in Figure 3 by program component.

The compliance REC retirements made by UMD's supplier are made on behalf of the campus and provide the same degree of Scope 2 emissions offset as would be the case if UMD acted as its own retail supplier and made the compliance REC purchases and retirements itself.[5] Because the Massachusetts RPS percentages are less than 100% for the next three decades (assuming current state law), UMD must act directly to purchase and retire RECs for that portion of its electricity grid purchases not covered by the actions of its supplier in order to offset 100% of its Scope 2 emissions. We refer to these as supplemental RECs. UMD's estimated supplemental REC need through 2040 are shown in Figure 4, hovering between roughly 7,500 RECs and 12,000 RECs per year between 2021 and the early 2030s before declining to zero in 2050. Despite increasing campus electric use in the Alternative Case due to campus electrification, the Commonwealth's increasing RPS obligation makes the volume of supplemental RECs UMD must purchase and retire to offset 100% of its Scope 2 emissions manageable.

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[2] This percentage includes all RECs qualifying for Massachusetts' Clean Energy Standard (includes Class I), Clean Energy Standard Expansion, and Class II RECs that are associated with generation from plants that do not qualify as Class I but whose generation is nevertheless considered renewable by the Commonwealth. The Alternative Energy Portfolio Standard and Clean Peak Standard obligations are not included in this calculation because the two programs are structured to mandate alternative energy sources, not renewable electricity generation.

[3] CES-E aims to enable Massachusetts to claim the emissions credit from legacy zero emissions generation resources in New England and adjacent regional grids, including but not limited to nuclear generation from Millstone and Seabrook Stations and Quebec hydro from Phase II and NECEC.

[4] The 100% RPS outcome in 2050 is an estimate. The CES-E compliance obligation starts at 20% of retail load in 2021 but in subsequent years is based on a formula that reduces the obligation if statewide retail electric sales increase. We have assumed state retail sales increase an average 2.0% per year between 2020 and 2050, resulting in a roughly 75% increase in statewide electric load compared to today. The actual level of load growth over the next thirty years will depend on the extent to which the state drives electrification of space heating and transportation.

[5] We note that they also provide the same degree of emissions offset as would be the case where UMD retires RECs from a renewable energy project it owns that is located behind the UMD meter. Any distinction drawn between these three cases – (a) non-compliance RECs from renewable generation located behind the UMD meter, (b) compliance RECs purchased by UMD acting as its own retail electricity supplier and (c) compliance RECs purchased by UMD's retail electricity supplier are artificial. They are not based on differences in emission consequences of the three cases, because there are no differences.

Figure 3 **Massachusetts Renewable Energy Compliance Obligations: 2020 – 2050**

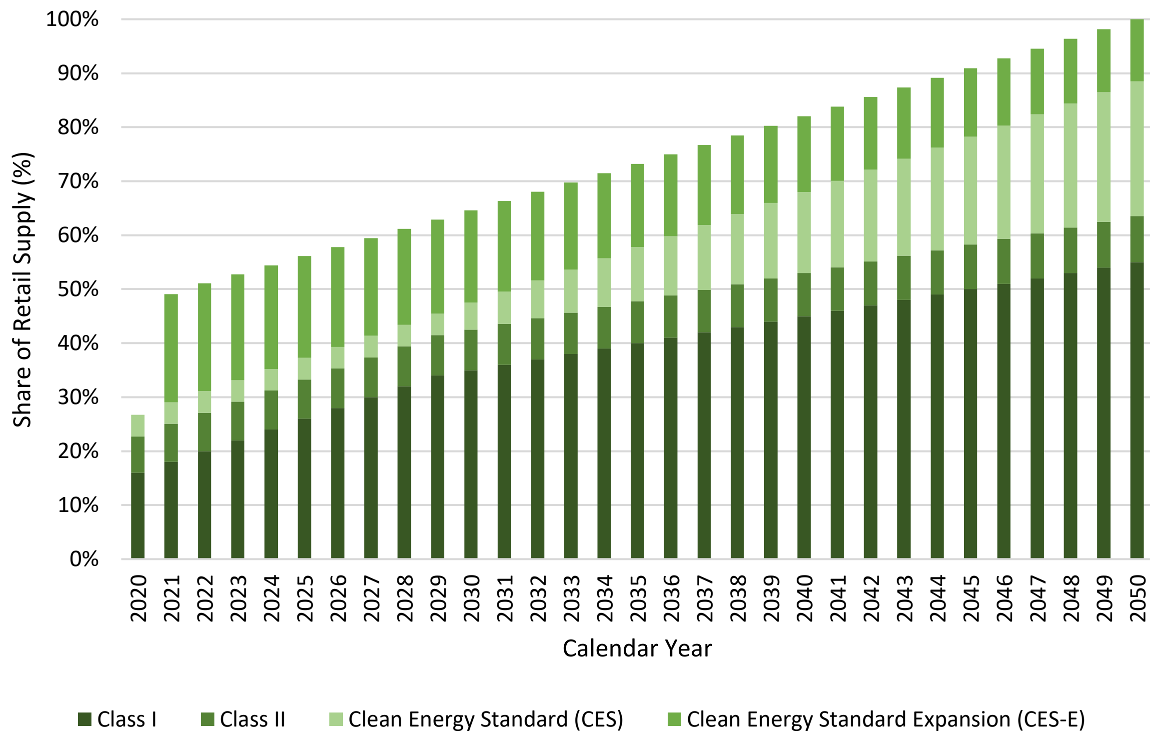
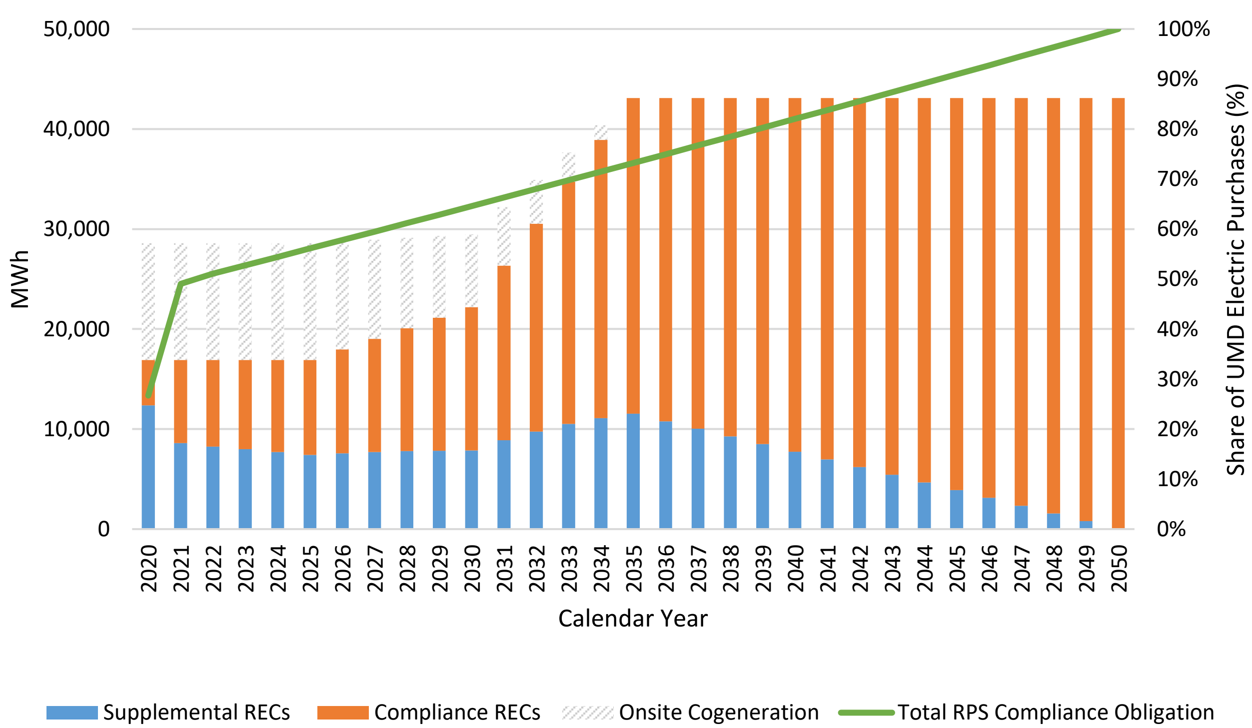


Figure 4 **REC Requirements to Offset 100% of UMD Scope 2 Emissions**



Options for Purchasing and Retiring RECs

The first option for UMD to acquire and retire supplemental RECs is from renewable generation located on campus. This type of renewable generation meets two important criteria – additionality and geographic proximity. To the extent that UMD elects to install new rooftop, ground-mounted, and/or solar parking canopies onsite, the campus can choose to retain and retire the RECs generated by behind-the-meter systems. The challenge with this option is that the actual or implied costs of these RECs are quite high. With current renewable generation installation costs, UMD's physical footprint, and the design of Massachusetts' solar incentive programs, we do not believe that UMD can economically meet its full supplemental REC need under the Alternative Case by only using onsite renewable generation. UMD would need to deploy an estimated 7 MW of solar generation on or adjacent to campus and own and retire all RECs generated by the system(s) to be able to claim a 100% offset in the campus' expected Scope 2 emissions. Installing solar generation at this scale behind the campus' meter would require a dedicated footprint of 35 - 50 acres for the system and would require substantial upgrades to UMD's internal electric system and the campus' interconnection with Eversource's local transmission system.

Another challenge to this approach is the design of state solar incentives. To receive generous state financial incentives for new solar installations, system owners must now forfeit ownership of all RECs to the local electric utility for 20 years. UMD would face significantly higher purchase pricing for onsite solar if the campus elects to forego the state incentive in order to be able to own the RECs. Let's consider this challenge in the case of solar parking canopies, the most likely solar technology UMD will install onsite based on the campus' planned land use. UMass Amherst is planning to install 3 MW of new solar parking canopies on campus in the next year. With the current state incentives and a third-party system owner, the campus' power purchase agreement rate for the parking canopies will be approximately $85 per MWh. UMass Amherst's unsubsidized power purchase agreement rate without the incentive would triple to $250 per MWh for a 20-year term.[6] Based on this economic proposition, UMass Amherst elected to forego owning the system's RECs in order to achieve the lower purchase pricing.

The second option is for UMD to purchase and retire supplemental RECs from renewable generators located off campus. These RECs could be from existing large-scale solar and/or wind projects in the Midwest, Southwest U.S., and/or New England. As with the first option, UMD can claim offsets to its Scope 2 emissions by purchasing and retiring RECs from any of these generation facilities. This option offers very low costs but sacrifices additionality and may sacrifice geographic proximity. We refer to this option as the Green-e option, described in more detail below.

The third option is for UMD to execute one or more long-term virtual power purchase agreements ("VPPA") with a project developer to construct a new renewable generator located off campus in

[6] Another example of this challenge is community solar and net metering projects. While UMD has contracted with multiple megawatts of solar generation projects located off campus in the South Shore region, UMD is unable to claim any of the renewable benefits associated with this generation. Similar to the first option, ownership of RECs from these projects comes with a significant price premium, which would erode the economic benefits that UMD currently enjoys from its net metered contracts. New community solar and net metering projects may still be developed but are expected to continue rely on lucrative state incentives paid in exchange for the RECs generated.

Massachusetts or out of state.[7] These offsite projects could range in size from small community-scale solar (5 - 10 acres) to utility-scale generation projects (250 - 500+ acres). There are several examples of UMD's peers executing VPPAs in recent years, including the Massachusetts Institute of Technology executing a VPPA with a new utility-scale solar project in North Carolina and several liberal arts colleges in Massachusetts executing a VPPA with a new utility-scale solar project in Maine.[8] This option provides additionality and perhaps geographic proximity but is likely to cost significantly more than the Green-e option.

Green-e RECs

A common way colleges and universities acquire and retire RECs to claim offsets in their Scope 2 emissions is by purchasing RECs from existing generators in voluntary markets. Voluntary markets refer to REC sales where an end user acquires and retires RECs on a voluntary basis; that is, the purchase and the retirement of those RECs does not help an end user satisfy compliance obligations under a state renewable portfolio standard, regional greenhouse gas trading program, or other mandated program.

There are numerous sellers and marketers of RECs serving the voluntary market. UMD can conduct a competitive solicitation process to select a provider of such RECs. If UMD were to conduct a solicitation for RECs, the campus would need to decide which certification and verification program to utilize for contracted RECs. There are several different programs that REC sellers and buyers operating in the voluntary REC market can use to certify and verify that purchased RECs are credibly sourced from renewable generation and are not being counted towards other institutions' emissions inventories. CES recommends acquiring only Green-e-certified RECs.

Green-e Energy is the leading independent certification and verification program for voluntary REC purchasing in the U.S. The Green-e certification program is administered by the Center for Resource Solutions, a nonprofit organization based in San Francisco, California. To be certified as offering a Green-e product a REC seller is required to disclose the quantity, type and geographic source of each REC certified. There are four primary criteria for Green-e certification. First, electricity must come from eligible generation sources, which include wind, solar, geothermal, and certain biomass and low-impact hydropower plants. Second, only renewable generators built within the last 15 years of a sale date are certified under the Green-e label. For Green-e RECs sold in 2020 eligible generators had to have begun operations or been repowered after 2006. Third, Green-e RECs cannot be used by a party to satisfy a state-mandated renewable energy program. Lastly, Green-e RECs sold in a given calendar year must be generated within the 12 months of that calendar year, the six months before the calendar year began, or the three months after the calendar year has ended. This creates a 21-month window of eligible generation dates from which renewable energy generation can be used toward Green-e certified sales in any given year.

The most attractive aspects of Green-e RECs are their low cost and short contract terms. The price of Green-e RECs is approximately $1 per MWh, inclusive of transaction fees. As discussed elsewhere, the price

[7] This contract could be structured in two ways: for physical delivery of contracted energy and RECs to UMD if the generator is located in New England or as a virtual settlement whereby UMD only acquires RECs from the project. A virtual settlement can be in all cases regardless of whether the generator is located in New England or outside the region.

[8] More information on Amherst, Hampshire, and Smith Colleges' VPPA can be found at https://www.competitive-energy.com/news/2019/10/24/five-leading-liberal-arts-college-partner-to-create-new-solar-energy-facility-in-maine.

is a fraction of the cost CES estimates UMD will pay its electricity supplier for 2020 compliance with Massachusetts' mandated renewable energy programs, or of the potential cost UMD may pay for RECs from new in-region wind or solar generators today. Further, UMD would not have to commit to 10- to 20-year contract terms like it would for a new renewable generator through a VPPA. Unbundled RECs can be purchased through one-time transactions in the spot market or through short term contracts running between one and five years, providing buyers flexibility to modify contracted volumes or purchasing strategies over time.

While purchasing RECs from existing generators provides a low cost, flexible means for UMD to claim Scope 2 emissions offsets, this approach is increasingly being viewed critically by students, communities, and policymakers. Criticism is based in the contention that many existing renewable generators that produce Green-e RECs would likely be operating without the REC sales revenue, and therefore the purchase of RECs does not have an incremental impact in reducing global emissions from electricity generation – that is, the project lack additionality.[9]

CES believes that Green-e RECs can provide a useful tool to meet some of UMD's REC purchase and retirement requirements if the campus has budgetary restrictions in the coming years, or if the campus is uncertain on the final timeline of potential infrastructure changes on campus coming out of the Energy Master Plan. While purchasing trends around the country clearly show a preference among higher education institutions to shift away from Green-e RECs from existing generators and to more highly favor projects that provide additionality, CES is finding that most institutions with carbon reduction objectives are continuing to utilize this tool, for at least a portion of their Scope 2 related emissions offsets and are likely to do so for some time to come.

Virtual Power Purchase Agreements

A contract for differences ("CFD"), or virtual power purchase agreement ("VPPA") as it is known in the electric generation industry, is a contract that fixes the future price of a commodity or other good or service. CFDs are widely used in the U.S. economy for long-term business arrangements. Among the more common uses of CFDs are in finance, where a CFD is referred to as an interest rate fixed for floating swap, and in transactions involving foreign currencies.

This same concept works for long-term electricity contracts. A VPPA allows UMD to enter into a long-term contract with a new, large-scale wind or solar generator located remotely from UMD's campus. The generator could be located in Massachusetts, in other New England states, or outside the region. For project developers a VPPA with a credit-worthy counterparty like UMD provides a financeable contract to construct a generation project. For UMD, a VPPA provides a means to leverage the pricing advantages of large-scale offsite renewable energy development and to demonstrate additionality in its REC purchases. Importantly, a VPPA does not require physical delivery of energy generated by the project, so UMD would have the option

[9] A related argument among critics of unbundled Green-e RECs is that investment in new wind generation, the largest source of unbundled Green-e RECs in the country, has been largely driven by federal incentives for renewable energy and not by project owners' expectations of REC revenue as a primary value stream. This, however, is not as significant a source of criticism as the additionality issue.

to continue purchasing electricity supply for use on campus from the competitive market or from the local utility's default service.[10]

Under a VPPA, UMD would agree to pay a fixed price to the generator for electric energy and RECs generated at its facility. Let's say that price for energy and RECs is fixed at $50 per MWh for a term of 20 years. For every MWh of electricity that the generator produces and delivers to the grid UMD, would pay the generator $50. That same output would then be sold by the generator into the local spot market at a variable wholesale price. The generator would pay UMD the variable price corresponding to the period in which the MWh is delivered to the grid. If the variable market price for a MWh is $40 at the time the generation was delivered to the grid, the net cost to UMD would be $10. If the variable price for a MWh is $60, its net cost would be minus $10, and UMD would receive $10 in payment from the generator.

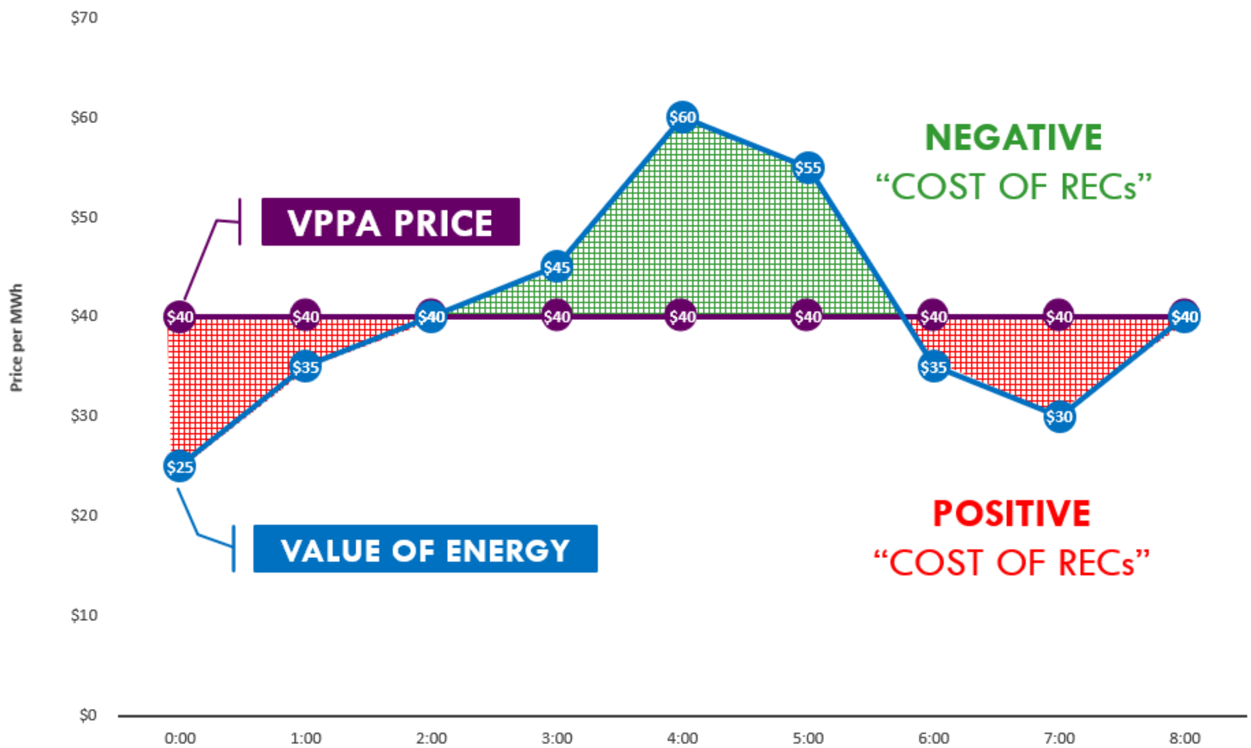
This hourly settlement process is shown below in Table 1 and illustrated in Figure 5. At the end of each month, UMD would receive an hourly reconciliation of generation and corresponding variable market prices from the generator and either a payment or an invoice. This net settlement value is referred to as the "implied REC cost". If the net settlement requires UMD to make a payment to the generator, the implied REC cost is a positive value. If the net settlement amount is negative and UMD receives a payment from the generator, the implied REC cost is negative.

Table 1 VPPA Hourly Settlement Process - Example

Hour Ending 1	
$50 per MWh	Fixed price UMD guarantees generator
-$40 per MWh	Energy price generator receives from local spot market
$10 per MWh	Implied REC cost (positive value indicates UMD owes generator)
Hour Ending 2	
$50 per MWh	Fixed price UMD guarantees generator
-$60 per MWh	Energy price generator receives from local spot market
-$10 per MWh	Implied REC cost (negative value indicates generator owes UMD)
Hour Ending 3	
$50 per MWh	Fixed price UMD guarantees generator
-$50 per MWh	Energy price generator receives from local spot market
$0 per MWh	Implied REC cost (zero value indicates neither party owes the other)
Hour Ending 4	
$50 per MWh	Fixed price UMD guarantees generator
-$20 per MWh	Energy price generator receives from local spot market
$30 per MWh	Implied REC cost (positive value indicates UMD owes generator)

[10] While there is never "physical" delivery under a VPPA in the common-sense notion of the term, geographic proximity between the generator and UMD contracted using a virtual settlement can convey similar benefits as a physical contract for delivery of energy and RECs in certain cases.

Figure 5 **VPPA Hourly Settlement Example**



Indicative VPPA Pricing & Implied REC Costs

Table 1 presents a range of prices for different renewable generator project types based on recent competitive VPPA solicitations CES has administered for other colleges, universities, and private companies. The indicative prices shown in Table 2 are fixed for contract terms between 10 and 20 years, depending on the project location, and are for electric energy (to be sold and netted as described above) and RECs. These RFPs have requested project pricing for new renewable generators throughout New England and across other U.S. regions. Responses have included wind projects throughout the Midwest, Texas, the Mid-Atlantic, and Maine and solar projects throughout the Southwest, Texas, the Mid-Atlantic, and New England. CES can provide indicative pricing for other states or regions as requested by UMD.

Table 2 **Indicative VPPA Pricing Range by Generation Type and Project Location**

Generation Type	Low End ($ per MWh)	High End ($ per MWh)	Mid-Point ($ per MWh)
New England Solar	$50	$60	$55
Maine Onshore Wind	$65	$75	$70
Nebraska Wind	$15	$25	$20
Texas Solar	$20	$30	$25

It should be emphasized these prices are indicative only. The timing of a competitive solicitation issued by UMD, and resulting term and magnitude of the MWh commitment, will ultimately dictate project pricing received. Over the next decade there are several factors that could raise or lower pricing from new renewable generation. Key federal incentives for wind and solar systems are set to phase down in the coming years. All other things being equal, we would expect the phasing out of these tax advantages to raise pricing for new projects. On the other hand, the wind and solar industries are projecting continued cost declines that could help counteract declining external incentives and could produce lower project pricing for VPPAs executed later this decade.

To take advantage of new technologies and falling unit costs for wind and solar and to allow flexibility to respond to changing conditions in U.S. electricity markets and policy over time, CES recommends the UMass System considers organizing long-term REC purchases for multiple campuses into tranches that are implemented in phases. UMD's supplemental REC needs are relatively small compared to a utility-scale generator's output, so leveraging the purchasing power and grid purchases across the UMass System could help maximize the University's purchasing power. Based on the timeline being considered in the Energy Master Plan, supplemental REC proposals could be solicited in multiple tranches over the next 10 years. For example, one RFP could be run in 2021/2022 and a second RFP being administered in 2025/2026. Because new renewable generation projects often require 2-3 year lead times to come on-line, RECs would likely not become available until 2024/2025 under the first solicitation and until 2028/2029 under the second. Further, because VPPAs have contract terms between 10 and 20 years, the resulting contracts would expire before 2050, ACUPCC's Carbon Neutrality target date. UMD would need to complete a follow up solicitation to acquire additional RECs to meet the campus' emissions goals for 2050 and future years.[11]

Comparing the mid-point indicative prices for each generation type and location – $55 per MWh for New England solar, $70 per MWh for Maine wind, $20 per MWh for Nebraska wind, and $25 per MWh for Texas solar – with the value of energy in those respective markets, there are clear pricing advantages for out-of-region renewables. The better economies of scale and production factors for wind generation in the Midwest and solar generation in Texas or the Southwest generally produce lower pricing for RECs that offer additionality than from new solar or onshore wind facilities in New England. In recent RFPs CES has seen the implied REC prices for out-of-region wind and solar between 40% and 70% lower than implied REC pricing for projects located in New England.

To estimate the REC costs for UMD, CES has applied the mid-point prices shown in Table 2 against local spot market prices in a project's corresponding location. This value of energy calculation shown in Table 3 represents the average value a renewable generator would have achieved in 2017, 2018, and 2019 based on the expected hourly generation profile of each generator. New England's higher wholesale electricity costs are driven by constrained natural gas pipeline capacity into the region that increases the cost of the marginal fuel (gas) used in the ISO New England generation fleet for most hours of the year.

[11] An RFP could explore VPPA options with longer contract terms to extend through 2050.

Table 3 Value of Energy by Generation Type and Project Location: 2017 – 2019

Generation Type	2017 ($ per MWh)	2018 ($ per MWh)	2019 ($ per MWh)	3-Year Average ($ per MWh)
New England Solar	$32.54	$42.01	$29.88	$34.81
Maine Onshore Wind	$33.26	$44.64	$32.63	$36.84
Nebraska Wind	$22.09	$21.88	$24.04	$22.67
Texas Solar	$26.70	$35.03	$25.26	$29.00

Table 4 completes the implied REC cost calculation by subtracting the three-year value of energy in each project location from the corresponding indicative mid-point purchase price. Table 3 assumes an annual purchase of 12,000 RECs per year by UMD. As noted above, the implied REC costs for projects in the Midwest and south are lower than for those in New England. In fact, over the past three years, Nebraska wind and Texas solar would have had negative implied REC cost, meaning UMD would have received a net payment over the three years instead of paying for the RECs.[12]

Table 4 Implied REC Cost Estimates: Annual Purchase of 12,000 RECs through a VPPA

Generation Type	Mid-Point Price ($ per MWh)	Value of Energy ($ per MWh)	Implied REC Cost ($)	Annual Cost 100% Status Quo Grid Purchases ($)
New England Solar	$55.00	$34.81	$20.19	$242,280
Maine Onshore Wind	$70.00	$36.84	$33.16	$397,920
Nebraska Wind	$20.00	$22.67	($2.67)	($32,040)
Texas Solar	$25.00	$29.00	($4.00)	($48,000)

While reviewing local wholesale prices retrospectively is a helpful tool to measure potential financial performance of a VPPA, the annual cost of RECs to UMD purchased through a VPPA will vary year to year depending on future conditions in the electricity market(s) where contracted project(s) are located and interconnected. First, with natural gas serving as the marginal generation fuel in most markets around the U.S., the future price of gas and the efficiency of marginal generators will be a key factor in determining future spot electricity prices. Trends in both factors indicate continued downward pressure on market clearing prices for electricity. Second, the penetration of renewable generation in a project's area and local transmission access are key, because wind and solar generation suppress spot pricing, especially where congestion arises due to limited transmission capacity to move renewably generated electricity to major metropolitan load centers. In those areas that are seeing large increases in renewable generation development, spot energy prices tend to be lower. CES reviews these factors, among others, as part of its cost analysis and risk evaluation for all REC RFPs it issues.

[12] We would not expect negative prices to continue. These implied negative REC prices will attract more renewable energy project development, which will tend to reduce market clearing prices.

Recommendations

The increasing percentage obligations under the Massachusetts RPS means that an increasing percentage of the costs UMD incurs to offset 100% of its Scope 2 emissions will be included in the price it pays its retail electricity supplier for electricity over the next thirty years. While we expect the implied per REC costs to fall over this period as Massachusetts improves its program designs and the costs of renewable energy projects decline in real terms, the lion's share of UMD's costs to offset its Scope 2 emissions will continue to be incurred through payments to its electricity suppliers. In Ramboll's Alternative Case, scenario, the number of supplemental RECs that UMD will have to purchase will be manageable – varying between 7,500 and 12,000 over the next 10 to 15 years, before declining through 2050 as suppliers' RPS obligations increase to 100%.

Figure 6 presents a range of incremental REC costs UMD can expect to pay each year over the next decade to completely offset its Scope 2 campus emissions. At the low end, the costs are in the $7,500 per year range for 100% Green-e RECs *without additionality and without geographic proximity*. This assumes 7,500 RECs purchased per year, the average supplemental REC volumes expected between 2020 and 2025. At the high end, the costs are in the $480,000 per year range for RECs from new offshore wind projects under 20-year PPAs. This assumes 12,000 RECs purchased per year, the peak supplemental REC volume forecasted for UMD based on Ramboll's projections of campus electricity use under the Alternative Case.

Figure 6 REC Options and Cost Ranges

	Price		Quantity of RECs	
REC Option	$/REC	7,500	→	12,000
Green-e Certified	$1.00	$7,500	Increasing Cost	$12,000
Midwest Wind	$3.00	$22,500		$36,000
Southwest Solar	$5.00	$37,500		$60,000
N.E. Solar	$25.00	$187,500		$300,000
N.E. Offshore Wind	$40.00	$300,000		$480,000

The wide range of potential costs begs the question of how UMD should reflect its various REC purchasing options in the Energy Master Plan's cost analysis. CES recommends UMD defines three REC purchasing strategies, presented below as 100% Green-e RECs, 100% Additionality, and a Mixed Purchases, into the plan's cost analysis to demonstrate the expected low end and high-end costs of potential REC purchases.

1. <u>100% Unbundled RECs</u>. UMD prioritizes low-cost REC acquisition and purchases 100% Green-e national certified RECs through spot-market purchases and under short-term contracts.

2. <u>100% Additionality</u>. UMD prioritizes additionality in its REC acquisition and purchases only RECs from new renewable generator projects. This may include multiple generation technologies and a mix of purchases from in-region and out-of-region generators.

3. Mixed Purchases. UMD purchases a mix of Green-e national unbundled RECs and RECs from new generators that offer additionality. This approach aims to balance cost and additionality objectives and could potentially be achieved by purchasing RECs in lower-volume tranches and/or through REC arbitrage (i.e., selling a portion or all in-region RECs into local compliance markets depending on annual budget targets and outcomes). Under this approach UMD may choose to purchase a portion of its REC requirement from new in-region or out-of-region generators under long-term agreements and to purchase Green-e RECs in the spot market.

CES recommends all three strategies be considered as potential means for UMD to purchase and retire the quantity of supplemental RECs required to eliminate its Scope 2 emissions. CES recommends any formal solicitation for supplemental RECs be structured to reflect the four considerations noted below. CES is available to discuss how these considerations can be incorporated into a competitive RFP process administered by UMD.

- Procurement Timeline. Because new renewable generators can take several years to be financed, permitted, and constructed, any REC solicitation/RFP needs to consider development lead-times when developing a target timeline for purchases. To take advantage of falling costs of wind and solar generation and to allow flexibility to respond to changing conditions in U.S. electricity markets and policies, CES recommends the UMass System organizes REC purchases into tranches that are implemented over time.

- Volume Targets. To determine the volume of RECs to solicit in each purchasing tranche UMD will need to determine whether the campus will be issuing an RFP on its own or if the UMass System will be administering an RFP on behalf of UMD and other UMass campuses. While the UMass System's purchasing power may help improve project pricing being offered by developers and may allow for greater flexibility in establishing purchasing tranches, UMD's preferences on project characteristics may differ from other campuses' preferences. To address uncertainty in future campus electricity usage, UMD could utilize short-term Green-e REC purchases to fill any REC shortfalls, as UMD finalizes its plans for future campus energy infrastructure.

- Project Characteristics. An RFP can be crafted to solicit proposals for a variety of renewable generation technologies, including in-region and out-of-region (geographic proximity) purchasing options and existing or new (additionality) generators. By allowing a mix of proposal submissions, UMD can evaluate the full range of project options and pricing available.

- Electricity Supply Procurement. UMD should structure all supplemental REC purchasing options presented in this memo as an overlay to its existing retail electric supply purchasing structure. By doing so, the supplemental REC acquisition process will have no impact on energy procurement.

Carbon Offset Procurement

Overview of Carbon Offset Options

Carbon offsets, also referred to as Verified Emissions Reductions ("VERs"), represent a unit of carbon dioxide-equivalent that is reduced, avoided, or sequestered and claimed to mitigate increases in global greenhouse gas emissions by offsetting Scope 1 and/or Scope 3 emissions being generated elsewhere. The concept of carbon offsets is based on the notion that reducing greenhouse gas emissions by financially supporting an offset project has an equivalent global emissions outcome as reducing an entity's own emissions footprint through direct changes in operations and energy consumption.

Entities purchase carbon offsets to be able to claim Carbon Neutrality, which implies the purchased offsets' avoided emissions equal the purchaser's own Scope 1 and Scope 3 emissions (plus REC purchases to offset Scope 2 emissions) for a defined period, typically by year. Carbon offset projects span a broad variety of actions that can be taken to avoid or sequester carbon emissions, including landfill gas capture and destruction, organic waste composting, household fuel switching in developing countries, agricultural methane capture, ozone depleting substance capture, and tree planting, to name but a few examples. For purchasers of carbon offsets an important component in selecting offset projects is the notion of additionality. Additionality means the emissions avoidance or sequestration would not have occurred without the financial support provided by the ability to sell offset claims; all credible third-party verification sources for carbon offsets qualify projects on this basis. Other important traits of carbon offsets are that they are real, verified, enforceable, and permanent.

Various registries and standards have been developed to verify greenhouse gas emissions avoidance or sequestration from carbon offset projects. These registries and standards aim to address purchasers' concerns that the emissions impact claimed for an offset project can be verified and is not being double counted through project claims being sold to multiple purchasers. Depending on an institution's emissions reduction goals and the requirements of a given emissions protocol, it is important to investigate the registries and standards a proposed project meets. Examples of these registries and standards are listed below.
A carbon offset project may seek qualification under multiple standards and/or listing on multiple registries. The number of different standards and registries can create confusion for those looking to develop and implement a strategy for the purchase of carbon offsets. Buyers need to consider many options when considering a carbon offset purchase including geographic location, project type, vintage year, the listing registry and price. In many cases it is appropriate to issue a request for bids, seeking pricing and project details from a wide variety of project sponsors. It is also possible for buyers to invest in projects that are not yet developed, although this can introduce uncertainty in the number and cost of associated credits.

- Clean Development Mechanism (CDM): this international standard was defined in the 2007 Kyoto Protocol to facilitate additional clean development projects in developing countries through the financial support of other nations. CDM host countries are required to confirm that projects contribute to their own national development. The standard requires proof of additionality, as well as third-party verification of baseline emissions and project reductions. Carbon offsets generated under the CDM standard may also be referred to as Certified Emissions Reductions ("CERs").

- Climate Action Reserve (CAR): The program was originally developed as the California Climate Action Registry by the State of California in 2001. CAR now serves as one of the major standards in North America. Each project is verified to ensure that they are real, additional, permanent, and enforceable. The program also lists tertiary goals aimed to ensure registered projects are not harmful socially or economically to the subject community. Carbon offsets generated under the Climate Action Reserve may also be referred to as Climate Reserve Tonnes ("CRTs").

- Verified Carbon Standard (VCS): VCS (also called Verra) is a non-profit NGO, founded in 2005, that now maintains one of the leading global voluntary GHG reduction programs. Projects are classified into categories, which must pass through conservative quality assurance principles defined by VCS in an aim to reduce overstatement concerns expressed by critics. Projects are verified and approved by a validation body to confirm that they are: additional, real, measurable, conservative, and permanent. Carbon offsets generated under the VCS may also be referred to as Verified Carbon Units ("VCUs").

- The Gold Standard: Established in 2003 by the World Wildlife Foundation, the Gold Standard has a focus on mitigation as well as the substantial co-benefits that can be derived from successful implementation. Although the standard focuses on the core carbon offsetting items—additional, real, and verifiable—their advertised differentiator is a defined focus on economic, health, welfare, and environmental impacts on the community hosting the project.

- American Carbon Registry (ACR): ACR was founded in 1996 as the first private voluntary carbon offset program by Winrock International—a non-profit organization. The standard focuses on projects meeting the conditions of additionality, permanence, measurability, and conservatism. Projects are also independently verified.

Indicative Carbon Offset Pricing

The cost of carbon offset purchases for UMD will depend on UMD's criteria for project type, characteristics, and location, and whether the federal government implements a control regime on carbon emissions. On the low end of pricing options, offsets currently cost as little as $2 to $5 per $MTCO_{2e}$. Landfill gas capture and destruction and reforestation projects typically fall into this lowest-cost category of offset projects. In contrast, there are a range of offsets options with much higher pricing, ranging between $20 to $100 per $MTCO_{2e}$. Like pricing, purchasing terms for carbon offsets vary depending on the project. Certain offset projects require long-term contractual commitments, whereas certain offsets can be purchased on short-term or year-to-year contracts. There are numerous providers of carbon offsets serving the voluntary offset market for colleges and universities, so these factors can be evaluated and compared in a competitive solicitation process that requests a wide range of offset options and projects.

If UMD elects to pursue achieving Carbon Neutrality by 2030, CES recommends using $10 per as a preliminary budget estimate for carbon offset purchases, which reflects a mid-point price observed in the current voluntary offset market. Ramboll estimates UMD will have 7,160 $MTCO_{2e}$ for Scope 1 emissions in 2030 associated with campus heating and cooling operations and 5,000 $MTCO_{2e}$ for remaining Scope 1 and Scope 3 emissions. Taken together, estimated Scope 1 and Scope 3 emissions total 12,160 $MTCO_{2e}$. UMD would need to purchase a corresponding quantity of carbon offsets to declare Carbon Neutrality in 2030. In future years, carbon offset quantities would need to be adjusted based on any addition increases or decreases in the campus' Scope 1 and Scope 3 emissions. Ramboll is projecting a decrease in campus Scope 1 emissions from 7,160 $MTCO_{2e}$ in 2030 to 960 $MTCO_{2e}$ in 2035. Assuming a weighted carbon offset price of $10 per $MTCO_{2e}$, UMD's estimated 2030 offset need produces a preliminary budget estimate of roughly $122,000 per year. As noted above, this cost could change depending on the final project(s) selected by UMD, UMD's timeline for targeting Carbon Neutrality, and future legislation.

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