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Salem State University North Campus Clean Energy Feasibility Study

Salem, Massachusetts

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Contents

Executive Summary

Massachusetts, the United States, and the entire planet are facing a climate crisis. Salem State University is committed to supporting state efforts to combat the global climate crisis and has developed the North Campus Clean Energy Feasibility Study. This study provides a high level, phased roadmap that will allow Salem State to eliminate fossil fuel use in building heating and cooling systems to meet its goal of carbon neutrality by 2050 for the North Campus. The key components of this roadmap include:

1. **Transition Away from Steam:** Conversion of the central heating system from steam to Low Temperature Hot Water (LTHW): transition the North Campus off of steam by replacing the steam distribution system with a more efficient LTHW distribution system. LTHW can be generated through electric sources and will allow SSU to stop burning fossil fuels for building heating.

2. **Provide a new District Energy System:** in addition to the new low temperature hot water distribution system, providing a centralized chilled water plant and hydronic distribution system will increase cooling efficiency and allow for simultaneous generation of hot and chilled water through heat recovery equipment operating at maximum efficiency.

3. **Expand the Geothermal Energy System:** by expanding the use of onsite renewable technologies including geothermal heat exchange, SSU can further reduce energy use and carbon emissions.

4. **New Construction and Renovation high energy performance standards:** As new buildings are built and existing buildings renovated such as the proposed Meier Hall Science Lab addition and Horace Mann renovation, ensure their designs are focused on energy efficiency and are compatible with the low temperature hot water system.

Three options were considered for this roadmap, including Centralized, Decentralized and Hybrid Options for the North Campus heating and cooling systems. Each option included modeling heating and cooling systems that resulted in the elimination of all carbon emissions associated with the North Campus heating and cooling systems. Energy use, energy cost and capital costs were determined for each option over the 30 year study period in order to evaluate and compare these options. The Centralized Option was selected as the recommended option as it provided the largest reductions in both energy use and energy costs while achieving the carbon reduction goals.

The Centralized Option was then compared to the campus Business As Usual (BAU) scenario, including a forecast of energy consumption and cost, operations and maintenance expenses, energy system capital expenditures, and GHG emissions. The BAU scenario includes continued use of the existing campus steam heating system, existing decentralized cooling systems and incorporates currently forecast campus projects including the Meier Hall Science Lab addition and Horace Mann renovation. The Centralized Option features a new District Energy System, expanded geothermal system, wastewater heat recovery system and new high performance building standards for currently forecast campus projects. The implementation of the Centralized Option would also demonstrate leadership in energy efficiency among peer institutions, result in net cost savings over the next 30 years and significantly contribute towards compliance with the state energy goals included in Executive Order 594. A comparison of the BAU scenario and Centralized option is included in Table 1 below.

Table 1: Comparison of BAU and Centralized Option

Feature	**Business as Usual (BAU)**	**Centralized Option (low carbon) Selected Option**	**Benefits of Centralized Option**
Heat Technology	• Fossil Fuels (gas) • Central Steam Boilers – natural gas (need replacement in 2041) • Peabody & Bowditch – natural gas boilers • Berry Library – Geothermal (existing)	• Electrified systems • Expanded Geothermal – Central Plant connected to all buildings • Wastewater Heat Recovery • Air Source Heat Pumps	• Reduced GHG Emissions • Reduced Maintenance • Reduced Water Usage • Improved Comfort • Improved Air Quality
Air Conditioning	Limited • Window units in some buildings • Central AC in Theater and Library	• Technology in place for all buildings to have central AC except Peabody & Bowditch	• Improved A/C Capability • Improved Comfort
Distribution Infrastructure	Campus Heating System: • Inefficient Existing Steam Plant (65% efficient) – no upgrades planned • Aging Steam Distribution Piping	New Distribution Infrastructure • Low Temp Hot Water Loop (130F, 95% efficient) • Chilled Water Loop	• New Utility Distribution • Improved Safety
Horace Mann Renovation & Meier Hall Science Lab Addition	• High performance • Connected to steam system	• High Performance • Fossil-fuel free	• Reduced GHG Emissions • Improved Air quality
Existing Building Infrastructure	• No upgrades planned	• New heating & cooling systems throughout buildings	• Reduced Maintenance

The clean energy roadmap recommendations for implementing the Centralized Option for the North Campus will require a $20.4M capital investment over ten years, starting in 2029, compared to the $8.6M capital investment required for the business as usual (BAU) case. Over a 30 year life cycle cost comparison, the Centralized Option saves $2.5M over the BAU case, resulting in a 2047 break even point. The break even point occurs 18 years after the first capital investment in the Centralized Option. The present value of cashflow for the BAU case and the Centralized Option is shown in Figure 1 below, indicating the break even point at 2047. The $20.4M capital investment does not include funding for the near-term projects including the Meier Hall Science Lab addition and Horace Mann renovation, as these projects are both currently included in Salem State's Bold Campus Unification and Modernization master plan and these funds would be required under either option. Capital investment cost estimates include all soft costs, including design fees, contingencies, etc.

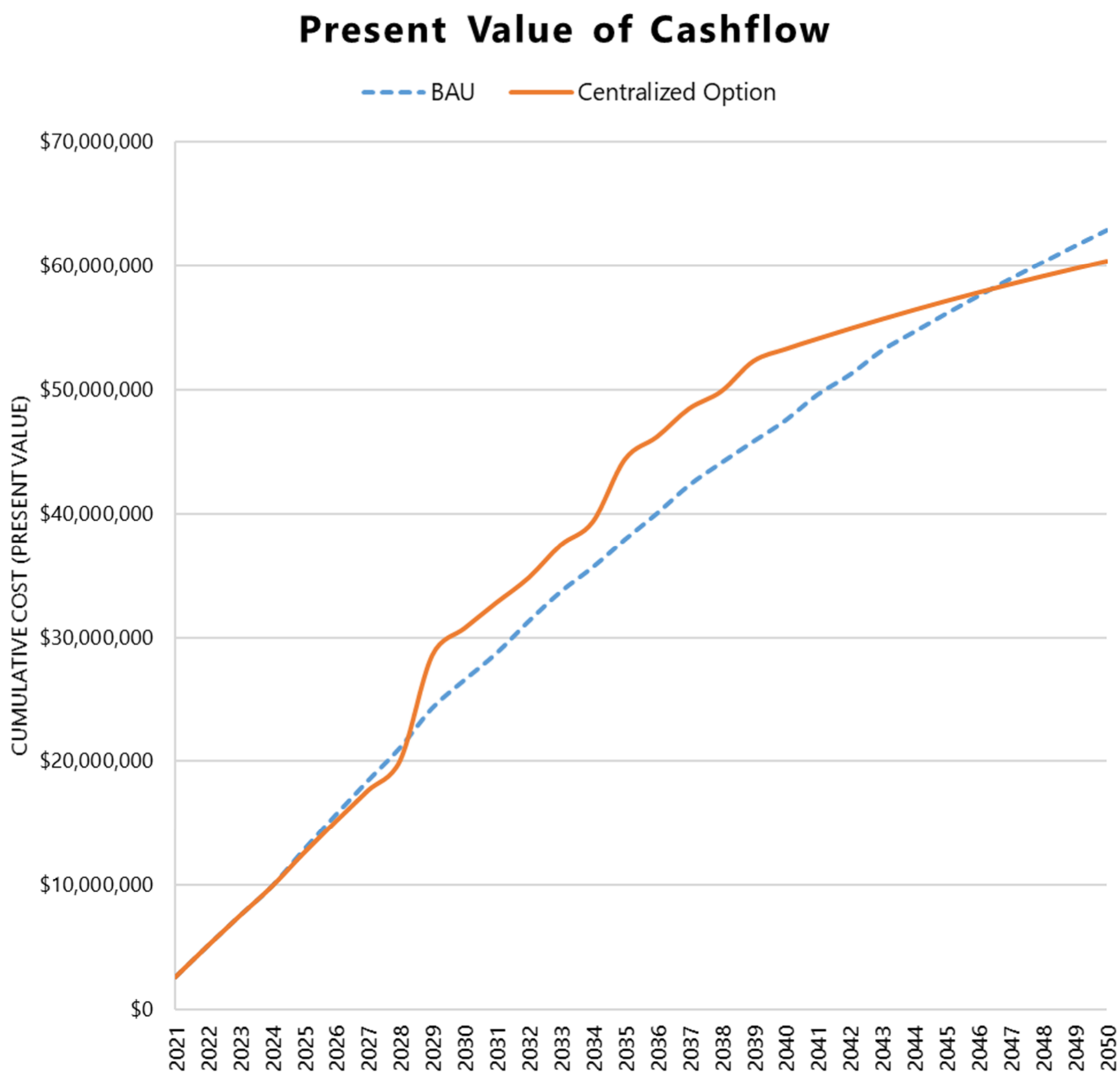

Figure 1: LCCA Net Present Value Cashflow Comparison

The implementation timeline for the Centralized Option is included below in Figure 2 and the 2040 final phase of the road map is included in Figure 3.

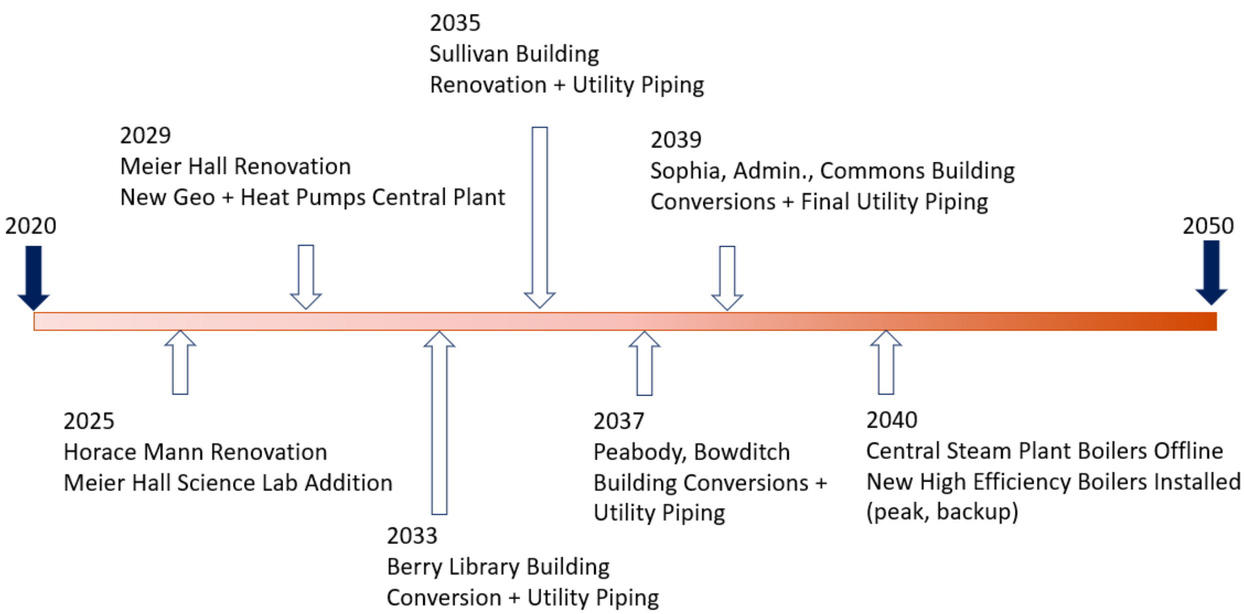

Figure 2: North Campus Implementation Timeline - Centralized Option

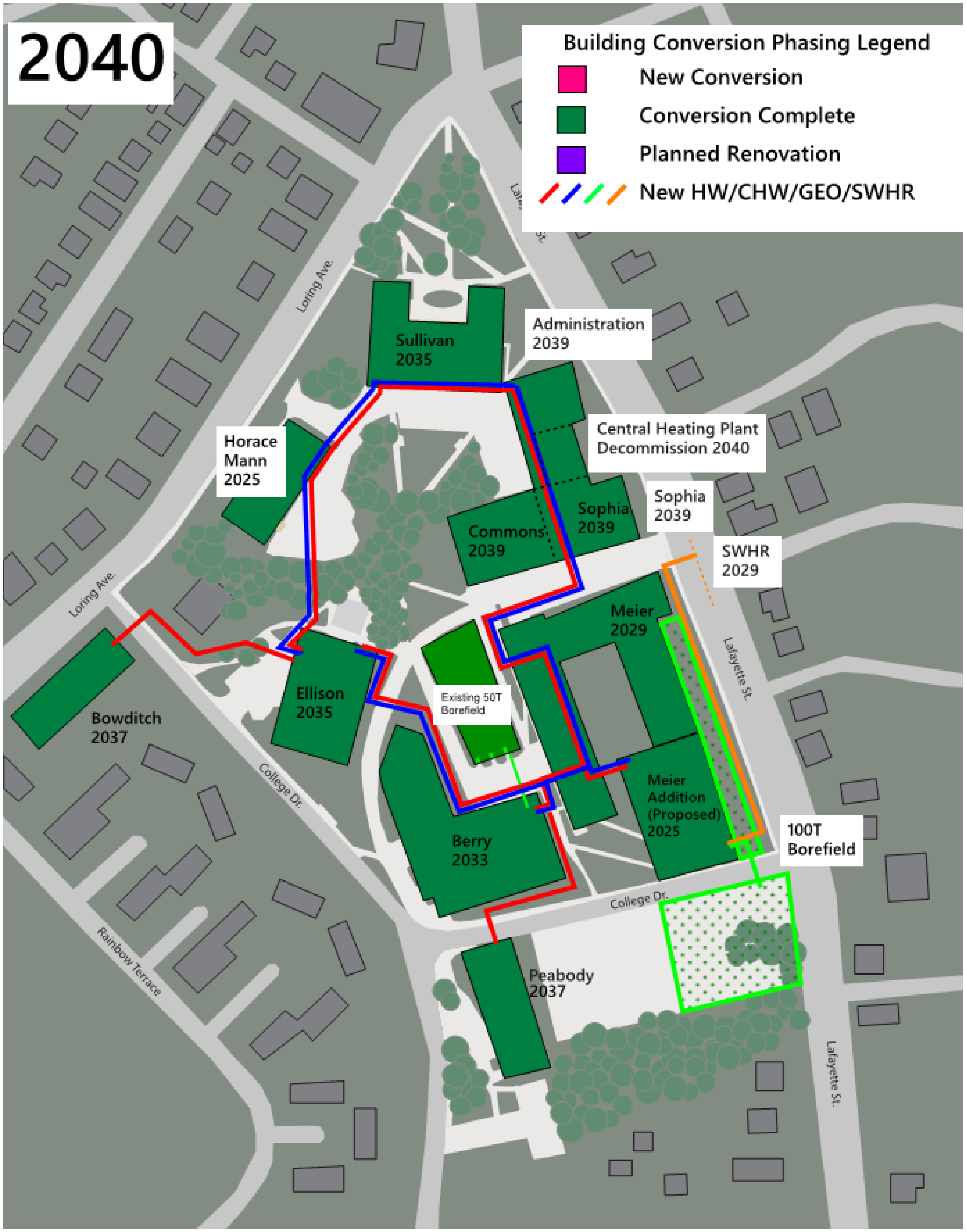

Figure 3: North Campus Roadmap Phasing Plan - 2040

The Centralized Option reduces greenhouse gas emissions from heating and cooling systems by 82% in 2040 and eliminates all carbon emissions by 2050 over a 2021 GHG emissions baseline. The GHG emissions reductions are summarized in Table 2 and Figure 4Table 3 below. The majority of the GHG reductions are associated with transitioning the campus off steam heat and replacing the Central Steam Plant with a centralized district energy system utilizing electrified systems and geothermal heat exchange. A summary of the GHG reduction strategies including their relative impact on the North Campus carbon neutrality goals are included below in Table 3. The roadmap did not identify funding for these energy improvements however having a roadmap in place will enable Salem State to identify and take advantage of potential funding sources in the future. The Centralized Option will help Salem State University comply with the reduction of greenhouse gas emissions required by MA Executive Order 594.

In addition to greenhouse gas emissions and energy use reduction, the Centralized Option will reduce maintenance costs by over $1.5M annually after the existing central steam plant is taken offline in 2040.

Table 2: North Campus Clean Energy Feasibility Study Results Summary

	Business As Usual (BAU)	Centralized Option	Notes
Capital Investment (2021 dollars)	$8,600,000	$20,400,000	
30 Year NPV Cost (2021 dollars)	$62,864,502	$60,392,000	
GHG Emissions - 2040 (MTCO2e/yr)	2,903	526	82% Reduction
GHG Emissions - 2050 (MTCO2e/yr)	2,524	0	100% Reduction
Annual Energy Use - 2050 (MBTU/yr)	60,100,000	24,200,000	60% Reduction
Total 30 Year GHG Emissions 2021-2050 (MTCO2e)	89,384	48,143	46% Reduction

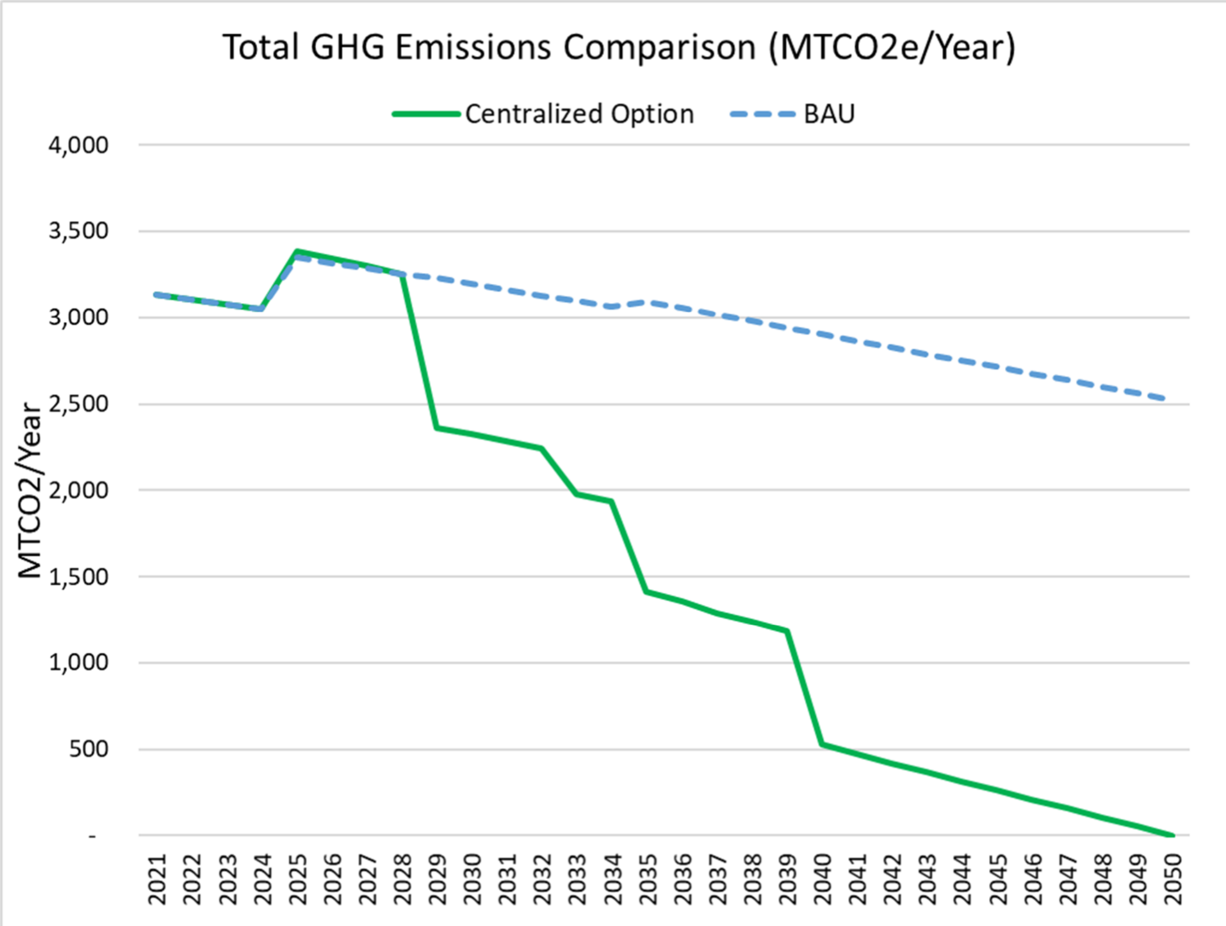

Figure 4: 2021-2050 GHG Emissions Comparison

Table 3: North Campus Roadmap GHG Reduction Strategy Impact

GHG Reduction Strategy	Features	Impact
Accelerate Energy Efficiency	• Reduce GHGs and cost • Allows smaller-sized infrastructure	Low/Medium
New Building Standards	• New buildings must be efficient, reliant on electricity or renewable technologies	Medium
Transition Away From Steam	• Replace inefficient steam system with low-temperature hot water (LTHW)	High
Expanded Use of Renewable and Efficient Energy Technologies	• Solar, geothermal energy and air source heat pumps	Highest

Project Team

Core Project Working Group
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Consultant Team
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As part of the Earth Days events at Salem State, team members from the Core Project Working Group and the Consultant Team presented their progress on the North Campus Clean Energy Feasibility study, including major energy and carbon reduction strategy recommendations, to the broader Salem State community. A link to this presentation is included here: https://www.screencast.com/t/dxTzZ7Nat[1].

List of Abbreviations

ASHP	Air source heat pump
BAU	Business as Usual
CHW	Chilled Water
COP	Coefficient of Performance
CSP	Central Steam Plant
DX	Direct Expansion (refrigerant based)
EERC	Energy Escalation Rate Calculator
ETS	Emissions Trading System
EUI	Energy Use Intensity (kbtu/h / year)
GHG	Greenhouse Gas
GHX	Ground source heat exchangers, Geothermal Heat Exchanger
GSHP	Ground source heat pump
HTHW	High Temperature Hot Water (160-180°F)
HVAC	Heating Ventilation and Air Conditioning
kBTU	Thousand British Thermal Units
KVA	Kilovolt-amp - unit of power
LCCA	Life Cycle Cost Analysis
LTHW	Low Temperature Hot Water (120 – 140°F)
MTCO2e	Metric Ton of Carbon Dioxide equivalent
NPV	Net Present Value
PPA	Power Purchase Agreement
PPH	Pounds Per Hour (steam)
PSIG	Pounds per Square Inch (gauge) – unit of pressure
REC	Renewable Energy Credit
RFO	Renewable Fuel Oil
RTU	Roof Top Unit
SWHR	Sewage Water Heat Recovery
WCCH	Water Cooled Chiller

Definitions

Scope 1 Emissions: Direct greenhouse (GHG) emissions that occur from sources that are controlled or owned by an organization (e.g., emissions associated with fuel combustion in boilers, furnaces, vehicles).[2]

Scope 2 Emissions: Indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. [1]

COP: Coefficient of Performance. The ratio of useful heating or cooling provided to work (energy) required to produce said heating or cooling. Higher COPs equate to higher equipment efficiencies.

Introduction

Salem State University received a $100,000 Clean Energy Feasibility Study Grant from the Massachusetts DOER Leading By Example program to determine how to move away from fossil fuels to meet the university's goal of carbon neutrality by 2050. Salem State University has engaged MEP Associates, a Salas O'Brien Company, to perform a Clean Energy Feasibility Study that will recommend a high-level, phased roadmap for heating and cooling their North Campus buildings by transitioning from fossil fuels to clean, efficient and sustainable energy sources by 2050.

The project recommendations include guidance on strategies, technologies, fuel sources, and analysis of maintaining the centralized system that serves eight buildings versus a decentralized approach. The project recommendations also provide specific energy use targets and suggested high efficiency, electrically driven HVAC system technologies for the near-term campus expansion shown in the University's Master Plan, Horace Mann building renovation and the proposed Meier Hall Science Lab addition. The options analyzed have been compared to the campus Business As Usual (BAU) reference case to inform capital investment, utility costs, operations and maintenance costs, energy use and carbon emissions reductions.

Salem State University has a strong tradition of commitment to sustainability as exemplified by its Board of Trustees, President, faculty, staff, students and alumni. Salem State revised it's investment strategy to divest from fossil fuels in 2018 and has adopted a goal to be carbon neutral by 2050. Salem State offers approximately 30 courses focused on sustainability and has seen significantly increased interest in climate change courses in recent years. Many students are involved in sustainability groups on campus, including a strong Sunrise movement, advocating for the removal of fossil fuels and climate change education. At the facilities and operations level, Salem State's campus is home to five LEED certified buildings, has five photovoltaic (PV) arrays installed and utilizes renewable geothermal systems for heating and cooling at Berry Library.

Executive Order 594 Leading By Example: Decarbonizing and Minimizing Environmental Impacts of State Government requires state agencies to collectively reduce greenhouse gas emissions from fossil fuel use in buildings and vehicles by:

- 20% by 2025
- 35% by 2030
- 60% by 2040
- 95% reduction by 2050

These GHG emissions reductions do not include emissions from electricity and are focused on reducing emissions from fossil fuels. Significant reduction and/or elimination of fossil fuel use by all state buildings and fleets, whether through increased renewable capacity, strategic electrification, or other means, will be critical to meeting these long-term statewide goals. In working toward a net zero future, Salem State wants to ensure that its energy plan supports statewide goals. Moving to electrification will also reduce local air pollution from on site combustion of fuels as well as replace and update aging infrastructure.

Between 2004 and 2020, Salem State has been able to reduce its carbon emissions by 38% across all campuses. Campus carbon emissions from 2004 to 2020 for all Salem State Campuses are shown below in Figure 5. Of the 38% overall emissions reduction in 2020, carbon emissions associated with purchased electricity (Scope 2) were reduced by 50% while carbon emissions associated with onsite fossil fuels (Scope 1) were reduced 23%[3]. Reduced campus operations caused by the Covid-19 pandemic contributed to the carbon emissions reductions for 2020 and may not be repeatable as campus operations return to pre-pandemic levels.

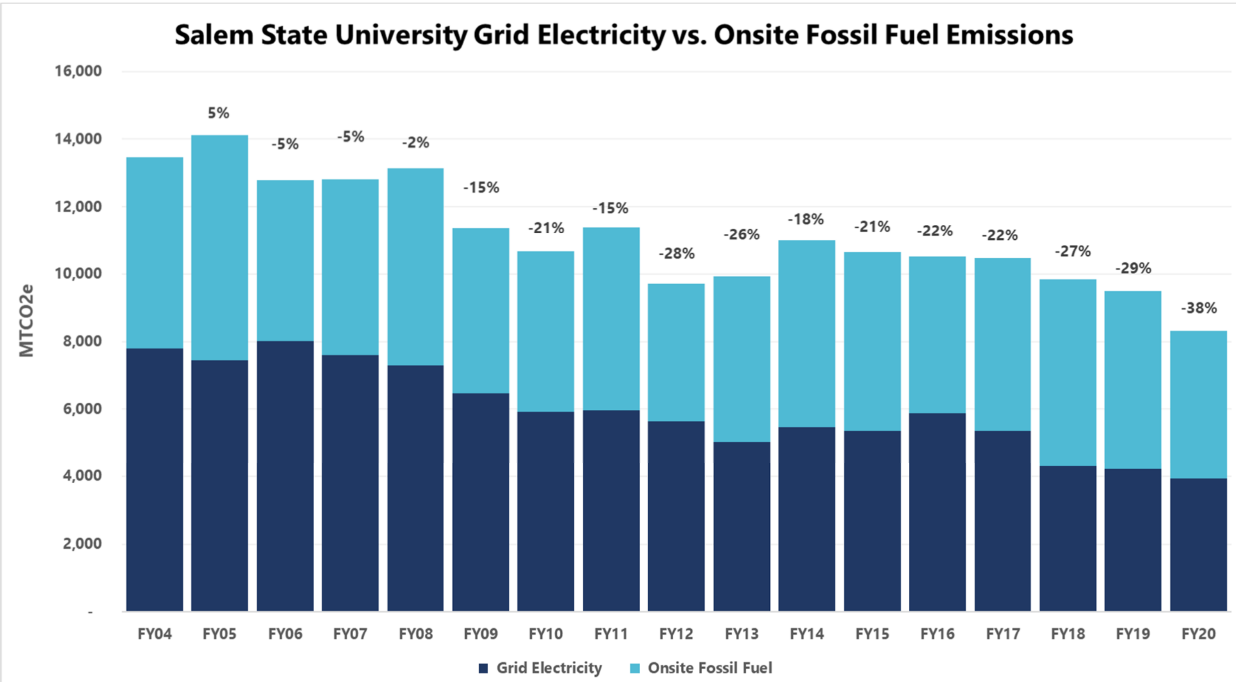

Figure 5: Salem State University Historic GHG Emissions: Grid Electricity Emissions vs. Onsite Fossil Fuel Emissions (Entire Campus)

Existing Systems

Campus Buildings

The SSU North Campus is comprised of 11 major buildings, including the Central Steam Plant (CSP), and almost 700,000 SF. A summary of the North Campus buildings, including year built and approximate square footage is included in Table 4 below and a map of the campus in included in Figure 6. The Administration Complex is comprised of four major buildings including the Administration Building, Commons Dining Hall, the Sophia Gordon Center for Creative and Performing Arts (Sophia Theater) and the CSP. The CSP provides steam for eight North Campus buildings and is located in the basement of the Administration Complex. Also located on the North Campus is a large parking garage, which is neither heated or cooled and is not included in this study.

Table 4: North Campus Buildings

Building	Year Built	Overall Square Footage
Administration Complex	1958	90,558
Administration Building		*23,267*
Commons Dining		*35,089*
Central Steam Plant		*6,106*
Sophia Theater	*2015*	*26,096*
Berry Library	2012	124,000
Bowditch Hall	1965	64,183
Ellison Center	1966	49,776
Horace Mann	1902	44,395
Meier Hall	1963	160,345
Peabody Hall	1965	73,352
Sullivan Building	1896	83,851
Total		690,460

Figure 6: Salem State University North Campus

Central Steam Plant (CSP)

The Central Steam Plant (CSP) contains two 600 hp Cleaver Brooks firetube boilers operating in a duty / standby configuration. Each boiler is rated at 20,700 pounds per hour (pph) and generates medium pressure steam at 90 psig which is distributed to the buildings. Each building connection includes a pressure reducing station to reduce the steam pressure. Boiler #1 was installed in 2008, Boiler #2 was installed in 2006. Both boilers can burn natural gas or no. 2 fuel oil. Fuel oil is only used to keep the standby boiler hot, in the event the duty boiler is taken offline. There are three 5,000 gallon underground fuel oil storage tanks at the CSP, however only one tank is currently in use. The CSP operates from fall to spring and is offline during the summer.

The steam boilers generate medium pressure steam at 90 psig and 330°F with an 83% efficiency. The majority of buildings on campus use the steam from the CSP to generate high temperature hot water (180°F) for heating. By generating the heating medium to such a high temperature (330°F) the CSP maximum thermal efficiency potential is much lower than what could be achieved with a condensing hot water boiler application, with efficiencies at high as 95%. Additional distribution losses for the steam and condensate return piping network are estimated at 18%, as much of the steam distribution system has reached or exceeded its expected service life. The boiler efficiency combined with the distribution losses results in an overall efficiency of 65% for the central steam plant.

Standalone HVAC Systems / Buildings

Heating

The two North Campus dorm buildings, Bowditch and Peabody, are not connected to the central steam plant. These buildings each have two natural gas boilers generating high temperature hot water for building heating.

Cooling

The majority of cooling on campus is provided through individual stand-alone systems. There is no centrally distributed chilled water utility piping on campus. Buildings are cooled with either a local air cooled chilled water system, direct expansion (DX) systems, RTUs, or window air conditioners.

Geothermal

Berry Library includes a geothermal heat pump system including a 380-ton modular heat pump coupled with a ground source heat exchanger. The ground source heat exchanger consists of 48 boreholes, 500' deep, installed in the north courtyard. Berry Library received LEED Silver certification and is one of five LEED buildings on Salem State's campus. Berry Library also includes a cooling tower for supplemental heat rejection and is connected to the CSP for supplemental heating. The HVAC systems at Berry Library, including the geothermal systems, are currently undergoing a retro-commissioning project to improve and maintain building operation and system efficiency.

Campus Central Plant Electrical Systems

Meier Hall Electrical Systems

The existing building is fed via a 500 KVA 13.8kV to 208V to a 2000-amp switchboard protected by a 2000-amp main breaker. The current peak demand is 900 amps at 208V,3P.

Berry Library Electrical Systems

The existing building is fed via a utility transformer 13.8kV to 480/277V to a 2500-amp switchboard protected by a 2500-amp main breaker with ground fault protection. The building emergency life safety and equipment branch of the essential power supply system is via a 350-kW diesel generator.

Ellison Electrical Systems

A new utility pad mounted transformer was installed in 2010 when the project updates occurred. A replacement 1600A, 208/120V switchboard and duct bank with conductors was installed at this time. Several panelboards were replaced as well. The emergency system is served via a 55-kW diesel generator that is existing to the building.

Sophia Theater Electrical Systems

A new utility pad mounted transformer was installed in 2014 when the project updates occurred. A replacement 2500A, 208/120V switchboard and duct bank with conductors was installed at this time. Several panelboards were replaced as well. The emergency system is served via an existing relocated 60-kW diesel generator.

Horace Mann Electrical Systems

The current peak demand is 250 amps at 208V,3P. Current building use is limited, and electric meter readings may not reflect an accurate potential maximum load.

Administration, Bowditch, Commons Dining, Peabody & Sullivan Electrical Systems

Existing infrastructure drawings and documents do not reveal the sources of supply or capacities of the existing electrical infrastructure for these buildings. It is recommended that the campus develop an overall campus one-line diagram of the electrical distribution system and include detail on individual buildings electrical infrastructure with system capacities and distribution information where information is unknown. From a utility metering perspective, the Administration building and the Sullivan building share a meter, as do Ellison and Bowditch. There are seven total electrical meters currently being billed to the North Campus.

Campus Solar

Salem State has five solar array installations with a total capacity of 599 kilowatts DC of renewable, photovoltaic energy. Berry Library includes a 174 kilowatt rooftop solar array. Three of the solar arrays have been provided under Power Purchase Power Agreements (PPAs) where Salem State does not currently retain the Renewable Energy Credits (RECs). The remaining two solar arrays are owned by Salem State which sells the associated RECs.

Additional details on the North Campus existing systems can be found in Appendix A: Existing Conditions Report.

Campus Growth Forecast

The SSU Bold Campus Unification and Modernization Project includes the renovation of the Horace Mann Building and the construction of a Meier Hall Science Lab addition. While the planned new science building is referred to as an addition to Meier Hall, it is expected that this new addition will be provided with new, dedicated building services and not be connected to the existing systems at Meier Hall. Both of these projects are expected to occur within the next five years and represent the earliest near-term capital investment in major renovation and new construction planned for the North Campus. SSU has an opportunity to ensure these new projects align with the campus sustainability goals and the recommendations outlined in this Clean Energy Feasibility Study. In addition, SSU can use these near-term projects as the foundation for a transition off fossil fuels and carbon emissions reduction. This campus growth forecast will be included in the energy use and carbon emissions profiles modeled for the Business as Usual (BAU) forecast as well as for the recommended options considered. The specific energy use associated with the campus growth forecast is discussed later in this report.

Horace Mann Renovation

The Horace Mann building was most recently occupied by the Salem Public School district and used as an elementary school. The four-story building has been unoccupied since the elementary school moved out in 2018. The Horace Mann building renovation will relocate the Maguire Meservey College of Health and Human Services (MMCHHS) from the South Campus including building program for nursing, social work, criminal justice, occupational therapy and healthcare studies.

Meier Hall Science Lab Addition

The Meier Hall Science Lab addition programming is expected to include seven new state of the art wet labs for the biology and chemistry departments, providing increased capacity in, and easier access to, modernized lab space for the life science courses required for healthcare majors. It is expected to include 70,000 square feet of lab space for lab science courses.

High Performance Building Standards for New Construction and Renovations

High Performance building standards will establish policies for new construction and major renovations to include energy efficiency design criteria aimed at reducing building energy use and not utilizing fossil fuels. These measures include requirements that improve the thermal performance of the building's envelope, HVAC, lighting, and other mechanical systems to reduce its cooling, heating and electricity demands. These design elements are more cost-effective to install or integrate during initial construction or renovation, versus a post occupancy retrofits, and can dramatically lower the operational costs for the lifetime of the building. These policies help ensure energy efficient design elements are not value engineered out of the design and should be an integral part of the campus master plan. It is critical that new construction utilizes high performance envelope, high efficiency heating and cooling systems and incorporates technologies that support LTHW heating systems. Additional information on specific energy efficient building standards for Horace Mann renovation and Meier Hall Science Lab addition are provided in a later section of this report.

Campus Energy Use Intensity (EUI) Improvement

SSU has made notable improvements to their overall campus EUI over the last two decades reducing the overall campus EUI from 118 in 2004 down to 77 in 2020, meeting the state goal of a 35% reduction in EUI by 2020. SSU has invested in Energy Conservation Measures (ECMs) through Investment Grade Audits (IGAs) provided by Energy Services Companies (ESCO) and is currently collaborating with DCAMM and National Grid on smaller energy upgrades. There is potential to continue the trend of energy use reduction, further lowering the EUI for the North Campus, however as previous ECMs and IGAs have already the implemented the most cost effective energy saving strategies, significant capital spending will be required to address remaining opportunities. Building envelope improvements and major upgrades to heating and cooling systems are challenging to implement through ECMs or IGAs, due to their high capital investment and resulting longer payback. These types of upgrades are better addressed during major renovations and can contribute to the campus EUI reduction through application of the high performance building standards referenced above.

Business as Usual (BAU) Forecast – Natural Gas Steam System

The BAU forecast forms the foundation for a comparison of the relative costs and benefits of the recommended option included in this study. It includes a forecast of energy consumption and cost, operations and maintenance expenses, energy system capital expenditures, and GHG emissions. The BAU case will outline the historic and forecasted GHG emissions and energy consumption for the campus through 2050. The BAU forecast is based on historical energy performance of the North Campus from 2016 to 2020 and has been forecasted through the end of 2050. The relative performance of the BAU and the recommended option will be based on GHG emissions over time with the goal of eliminating all GHG emissions by 2050. The Clean Energy Feasibility Study will focus on Scope 1 emissions associated with the combustion of fossil fuels and Scope 2 emissions associated with purchased electricity, for the North Campus heating and cooling systems.

The annual heating and cooling load profile for the campus BAU case is included in Figure 7 below. The thermal profile summarizes the existing heating and cooling loads for the campus, with the cooling loads shown in blue and the heating loads shown in red. The two key components of this thermal profile are the thermal peaks and total energy consumed.

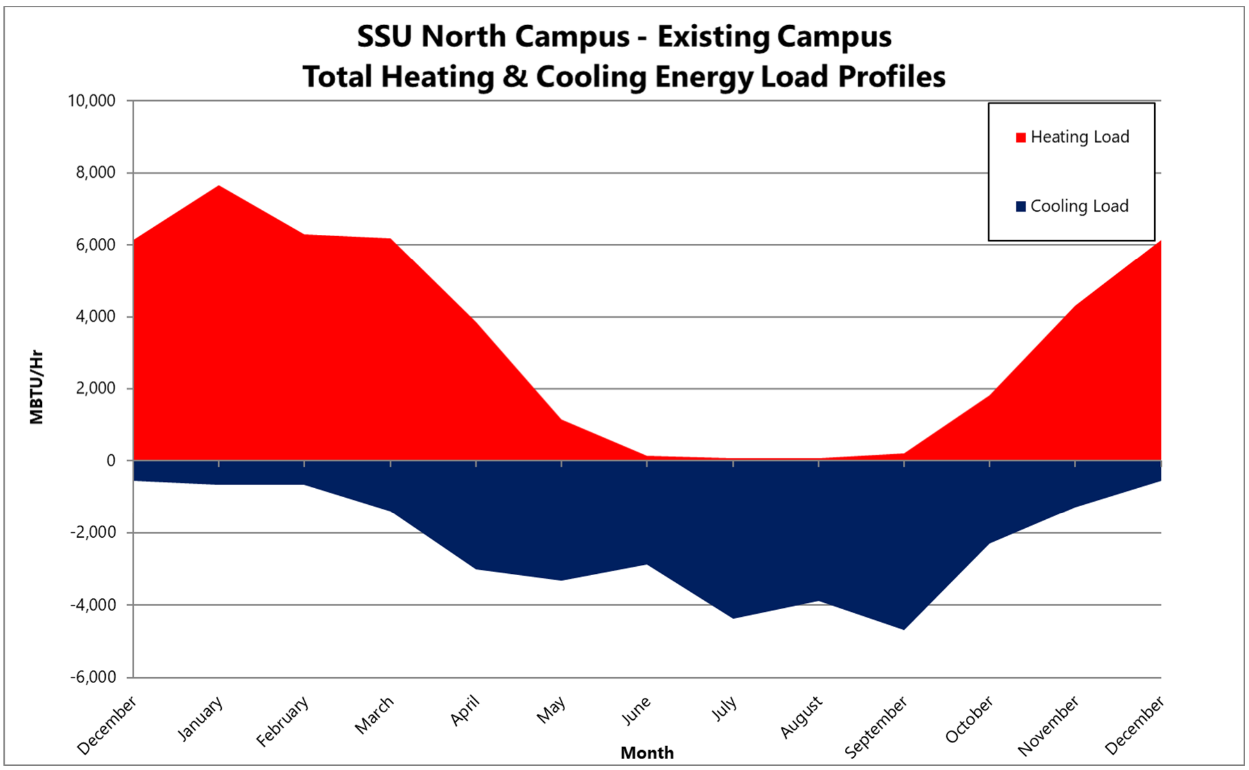

Figure 7: BAU Thermal Profile

The BAU implementation plan is based on the North Campus growth forecast, including the renovation of Horace Mann and the Meier Hall Science Lab addition both occurring in 2025. In addition to the planned growth, this study assumes that both Meier Hall and Sullivan will undergo major renovations during the

30 year study period. Meier Hall and Sullivan are large, academic buildings essential to SSU academics and are overdue for renovations. In order to capture the energy use of these building renovations, Meier Hall renovation is modeled in 2029 and Sullivan renovation is modeled in 2033. While these major renovations are not currently part of SSU's master plan for the campus, they have been included in the study, as they are likely to occur sometime within the study period. Renovations to the building heating and cooling systems would include modern and centralized systems, including adding air conditioning and mechanical ventilation throughout. Heating systems would be designed to operate on LTHW. The existing air conditioning and ventilation systems in both buildings only cover a portion of the building. The new heating and cooling systems would be more efficient than the existing systems, however the overall building energy use would increase as the entire building would be ventilated and air conditioned under a major renovation. New HVAC systems provided under a major renovation would be applied to the entire building and would increase overall energy use as a result. No additional new construction or major renovations are planned for the BAU case from 2033 through 2050.

Energy and GHG Emissions

The predicted energy use, carbon footprint and utility costs for the BAU case today (2020) and at the end of the current campus planning period, 2033, are summarized below in Table 5. The 2025 energy and carbon predictions include a renovated Horace Mann building and the Meier Hall Science Lab addition. For the BAU scenario, the Horace Mann renovation and Meier Hall Science Lab addition include energy use based on a code minimum building under the International Energy Conservation Code (IECC) 2018 which requires condensing boilers operating at 95% overall efficiency for heating and air cooled chillers operating at 0.86 kW/T for cooling. The costs for the Horace Mann renovation and the Meier Hall Science Lab addition are not being carried as part of this study for the BAU. The 2029 energy and carbon predictions include a renovated Meier Hall also at code minimum energy performance. The 2033 energy and carbon predictions include a renovated Sullivan Building at code minimum energy performance. After 2033, with no additional campus growth forecast, the energy and carbon predictions are unchanged. The electricity and natural gas greenhouse gas emissions factors used are included in Table 6. All dollar amounts are in 2021 dollars.

Table 5: North Campus HVAC System Energy & Carbon Emissions

	BAU Systems (2021)	BAU Systems (2025)	BAU Systems (2029)	BAU Systems (2033)
Elec (kWh/yr)	2,827,367	3,549,820	3,611,807	3,680,782
NG (Therm/yr)	431,810	475,587	475,587	475,587
Elec Utility ($/yr)	$477,825	$599,920	$610,395	$622,052
NG Utility ($/yr)	$449,082	$494,611	$494,611	$494,611
Total Utility ($/yr)	$926,907	$1,094,530	$1,105,006	$1,116,663
Cooling Energy (MBTU/yr)	9,646,978	12,111,984	12,323,485	12,558,827
Heating Energy (MBTU/yr)	43,180,951	47,558,709	47,558,709	47,558,709
Total Heating & Cooling Energy (MBTU/yr)	52,827,930	59,670,694	59,882,195	60,117,537
Carbon Emissions - Elec (MTCO2e/yr)	844	827	707	568
Carbon Emissions - NG (MTCO2e/yr)	2,292	2,524	2,524	2,524
Total Carbon Emissions (MTCO2e/yr)	3,135	3,351	3,231	3,092

Table 6: Greenhouse Gas Emission Factors

Utility CO2e Emissions Factors – 2021	
Electricity (lb CO2e/KWH)	Natural Gas (lb CO2e/Therm)
0.66	11.70

Massachusetts is committed to providing 100% renewable electricity by 2050, eliminating all carbon emissions associated with purchased electricity after 2050. The Massachusetts Department of Energy Resources (DOER) has provided electricity GHG emission factors specific to Massachusetts, included below in Figure 8. These emissions factors are used to model predicted GHG emissions associated with purchased electricity included in Table 5 above. The declining electric grid GHG emissions factor contributes to the electrical carbon emissions reduction for the North Campus.

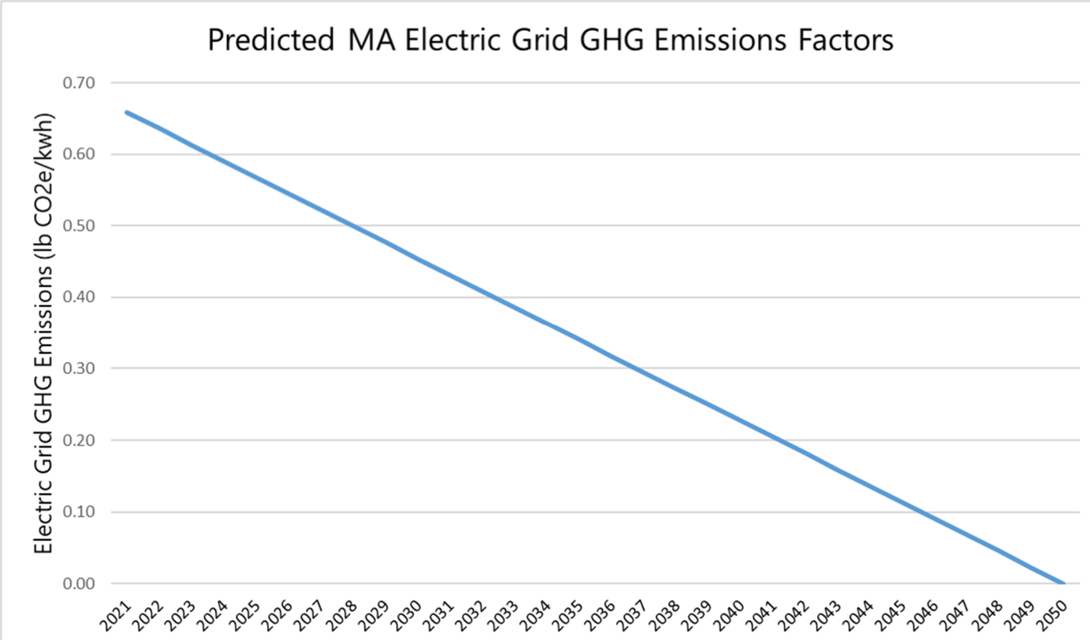

Figure 8: Expected Massachusetts Grid Emissions Factors through 2050

Operations and Maintenance

MEP and Salem State developed the operations and maintenance expenses related to the current HVAC equipment installed on campus. These expenses include maintaining the central steam plant and steam distribution systems, the individual building heating and cooling systems throughout the campus as well as the required staff.

Salem State has two departments that are responsible for the heating and cooling operations and maintenance on campus. The Central Steam Plant includes five full time employees dedicated to the CSP operation and maintenance. This central steam plant staff is required to supervise the boiler plant 24 hours a day, seven days a week whenever the plant is operating and boilers are on. The HVAC Department includes four full time employees responsible for maintaining the heating and cooling systems at each building. The BAU case includes an annual operation and maintenance expenses of $1,596,062.

The CSP annual maintenance costs are based on expected costs associated with the type and size of the existing boilers, input from the CSP operator staff and operational expenses from recent years, 2013 - 2020. The existing steam plant requires specifically trained and licensed full-time employees to operate and maintain the boilers and ancillary equipment, as well as the steam and condensate return distribution system. Additional maintenance includes monitoring and maintaining the chemical treatment, patching distribution piping in tunnels, maintaining steam traps and condensate pumps - both in the heating plant and throughout the steam distribution system. Salary included in the annual maintenance costs includes a 40% allowance for all fringe benefits. During the summer, when the central steam plant is down, the central steam plant operators have an opportunity to support the HVAC department, however due to licensing requirements, the HVAC department staff cannot operate the CSP.

For heating and cooling equipment outside of the CSP, the annual maintenance costs were estimated by using the type and capacity of equipment on campus. A summary of the maintenance costs is included below in Table 7. These annual maintenance cost estimates have been developed over previous campus energy master planning projects, with input from manufacturers, facilities and operation staff. These maintenance costs were applied to both the BAU and the options evaluated, where the equipment listed is applicable. A summary of maintenance costs by year and equipment type is included in Appendix D.

Table 7: Operations and Maintenance Expenses

Annual Maintenance Cost Estimates	
System Type	**Cost**
Split System	$50/Ton
Window Air Conditioner	$18/Unit
Water-cooled Chiller System	$70/Ton
Air Cooled Chiller System, Air Source Heat Pump System	$50/Ton
Direct Expansion RTU System	$25/Ton
City Water Chiller System	$70/Ton
Water to Water Heat Pump System	$70/Ton
Boiler (>12,000 MBH)	$5,200 ea.

City Water Use

As the CSP boilers operate, they periodically require make up water to replace steam or condensate return losses that normally occur during operation or due to a leak or system maintenance. The city water used as make up water for the CSP boilers is metered by CSP staff. For 2020, the CSP annual city water use was approximately 245,000 gallons, resulting in $9,900 billings.

Capital Expenditures

Capital expenditures for the BAU case include the replacement of existing heating and cooling systems that have already exceeded their expected service life or would exceed their expected service life during the study period. Replacement of existing heating and cooling systems include all central equipment, such as the central steam plant boilers and steam utility piping distribution, as well as all terminal devices, such as radiators and fan coil units. These replacement costs for existing heating and cooling systems provide a baseline cost comparison for the potential clean energy transition scenarios. The BAU capital expenditures assume replacement costs only and does not include upgrades or improvements and would maintain the existing decentralized cooling systems. A summary of the HVAC replacement costs by year are provided in Table 8. All dollar amounts are in 2021 dollars. While the study period extends to 2050, there are no additional capital expenditures anticipated after 2045. Additional details on the heating and cooling systems replacement costs are provided in Appendix D. Cost estimates for this study were developed using RS Means cost, direct input from manufacturers and prior experience on energy master planning projects. RS Means is a database of construction cost estimating information that accounts for location and is updated annually.

Table 8: BAU Capital Cost Summary by Year

Year	Replacement Heating & Cooling System Costs
2025	$473,549
2026	$431,095
2027	$431,095
2028	$431,095
2029	$1,274,504
2030	$42,454
2031	-
2032	$762,571
2033	$589,484
2034	-
2035	$571,197
2036	$450,256
2037	$901,751
2038	$52,110
2039	-
2040	$42,454
2041	$1,083,763
2042	-
2043	$1,083,763
2044	-
2045	$42,454
2046	-
2047	-
2048	-
2049	-
2050	-
Total	$8,663,594

Campus Clean Energy Options

Carbon mitigation solutions are specific projects, technologies, and other operational and infrastructure changes that will help SSU avoid and reduce GHG emissions on their North Campus relative to the campus BAU actions. The solutions considered for the SSU North Campus are summarized below in Table 9. The solutions are listed in their suggested order of implementation. Essential aspects of each of the solutions are described in their individual sections below. Additional details on the solutions considered in this study are available in the Options Considered & Finalist Options Selected Report in Appendix B.

Table 9: Carbon Mitigation Solutions Summary

#	Solution	Expected GHG Impact
1	High Performance Building Standards for New Construction & Renovations	Small
2	Building Energy Conservation Measures (ECMs)	Medium
3	District Chilled Water System	Large
4	Low-temperature Hot Water (LTHW) Conversion	Large
5	Ground Source Heat Exchange (GHX)	Large
6	Air Source Heat Pumps	Medium
7	Wastewater Heat Recovery (HR)	Small
8	Renewable Fuel Oil (RFO) Boiler	Medium

Summary of Solutions Considered

High Performance Building Standards for New Construction and Renovations

High performance building standards will establish policies for future new construction and renovations of existing buildings to include energy efficient design criteria aimed at reducing building energy use while also not burning fossil fuels. These building standards will include performance requirements for buildings envelope systems, lighting, electrically driven HVAC and energy efficiency equipment and appliance standards to reduce cooling, heating and electricity demands. These policies will ensure energy efficient features are not value engineered out of the design.

Building Energy Conservation Measures (ECMs)

Energy Conservation Measures (ECMs) include building upgrades, retrofits and repairs that can be implemented to improve energy efficiency and reduce operation and maintenance costs. ECMs can include lighting system retrofits, HVAC system and control upgrades and retro-commissioning. Any ECMs that focus on heating system improvements should be compatible with LTHW. As ECMs reduce heating and cooling demand, energy use and the associated carbon emissions are also reduced.

District Chilled Water System

This solution would provide a centralized, distributed chilled water (CHW) system for the North Campus. A centralized chilled water system presents an opportunity to optimize equipment efficiency, controls and maintenance compared to the existing standalone equipment. In addition, a centralized, distributed CHW system, when coupled with a centralized, distributed low temperature hot water (LTHW) system will allow for the use of heat recovery chillers and heat pumps to meet simultaneously occurring heating and cooling loads on campus. Heat recovery systems can generate both hot and chilled water simultaneously at a very high coefficient of performance (COP) and without the direct burning of fossil fuels or the need for heat rejection equipment, such as cooling towers. Heat recovery chillers and heat pumps are electrically driven and do not require fossil fuels for operation. Heat recovery systems are often utilized with ground source heat exchange systems for additional reduction in fossil fuel use outside of simultaneous heating and cooling periods. These systems are discussed in additional detail in the following sections. Both a centralized CHW system and centralized LTHW are required in order to take advantage of the high COP hot and chilled water generation through simultaneous heating and cooling equipment. A district chilled water system could also better support expansion by connecting new buildings or providing air conditioning to existing buildings, as central air conditioning becomes more common and expected by staff, faculty and students, in this region. These significant benefits of the district chilled water system are not included in the BAU.

Low-temperature Hot Water (LTHW) Conversion

Low temperature hot water (LTHW) conversion includes converting existing steam and high temperature hot water heating systems to LTHW. Heating hot water will be distributed to the campus buildings at 120-140°F, lower than standard high temperature hot water systems that distribute at 160-180°F and lower than the existing central steam plant generation, 330°F steam at 90 psig. Benefits of the lower operating temperature include reduced heat losses in distribution, lower operation and maintenance costs, improved safety, and a wider array of electrified energy sources available for generation when compared to steam and high temperature hot water. Typical steam distribution system losses can be significant, in the 15-30% range even for well-maintained systems, compared to negligible losses for hot water systems. All buildings utilizing steam or high temperature hot water will require a building conversion to replace existing heating systems with new low temperature compatible equipment.

Ground Source Heat Exchange (GHX)

A Geothermal Heat Pump or Ground-Source Heat Pump (GSHP) system is a heating and cooling system that transfers heat to and from the ground. Ground source heat exchangers (GHX) use the relatively stable temperatures of the earth as a heat source in the winter and as a heat sink in the summer. A ground source heating and cooling system consists of water source heat pumps and heat recovery chillers coupled with a geothermal bore field heat exchanger used for campus district heating and cooling. This technology is best suited for a LTHW system rather than the current steam system as heat pumps and heat recovery chillers generate LTHW more efficiently than high temperature hot water. GSHP systems can be used in central plant or standalone, individual building applications.

Sufficient open space for a geothermal heat exchanger is available on the North Campus through a combination of parking lots and landscaped areas in front of Sullivan and Meier Hall. While having one single, contiguous site for a geothermal heat exchanger is ideal, having multiple smaller interconnected smaller sites will increase installation costs. The nearby O'Keefe Athletic Complex includes large parking lots which could potentially be used for ground source heat exchange. While it is possible to connect the O'Keefe Athletic Complex to the North Campus, it would require underground utility coordination with multiple municipal streets. Due to the added costs and complexity of the pipe routing, utilizing the parking lots at O'keefe for geothermal heat exchange installation were not considered at this time.

Air Source Heat Pumps

An Air Source Heat Pump (ASHP) is a heating and cooling system that transfers heat to and from the outdoor air in order to generate chilled water for cooling and LTHW for heating. Similar to water source heat pumps, this technology is best suited for a LTHW system rather than the current steam system or high temperature hot water systems. ASHPs are installed outdoors and are less efficient than water source heat pumps. ASHPs have a cheaper installed cost compared to water source heat pump systems. ASHPs sized to meet system peaks which occur during limited hours of the year would provide a less capital-intensive alternative to a GSHP system, primarily related to the avoided ground source heat exchanger costs. ASHP systems can be used in central plant or standalone, individual building applications. ASHP technology is evolving, allowing a broader application across a wider market, with the potential to bring down capital investment.

Wastewater Heat Recovery (HR)

Wastewater Heat Recovery (HR) is the process of using wastewater as a heat sink or heat source for a water to water heat recovery chiller / heat pump system. Wastewater is diverted from the sewer line and heat is extracted from or rejected to the wastewater and is returned to the sewer line. Wastewater HR systems can be utilized at the campus level or at the building level. At the campus level, the wastewater HR system can augment the ground source heat exchange system by reducing the number of boreholes needed, as wastewater HR systems can be less capital-intensive than geothermal heat exchangers. For individual buildings, wastewater HR can be utilized to generate domestic hot water (DHW) for buildings with high domestic hot water usage, such as dormitories. Coordination with the local wastewater treatment facility is required to ensure that heat transfer to and from the wastewater stream does not negatively impact wastewater treatment operations at the treatment facility. As dormitories, or other individual buildings with high domestic hot water usage, are renovated or have their domestic hot water systems replaces, standalone wastewater HR systems providing domestic hot water should be considered, where applicable and as existing conditions allow.

Renewable Fuel Oil (RFO) Boiler

RFO boilers can meet a portion of the campus heating load not met by GSHP and ASHP systems, as well as provide heating system redundancy requirements. The new RFO boilers and new fuel storage system would be integrated into the new LTHW distribution system and located in the existing steam plant. The three existing underground fuel oil storage tanks near the central steam plant, each 5,000 gallons, could be replaced or repurposed for RFO storage. This solution assumes the combustion of RFO would be considered biogenic and carbon-neutral on a short timescale and considered renewable. Alternative renewable fuels, including renewable biogas, could also be considered if a sufficient supply of a cost effective, biogenic fuel is made available in the future.

Solutions Considered but Not Modeled

Onsite Photovoltaic (PV)

Onsite PV includes the installation of photovoltaic generation systems on campus to generate electricity directly delivered to campus buildings. PV installations could include rooftop, ground-mounted and/or parking canopy systems. The electricity generated from onsite PV installations will directly reduce the amount of electricity that would otherwise be purchased from the grid. While additional onsite electricity generation could potentially reduce scope 2 emissions, with Massachusetts committed to providing 100% renewable electricity by 2050, onsite renewable generation and associated Renewable Energy Credits (RECs) generated by onsite PV installations would no longer be necessary after 2050. Salem State University will continue plans to install onsite PV as roofs are re-done or parking lots are repaved and when projects, via a power purchase agreement (PPA), are cash-positive for the University. These projects will not retain the renewable energy credits associated with the onsite renewable generation.

Onsite Solar Thermal

Onsite Solar thermal systems include solar hot water panel arrays that would produce hot water to be distributed to the campus for heating. Solar hot water panels can be installed on roofs, parking structures and can also be surface mounted at grade. In addition to the solar hot water panels, new distribution pumps and piping will be required to connect the panels to the campus hot water distribution systems. The solar thermal system would reduce the need for fossil fuel combustion and would produce hot water year-round. For solar thermal arrays to be effective, the campus needs a year-round heating load. While the North Campus is expected to have a summer heating load, it will be met through heat recovery chillers or heat pumps providing simultaneous heating and cooling at high efficiency. The summer heating load is not large enough to warrant both heat recovery and solar thermal. As the heat recovery meets both heating and cooling loads, this is the preferred solution and onsite solar thermal will not be modeled as part of this study.

Renewable Energy Credits

A Renewable Energy Credit (REC) is a tradeable certificate that represents the environmental attributes of one megawatt-hour (MWh) of electricity generated by a renewable energy source. One REC is produced for each MWh of renewable electricity generated. By purchasing and retiring (i.e., not reselling) a REC, SSU can offset its GHG emissions associated with electricity the campus purchases and imports from the power grid. RECs that SSU acquires and retires can be generated from renewable generation systems located either on or off campus. Massachusetts current goal of providing 100% renewable electricity by 2050 would eliminate the need for voluntary REC purchases by SSU after 2050. In an effort to ensure available funding is directed towards education and students, SSU has elected to not purchase RECs as part of their GHG emissions reduction strategy.

Carbon Offsets

Carbon offsets represent a purchased unit of carbon dioxide-equivalent (CO_2e) that is reduced, avoided, or sequestered and claimed to mitigate increases in global GHG emissions by offsetting 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. Similar to RECs, SSU has elected to not purchase carbon offsets as part of their GHG emissions reduction strategy.

Options Analysis

Three options were considered in order to determine if Salem State should maintain the centralized system or pursue building-specific solutions for the North Campus clean energy transition. The Centralized Option includes a new central energy plant utilizing electric heat recovery equipment and renewable fuel oil boilers replacing the existing central steam plant. The Decentralized Option includes standalone heating and cooling systems for each building. The Hybrid Option combines components from both the Centralized and Decentralized Options. The Hybrid Option included a smaller central energy plant serving buildings located at the North Campus core, while standalone systems were provided for buildings located at the campus perimeter. Options screening included evaluating technologies and solutions based on initial capital cost estimates, energy savings, and carbon reduction for a Centralized and Decentralized Option. A Hybrid Option combining portions from the centralized and decentralized approach was also developed and analyzed.

Option A – Centralized

The Centralized Option includes a district energy system generating hot and chilled water, with a new central energy plant with hot and chilled water distribution loops connecting all North Campus buildings. Under the Centralized Option, Bowditch and Peabody are only connected to the central hot water distribution system and are not provided with air conditioning. Salem State has other dorms located on the central campus that are air conditioned that meet their summer housing needs. The central energy plant includes heat recovery chillers coupled with a ground source heat exchanger. Traditional electric chillers and RFO boilers were modeled for peak cooling and heating. The new central energy plant is planned to be installed in the new Meier Hall science lab addition, and additional space will need to be allocated for the central plant as well as the additional electrical infrastructure in the building programming and design. The new RFO boilers will be installed in the existing central steam plant, to take advantage of the existing fuel storage systems and boiler flues. The annual heating and cooling load profile for the Centralized Option is included in Figure 9 below and annual energy, carbon and utility cost performance is included in Table 10.

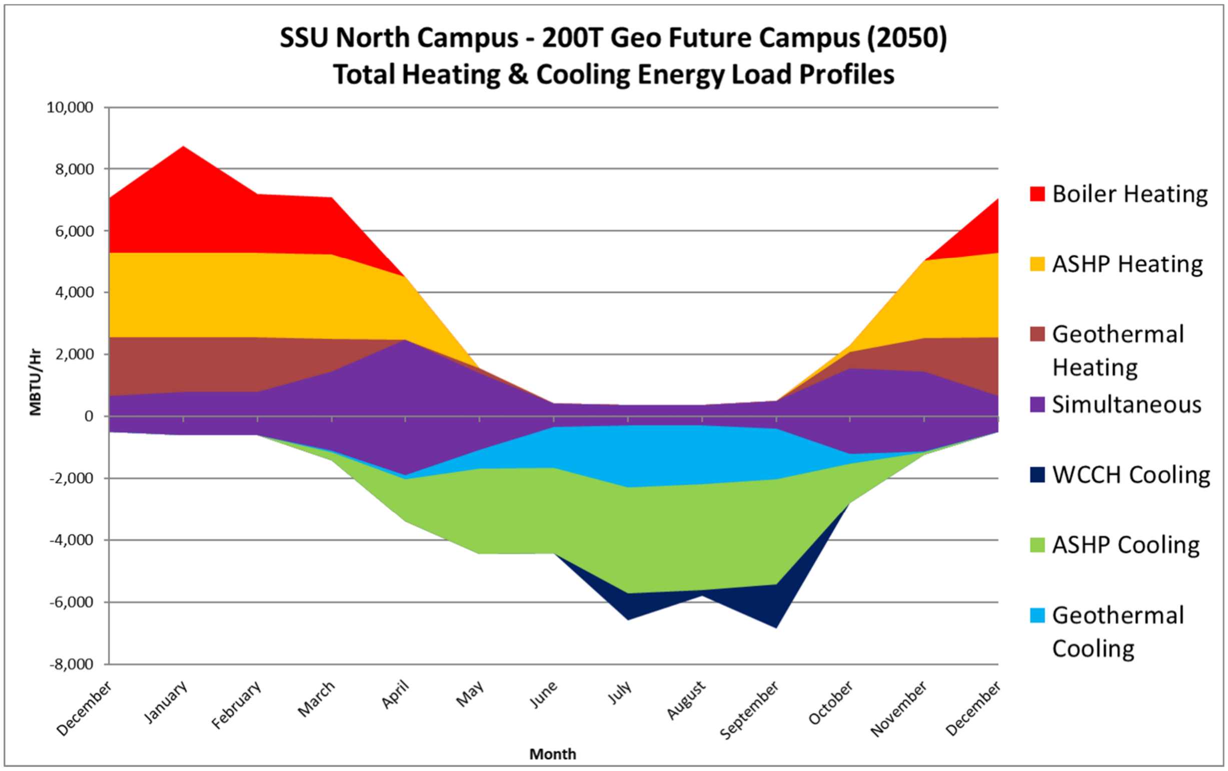

Figure 9: Centralized Option Thermal Profile

Table 10: Centralized Option Annual Performance (2050)

	BAU System	Centralized Option	Savings	% Change
NG Therm/yr	475,587	0	475,587	-100.0%
RFO Therm/yr	0	68,191	-68,191	100.0%
Elec KWH/yr	3,680,782	5,110,519	-1,429,737	38.8%
Total Energy MBTU/yr	60,117,537	24,256,178	35,861,359	-59.7%
NG Utility $/yr	$494,611	0	$494,611	-100.0%
RFO Utility $/yr	$0	$92,194	-$92,194	-
Elec Utility $/yr	$622,052	$863,678	-$241,626	38.8%
Total Utility $/yr	$1,116,663	$955,872	$160,791	-14.4%
GHG Emissions - Elec (MTCO2e/yr)	1,099	0	1,099	-100.0%
GHG Emissions - NG (MTCO2e/yr)	2,524	0	2,524	-100.0%
GHG Emissions - Total (MTCO2e/yr)	3,623	0	3,623	-100.0%

Option B - Decentralized

The Decentralized Option includes standalone HVAC systems for individual buildings. Air source heat pumps, capable of low ambient operation and sized for 100% heating and cooling capacity, were modeled for each building. No central plant equipment or utility distribution was included. The Decentralized Option would separate decarbonization efforts for individual buildings resulting in smaller projects that might be easier to fund and have less of an impact on campus operations vs. the Centralized Option. The annual heating and cooling load profile for the Decentralized Option is included in Figure 10 below and annual energy, carbon and utility cost performance is included in Table 11 below.

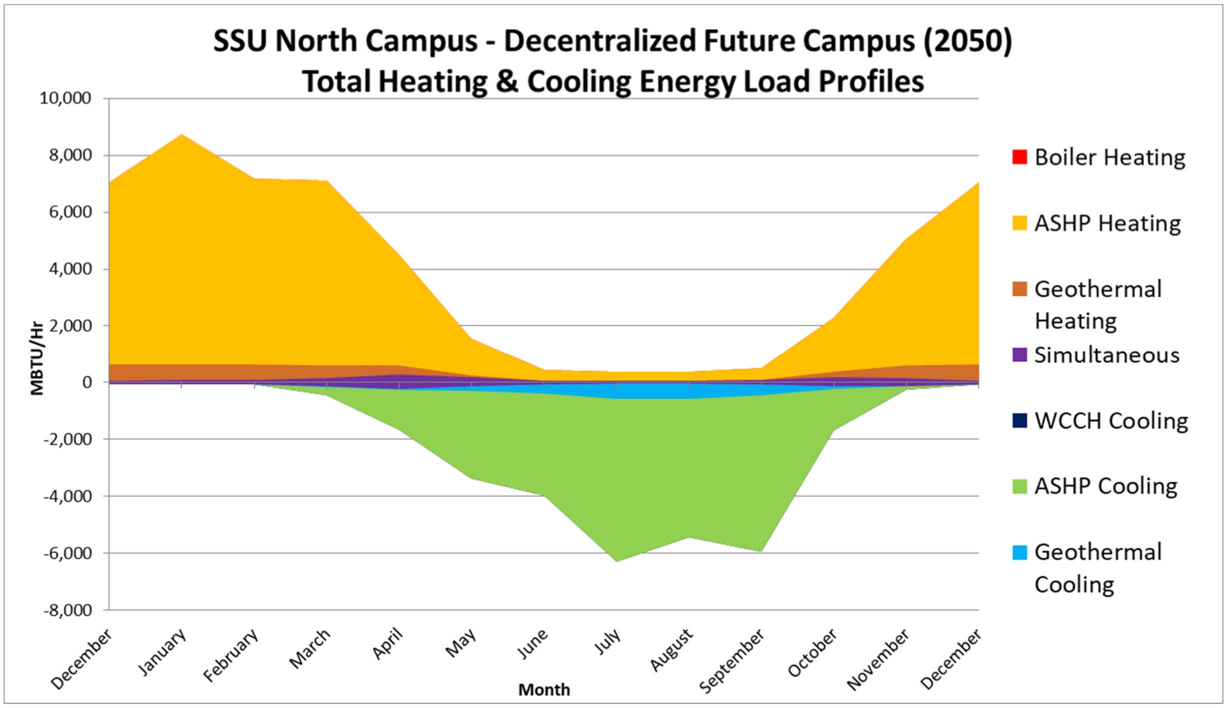

Figure 10: Decentralized Option Thermal Profile

Table 11: Decentralized Option Annual Performance (2050)

	BAU System	Decentralized Option	Savings	% Change
NG Therm/yr	475,587	0	475,587	-100.0%
RFO Therm/yr	0	0	0	-
Elec KWH/yr	3,680,782	7,087,331	-3,406,549	92.5%
Total Energy MBTU/yr	60,117,537	54,846,637	5,270,900	-8.8%
NG Utility $/yr	$494,611	$0	$494,611	100.0%
RFO Utility $/yr	0	0	0	-
Elec Utility $/yr	$622,052	$1,197,759	-$575,707	92.5%
Total Utility $/yr	$1,116,663	$1,197,759	-$81,096	7.3%
GHG Emissions - Elec (MTCO2e/yr)	1,099	0	1,099	-100.0%
GHG Emissions - NG (MTCO2e/yr)	2,524	0	2,524	-100.0%
GHG Emissions - Total (MTCO2e/yr)	3,623	0	3,623	-100.0%

Option C – Hybrid

The Hybrid Option includes a district energy system with a new central energy plant, hot and chilled water distribution loop connecting the Administration Building, Sophia Theater, Commons Dining, Meier Hall, the Meier Hall Science Lab addition, Berry Library and Ellison. Similar to the Centralized Option, the new central energy plant modeled included heat recovery chillers, ground source heat exchange and traditional chillers and RFO boilers for peak conditions. Standalone HVAC systems were modeled for buildings around the perimeter of the North Campus, including Peabody, Bowditch, Horace Mann and Sullivan. Similar to the decentralized approach, air source heat pumps, capable of low ambient operation and sized for 100% heating and cooling capacity, were modeled for these buildings. The annual heating and cooling load profile for the Hybrid Option is included in Figure 11 below and annual energy, carbon and utility cost performance is included in Table 12 below.

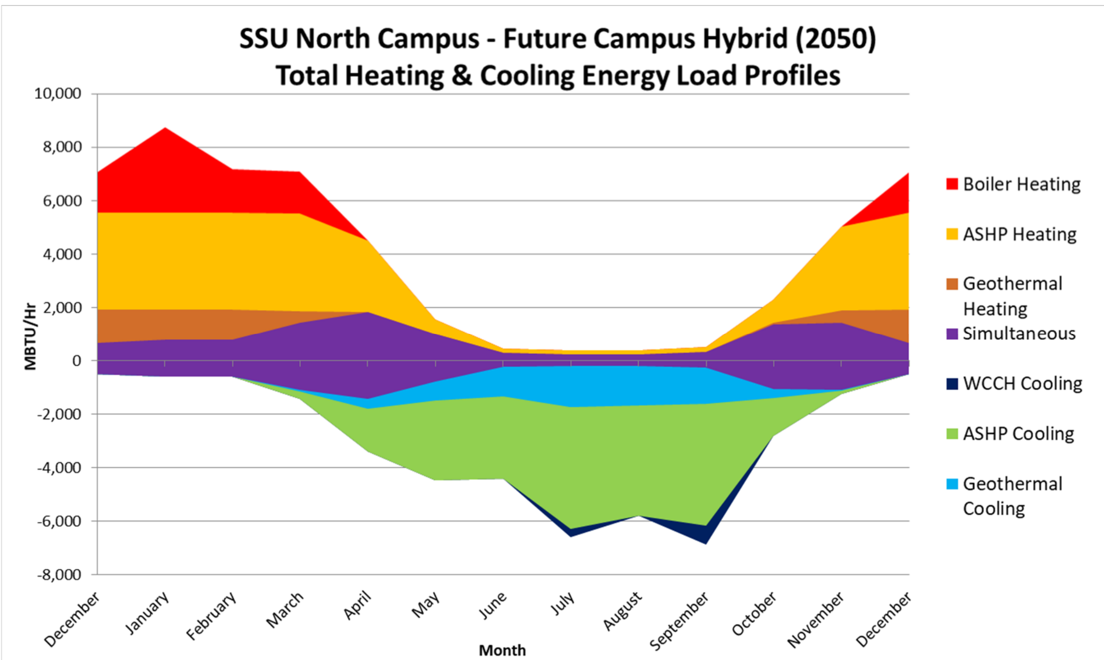

Figure 11: Hybrid Option Thermal Profile

Table 12: Hybrid Option Annual Performance (2050)

	BAU System	Hybrid Option	Savings	% Change
NG Therm/yr	475,587	0	475,587	-100.0%
RFO Therm/yr	0	45,269	-45,269	100.0%
Elec KWH/yr	3,680,782	5,641,976	-1,961,194	53.3%
Total Energy MBTU/yr	60,117,537	50,785,111	9,332,426	-15.5%
NG Utility $/yr	$494,611	$0	$494,611	-100.0%
RFO Utility $/yr	0	$70,620	-$70,620	100.0%
Elec Utility $/yr	$622,052	$953,494	-$331,442	53.3%
Total Utility $/yr	$1,116,663	$1,024,114	$92,549	-8.3%
GHG Emissions - Elec (MTCO2e/yr)	1,099	0	1,099	-100.0%
GHG Emissions - NG (MTCO2e/yr)	2,524	0	2,524	-100.0%
GHG Emissions - Total (MTCO2e/yr)	3,623	0	3,623	-100.0%

All three options had similar investment requirements, within 5% of each other, however the Centralized Option resulted in the greatest reduction in energy use (31%) and utility costs (20%) when compared to the BAU. The Centralized Option was selected as the recommended option to be further advanced into a clean energy roadmap with Life Cycle Cost Analysis (LCCA) and sensitivity analysis based on the improved energy use reduction achieved over the decentralized and hybrid options. The relative energy and utility cost performance for all three options is shown below in Table 13 and Table 14.

Table 13: Energy Cost Comparison for Options Considered

	BAU	Centralized		Decentralized		Hybrid	
		Cost	% Change	Cost	% Change	Cost	% Change
Total Utility $/yr	$1,116,663	$955,872	-14.4%	$1,197,759	7.3%	$1,024,114	-8.3%

Table 14: Energy Usage and GHG Emissions Comparison for Options Considered

	BAU	Centralized		Decentralized		Hybrid	
		Usage	% Change	Usage	% Change	Usage	% Change
Energy MBTU/yr	60,117,537	24,256,178	-59.7%	54,846,637	-8.8%	50,785,111	-15.5%
GHG Emissions (MTCO2e/yr)	3,623	0	-100%	0	-100%	0	-100%

Centralized Option (Recommended Option)

The Centralized Option includes a campus conversion from steam to a LTHW district heating system, with steam to LTHW building conversions for all campus buildings, a new chilled water central plant and distribution system, an expansion of the ground source heat exchange system and a wastewater heat recovery system. Peak cooling will be provided with traditional electric, water cooled chillers and peak heating will be provided by renewable fuel oil boilers. Implementation will occur over a sixteen-year period, starting in 2025 with the Horace Mann renovation and Meier Hall Science Lab addition. The Horace Mann renovation and Meier Hall Science Lab addition will initially be provided with stand-alone air source heat pumps while the new central energy plant is built. The new central energy plant, located in the Meier Hall Science Lad addition, will be built out in phases, increasing the capacity as LTHW and CHW utility piping distribution is connected to campus buildings. Once the new central plant and utility distribution are completed, the air source heat pumps will be integrated into the centralized distribution system.

The first major projects included under the Centralized Option recommendations do not start until 2025. Prior 2025 SSU should continue with ECM implementation and begin development of high performance building standards.

As the nearest planned new construction project, the Meier Hall science lab addition provides the best opportunity for locating the new central energy plant. The Meier Hall science lab addition design team will need to allow space in the new building program for new central plant equipment and supporting infrastructure. The Meier Hall science lab addition currently planned for 2025 is a critical component of this clean energy feasibility study, however there is some flexibility in the implementation schedule. The science lab addition construction could be scheduled for as late as 2029, when the first phase of central plant equipment is installed, and still keep the road map on track. If the science lab addition schedule was moved out beyond 2029, the phasing road map would also need to adjust accordingly, or alternatively, a different location for the new central energy plant would need to be determined. As the Horace Mann renovation is initially intended to operate as a stand alone building, while the new central energy plant and utility distribution are installed, there is additional flexibility in the construction schedule. The Horace Mann renovation could occur anytime between 2025 and 2039 and still be compatible with phased roadmap for implementation.

Building heating systems will require a conversion from steam to LTHW in order to be compatible with the new LTHW distribution system. All North Campus buildings will require a building conversion under the Centralized Option. The building conversions details are further described later in this report.

The final phase of the road map for 2040 is included below in Figure 12 which includes the current campus and a potential configuration for the future Meier Addition. A detailed year by year phased roadmap is included in Appendix C. The Centralized Option implementation plan is further summarized in Table 15 below. For the referenced implementation years, these represent the year the project is completed. Planning for funding, design and permitting would need to happen up to a few years before the year indicated. The following sections of the report outline the specific solutions modeled for the Centralized Option.

This implementation plan and schedule should be coordinated with any new construction and with the DCAMM deferred maintenance plan. As new projects on campus are developed, this plan should be shared with the design teams for integration.

The recommendations included in this report are intended to inform a high-level plan to achieve energy and carbon emissions reductions. The analysis used to determine these recommendations, including systems sizes, capacities and installation, have been established using the design criteria included in this report and appendices. As this roadmap progresses into detailed design and implementation phases, this design criteria would need to be reviewed and confirmed.

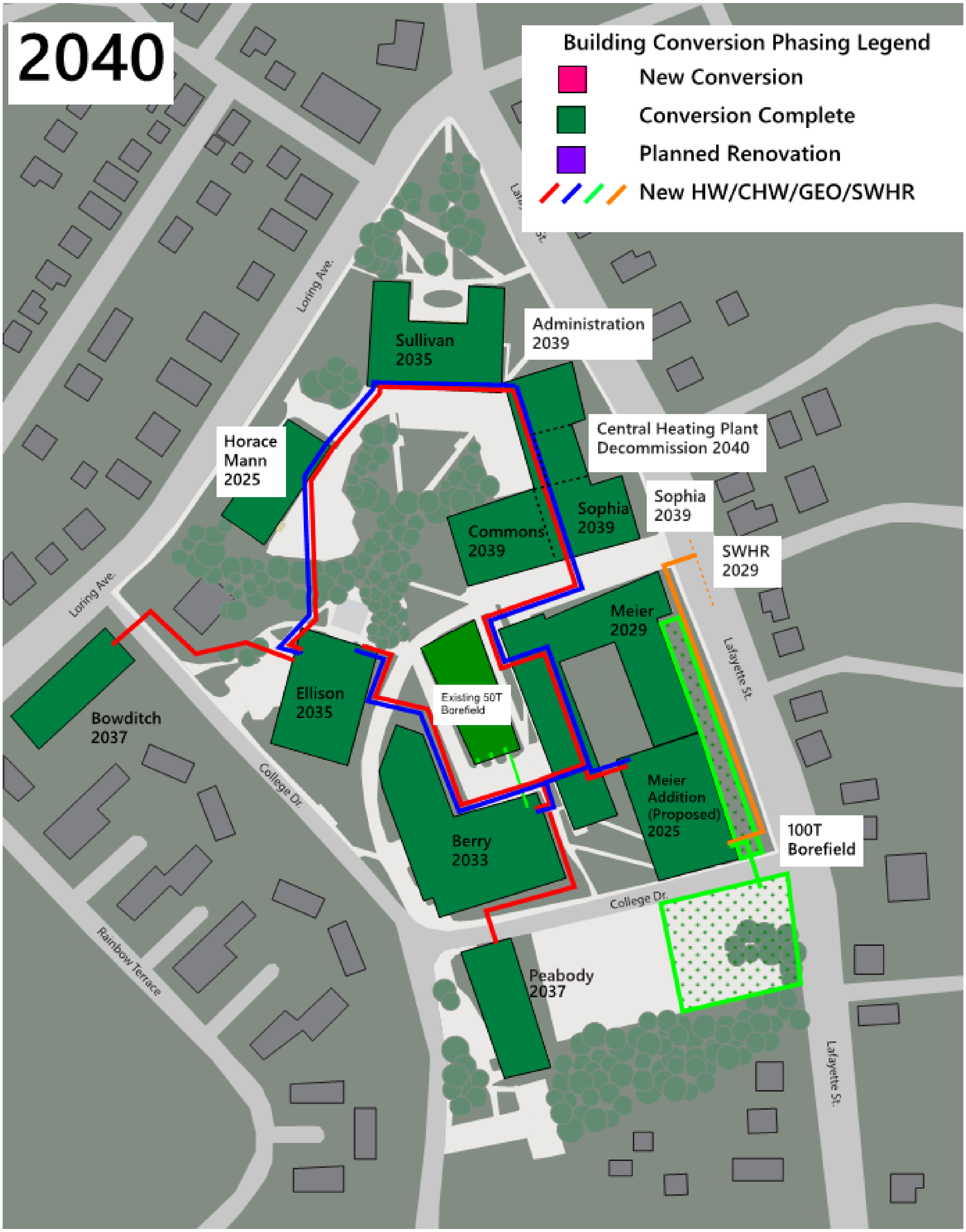

Figure 12: Centralized Option Final Phase Roadmap - 2040

Table 15: Centralized Option Implementation Plan by Year

Year	Building Conversions & LTHW/CHW Utility Piping	Planned Renovations & Additions	Energy Plant & Geothermal HX Installations
2025	-	Horace Mann Renovation (115 Ton ASHP, EUI =50) Meier Hall Science Lab Addition (285 Ton ASHP, EUI = 70)	Meier Hall Science Lab Addition, New energy plant core & shell
2029	Meier Renovation[i]	Meier Renovation	Meier Hall Science Lab Addition, New energy plant fit out: • 150 Ton heat recovery chiller • 215 Ton water cooled chiller New geothermal heat exchange (150 Ton) Wastewater Heat Recovery System Meier Hall Science Lab addition integration with new energy plant
2033	Berry Library	-	Interconnect existing geothermal heat exchanger at Berry Library
2035	Sullivan Renovation[i] Ellison	Sullivan Renovation	New energy plant: • 185 Ton water cooled chiller
2037	Bowditch[ii] Peabody[ii]	-	-
2039	Administration Bldg. Commons Dining Sophia Theater	-	New energy plant: • 170 Ton water cooled chiller • Peak RFO Boilers, 3x 3,000 MBH Horace Mann integration with new energy plant
2040	-	-	Central Steam Plant Decommissioned

I. Building conversion costs for Meier Hall and Sullivan are included. Costs for complete building and HVAC system modernization are not included. These costs would be included in the building renovation budgets.

II. Bowditch and Peabody are connected to the campus LTHW distribution for heating only. No air conditioning is provided for Bowditch and Peabody.

With the Horace Mann renovation and the Meier Hall Science Lab addition scheduled as the first phase of implementation, their building systems will initially operate as stand-alone, decentralized equipment. As the campus conversion progresses and the central energy plant and utility piping distribution is installed and interconnects the North Campus buildings, the heating and cooling systems at Horace Mann and Meier Hall Science Lab addition will be integrated into the central energy plant operation, allowing these systems to serve other buildings on campus and contribute to the overall installed capacity of the central energy plant.

Air source heat pumps have been modeled for the heating and cooling systems for the Horace Mann renovation and the Meier Hall Science Lab addition. ASHPs are electrically driven and can provide both heating and cooling through a single system, without burning fossil fuels. In order to meet the peak heating loads, the ASHPs will need to be selected for low ambient operation. Even under peak heating and cooling conditions, where the ASHPs operate at their lowest efficiency, these systems will still outperform fossil fuel boilers (COP<0.95) and electric chillers, with a much lower carbon emission footprint. The effect of outdoor air temperature on ASHP efficiency can be seen through the average monthly heating and cooling ASHP efficiencies in Table 16 which were determined using performance curves provided by the ASHP manufacturer. These values were used in the modeling of energy performance for buildings on the ASHP system.

Table 16: ASHP Modeled Efficiencies

Month	Heating COP	Cooling COP
January	2.35	5
February	2.15	5
March	2.45	5
April	2.85	4.8
May	3.27	4
June	2	3.6
July	2	3.2
August	2	3.34
September	2	3.66
October	3.15	4.3
November	2.65	4.9
December	2.15	5

Horace Mann renovation, Meier Hall Science Lab addition Energy Use

As the Horace Mann renovation and new Meier Hall Science Lab addition are not yet complete, their modeled building energy use was based on an assumed Energy Use Intensity (EUI) determined through benchmarking against other buildings in the New England area with similar occupancy types. In order to align the expected energy use with SSU's energy reduction and carbon neutrality goas, these EUI benchmarks were further reduced to represent high-performance building designs. Considering these buildings will not be constructed or renovated until 2025, it is likely they will fall under a new version of the energy code. As the energy code updates are expected to improve building energy efficiency, these EUI targets will likely be less aggressive when compared to the new energy code. The target EUIs included in the Centralized Option energy forecast for the Horace Mann renovation and Meier Hall Science Lab addition designs are included in Table 17. These maximum EUI targets for campus growth will require energy efficient designs, including optimizing building envelope performance, minimizing internal loads and specifying energy efficient HVAC equipment. Capital cost premiums, relative to a theoretical code-compliant baseline, are not included in the modeled results since these would not be considered energy system costs, but rather capital costs embedded in the renovation or construction budget. The costs for the Horace Mann renovation and the Meier Hall Science Lab addition are not being carried as part of this study for either the BAU case or the Centralized Option.

Table 17: Target EUIs for Campus Growth

Building	EUI
Horace Mann Renovation	50
Meier Hall Science Lab Addition	70

Building Energy Conservation Measures (ECMs)

SSU has reduced site EUI for the overall campus by 25% from 2004 to 2019. As SSU has demonstrated a commitment to reducing building energy use through ECMs as part of their business as usual operations, the Centralized Option will include an additional energy reduction and associated costs to represent a premium energy reduction performance and investment above what SSU would normally achieve under their BAU case.

The most recent energy use reductions are a result of Investment Grade Audits (IGA) conducted in 2013, 2014 and 2016. The potential for future energy use reduction through ECMs was determined by analyzing the ECM costs and energy performance included in past IGAs. Annual EUI reductions have been getting smaller as previous IGAs have targeted low cost, high yield ECMS. As a result, future ECMS are expected to have longer paybacks, smaller energy reductions and higher investment costs.

The campus energy forecast includes three $75,000 investments in building ECMs occurring in 2025, 2030 and 2035, each resulting in a 0.5% EUI reduction for the campus. This investment and energy reduction is in addition to SSU would achieve under the BAU case. No additional energy improvement was modeled after 2035 and while it is likely SSU would continue to invest in this program after 2040, this is beyond the investment period for the Centralized Option. In addition, based on the campus energy use, each of these ECM investments are anticipated to have a 15-year payback. The final investment period, starting in 2035, would be fully realized by 2050, the end of the study period.

Building Conversions

For compatibility with the future campus LTHW distribution system for heating, all campus buildings utilizing steam will require a heating system conversion, including the removal of mechanical equipment served by steam or high temperature hot water, and replacement with equipment sized to meet the building heating loads at the LTHW design temperature. Building conversion work includes the replacement of both central equipment, such as air handling units, and terminal equipment, such as finned tube radiators and fan coil units. A total of nine buildings and 685,000 GSF will be converted from steam to LTHW heating systems at a cost of $8.1M.

The building conversion costs were estimated by grouping buildings according to their expected degree of difficulty, high, medium or low, in converting the heating systems to LTHW, and then assigning a dollar per square foot cost to each level. Factors considered when grouping buildings included occupancy type, age of the building, existing system types. For example, Meier Hall was considered a high degree of difficulty based on the number of labs, the current use high temperature hot water and the building age (built in 1963). In contrast, Berry Library, built in 2012 with systems that already use LTHW, was considered a low degree of difficulty building conversion. The dollar per square foot costs for each difficulty level are informed by previous studies and cost estimates for similar campuses and actual building conversion costs from campuses that have recently completed similar building conversion work. Building conversion costs include all soft costs, such as design fees, contingency, etc.

The building conversions will be completed in the phased approach outlined in the above implementation plan and aligned with currently planned building renovations. The building conversion costs, in 2021 dollars, are summarized below in Table 18. Further cost breakdown of the building LTHW conversions is provided in Appendix D.

Table 18: Building Conversion Cost Summary

Building	**Area (Sq. Ft.)**	**Degree of Difficulty**	**Total Cost**
Administration	23,267	Medium	$304,798
Commons Dining Hall	35,089	Medium	$459,666
Sophia Theater	26,096	Low	$159,186
Berry Library	124,000	Low	$756,400
Bowditch Hall	64,183	Low	$391,516
Ellison Campus Center	49,776	Medium	$652,066
Meier Hall	160,345	High	$3,206,900
Peabody	73,352	Low	$447,447
Sullivan	83,851	High	$1,677,020
Total	639,959		$8,054,998

Under the Centralized Option implementation plan, as buildings are converted from steam to LTHW, the LTHW utility piping, and chilled water piping (where applicable) are also installed, connecting the building to the new central energy plant. The utility pipe routing and phased installation are shown on the phasing maps included in Appendix C.

Beyond LTHW compatibility, there are additional benefits associated with the building conversions. Having a newly upgraded heating system with modern controls can contribute to better thermal comfort, resulting in improved occupant satisfaction and performance. For some buildings, upgraded heating systems provided under the building conversion scope can correct existing deficiencies including insufficient or lack of ventilation air. Improved ventilation can result in better indoor air quality, including reduced carbon dioxide levels, and contribute to a healthier building. Reduced carbon dioxide levels in the classroom have been shown to improve student’s alertness and ability to concentrate. High levels of carbon dioxide, indicating a lack of fresh air, negatively affects the learning ability of students.

New Energy Plant

A new central energy plant, designed to be located in the Meier Hall Science Lab addition, will include a modular 150 Ton heat recovery chiller coupled with a geothermal heat exchanger, 570 Tons of water-cooled chillers and three 3,000 MBH high efficiency dual fuel boilers. The primary fuel source for the boilers will be renewable fuel oil with natural gas available as backup. The new central energy plant will be constructed in phases, adding capacity as buildings are converted and utility piping is installed.

Air source heat pumps installed at Horace Mann and Meier Hall Science Lab addition will be integrated into the central energy plant so they can provide chilled water and low temperature hot water to the rest of the campus. The geothermal heat pump system installed in Berry Library will be integrated into the central energy plant. The geothermal heat exchanger serving Berry Library will also be integrated into the new geothermal systems.

For the Centralized Option, the peak heating and cooling loads and annual heating and cooling energy by system type are included below in Table 19.

Table 19: Centralized Option Performance by System Type

System Type	Peak Heating	Peak Cooling	Annual Heating & Cooling Energy
Heat Recovery Chillers & Geothermal HX	25%	20%	45%
Air Source Heat Pumps	21%	27%	40%
RFO Boilers	53%	-	10%
Water Cooled Chillers	-	54%	5%

The annual heating and cooling load profile for the Centralized Option is included in Figure 13 below, with the expected contribution from each system type highlighted.

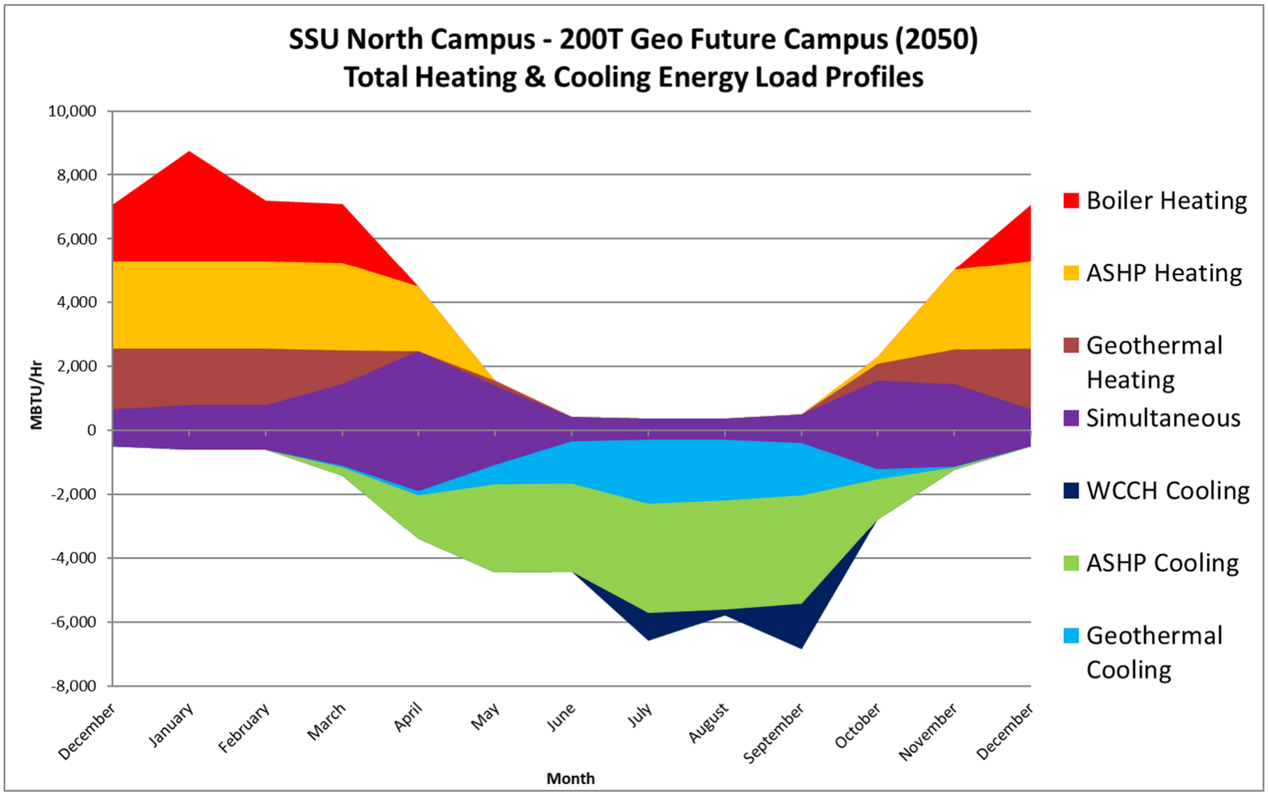

Figure 13: Centralized Option Thermal Profile

GHX

The geothermal heat exchange system modeled under the Centralized Option will require 55 bore holes, each 800 feet deep, spaced 20 feet on center. The geothermal heat exchanger layout, as indicated below in Figure 14, requires 0.6 acres of existing parking lot and landscaped areas. After construction, the parking lot will be repaved and able to be used for parking. The landscaping would also be restored after construction of the geothermal heat exchangers. The ground source heat exchanger included in this study has been estimated to cost approximately $2.2 million. Further cost breakdown is provided in Appendix D.

Figure 14: Geothermal Heat Exchanger Installation

Wastewater HR

The wastewater heat recovery system modeled for the Centralized Option assumes tapping into the sewage main that runs down Lafayette Street. A new 6,000-gallon underground wastewater holding tank will be required near the sewage line point of connection. Direct buried piping will connect the storage tank to the central energy plant. A wastewater separator / filter temporarily removes solids from the wastewater before being passed through an application specific heat exchanger where thermal energy from the new heat recovery chiller central plant is extracted from or rejected to the wastewater, before being returned to the sewer main.

Space within the new central energy plant will be required to house the new filtration system, heat exchangers and distribution pumps. The proposed wastewater HR layout is included below in Figure 15. The Centralized Option implementation plan assumes the wastewater HR system will be installed in 2029, the same year as the geothermal heat exchanger. The Wastewater HR systems will cost approximately $685,000. Further cost breakdown is provided in Appendix D. The wastewater HR system would reduce the geothermal heat exchanger size from 81 to 55 bore holes, reducing the ground source heat exchange system initial capital costs by approximately $930,000. The wastewater HR system implementation provides a net reduction of $245,000 over a ground source only system. As the wastewater HR system would offset geothermal installation, it is included in the same installation year as the geothermal heat exchanger.

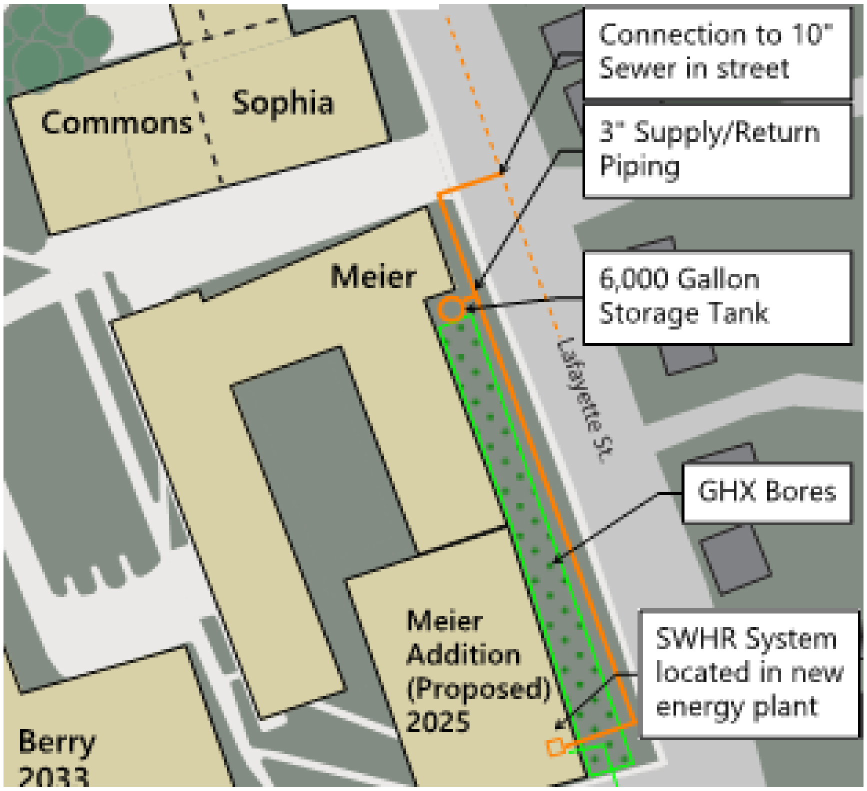

Figure 15: Wastewater Heat Recovery System

Electrical Infrastructure

Meier Hall Science Lab Addition Electrical Systems

With the location of the new central energy plant planned for the Meier Hall Science Lab addition, additional electrical service capacity will be required above what would be necessary to support just the building program. Added central plant electrical loads include a heat recovery chiller, water cooled electric chillers, pumps and other ancillary mechanical equipment, resulting in a load of 2128 amps. This additional load will require an additional 13.8V/480V transformer adjacent to the new science lab addition to serve the new addition and associated mechanical equipment. A new 3000A, 480/277V, 3P switchboard will be required to accommodate the new loads.

For the purposes of emergency power and to provide a backup source for the new central plant, it is recommended to provide a new pad mounted 750KW diesel generator to be located adjacent to the new science lab addition for emergency backup power for new mechanical loads.

Horace Mann Electrical Systems

The existing building is slated for a renovation in 2025 which will include mechanical system upgrades. It is recommended to replace all service gear at that time to accommodate all new loads due to the age of the facility and expected increase in electrical load due to added air conditioning.

Estimated Capital Costs

The Centralized Option costs include the design and construction of utilities for low temperature hot water and chilled water distribution piping, geofield utility piping and heat exchangers, energy plant equipment and building conversions. A summary of costs for the Centralized Option are included in Table 20 below.

Table 20: Centralized Options Capital Costs

Year	Energy Conservation Measures	Utility Piping	Geofield & Wastewater HR	Central Energy Plant	Building Conversions	Total
2025	$75,000	-	-	-	-	$75,000
2029	-	$1,736,763	$2,860,210	$581,378	$3,206,900	$9,881,511
2030	$75,000	-	-	-	-	$75,000
2033	-	$459,731	-	-	$756,400	$1,216,131
2035	$75,000	$2,609,230	-	$492,718	$2,329,086	$5,975,795
2037	-	$516,942	-	-	$838,964	$1,355,906
2039	-	$805,041	-	$1,040,679	$923,649	$2,769,369
Total (Through 2040)	$225,000	$6,127,707	$2,860,210	$2,114,775	$8,054,998	$20,422,452

Cost estimates for utility piping, geofield heat exchange and wastewater heat recovery systems include all soft costs, such as design fees, contingency, etc.

Estimated Maintenance Costs

From 2021 through 2025, the Centralized Option assumes the same operations and maintenance annual costs as the BAU case, including the CSP budget and the HVAC department budget. Starting in 2025, as heating and cooling assets are added to the new central energy plant, the operations and maintenance costs for the Centralized Option increase. With the central steam plant phased decommissioning over five years from 2036 to 2041, the steam maintenance budget is also phased out over the same time period and completely eliminated by 2041. Two additional full time staff are added to the HVAC department budget starting, one in 2036 and another in 2041, resulting in six full time employees required for the HVAC department to support the new central energy plant and the individual building heating and cooling systems.

The Centralized Option annual operations and maintenance costs significantly decrease after the existing central steam plant is taken offline in 2040. Compared to the BAU case maintenance costs of $2,615,577 for 2041, the Centralized Option maintenance costs are $1,078,331, an annual reduction of $1,537,246. A summary of the maintenance costs is included above in Table 7. A summary of maintenance costs by year and equipment type are included in Appendix D.

Rebates and Incentives

There are potential rebates and incentives available through state agencies and utility companies for projects that reduce energy use and reduce greenhouse gas emissions. In addition to traditional, prescriptive rebates and incentives, and due to the complex, custom nature and long implementation schedule outlined here, there may be an opportunity for a custom rebate geared towards specific components of this study. Additional coordination with state agencies and utility companies during design and implementation will be required to develop any custom rebate or incentive opportunities.

Performance: Energy, Carbon, Utility cost

The energy consumption for the BAU case and the Centralized Option were calculated for each year of the 30 year study incorporating changes to the campus and installation of new energy systems, refer to Table 21 below. The resulting total energy consumption for the BAU scenario and electrical, natural gas and RFO energy consumption for the Centralized Option is detailed in Figure 16 below. This figure illustrates the significant energy consumption reduction going from the BAU to Centralized Option and also highlights the Centralized Option's transition from natural gas to RFO in 2040 for peak heating.

Table 21: Centralized Option Results Timeline

	Existing BAU Systems (2021)	Meier Addition + HM Renovation (2025)	Meier Reno + GHX + Wastewater HR (2029)	Berry Conversion + Existing GHX Connect (2033)	Sullivan Reno + Ellison Conversion (2035)	Bowditch, Peabody Conversions (2037)	Admin, Commons, Sophia Conversions, RFO Boilers (2040)	2050
Elec (kWh/yr)	2,827,367	4,251,203	4,021,151	4,240,887	5,103,451	5,035,550	5,110,519	5,110,519
NG (Therm/yr)	431,810	431,929	281,872	232,898	117,396	116,063	0	0
RFO (Therm/yr)	0	0	0	0	0	0	68,191	68,191
Elec Utility ($/yr)	$477,825	$718,453	$679,574	$716,710	$862,483	$851,008	$863,678	$863,678
NG Utility ($/yr)	$449,082	$449,206	$293,147	$242,214	$122,092	$120,706	$0	$0
RFO Utility ($/yr)	$0	$0	$0	$0	$0	$0	$92,194	$92,194
Total Utility ($/yr)	$926,907	$1,167,659	$972,721	$958,924	$984,575	$971,714	$955,872	$955,872
Energy (MBTU/yr)	52,827,930	57,698,034	41,907,397	37,759,727	29,152,608	28,787,640	24,256,178	24,256,178
GHG Emissions - Elec (MTCO2e/yr)	844	1,093	867	742	787	673	526	0
GHG Emissions – NG (MTCO2e/yr)	2,292	2,292	1,496	1,236	623	616	0	0
Total GHG Emissions (MTCO2e/yr)	3,135	3,386	2,365	1,978	1,411	1,289	526	0

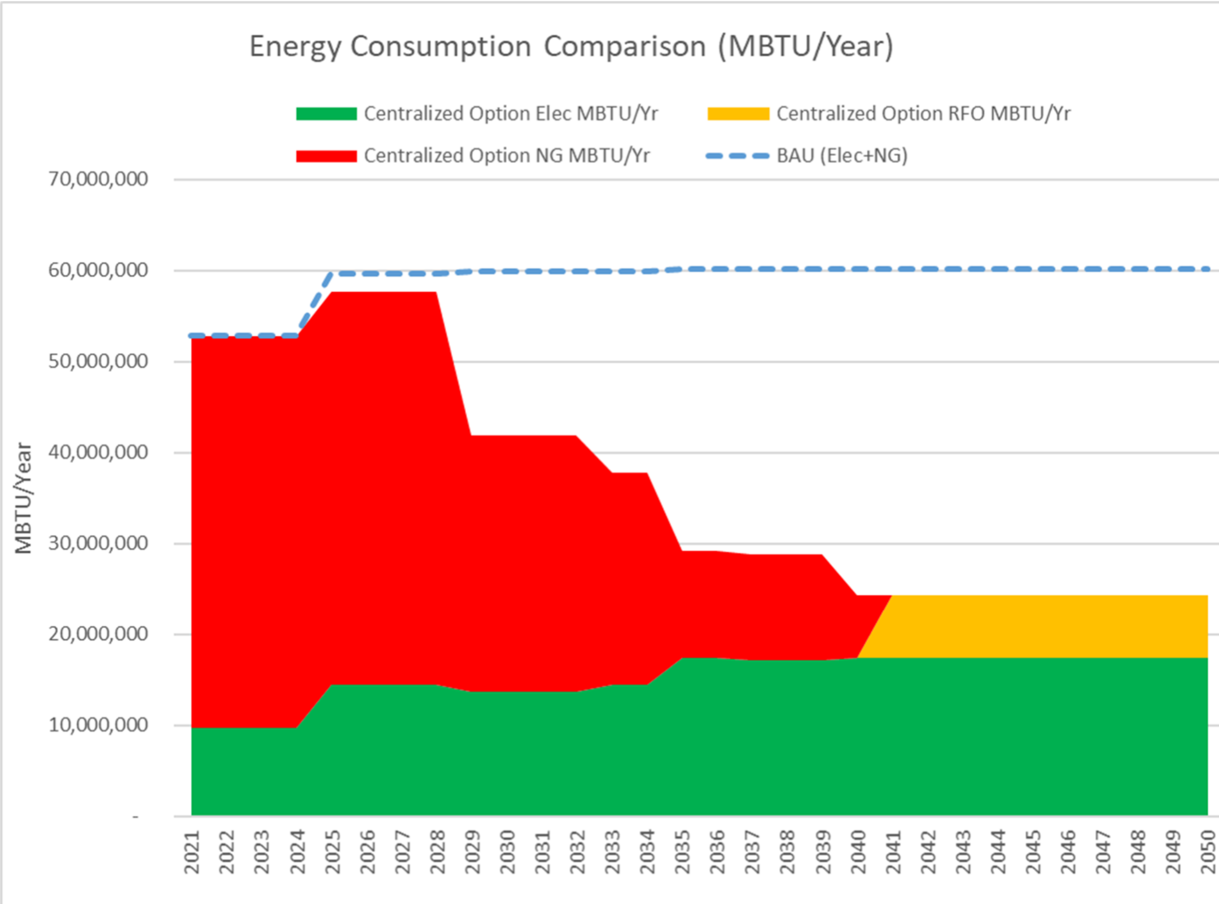

Figure 16: Relative Energy Performance

The energy costs for the BAU case and the Centralized Option were also calculated for each year of the 30 year study. The resulting total energy cost for the BAU scenario and electrical, natural gas and RFO energy costs for the Centralized Option are detailed in Figure 17 below.

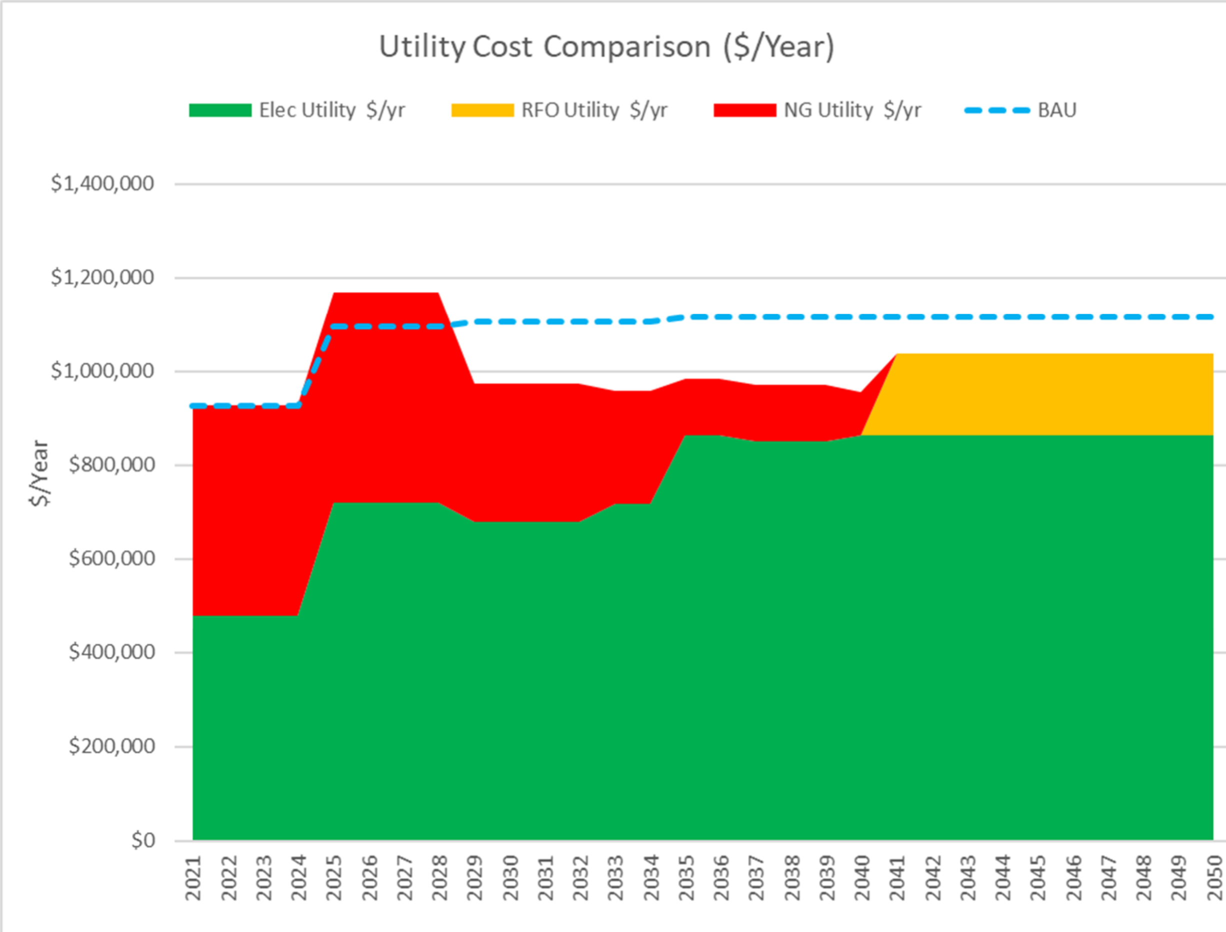

Figure 17: Relative Utility Costs

Carbon emissions for each year of the study were also evaluated for the BAU case and the Centralized Option. The total carbon emissions for the BAU case as well as the electrical and natural gas carbon emissions for the Centralized Option are detailed in Figure 18. This figure illustrates the transition to RFO, for peak heating in 2040 as well as the greening of the electrical grid.

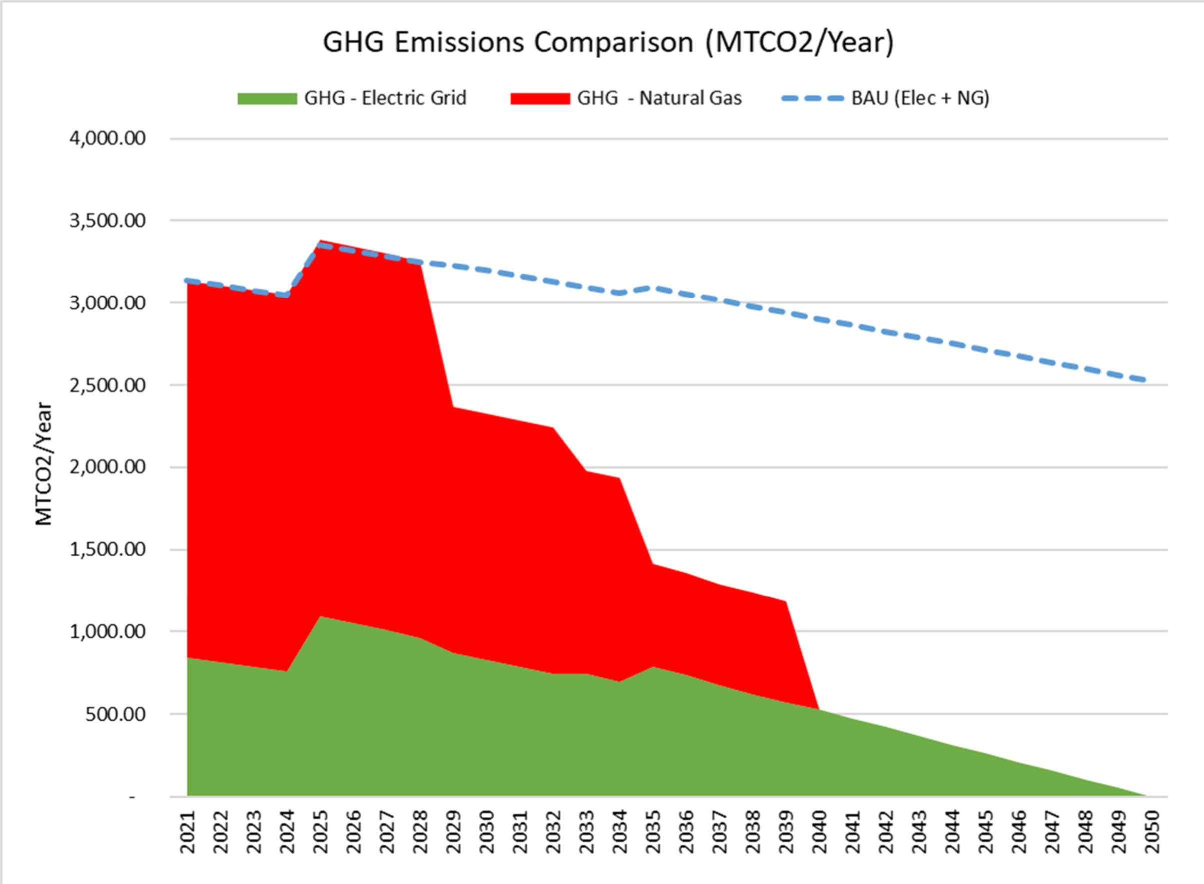

Figure 18: Relative GHG Emissions

By switching to the systems recommended under the Centralized Option the total avoided GHG emissions for the North Campus will be 41,241 MTCO2e between 2021 and 2050, which is equivalent to the consumption of 100,000 barrels of oil[4]. The North Campus GHG reductions relative to the 2004 and 2021 baseline emissions are included below in Table 22. The Centralized Option will result in a 100% GHG emission reduction by 2050, exceeding the State goal.

Table 22: North Campus GHG Reductions

Year	State Goal (2004 Baseline)	Centralized Option	
		(2004 GHG Baseline)	(2021 GHG Baseline)
2025	20%	39%	16%
2030	35%	58%	42%
2040	60%	90%	87%
2050	95%	100%	100%

Life Cycle Cost Analysis (LCCA)

The relative economic and environmental performance of each option was evaluated using a Life-Cycle Cost Analysis (LCCA) model. The LCCA model used the discount and escalation rates included in Table 23. The forecast period is 30 years with the first forecast year being 2021 and the final forecast year being 2050.

Table 23: LCCA Discount and Annual Escalation Rates

LCCA Rate Information	
Inflation Rate	2.38%
Real Discount Rate	4.50%
Natural Gas Escalation Rate	2.60%
RFO Escalation Rate	2.38%
Electric Escalation Rate	2.00%
City Water Escalation Rate	3.58%
Nominal Discount Rate	6.99%
Carbon Tax Escalation Rate	2.38%

The Centralized Option was compared to the BAU Reference Case using the Net Present Value of all future cash flows throughout the forecast period. The LCCA model discounts all future cash flows to 2021 dollars using a 4.5% real discount rate. The inflation rate of 2.38% represents the average yearly inflation rate provided by the US Bureau of Labor Statistics from 1990 to 2021. Escalation rates for natural gas and electricity were determined using the Department of Energy's Energy Escalation Rate Calculator (EERC) version 2.0-20, with input from DCAMM and DOER. The EERC determines escalation rates for a specified period based on the Energy Information Administration (EIA) energy price projections by state. The escalation rate for city water is based on historic water billing rates provided by the City of Salem Department of Public Works from 2002 to 2020 and are included in Appendix D.

Social Cost of Carbon (Carbon Tax)

Applying a social cost of carbon can help understand the long-term environmental and financial risks associated with carbon emissions of infrastructure decisions. The EPA and other federal agencies use estimates of the social cost of carbon to value the climate impacts of rulemakings. The social cost of carbon is a measure, in dollars, of the long-term damage done by a metric ton of carbon dioxide ($MTCO_2$) emissions in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO_2 reduction).[5] A carbon tax could also be structured to cover other greenhouse gas emissions by calculating their global warming potential relative to carbon dioxide.

As of the writing of this report, there is no Massachusetts or federal tax or fee imposed on carbon emissions. Outside of the United States, many countries have enacted a carbon tax. Within the United States, various states and regions, including Oregon, Washington, California and New England, have or are currently considering a carbon tax or Emissions Trading Systems (ETS). A carbon tax would drive up the cost of fossil fuels, making low or zero-carbon investments more market competitive. An ETS, or cap-andtrade system, would cap total emissions levels and allow those with low emissions to sell their excess emissions capacity to higher emitters. The trading systems would establish a market price for greenhouse gas emissions.

The economic implications of taxing pollution are well understood, but political viability remains the primary challenge, making it difficult to determine what value to use in this analysis. The World Bank State and Trends of Carbon Pricing 2020[6] published the current nominal carbon tax rates by countries that have implemented carbon pricing initiatives, ranging from $25/ton (UK, Denmark) to $119/ton (Sweden). The $51/ton used in this study aims to approximate an average carbon cost.

The LCCA includes a voluntary, annual carbon tax of $51 per ton of CO_2 emissions starting in 2025, with a 2.38% annual escalation rate to match inflation. The dollar per ton tax included in this LCCA is a simplified approach to capturing this potential cost of operations. No specific legislation, tax or ETS has been assumed in this analysis, however, the financial metrics related to a carbon tax provides a good representation of potential taxes or ETS scenarios that SSU could be subjected to in the future. Based on the wide range in example taxes instituted by other countries, a possible carbon tax remains a point of uncertainty for this analysis. The impact of a potential carbon tax will be reviewed further in the sensitivity analysis section below.

The 2025 carbon tax of $51 per ton of CO_2 emissions escalated at 2.38% per year results in a 2050 carbon tax of $92 per ton of CO_2 emissions. The assumed carbon tax forecast is shown in Figure 19 below.

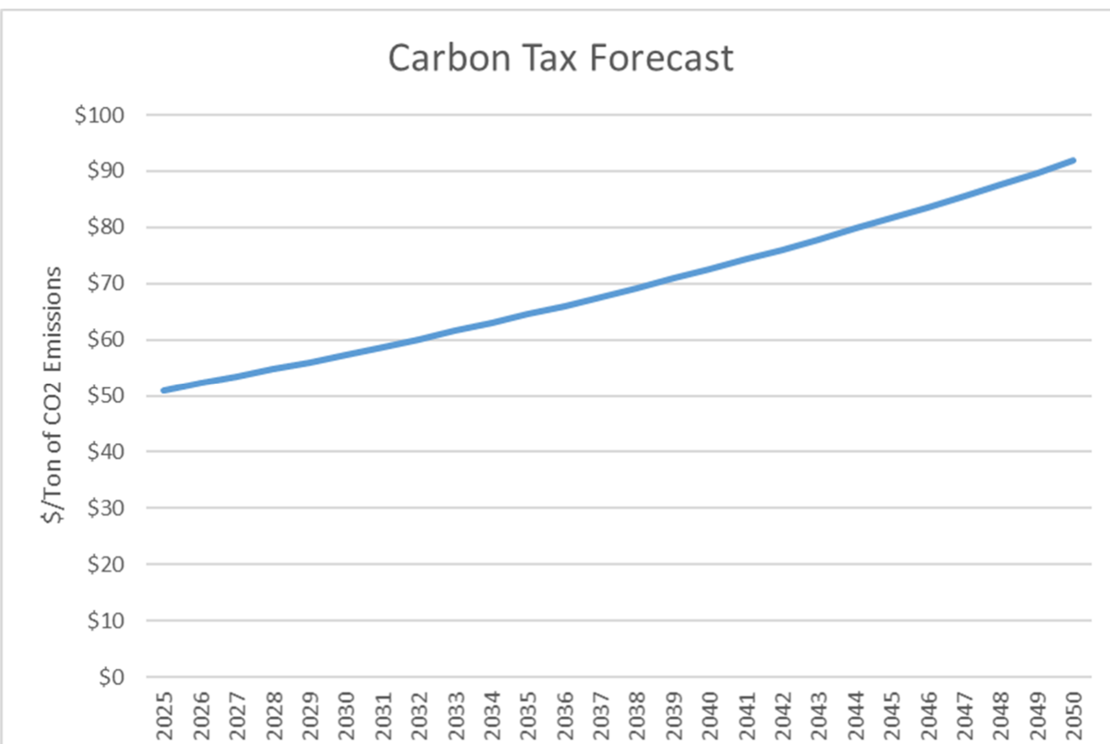

Figure 19: Carbon Tax Forecast

Purchased Carbon Offsets

The LCCA does not include the cost of purchasing carbon offsets to negate any CO_2 emissions released by the campus thermal energy systems. Carbon offsets can take the form of certificates which represents the reduction of a ton of carbon dioxide emissions. This reduction is achieved through the funding of projects which remove or avoid carbon emissions such as renewable energy projects and carbon capture projects.

Capital Costs

Capital costs for the BAU case include replacement of HVAC systems that have reached the end of their service life during the study period, including the replacement of the two boilers in the central steam plant. For the Centralized Option, capital costs include new utility piping, geothermal heat exchanger, the new energy plant and building conversions. Both the BAU and Centralized Option capital costs are summarized in Appendix D. Figure 20 below illustrates the comparative flow of capital costs (in 2021 dollars) throughout the forecast period.

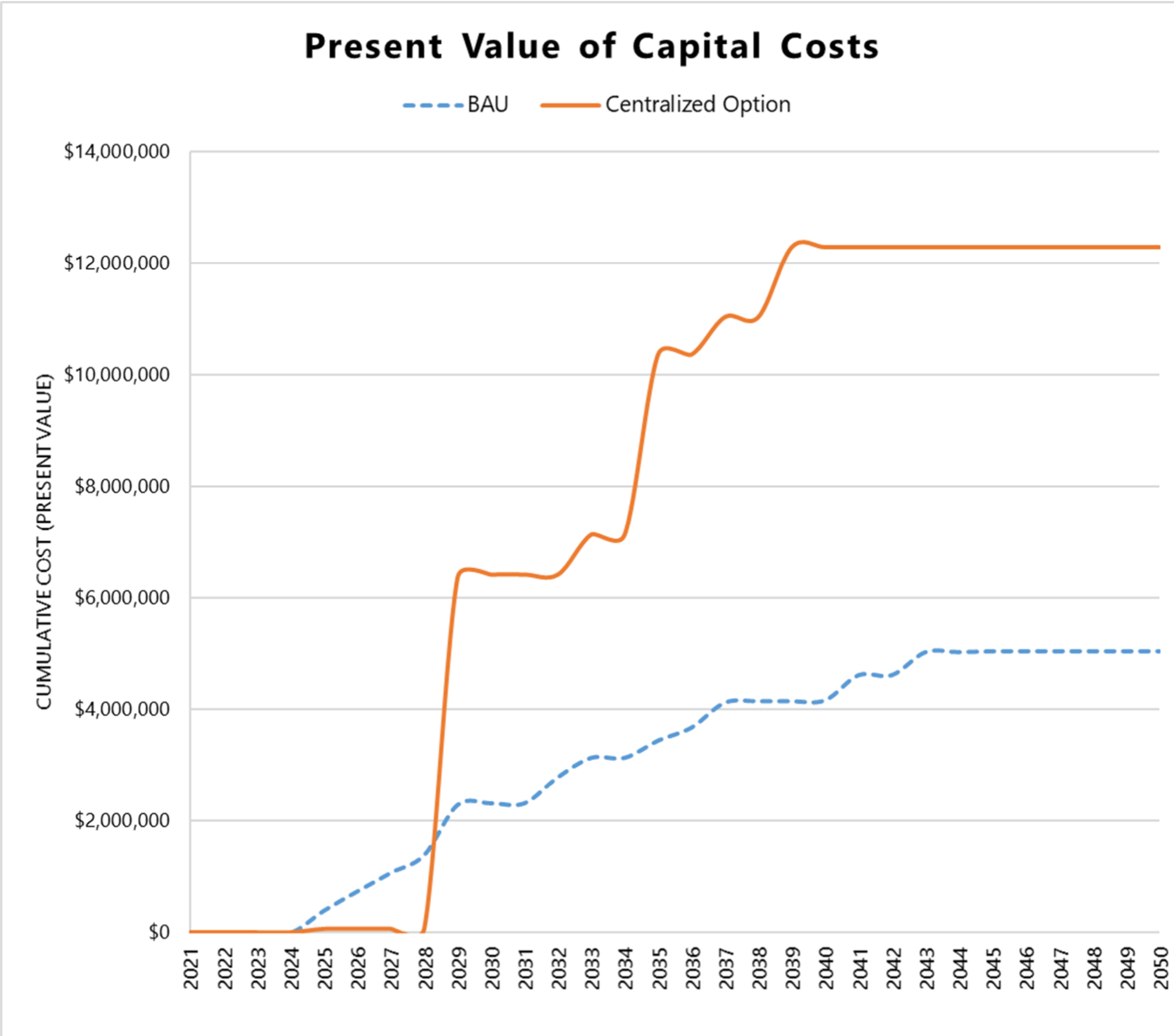

Figure 20: Capital Costs Comparison

Utility Costs

Purchased Fuel Pricing

According to utility bills provided by Salem State, the average price for natural gas was $1.04 per Therm for Fiscal Year 2021, including commodity and distribution. A 2.6% escalation per year was used for natural gas in the LCCA, resulting in a 2050 natural gas price approaching $2.19 per Therm. The assumed natural gas price forecast is shown in Figure 21 below.

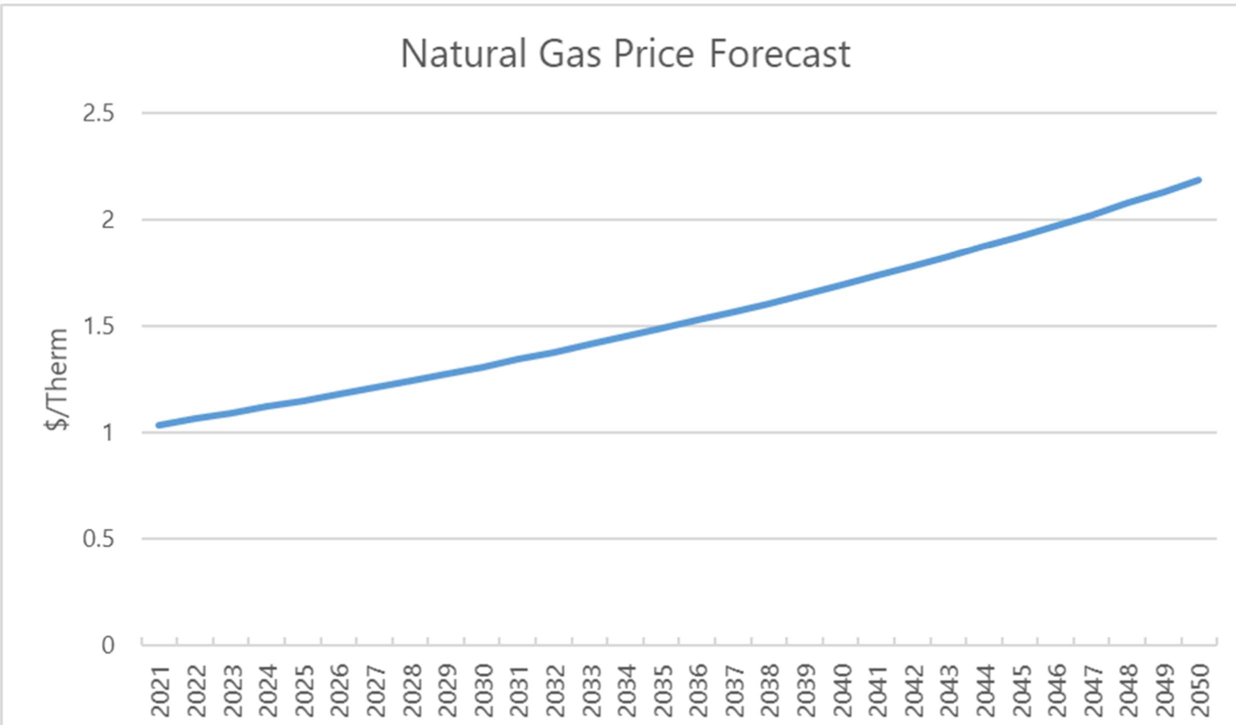

Figure 21: Natural Gas Price Forecast

For RFO costs, this analysis assumes a starting point of $2.40 per gallon, including delivery charges, based on preliminary quotes from a local supplier. A 2.38% escalation rate per year was used for RFO in the LCCA, resulting in a 2050 RFO price of $4.75 per gallon. The assumed RFO price forecast is shown in Figure 22 below. The Centralized Option includes limited RFO utilization for peak heating after the CSP is decommissioned in 2040.

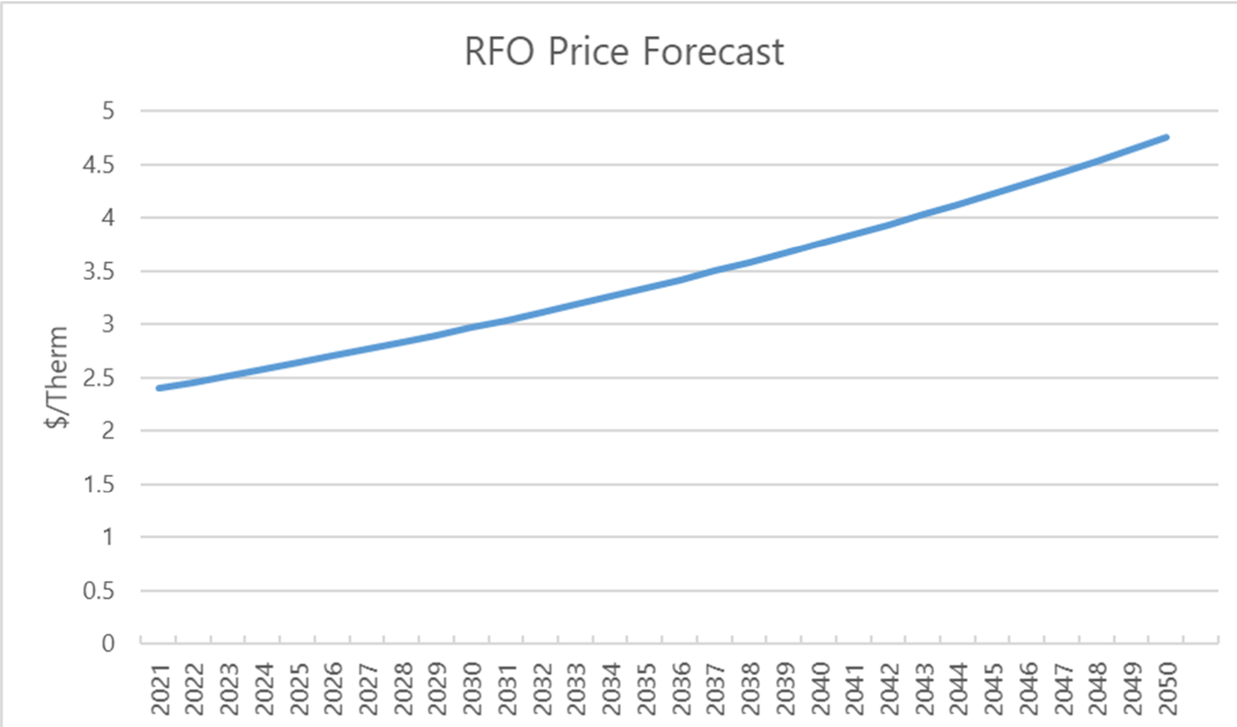

Figure 22: RFO Price Forecast

Purchased Electricity Pricing

According to the utility bills provided by Salem State, the average price for electricity was $0.17 per kWh for Fiscal Year 2021, including demand charges. A 2.0% escalation per year was used for electricity in the LCCA, resulting in a 2050 purchased electricity price exceeding $0.30 per kWh. The assumed price forecast is shown in Figure 23 below.

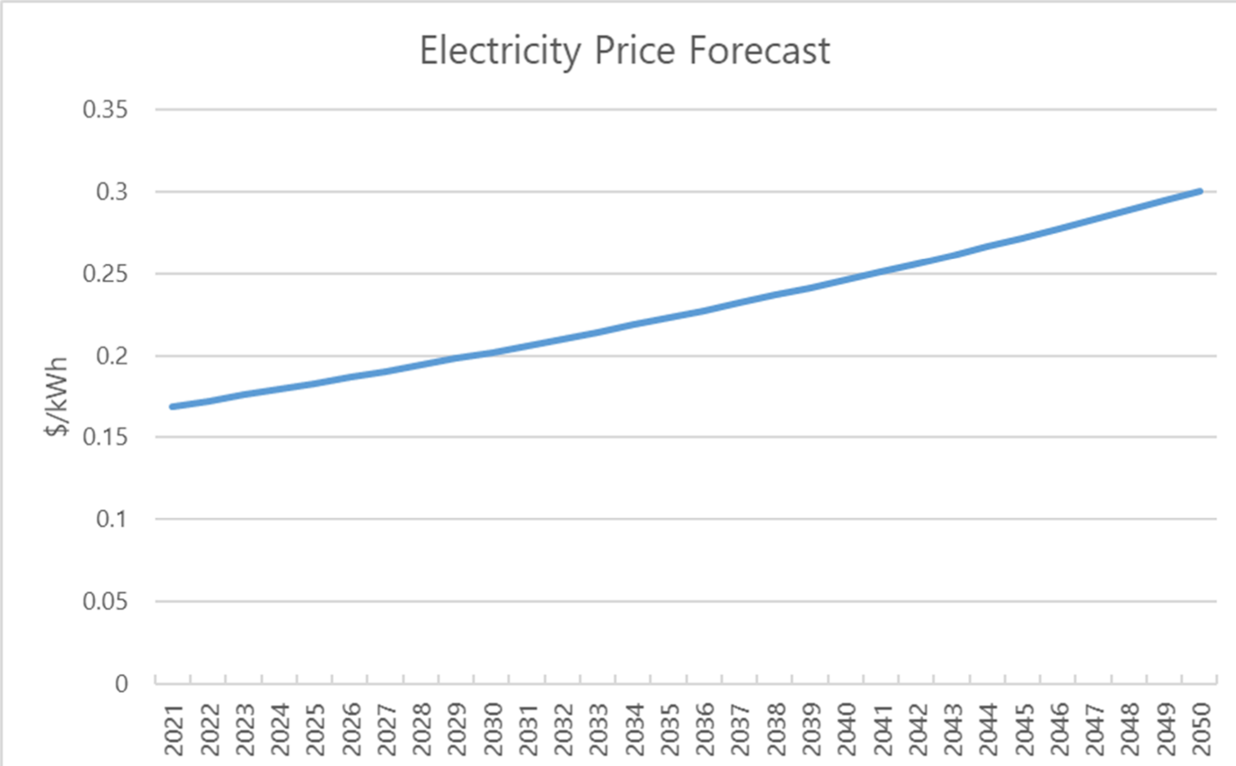

Figure 23: Electricity Price Forecast

Relative Economic and GHG Performance

A summary of costs and the present value comparison of the Centralized Option to the BAU case is included below in Table 24 and Figure 24.

Table 24: LCCA Economic Comparison BAU vs Centralized Option

30 Year Life Cycle - Economic Comparison			
Option:	**BAU**	**Centralized Option**	**Savings**
Elec Utility Cost	$9,505,340	$11,563,471	-$2,058,131
NG Utility Cost	$8,452,443	$4,503,311	$3,949,131
RFO Utility Cost	$0	$374,206	-$374,206
Total Utility Costs	$17,957,783	$16,440,988	$1,516,794
Investment Costs	$5,038,792	$12,278,860	-$7,240,069
Maintenance Costs	$36,994,029	$30,143,216	$6,850,813
City Water Costs	$262,025	$182,283	$79,742
NG Social Carbon Costs	$2,197,931	$801,244	$1,396,686
Elec Social Carbon Costs	$413,943	$545,409	-$131,465
Carbon Offset Costs	$0	$0	$0
30 Year Life Cycle Cost	$62,864,502	$60,392,000	$2,472,502
30 Year Life Cycle Cost w/o Carbon Tax	$60,252,628	$59,045,347	$1,207,281

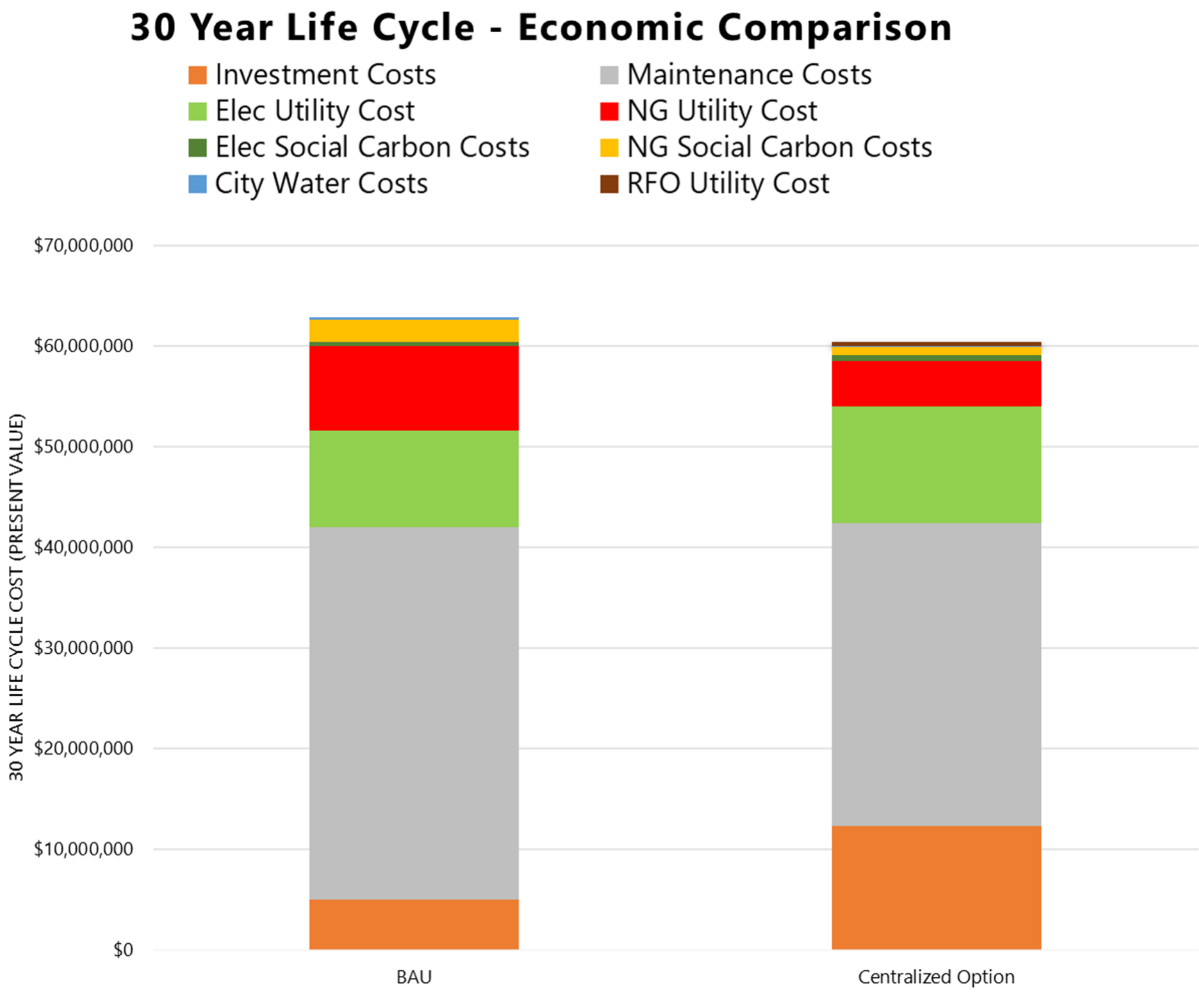

Figure 24: LCCA Present Value Comparison

The present value of cashflow for the BAU case and the Centralized Option is shown in Figure 25 below, inclusive of a carbon tax assumption. Compared to the BAU case, the break even point for the Centralized Option occurs in year 27 (2047). Over the 30 year LCCA, the Centralized Option saves $2.5M over the BAU case, inclusive of the carbon tax.

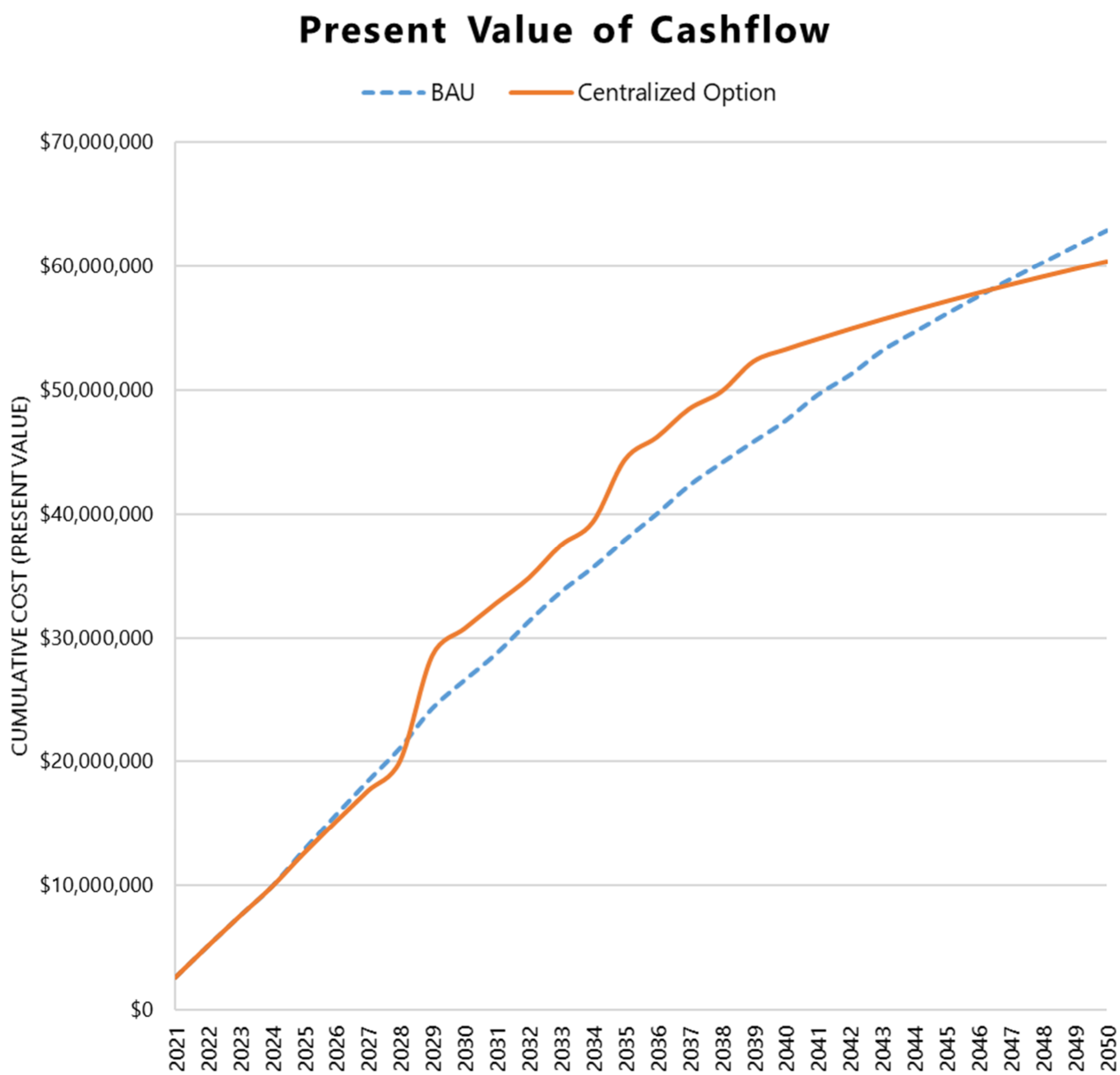

Figure 25: LCCA Net Present Value Cashflow Comparison

Due to the uncertainty around a carbon tax and the fact that it does not currently exist, the LCCA was also evaluated with the exclusion of a carbon tax. A summary of costs and the present value comparison of the Centralized Option to the BAU case without any carbon taxes is included below in Figure 26 and Figure 27.

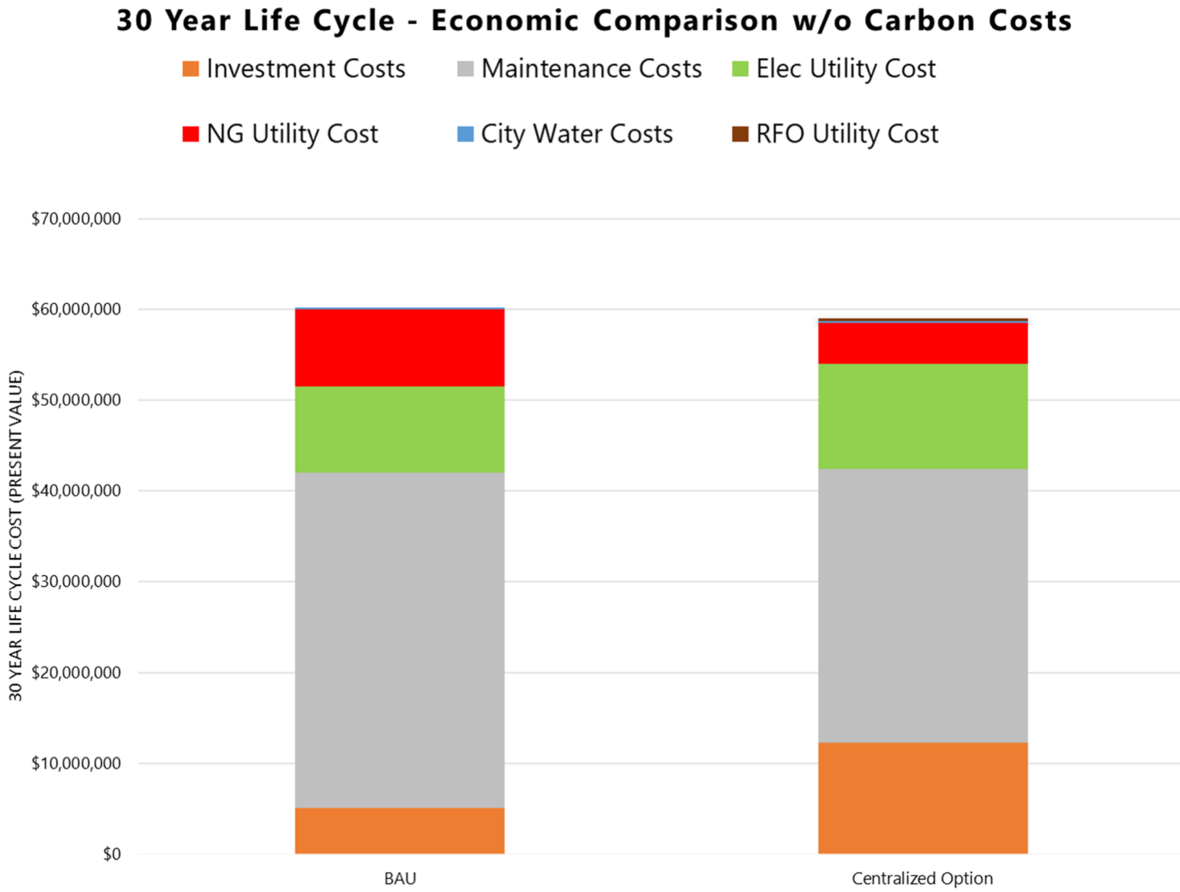

Figure 26: LCCA Present Value Comparison Without Carbon Costs

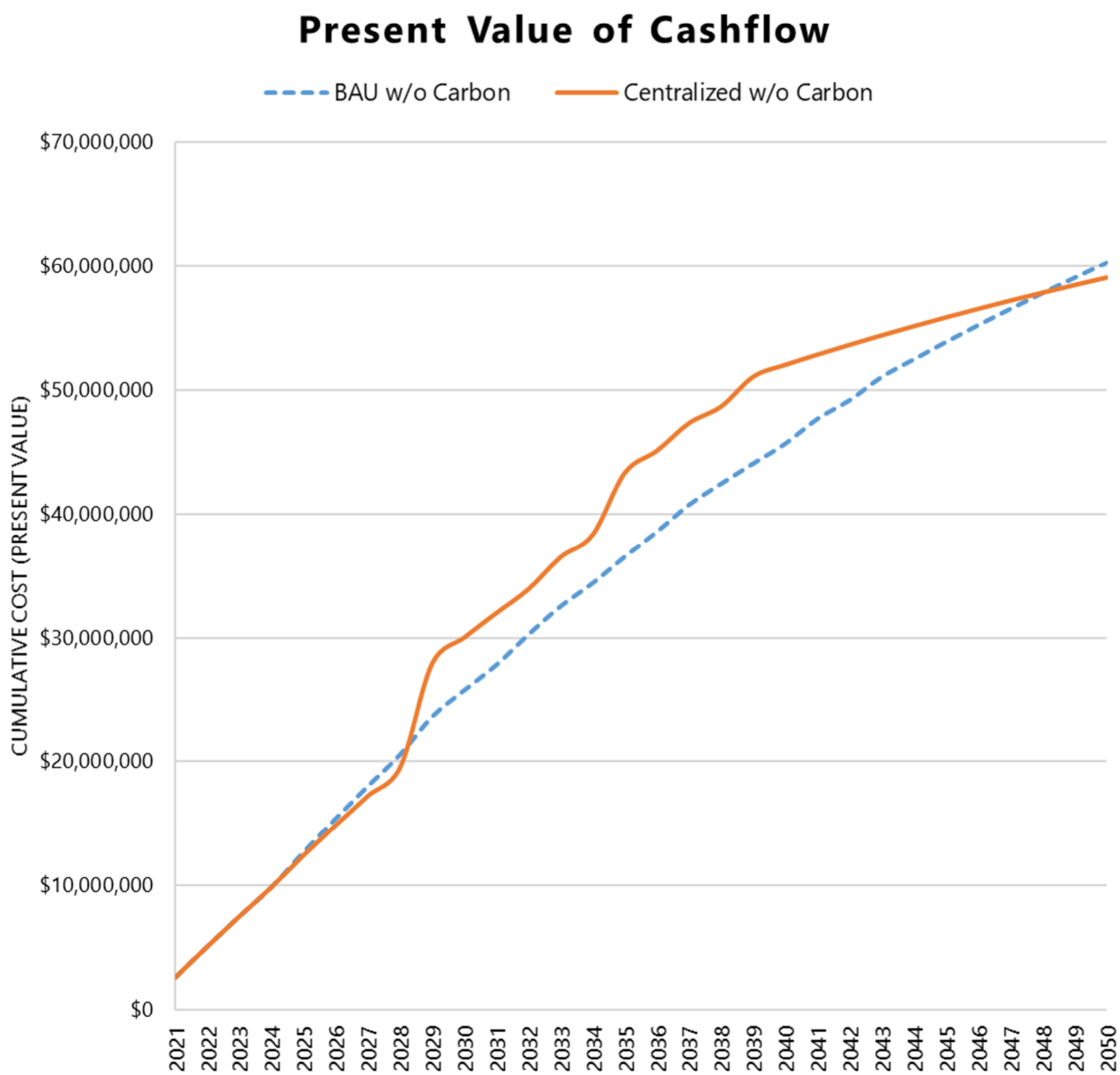

Figure 27: LCCA Net Present Value Cashflow Comparison Without Carbon Costs

The break even point for the Centralized Option without a carbon tax occurs in year 29 (2049), 2 years after the Centralized Option with carbon tax included. Without the carbon tax included, the Centralized Option still saves $1.2M compared to the BAU case over the 30 year LCCA.

Sensitivity Analysis

A sensitivity analysis was performed on commodity pricing and capital investment pricing to understand the potential impact of significant price changes during the 30 year study period on the life cycle cost savings.

The relative economic performance is dependent on key assumptions, including utility escalation rates for natural gas and electricity, that have an inherent level of uncertainty over the 30-year study period. Utility rates and capital investment costs are market driven and subject to somewhat unpredictable variability. Similarly, variability is expected for a carbon tax, as the specific requirements and implementation of this emerging monetary disincentive are not yet known. To understand the impact of significant fluctuations for the utility rates, capital costs and carbon taxes, a sensitivity analysis was conducted by applying a positive or negative uncertainty percentage to the model inputs and evaluating the 30 year net present value savings between the Centralized Option and the BAU. The uncertainties used are included in Table 25 below. The capital investment costs below are the 30-year net present value converted costs included in the LCCA.

As the carbon tax remains a large unknown for the LCCA, the uncertainty percentages used in the sensitivity analysis have been established to represent a potentially realistic low price decrease and high price increase. For the low end price uncertainty, since there is currently no state or federal carbon tax, a 100% decrease aims to model $0 carbon tax. For the high end price uncertainty, a 250% increase would represent a carbon tax on the maximum range published by the 2020 World Bank State and Trends of Carbon Pricing.

Table 25: Sensitivity Analysis Uncertainties

Utility	Original	Highest Price % Increase	Highest Price	Lowest Price % Decrease	Lowest Price
Electrical ($/kWh)	$0.17	20%	$0.20	-20%	$0.14
Natural Gas ($/Therm)	$1.04	20%	$1.25	-20%	$0.83
Carbon Tax (Social Carbon)	$51.00	250%	$178.50	-100%	$0.00
Capital Investment Cost BAU	$5,038,792	20%	$6,046,550	-20%	$4,031,033
Capital Investment Cost Centralized Option	$12,278,860	20%	$14,734,632	-20%	$9,823,088

The following scenarios included in Table 26 below were evaluated and compared against the original net present value results. Plus signs indicate a price increase while minus signs indicate a price decrease. The sensitivity analysis will allow SSU to understand the impact on the roadmap of pricing changes, up or down, from what was modeled.

Table 26: Sensitivity Analysis Scenarios

#	Scenario Description	Price Changes			
		Elec Change	NG Price Change	Carbon Price Change	Capital Investment Price Change
0	Original	0%	0%	0%	0%
1	+Electricity	20%	0%	0%	0%
2	-Electricity	-20%	0%	0%	0%
3	+20% Natural Gas	0%	20%	0%	0%
4	-20% Natural Gas	0%	-20%	0%	0%
5	+Capital Investment	0%	0%	0%	20%
6	-Capital Investment	0%	0%	0%	-20%
7	+Carbon	0%	0%	250%	0%
8	-Carbon	0%	0%	-100%	0%
9	+Elec & -Natural Gas	20%	-20%	0%	0%
10	+Elec & -Nat Gas & +Capital Investment	20%	-20%	0%	20%
11	**+Elec & - Nat Gas & -Carbon & +Capital Investment (Worst Case)**	**20%**	**-20%**	**-100%**	**20%**
12	-Elec & +Natural Gas	-20%	20%	0%	0%
13	+ Elec & +Natural Gas	20%	20%	0%	0%
14	-Elec & -Natural Gas	-20%	-20%	0%	0%
15	+Elec & +Natural Gas & -Carbon	-20%	20%	-100%	0%
16	**-Elec & +Natural Gas & +Carbon & -Capital Investment (Best Case)**	**-20%**	**20%**	**250%**	**-20%**
17	-Elec & +Natural Gas & +Carbon	-20%	20%	250%	0%

From the sensitivity analysis, a best case scenario which occurs in row 16 with the highest 30 year life cycle cost savings and worst case scenario which occurs in row with the lowest cost savings were identified. The best case scenario occurs with a reduced electricity cost, increased natural gas cost, increased carbon cost and reduced capital investment cost. The worst case scenario occurs in row 11 with inputs inverse to the best case which are an increased electricity cost, decreased natural gas cost, decreased carbon cost and increased capital investment cost. The model inputs and the results for the sensitivity analysis can be found in Table 27 and Figure 28 below. The complete sensitivity results can be found in Appendix F, including scenario descriptions and impact on net present values.

Table 27: Sensitivity Analysis Results

Option	Centralized Option
Best Savings (-20% Elec, +20% Nat Gas, +250% Carbon, -20% Cap Inv)	$8,210,179
Original NPV	$2,472,502
Worst Savings (+20% Elec, -20% Nat Gas, -100% Carbon, +20% Cap Inv)	-$1,367,344

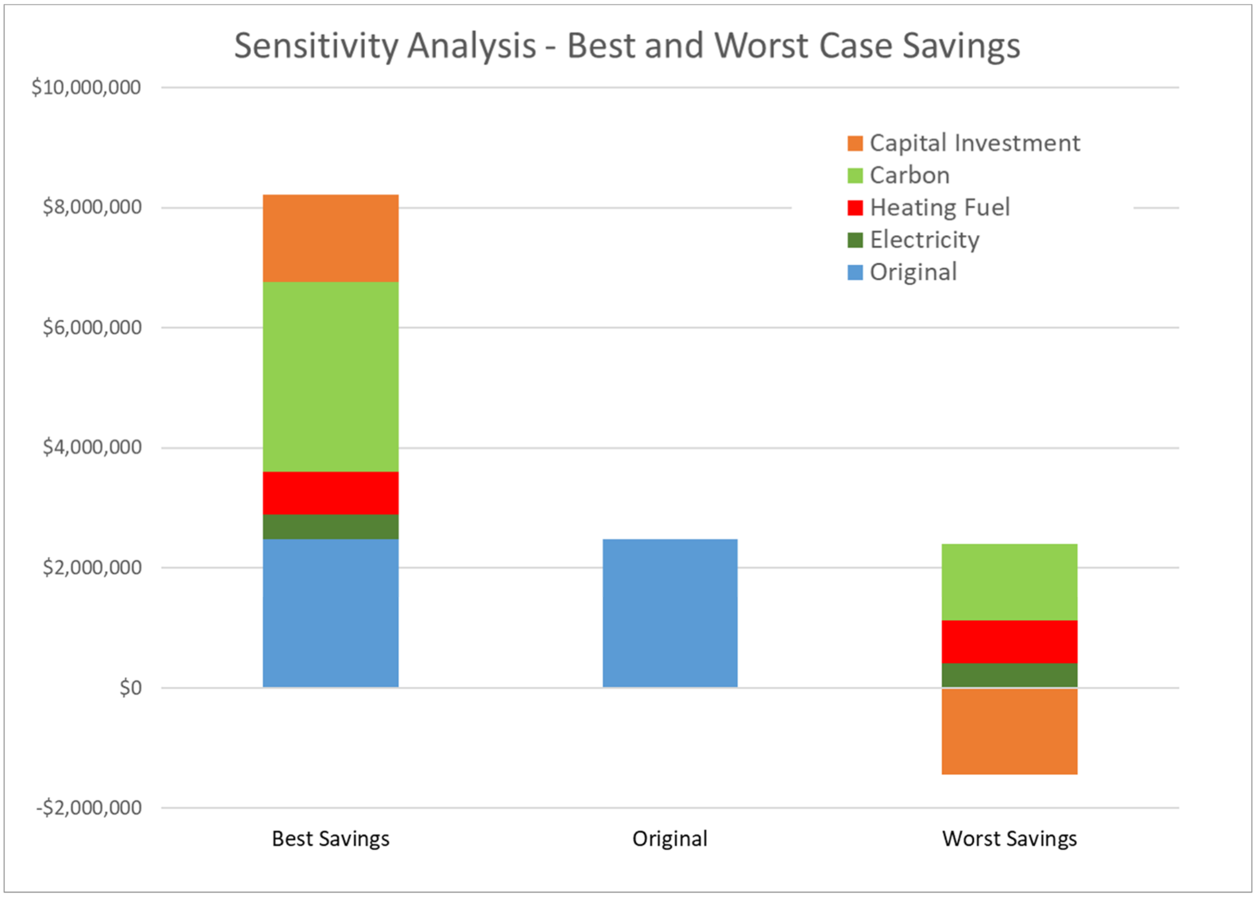

Figure 28: Sensitivity Analysis Results

Conclusion & Recommendations

The Centralized Option with carbon tax provides $2,472,502 in savings compared to the BAU over the 30 year study period, and eliminates 100% of carbon emissions from the campus thermal systems by 2050. Although the Centralized Option without carbon tax has a smaller net present value savings of $1,207,281 when compared to the BAU, it still provides a 100% carbon emissions reduction from the campus thermal systems. The Centralized Option implementation will require a significant capital investment of $20.4M over 16 years and will result in a 60% reduction in energy use and 8% reduction in utility costs by 2050.

To reach its carbon neutrality goal by 2050, Salem State will need to implement clean energy technologies on campus aimed at eliminating fossil fuel use. This Clean Energy Feasibility Study provides a high level, phased roadmap for the North Campus to eliminate fossil fuel use in building heating and cooling systems by 2050. The results of this study, focused on North Campus buildings, are also transferrable to the decarbonization planning for other campus buildings.

As Salem State transitions away from steam, the road map recommends maintaining a centralized approach for campus heating and cooling which utilizes electrified and renewably driven equipment. A new centralized district energy system would allow for improved efficiency, better utilization of chilled water capacity, increased resiliency and redundancy, reduced maintenance and also allow for campus simultaneous heating and cooling loads to be met with high efficiency heat recovery technology. In addition, a water-based campus energy distribution system allows for a high level of flexibility to adapt to new technologies, as technology, policy, environmental and market conditions evolve. Transitioning away from a centralized steam heating system also significantly reduces annual operations and maintenance costs.

At the start of the roadmap in 2025, with the near-term projects at Horace Mann and the proposed Meier Hall Science Lab addition, Salem State has the opportunity to incorporate high performance design standards into all campus growth. This roadmap uses these projects as a starting point for the campus transition off steam and fossil fuels by recommending low EUI targets and all electric heating and cooling systems. Even as standalone buildings, the renovated Horace Mann and the Meier Hall Science Lab addition can immediately contribute to the carbon emissions reduction goals.

The planning and implementation of this transition will require sustained effort from now through 2040. Salem State believes that this plan will help position the university well for funding opportunities and plans to work with its partners to plan, fund, and implement the campus energy transformation outlined in this report, to the fullest extent possible. By implementing the Centralized Option included in this clean energy road map, Salem State will be better equipped financially to deal with any future carbon tax scenarios. Addressing climate change by moving away from fossil fuels is important to Salem State's faculty, staff, alumni, leadership and most importantly to Salem State's students. They are the generation that will live with the impacts of the climate crisis and it is important to them that Salem State exhibit leadership in this area. The investment in this new energy platform will be particularly beneficial to Salem State in the long term when a carbon tax is likely to be enacted. The transition from fossil fuels primarily towards electrified systems relying on a renewable grid electricity for Salem State’s North Campus is possible and the steps outlined within this study provide a feasible roadmap to achieve this transition, which will heat and cool the North Campus for the next 50+ years.

Next Steps

If Salem State elects to move forward with this clean energy road map, the following next steps can help prioritize decarbonization efforts and prepare the campus for renewable technologies outlined above. With the first phase of the road map starting in 2025, there is time now to focus on how to both plan and fund this transition.

1. Existing Buildings and Infrastructure
    a. Identify and implement energy conservation measures (ECMs) to reduce campus energy use and carbon emissions.
    b. Ensure that all building renovations, deferred maintenance, and routine maintenance support efficiency and the adoption of low temperature water heating units. Examples include:
        - Window repair and replacement windows
        - Building envelope improvements
        - Radiation to support low temperature hot water
        - Controls upgrades
    c. If central air conditioning is added to any building or space, ensure that it is compatible with future heat pump technology and this plan.
    d. If the central plant systems fail or require major investment, accelerate the implementation of this plan.
    e. Ensure that Berry Library GSHP is working properly.
    f. Participate in all utility rebate programs and consider additional projects for efficiency.

2. New Construction and Major Renovations
    (Horace Mann renovation, Meier Hall Lab Science Addition, and other renovations)
    a. Ensure that the selected design intent reflects the key role these projects play in the campus decarbonization.
    b. Set project scope and budget to reflect the enabling steps for campus decarbonization that are critical in major projects
    c. Set aggressive EUI targets in all major projects
    d. Establish design team selection criteria that reflect the campus decarbonization goals
    e. Engage a third part review of systems design and fully commission all new construction

3. LTHW Conversion & New District Energy System
    a. Detailed analysis of required building conversions.
    b. Detailed investigation of routing options for new utility piping.
    c. Detailed construction and life-cycle costs estimates.

4. Ground-source Heating and Cooling

    a. Geothermal test bores in proposed location for ground source heat-exchanger.
    b. Detailed construction and life-cycle costs estimates.

5. Wastewater Heat Recovery
    a. Wastewater heat recovery is a relatively new concept in Massachusetts. Coordination with the local wastewater treatment plant, and potentially the Department of Environmental Protection or other State agencies, will be required to get their support for this innovative technology. Start having these discussions as early as possible.

6. Funding / Financial Planning
    a. Identification of potential funding sources including utilities, federal and state sources, non-profit grants, donors, third-party financing options, as well as prescriptive and custom rebates or incentives.

Appendix:

Appendix A: Existing Conditions Report

Appendix B: Options Considered & Finalist Options Selected Report

Appendix C: Centralized Option Phasing Maps

Appendix D: BAU & Centralized Option Cost Estimate Details

BAU & Centralized Option
D1. Capital Cost Summary
D2. Campus Utility Piping Costs
D3. Maintenance Costs

Centralized Option:
D4. Building Conversion Costs
D5. Energy Plant Costs
D6. Geothermal Costs
D7. Wastewater Heat Recovery Costs

BAU:
D8. City of Salem Department of Public Works Historic Water Rates

Appendix E: LCCA Summary Tables

Appendix F: Sensitivity Analysis

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[1] Earth Days - SSU North Campus Clean Energy Roadmap https://www.screencast.com/t/dxTzZ7Nat

[2] https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance

[3] Salem State University Energy Progress Overview, Department of Energy Resources, Leading By Example, October 27, 2020

[4] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[5] EPA. (2017) The Social Cost of Carbon https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

[6] World Bank. 2020. State and Trends of Carbon Pricing 2020. Washington, DC: World Bank

expect a difference

Existing Conditions Report

Salem State University North Campus Clean Energy Feasibility Study

Salem, Massachusetts

Final Report

January 11, 2021

S67.20.01 / 2020-61245-00

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Introduction

As part of the North Campus Clean Energy Feasibility Study, MEP has conducted a high level survey of the Salem State University (SSU) North Campus including a review of as built drawings provided by Salem State, building walkthroughs with Salem State facilities staff and a review of each building's HVAC systems. This report summarizes the existing conditions and their potential impact on clean energy master planning opportunities.

The SSU North Campus consists of 10 major buildings. A summary of the North Campus buildings, including year built and square footage is included in Table 1 below and a map of the campus in included in Figure 1. The Administration Complex is comprised of four major buildings including the Administration Building, Commons Dining Hall, the Sophia Gordon Center for Creative and Performing Arts (Sophia Theater) and the Central Heating Plant (CHP) for the campus which is located in the basement of the Administration Building. Also located on the North Campus is a large parking garage, which is neither heated or cooled and is not included in this study.

Table 1: North Campus Buildings

Building	Year Built	Overall Square Footage
Administration Complex	1958	90,558
Administration Bldg.		*23,267*
Commons Dining		*35,089*
Central Heating Plant		*6,106*
Sophia Theater	*2015*	*26,096*
Berry Library	2012	124,000
Bowditch Hall	1965	64,183
Ellison Center	1966	49,776
Horace Mann	1902	44,395
Meier Hall	1963	160,345
Peabody Hall	1965	73,352
Sullivan Building	1896	83,851

Figure 1: Salem State University North Campus

Campus Energy Use Intensity (EUI)

Based on utility data provided by SSU, the EUI for the 10 major buildings on the North Campus is 79 kbtu/SF. Building level EUI is not available, as each building is not individually metered for all utilities. Buildings connected to the central heating plant do not have steam meters, and not all buildings have their own electrical meter (e.g. Ellison and Bowditch share an electrical meter.)

Central Heating Plant

The Central Heating Plant (CHP) at SSU's North Campus is located next to the Administration building and provides medium pressure steam to the North Campus buildings listed in Table 1 above, with the exception of Bowditch and Peabody. Bowditch and Peabody residence halls were initially connected to the CHP but were removed in the 1970's and provided with local boilers for heating hot water (HHW) and domestic hot water (DHW). Berry Library has a geothermal heat pump system that provides heating and cooling to the building and uses steam from the central plant for supplemental heating.

The CHP contains two Cleaver Brooks firetube boilers operating in a duty / standby configuration. Each boiler is rated at 20,700 pounds per hour (pph) and generates medium pressure steam at 90psig which is distributed to the buildings. Each building connection includes a pressure reducing station to reduce the steam pressure to low pressure. Boiler #1 was installed in 2008, Boiler #2 was installed in 2006. Both boilers can burn natural gas or no. 2 fuel oil. Fuel oil is only used to keep the standby boiler hot, in the event the duty boiler has to be taken offline. There are three underground fuel oil storage tanks on campus, however only one tank is currently in use. The CHP operates from fall to spring and is offline during the summer. The central heating plant, including boilers #1 and #2 are shown below in Figure 2.

Figure 2: Central Heating Plant Boilers

The steam distribution system includes two main steam branches serving the campus, one departing to the west serving Administration, Sullivan, Horace-Mann and Ellison, and the other to the south, serving Commons, Sophia, Meier and Berry. Steam distribution piping is tunnel-installed, direct buried and building-installed, as the main steam piping routes directly through certain buildings. The campus steam distribution system includes approximately 3,480 total linear feet of piping, including both steam and condensate return piping. The majority of the steam distribution piping was installed in the 1960s when the central plant and a majority of the buildings were built and has exceeded its expected service life. Repairs and replacement of steam distribution near Ellison, Sophia and Meier have been completed in the last five years. Steam piping installed in a tunnel connecting Sullivan to Horace Mann is shown below in Figure 3 and Figure 4.


Figure 3: Steam Tunnel Connecting Sullivan and Horace Mann


Figure 4: Steam Piping Leaving Sullivan

Administration Complex

The Administration Complex is comprised of four connected buildings including the Administration Building, Commons Dining Hall, the Central Heating Plant and the Sophia Theater.

Administration Building

The Administration building is a three-story administrative office building. Steam from the CHP is converted to heating hot water and distributed to terminal heating units, including perimeter Finned Tube Radiators (FTR) and unit ventilators.

First floor HVAC systems were renovated in 1995 including two split type heat pumps, approximately 9 tons each. Indoor units are ceiling hung with air cooled condensing units located on the adjacent roof. A supply fan provides unconditioned ventilation air to the return of each indoor unit. The first floor of the Administration Building has a single-story addition that connect connects to Commons Dining. This area is served by three small rooftop units (RTU-4,5,6) with direct expansion (DX) cooling and electric heat, located on the single-story addition roof and installed in 2012.

Second floor HVAC systems were renovated in 1994 including three rooftop units (RTU-1,2,3) with DX cooling and natural gas heating and then later replaced in 2016. RTU capacities are included below in Table 2. The administration building RTUs are shown below in Figure 5.

Table 2: Administration Building RTU Capacities

Unit	Manufacturer	Cooling Capacity (Tons)	Cooling EER	Heating Capacity Input (MBH)	Heating Efficiency
RTU-1	Carrier	7.0	11.1	180	82%
RTU-2	Carrier	10.0	11.1	224	82%
RTU-3	Carrier	4.0	13.0	115	81%
RTU-4	Trane	5.0	11.5	17.3 (kW)	-
RTU-5	Trane	5.0	11.5	17.3 (kW)	-
RTU-6	Trane	5.0	11.5	17.3 (kW)	-

Figure 5: Administration Building RTUs

Commons Dining

The Commons Dining is a three-story dining hall, renovated in 1996. HVAC systems include five DX cooling, natural gas heating RTUs, three located on the high roof and two located on the low roof that connects the Commons Dining to the Administration Building. RTU-1,2,3 are located on the high roof, and RTU-4,5 are located on the low roof. RTU-4 and RTU-5 were replaced in 2016. RTU capacities are included below in Table 3.

Table 3: Commons Dining RTU capacities

Unit	Manufacturer	Cooling Capacity (Tons)	Cooling EER	Heating Capacity Input (MBH)	Heating Efficiency
RTU-1	McQuay	38	8.0	800	80%
RTU-2	McQuay	48	8.0	988	80%
RTU-3	Carrier	12	8.0	140	80%
RTU-4	Carrier	12	10.8	140	80%
RTU-5	Carrier	12	10.8	140	80%

A 752MBH input gas-fired Makeup Air Unit (MAU) also located on the high roof provides makeup air for the kitchen exhaust systems.

The 1996 renovation removed most of the Commons Dining HVAC systems from the campus steam system with the exception of a few cabinet unit heaters and unit ventilators serving entrance vestibules, loading dock and other miscellaneous, back of house areas.

Sophia Theater

The Sophia Theater is a three-story performing arts center that completed a modernization project in 2015, including LEED Gold certification. Building program includes a 432-seat theater and balcony, rehearsal room, and performance support spaces.

Air conditioning at Sophia Theater is provided by a 140-ton air cooled chiller installed on the roof. Chilled Water (CHW) pumps located in a second-floor mechanical room provide CHW distribution to three rooftop Air Handling Units (AHUs) and multiple Fan Coil Units (FCUs). Chiller performance is included in Table 4. The rooftop mounted air cooled chiller installed above the Commons Dining is shown below in Figure 6.

Table 4: Sophia Theater Chiller Performance

Unit	Manufacturer	Type	Capacity (Tons)	EER
CH-1	York / JCI	Air Cooled	140	10.4

Figure 6: Sophia Theater Air Cooled Chiller above Commons Dining

Sophia Theater is connected to the campus low pressure steam distribution system with a 5″ steam supply and 2″ condensate return line. The main steam distribution from the CHP that serves Sophia Theater and eventually connects to Meier and Berry was replaced in 2015. Two steam to hot water heat exchangers located in the basement provide heating hot water for distribution to terminal units. Three rooftop AHUs have steam heating coils. Steam equipment capacities in pounds per hour (PPH) are included below in Table 5.

Table 5: Sophia Theater Steam Equipment Capacities

Unit	Type	Capacity (PPH)
HX-1	Steam to Hot Water HX	875
HX-2	Steam to Hot Water HX	875
AHU-1	Steam Heating Coil	572
AHU-2	Steam Heating Coil	346
AHU-3	Steam Heating Coil	562

Berry Library

Berry Library and Learning Commons was built in 2014 and is LEED certified. In addition to library and library support programming, the building includes over 150 computer workstations, 12 reservable group study rooms, the Center for Academic Excellence, the Commonwealth Honors Program, Disability Services, TRIO Student Support Services and the Writing Center.

Heating and cooling for Berry Library is provided by a geothermal heat pump system including a 380-ton modular heat pump coupled with a ground source heat exchanger. The ground source heat exchanger consists of 48 boreholes, 500’ deep, installed in the north courtyard. The geothermal heat exchanger layout is included below in Figure 7. Heating hot water from the heat pump serves the heating coils in three AHUs and other terminal equipment. Chilled water from heat pumps serves only the cooling coils in the three AHUs. A closed circuit cooling tower, located on the roof, provides supplemental heat rejection for the ground source heat exchanger and heat pump system.

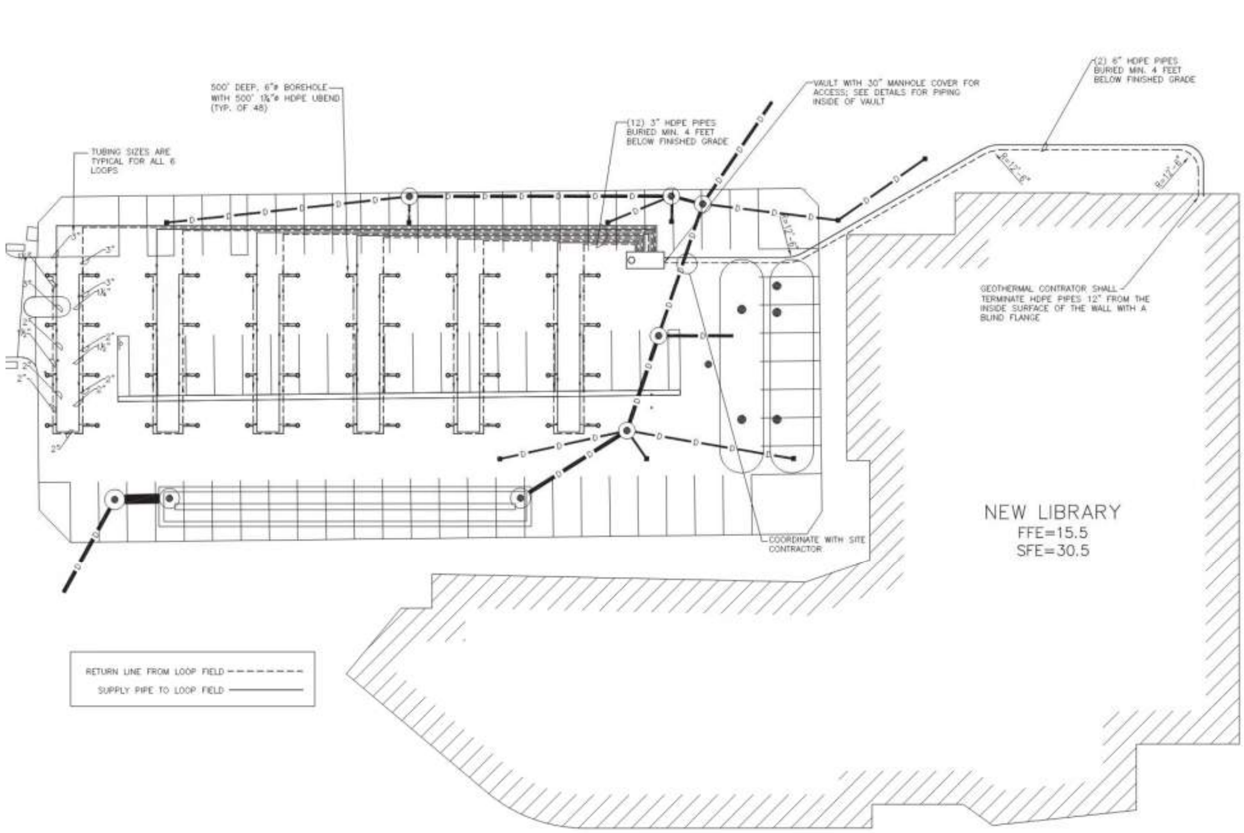

Figure 7: Berry Library Ground Source Heat Exchanger

Supplemental heating is provided by the CHP steam distribution. Two steam to hot water heat exchangers located in the level 4 mechanical room provide heating hot water for distribution to the three AHU’s heating coils and to Variable Air Volume (VAV) reheat coils. Heat exchanger capacities are included below in Table 6. The Steam Pressure Reducing Valve (PRV) on the incoming steam service from the CHP is sized at 2,100 pph, indicating that the steam to hot water heat exchangers are designed to be duty / standby, as the PRV max capacity is approximately equal to a single heat exchanger steam capacity. The AHU and VAV reheat coils are all sized based on the 120/110 supply/return temperatures generated by the heat pump, however the fin tube radiation (FTR), convectors, cabinet unit heaters and unit heaters are sized on the 160/140 supply/return temperatures generated by the steam to hot water heat exchangers.

Table 6: Berry Library Heat Exchanger Capacities

Unit	Type	Capacity (PPH)
HX-1.1	Steam to Hot Water HX	2,000
HX-1.2	Steam to Hot Water HX	2,000

Miscellaneous cooling systems include a computer room air conditioning system with indoor evaporator units and an exterior dry-cooler system serving an archival space located in the basement and a small split system providing cooling for a server room.

Domestic hot water is provided by two natural gas fired, 100 gallon storage type domestic water heaters installed in the level 4 mechanical room. Each domestic water heater has an input capacity of 75.1 MBH.

The Berry Library geothermal and heat pump systems are currently undergoing retro-commissioning aimed at ensuring proper equipment operation and improving building efficiency. The retro-commissioning results and recommendations will be reviewed for potential impact on the clean energy feasibility study.

Bowditch Hall

Bowditch Hall is a residence hall comprised of mostly dorm rooms with some common lounge and study spaces. Bowditch Hall has had several partial renovations including a bathroom renovation in 2019, and renovations to the study and lounge areas in 1971 and 2016. A domestic water heater upgrade by the Massachusetts State College Building Authority (MSCBA) is currently in design.

Bowditch Hall is not air conditioned. One window AC unit was observed, presumably serving the Resident Advisor suite or office. Bathroom exhaust and make up air is provided by an Energy Recovery Ventilator (ERV) located on the roof. The rooftop ERV is shown below in Figure 8.

Figure 8: Bowditch Hall ERV

Heating is provided by two natural gas boilers (B-1 & B-2) installed in the first-floor mechanical room. Boiler B-1 was installed in 2000 and boiler B-2 was installed in 2015. Boiler capacities are included below in Table 7. Two 7.5 hp HHW water pumps with Variable Frequency Drives (VFD) distribute HHW to terminal units, including FTR and unit heaters.

Table 7: Bowditch Hall Boiler Capacities

Unit	Type	Heating Capacity Input (MBH)	Efficiency
B-1	Natural Gas Boiler	1,905	80%
B-2	Natural Gas Boiler	1,905	80%

Domestic hot water is provided by a natural gas fired boiler with a large storage tank located in the first-floor mechanical room. The domestic water boiler was installed in 2012 and the storage tank appears to be original to the building. The capacity of the domestic water system is unknown.

Bowditch Hall was originally connected to the CHP steam distribution. It is unclear why or when Bowditch Hall was removed from the steam distribution, however it may be related to added summer dorm use and the steam plant not being operational during the summer, as the original domestic water systems were also provided by campus steam.

Ellison Center

Ellison Center is the student center for the campus built in 1966 and renovated in 1999. Building program includes classrooms, offices and assembly spaces. The 1999 renovation included the portions of the basement and first floor to accommodate the Office of Student Life: Counseling and Health Services;

Career Services; and the Office of Residence Life. The central HVAC systems were replaced in 1999, including the steam to hot water heat exchangers, pumps and air handling units (AHUs). The existing chiller and cooling tower were replaced with refrigerant based DX cooling systems. The chiller was removed, and the decommissioned cooling tower remains in the penthouse. The original heating and ventilation unit, HV-1, located in the basement was replaced with three central AHUs. All three AHUs provide heating, cooling and ventilation to the first floor. Cooling is provided by DX cooling coils with remote, air cooled condensing units located on the roof. The heating ventilation unit, HV-2, serving the Veteran's Hall, was replaced in 1997 with a unit that also provides air conditioning. The indoor unit is ceiling suspended in a stairway / corridor on level 2 and the air cooled condensing unit is located on the roof. The central systems are supplemented by various window AC units and split systems. The large air cooled condensing units installed at the roof are shown below in Figure 9.

Figure 9: Rooftop Air Cooled Condensing Units at Ellison

Ellison Center is connected to the campus low pressure steam distribution system with a 4" steam supply and 2" condensate return line. The main steam lines serving Ellison, from Horace Mann, have recently been repaired or replaced. Two steam to hot water heat exchangers located in the basement provide heating hot water for distribution within the building: one serving AHUs and the other serving perimeter radiation. The heat exchangers are original to the building. Heat exchanger capacities are included below in Table 8. HHW pumps, installed in 1999, distribute high temperature hot water (HTHW) at 190F to three AHUs, multiple heating and ventilation (HV) units and terminal devices.

Table 8: Ellison Steam Heat Exchanger Capacities

Unit	Type	Capacity (PPH)
HX-1	Steam to Hot Water	876
HX-2	Steam to Hot Water	1,813

<u>Horace Mann</u>

The Horace Mann building most recently occupied by the Salem Public School district and used as an elementary school. The four-story building has been unoccupied since the elementary school moved out in 2018. The current building program is consistent with an elementary school of this vintage and includes classrooms, few offices, a library and a cafeteria.

Horace Mann is not air conditioned. Two outdoor condensing units were observed located at grade. Ventilation is provided through operable windows.

Horace Mann is connected to the campus low pressure steam distribution system with a 4" steam supply and 2" condensate return line. Direct steam was utilized for heating until the building was converted to heating hot water in 1979. Existing steam to hot water heat exchanger capacity is included in Table 9. Steam to hot water heat exchangers and distribution pumps were added at the main steam connection in the basement. Steam radiators were replaced with hot water FTRs and unit heaters sized for 200/180 supply/return HTHW temperatures generated by the steam to hot water heat exchangers. The incoming steam service and steam to hot water heat exchanger is shown below in Figure 10.

Table 9: Horace Mann Steam Heat Exchanger Capacities

Unit	Type	Capacity (PPH)
HX-1	Steam to Hot Water	1,010

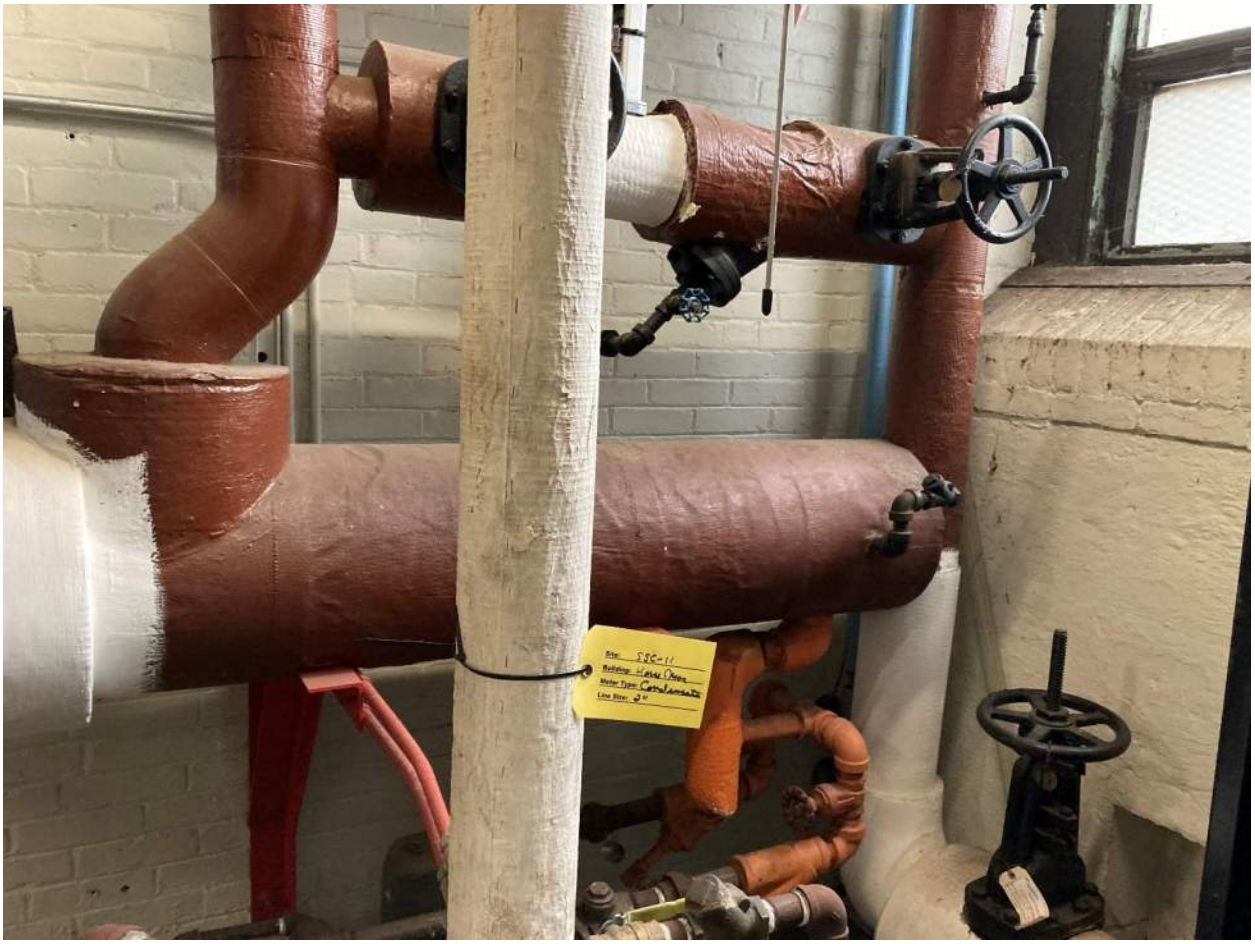

Figure 10: Incoming Steam service and Heat Exchanger at Horace Mann

Meier Hall

Meier Hall is a five-story lab building and home to the College of Arts and Sciences. The building program includes offices, classrooms and laboratory spaces. As built documentation for Meier Hall is limited, however a 2006 partial renovation added multiple split systems serving a new or renovated stairwell and a new AHU serving café and lounge spaces on the first floor.

Meier Hall does not have a centralized air conditioning or ventilation system. Air conditioning is provided through window AC units and multiple split systems that have been installed over time. Multiple exhaust fans are installed on the roof to meet lab specific exhaust requirements and general, restroom exhaust requirements. Ventilation is provided through unit ventilators and operable windows.

Meier Hall has two connections to the campus low pressure steam distribution system, one 6″ steam supply and 3″ condensate return line serving the west side and a 4″ steam supply and 2″ condensate return line serving the east side. Both steam connections have dual steam to hot water heat exchangers, generating HHW that is distributed to unit ventilators and FTR. HHW distribution includes primary pumps in the mechanical room and multiple HHW zone pumps providing HHW to terminal units. A typical classroom showing window AC units, FTR and unit ventilator is shown below in Figure 11.

Figure 11: Meier Hall Typical Classroom

A natural gas fired domestic water boiler and storage tank are located the west mechanical room. Input capacity to the domestic water boiler is 105 MBH. The domestic water systems at Meier Hall are shown below in Figure 12.


Figure 12: Meier Hall Domestic Water System

Peabody

Peabody Hall is very similar to Bowditch Hall in terms of initial construction and renovation history. Peabody Hall is a residence hall comprised of mostly dorm rooms with some common lounge and study spaces. Peabody Hall has had several partial renovations including a bathroom renovation in 2019, and renovations to the study and lounge areas in 1971 and 2016. A domestic water heater upgrade by the Massachusetts State College Building Authority (MSCBA) is currently in design.

Peabody hall is not air conditioned. Several window AC units were observed, presumably serving the Resident advisor suite or office. Bathroom exhaust and make up air is provided by an Energy Recovery Ventilator (ERV) located on the roof.

Heating is provided by two natural gas boilers installed in the first-floor mechanical room. The installation date for the boilers is unknown, however based on observations and the boiler efficiency, these are relatively new. Boiler capacities are included below in Table 10. Two 7.5 hp HHW water pumps with Variable Frequency Drives (VFD) distribute HHW to terminal units, including FTR and unit heaters.

Table 10: Peabody Hall Boiler Capacities

Unit	Type	Heating Capacity Input (MBH)	Efficiency
B-1	Natural Gas Boiler	1,500	85%
B-2	Natural Gas Boiler	1,500	85%

Domestic hot water is provided by a natural gas fired boiler with a large storage tank located in the first-floor mechanical room. The domestic water boiler nameplate was not visible, however based on observations in Bowditch and similarities between these two buildings, the domestic water boiler was also installed in 2012. The storage tank appears to be original to the building. Similar to Bowditch, the capacity of the domestic water system is unknown.

Peabody Hall was originally connected to the CHP steam distribution. It is unclear why or when Peabody Hall was removed from the steam distribution, however it may be related to added summer dorm use and the steam plant not being operational during the summer, as the original domestic water systems were also provided by campus steam. In 1977 the main steam line serving Peabody was replaced. As this would have been an expensive project, it is likely that Peabody was still on the campus steam system into the 1980s.

Sullivan Building

The Sullivan Building is a four-story building comprised mainly of offices and classrooms. There is a wood shop and a theater located in the basement. As built documentation for Sullivan Hall is limited, however a 1984 partial renovation added controls for unit ventilators and exhaust fans. A recent partial renovation to the Theater Classrooms added two DX split systems. The Sullivan building has a large, underutilized attic that could potentially be repurposed as a mechanical equipment room should this building undergo a major renovation.

The Sullivan Building does not have a centralized air conditioning or ventilation system. Air conditioning is provided through window AC units and multiple split systems that have been installed over time. Multiple exhaust fans are installed in the attic. Ventilation is provided through unit ventilators and operable windows.

The Sullivan Building is connected to the campus low pressure steam distribution system. The actual steam and condensate connection sizes and building capacity are not known. The building is heated with direct steam serving unit ventilators. A typical classroom showing a window AC unit and unit ventilator is shown below in Figure 13.


Figure 13: Sullivan Building Typical Classroom

Campus Opportunities

Horace Mann, Meier Hall

The SSU Bold Campus Unification and Modernization Project includes the renovation of the Horace Mann Building and the construction of a Meier Hall Addition. The Horace Mann building renovation will relocate the Maguire Meservey College of Health and Human Services (MMCHHS) from the South Campus including building program for nursing, social work, criminal justice, occupational therapy and healthcare studies. The Meier Hall Addition programming is expected to include seven new state of the art wet labs for the biology and chemistry departments. Both of these projects are expected to occur within the next five years and represent the earliest near-term capital investment in major renovation and additions planned for the North Campus. SSU has an opportunity to ensure these new projects align with the campus sustainability goals and the recommendations that will be outlined in the Clean Energy Feasibility Study. In addition, SSU can use these projects as a starting line for a transition off fossil fuels and carbon emissions reduction.

Energy Conservation Measures (ECMs)

Reducing the energy consumption for existing systems on campus will be an essential component of any new clean energy system for the North Campus. Implementing Energy Conservations Measures (ECMs) including envelope improvements, HVAC system efficiency upgrades, adding heat recovery, improving building control systems and lighting upgrades will reduce the campus energy use intensity and minimize the carbon neutral replacement energy systems for the campus.

For laboratory spaces such as Meier Hall, which can use up to 5 times more energy per square foot than typical office or classroom space, providing modernized exhaust systems, including variable flow and energy recovery and initiating "green lab" programs including high-efficiency equipment and education initiatives like a "close the sash" campaign can greatly reduce the energy demand and have a large impact on the overall campus energy use.

Central Chilled Water Distribution

The North Campus does not have a central chilled water (CHW) distribution system, instead relying on decentralized air conditioning at individual buildings, window AC units, split systems or simply not being air conditioned. While a central chilled water distribution system for a campus of this size is not common, the compact and efficient core campus layout lends itself to a central CHW distribution system, as the underground utility scope is minimized. A centralized chilled water system increases system efficiency and reliability and allows for efficient, non-combustion technologies to be introduced at a campus scale.

Geothermal

The large parking lot behind Peabody Dorm has potential for locating a geothermal heat exchanger, serving heat recovery chillers or heat pumps. The 1.5 acre parking lot has the potential for 125 bore holes, capable of serving over 300 tons of heating / cooling capacity.

Added Air Conditioning

For buildings that are utilized year round, for example Sullivan and Meier, the occupant experience would be improved if centralized air conditioning and ventilation replaced the current window AC units and unit ventilators. The added air conditioning load would increase the potential for a district energy system to provide simultaneous heating and cooling at very high efficiencies via heat recovery chillers or heat pumps.

Sewage Heat Recovery

Bowditch and Peabody dorms have potential to utilize wastewater heat recovery on their domestic water systems. Packaged wastewater heat recovery systems can be used to preheat domestic hot water or larger, more industrial systems can be incorporated into district energy systems to reduce the size of geothermal heat exchangers.

Berry Library Heat Recovery Chiller Systems

The 380 ton modular heat recovery chiller at Berry Library, installed in 2012, has at least 17 years of service life remaining. Assuming the heat recovery chiller was designed for the peak cooling condition, there is capacity for this unit to support air conditioning loads for other buildings during shoulder seasons and off peak conditions if connected to a centralized air conditioning system.

The heat recovery chiller at Berry Library is coupled with a geothermal heat exchanger. This existing geothermal heat exchanger could be integrated into a new, centralized geothermal system, reducing the amount of new geothermal heat exchangers required.

Sophia Theater Chilled Water Systems

The 140 ton air cooled chiller at Sophia Theater, installed in 2015, has at least 18 years of service life remaining. Assuming the air cooled chiller was designed for the peak cooling condition, there is capacity for this unit to support air conditioning loads for other buildings during shoulder seasons and off peak conditions if connected to a centralized air conditioning system.

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Options Considered & Finalist Options Selected Report

Salem State University North Campus Clean Energy Feasibility Study

Salem, Massachusetts

Final Report

March 22, 2021

S67.20.01 / 2020-61245-00

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Introduction

Carbon mitigation solutions are specific projects, technologies, and other operational and infrastructure changes that will help Salem State University (SSU) avoid and reduce greenhouse gas (GHG) emissions on their North Campus relative to the campus business as usual (BAU) actions. All solutions considered have the potential to reduce carbon emissions under the right application, however, there is a logical order that should be used when implementing these solutions. For example, solutions that avoid or reduce the need for energy and the related GHG emissions which often also save money should be implemented before solutions that offset emissions at a cost premium. This clean energy feasibility study uses the following broad categories for carbon emissions reductions: Avoid, Reduce, Replace and Offset, further described in Table 1 below.

Table 1: Carbon Mitigation Hierarchy

Category	Description	Examples
Avoid	Solutions that avoid activities that would otherwise create GHG Emissions	Energy Efficiency Building Standards applied to future renovations of existing buildings and new construction
Reduce	Solutions that reduce the energy and/or GHG intensity of an activity	Energy Conservation Measures such as steam pipe insulation, lighting retrofits, HVAC control upgrades
Replace	Solutions that swap out fuels, equipment, or systems to low- or no-emissions emitting alternatives	Biofuels, renewable electricity generation, district LTHW and district chilled water systems coupled with ground source heat exchange
Offset	Solutions that remove or avoid emissions outside the boundaries of the campus that would not otherwise occur if not for a financial payment	Purchased carbon offset programs

Abbreviations Used:
CHW – chilled water
CO_2e – carbon dioxide equivalent
CSP – central steam plant
EUI – energy use intensity (kBTU/ft^2/yr)
GHG – greenhouse gas
GHX – ground source heat exchange
HR – heat recovery
LTHW – low temperature hot water
MWh – megawatt hour
NG – Natural Gas
PV – photovoltaic
REC – renewable energy credit
RFO – renewable fuel oil

Solutions Overview

The solutions considered for the SSU North Campus are summarized below in Table 2, including how the solution fits within the carbon mitigation hierarchy. Essential aspects of each of the solutions are described in their individual sections below.

Table 2: Solutions Summary

Hierarchy Category	#	Solution	Expected GHG Impact
Avoid	1	Energy Efficiency Building Standards for New Construction and Renovations	Small
Reduce	2	Building Energy Conservation Measures (ECMs)	Medium
Replace	3	District Chilled Water System	Large
	4	Low-temperature Hot Water (LTHW) Conversion	Large
	5	Ground Source Heat Exchange (GHX)	Large
	6	Air Source Heat Pumps	Medium
	7	Wastewater Heat Recovery (HR)	Small
	8	Renewable Fuel Oil (RFO) Boiler	Medium
	9	Onsite PV	Small
	10	Onsite Solar Thermal	Small
Offset	11	Renewable Energy Credits	Not Considered
	12	Carbon Offsets	Not Considered

Solution Summaries

Energy Efficient Building Standards for New Construction and Renovations

Concept Overview

Energy efficient building standards will establish policies for future new construction and renovations of existing buildings to include high-performance design criteria aimed at reducing building energy use. These building standards will include performance requirements for buildings envelope systems, lighting, HVAC and energy efficiency equipment and appliance standards to reduce cooling, heating and electricity demands. These policies will ensure energy efficient features are not value engineered out of the design.

Energy Impact

Energy Use Intensity (EUI) is a measure of efficiency that expresses a building or campus annual energy use as a function of its size. As new buildings and existing building renovations are designed and built to meet the energy efficiency building standards, the overall campus EUI will be reduced, resulting in less steam demand for buildings connected to the central steam plant (CSP) and less hot water demand for buildings with local boilers. These energy reductions result in avoided purchased natural gas (NG). The cooling demand will also be reduced, resulting in avoided purchased electricity.

Environmental Impact

A reduction in energy use will reduce GHG emissions. In addition to lower GHG emissions due to reduced energy use, energy efficient buildings standards can also reduce water, wastewater and chemical use.

Economic Impact

- Reduced capital costs and building program space required for new HVAC systems.
- Avoided purchased electricity and NG.

Solution Status – Energy Efficiency Building Standards

- Energy Efficiency Building Standards for New Construction and Renovations will be included in the final clean energy feasibility study and assumes the following EUI for currently planned new building and renovations:
    - Renovated Horace Mann building EUI: 50
    - New Meier Hall Addition EUI: 70

Building Energy Conservation Measures

Concept Overview

Energy Conservation Measures (ECMs) include upgrades, retrofits and repairs that can be implemented to improve energy efficiency and reduce operation and maintenance costs. These ECMs can include lighting system retrofits, HVAC system and control upgrades, building envelope improvements and retro-commissioning.

Campus Opportunity

SSU has made notable improvements to their overall campus EUI over the last two decades reducing the overall campus EUI from 118 in 2004 down to 77 in 2020. There is significant potential to continue the trend of improvement, further lowering the EUI for the North Campus.

Energy Impact

ECMs will reduce campus electricity use and heating and cooling needs. Reduced steam demand for buildings connected to the central steam plant (CSP) and reduced hot water demand for buildings with local boilers will result in avoided purchased natural gas (NG). Reduced cooling demand will result in avoided purchased electricity.

Environmental Impact

- A reduction in energy use will reduce GHG emissions. In addition to lower GHG emissions due to reduced energy use, energy conservation measures focused on water use efficiency can also reduce water usage and wastewater generation.

Economic Impact

- SSU has invested in ECMs through Investment Grade Audits (IGAs) provided by Energy Services Companies (ESCO) and is currently collaborating with DCAMM and National Grid on smaller energy upgrades. Significant capital spending will be required to address remaining opportunities.
- ECM projects that replace older, less reliable equipment have the potential to reduce maintenance costs.
- ECM projects that reduce building energy consumption have the potential to reduce the size and cost of new thermal systems.
- Avoided purchased electricity and NG.

Solution Status - Building Energy Conversion Measures

- Building Energy Conservation Measures will be included in final clean energy feasibility study

District Chilled Water System

Concept Overview

This solution would provide a centralized, distributed chilled water (CHW) system for the North Campus. A centralized chilled water system presents an opportunity to optimize equipment efficiency, controls and maintenance compared to the existing standalone equipment. In addition, a centralized, distributed CHW system, when coupled with a centralized, distributed low temperature hot water (LTHW) system will allow for the use of heat recovery chillers and heat pumps to meet simultaneously occurring heating and cooling loads on campus. Heat recovery systems can generate both hot and chilled water simultaneously at a very high coefficient of performance (COP) and without the direct burning of fossil fuels or the need for heat rejection equipment, such as cooling towers. Heat recovery chillers and heat pumps are electrically driven and do not require fossil fuels for operation. Heat recovery systems are often utilized with ground source heat exchange systems for additional reduction in fossil fuel use outside of simultaneous heating and cooling periods. These systems are discussed in additional detail in the following sections. Both a centralized CHW system and centralized LTHW are required in order to take advantage of the high COP hot and chilled water generation through simultaneous heating and cooling equipment.

Campus Opportunity

The SSU North Campus currently has two individual buildings (Berry, Sophia) with CHW systems, however these systems are standalone and there is no CHW utility distribution network. Connecting individual buildings to a centralized CHW distribution system can improve the campus CHW production efficiency through system optimization and controls. Additionally, with a connected centralized CHW distribution system there is greater potential to meet campus simultaneous heating and cooling demands with heat recovery technology.

Energy Impacts

- Reduced electricity usage by combining less efficient, individual building air conditioning systems with a more efficient centralized system. For some buildings that are not fully air conditioned and utilize window AC units for partial air conditioning, a complete building HVAC upgrade that includes air conditioning and ventilation for the entire building with more efficient central systems may increase the overall building energy usage as previously unconditioned spaces are air conditioned and mechanical ventilation is added.
- Simultaneous heating and cooling, implemented with a LTHW system, would allow for a transition to electricity as a heating/cooling energy source and reduced NG usage.
- Connecting buildings that are partially air conditioned to a centralized CHW system would increase purchased electricity.

Environmental Impacts

- A transition to electricity for heating/cooling energy source will reduce GHG emissions as purchased grid electricity is increasingly sourced from renewable providers. Massachusetts has committed to provide all grid electricity from renewable sources by 2050.
- Reduced fossil fuel usage and associated GHG emissions
- A reduction in energy use will reduce GHG emissions.

Economic Impacts

- Capital Investments: a centralized CHW will require the installation of CHW supply and return distribution piping

- Capital Investments: central plant CHW equipment and the decommissioning and removal of standalone air conditioning systems at individual buildings
- A centralized CHW system would reduce operations and maintenance (O&M) costs by consolidating service and maintenance to a single location, vs. the current individual building air conditioning systems

Solution Status – District Chilled Water Systems

- A district chilled water solution will be included in final clean energy feasibility study

Low Temperature Hot Water Conversion

Concept Overview

Convert existing steam heating systems to low temperature hot water (LTHW). Heating hot water will be distributed to the campus buildings at 120-140°F, lower than standard high temperature hot water systems that distribute at 160-180°F and lower than the central steam plant generation, 330°F steam at 90 psi. Benefits of the lower operating temperature include reduced heat losses in distribution, lower O&M costs, improved safety, and a wider array of electrified energy sources available when compared to steam and high temperature hot water. Typical steam distribution system losses can be significant, in the 15-30% range even for well-maintained systems.

Campus Opportunity

In order to operate on LTHW, existing buildings will require a conversion from steam or high temperature hot water. North campus buildings with hydronic heating systems, including supply and return temperatures, are listed below in Table 3. For buildings that currently utilize hydronic heating systems the conversion process will be less involved than if the building is heated directly by steam (e.g. through steam radiators or steam unit ventilators.)

Table 3: North Campus Buildings with Hydronic Heating Systems

Building	HHW Supply / Return Temperature (°F)
Berry Library	120/110 – AHUs, Reheat Coils 160/140 – Unit Heaters, Convectors, FTRs
Bowditch	180/160
Ellison	190/170
Horace Mann	200/180
Meier Hall	180/160
Sophia	180/145
Peabody	180/160

The conversion from a steam system to a hot water system can be done in phases to minimize disruption to building operation. The building heating system conversion process will include the following:

- Convert existing building equipment (e.g. heat-exchangers and radiators) to operate within low temperature hot-water temperature ranges. Some buildings, such as Berry Library that already has some equipment design for operation at LTHW, will require little to no changes. Others may require major retrofits which might be scheduled as part of larger renovation work.
- In the early phases of implementation, the central steam plant will continue to produce steam, however, this will be converted to hot water at the building-level using heat exchangers. This will allow for a phased implementation while allowing the existing steam central steam plant equipment to live out its useful life.
- Once all of the campus buildings are converted to LTHW, the existing steam generating equipment and standalone boilers can be replaced with high-efficiency centralized equipment that produces hot water directly (vs. steam generation and conversion to hot water) such as condensing boilers, water source heat pumps and air source heat pumps.
- When the LTHW conversions and district CHW system are installed, the campus can take advantage of alternative energy sources such as ground source heating and cooling.

Energy Impacts

In early phases of implementation, NG will still serve as the primary input to the central steam plant, with a decrease in overall demand for thermal energy while electricity use will increase due to pumping energy required for hot water distribution.

As the existing steam generating equipment in the central steam plant is taken offline and replaced with a LTHW system that incorporates heat-recovery chillers / heat pumps, and ground-source heat exchange, there will be a significant decrease in NG consumption.

There will be an increase in electricity usage and demand as the LTHW requires more hydronic pumping than a steam system, and the heat recovery chillers / heat pumps use electricity to generate LTHW (vs. fossil fuels in the steam boilers.)

The switch from steam to hot water will dramatically improve the overall system efficiency by eliminating significant losses inherent in steam distribution systems while enabling a suite of electric and renewable thermal technologies. This electrification of the campus thermal system will still take advantage of the core benefits of a district energy system and the benefit of the regional greening of the electric grid becoming 100% renewably sourced by 2050.

Environmental Impacts

- Reduced GHG emissions from reduced fossil fuel use at the central steam plant, including reduced distribution losses
- Reduced make-up water usage resulting from steam and steam condensate loss through the steam distribution system
- Increased electricity use and electrical demand

Economic Impacts

Capital investment for conversion to LTHW will include:

- Building heating system conversions to allow the buildings to operate with LTHW as a heating source and the installation of LTHW distribution piping throughout campus. Building conversions will consist of replacement of steam or high temperature heating equipment, including radiators, heating coils, heat exchangers, modifications to piping distribution and pumping systems to accommodate heating system operation at low temperature hot water. Refer to Campus Opportunity section above for additional details on the building conversion process.
- Central plant building and/or renovation costs to house new LTHW system equipment.
- LTHW generation equipment including heat recovery chillers, ground source heat pumps, air source heat pumps, condensing boilers
- Increase in campus electrical infrastructure required to support new, electric central plant equipment.
- Decommissioning and removal of steam distribution piping and steam generating equipment at the CSP

A LTHW system would reduce O&M costs by:

- Lowering distribution system maintenance costs relative to the current steam system
- Reducing maintenance costs associated with the removal of central steam plant systems (steam boilers)
- Reducing operational costs (licensing, personnel) as medium pressure steam equipment is retired

Solution Status - LTHW

- Low Temperature Hot Water Conversion will be included in final clean energy feasibility study

Ground-Source Heat Pump System (Heating and Cooling)

Concept Overview

A Geothermal Heat Pump or Ground-Source Heat Pump system (GSHP) is a heating and cooling system that transfers heat to and from the ground. Ground source heat exchangers (GHX) use the relatively stable temperatures of the earth as a heat source in the winter and as a heat sink in the summer. A ground source heating and cooling system consists of water to water heat pumps and heat recovery chillers coupled with a geothermal bore field heat exchanger used for campus district heating and cooling. This technology is best suited for a LTHW system rather than the current steam system as heat pumps and heat recovery chillers generate LTHW more efficiently than high temperature hot water.

Campus Opportunity

The SSU North Campus is in an urban setting with limited open space. The large parking lot behind Peabody and across from Meier Hall represents the largest open space on campus and presents the best opportunity for locating the ground source heat exchangers. In addition, the ground source heat exchangers can also be installed in the landscaped open areas in front of Sullivan and between Meier Hall and Lafayette Street, leaving the large parking lot available for future development. Utilizing GSHPs requires the conversion from campus steam to LTHW. In addition, there is landscaped area around Meier and Sullivan that could be used for ground source heat exchangers. There is an existing ground source heat exchange system serving Berry Library which can be integrated with a new ground source heat exchange system. Many factors contribute to the ground source heat exchanger sizing, including location, site geological conditions and type and depth of heat exchanger used. Based on information included in a previous geothermal test well report from 2010 and the ground source installation at Berry Library, the ground source heat exchangers proposed under this study will require a "U-bend" type heat exchanger at 800 foot depth with wells spaced at 20 feet on center or approximately 100 wells per acre.

Energy Impacts

A ground source heating and cooling system would impact the following:

- NG use would be significantly reduced or eventually eliminated
- Electricity use and demand would be increased

Environmental Impacts

- Decreased NG use and related GHG emissions
- Reduced make up water use at cooling towers (Berry Library)
- Increased GHG emissions from purchased electricity (if not provided from renewable sources)

Economic Impacts

Capital costs for GSHPs would be part of an overall conversion to a LTHW thermal system. This would include heat recovery chillers and heat pumps, GHX pumps, campus distribution pumps for CHW and LTHW and ground source heat exchangers .

New central plant equipment will require maintenance; however, once installed, maintenance costs, and associated labor costs, are expected to be much lower than the current central steam plant steam boilers.

Solution Status – Ground Source Heat Pump System

- Ground-Source Heat Pump System (Heating and Cooling) will be included in final clean energy feasibility study

Air-Source Heat Pumps (Heating and Cooling)

Concept Overview

An Air Source Heat Pump (ASHP) is a heating and cooling system that transfers heat to and from the outdoor air in order to generate chilled water for cooling and LTHW for heating. Similar to water source heat pumps, this technology is best suited for a LTHW system rather than the current steam system or high temperature hot water systems. ASHPs are installed outdoors and are less efficient than water source heat pumps. ASHPs sized to meet system peaks which occur during limited hours of the year would provide a less capital-intensive alternative to a GSHP system, primarily related to the ground source heat exchanger costs.

Campus Opportunity

The North Campus has sufficient rooftop area and space on grade immediately adjacent to buildings for the installation of air source heat pumps.

Energy Impacts

An ASHP heating and cooling system would impact the following:

- NG use would be significantly reduced or eventually eliminated
- Electricity use and electrical demand would be increased

Environmental Impacts

- Decreased NG use and related GHG emissions
- Reduced make up water use at cooling towers (Berry Library)
- Increased GHG emissions from purchased electricity (if not provided from renewable sources)
- Potential for increased noise pollution from ASHPs installed outdoors

Economic Impacts

Capital costs for ASHPs would be part of an overall conversion to a low-temperature hot water thermal system. This would include air source heat pumps, distribution pumps and associated distribution piping.

New ASHPs will require maintenance; however, once installed, maintenance costs are expected to be much lower than the current HVAC systems on campus and the current central steam plant steam generation equipment.

Solution Status – Air Source Heat Pumps

- Air-Source Heat Pumps (Heating and Cooling) will be included in final clean energy feasibility study

Wastewater Heat Recovery (HR)

Concept Overview

Wastewater Heat Recovery (HR) is the process of using wastewater as a heat sink or heat source for a water to water heat recovery chiller / heat pump system. Wastewater is diverted from the sewer line and heat is extracted from or rejected to the wastewater and is returned to the sewer line. Wastewater HR systems can be utilized at the campus level or at the building level. At the campus level, the wastewater HR system can augment the ground source heat exchange system by reducing the number of boreholes needed, as wastewater HR systems can be less capital-intensive than geothermal heat exchangers. For individual buildings, wastewater HR can be utilized to generate domestic hot water (DHW) for buildings with high domestic hot water usage, such as dormitories.

Campus Opportunity

A campus level wastewater HR system could intercept the sewer main located in Lafayette Street which runs along the east border of the North Campus. This sewage main could be used as a heat sink/source for a wastewater HR system that would offset the size and costs of the ground source heating and cooling GHX. The wastewater HR system would reject heat during summer months and remove heat during the winter months. This would reduce the size of the geothermal heat exchange field (i.e. fewer boreholes would need to be drilled.)

Building level wastewater HR systems could be installed in Peabody and Bowditch dormitories which have high domestic hot water usages. A wastewater HR system could utilize captured heat from the building's wastewater as a heat source for the building's domestic hot water.

Energy Impacts

- Reduced NG
- Increased electricity use

Environmental Impacts

- Decreased NG use and related reduction of GHG Emissions

Economic Impact

Wastewater HR system capital investment would include connections to the wastewater source, heat exchangers, pumps, filtration systems, piping from the wastewater HR systems to the sewage main and a storage tank. Building level systems would also require a water to water heat pump.

Wastewater HR equipment will require annual maintenance.

Solution Status – Wastewater Heat Recovery

- This solution will be included in final clean energy feasibility study

Renewable Fuel Oil (RFO) Boiler

Concept Overview

Installation of a boiler system capable of burning liquid biofuels at the Central Steam Plant (CSP) to produce LTHW. The biofuels would be burned in a new boiler, which would be dual fuel: biofuel with a natural gas backup. For purposes of this study, RFO is considered a renewable fuel that would produce biogenic emissions excluded from Scope 1 GHG emissions.

Campus Opportunity

When the steam boilers in the CSP are decommissioned, they can be replaced with RFO boilers sized to meet the campus heating load not met by GSHP and ASHP systems, as well as provide heating system redundancy requirements. The new RFO boilers and new fuel storage system would be integrated into the new LTHW distribution system. There are three existing underground fuel oil storage tanks near the central steam plant, each 5,000 gallons, that could be replaced or repurposed for RFO storage.

Energy Impacts

The RFO boiler would shift energy use from NG to RFO.

Environmental Impacts

The RFO boilers would replace the existing NG steam boilers shifting fuel use from NG to RFO. The net result would be lower carbon emissions due to reduced fossil fuel use. State policy regarding the carbon emissions accounting for renewable fuel oils and biofuels are constantly evolving. New or updated policy concerning RFO carbon emissions accounting may change their potential to impact GHG reductions for the North Campus.

Economic Impacts

Capital Costs for an RFO boiler system will include the cost of new boilers, distribution pumping and biofuel infrastructure.

An RFO boiler system would add annual O&M costs and higher commodities costs over NG.

Solution Status – RFO Boiler

- Renewable Fuel Oil (RFO) Boiler will be included in final clean energy feasibility study

Onsite PV

Concept Overview

Installation of photovoltaic generation systems on campus to generate electricity directly delivered to campus buildings. Solar installations could include rooftop, ground-mounted, and/or parking canopy systems. The electricity generated from onsite PV installations will directly reduce the amount of electricity that would otherwise be purchased from the grid.

Campus Opportunity

SSU has five rooftop PV installations on campus, including one at the Berry Library roof and potential future installation at the roof of Meier Hall.

Solar systems require committing a rooftop, ground area, or parking lot to host the installation(s) for at least 20 years. As viable rooftop and ground space on the North Campus are required for other higher impact solutions mentioned in this report, the overall viability of additional onsite PV is not great.

If future ground mounted solar arrays are planned for existing surface parking lots, these should be coordinated with future GHX installations. After GHX are installed, the site can be restored to its original function (e.g. parking lot) and the ground mounted solar arrays installed after without impact on the GHX systems.

While additional onsite electricity generation could potentially reduce scope 2 emissions, with Massachusetts committed to providing 100% renewable electricity by 2050, RECs generated by onsite PV installations would no longer be necessary after 2050.

Solution Status – Onsite PV

- Onsite PV is not being carried forward into the final clean energy feasibility study, however it remains an important strategy for reducing costs especially with a power purchase agreement.

Onsite Solar Thermal

Concept Overview

Onsite Solar thermal systems include one or more solar hot water panel arrays that would produce hot water to be distributed to the campus for heating. Solar hot water panels can be installed on roofs, parking structures and can also be surface mounted on grade. In addition to the solar hot water panels new distribution pumps and piping will be required to connect the panels to the campus hot water distribution systems. The solar thermal system would reduce the need for fossil fuel combustion and would produce hot water year-round.

Campus Opportunity

For solar thermal arrays to be effective, the campus needs a year-round heating load. While the North Campus is expected to have a summer heating load, it will be met by heat recovery chiller providing simultaneous heating and cooling at high efficiency. The summer heating load is not large enough to warrant both heat recovery and solar thermal, and since the heat recovery meets both heating and cooling loads, this is the preferred solution. For winter only application, solar thermal systems cannot simply be turned on and off when needed. If the campus heating demand falls below the panel array capacity, the extra heating capacity will need to be discarded, resulting in increased pumping energy and possibly increased make up water use. In addition to operational issues, utilizing the solar thermal array only in the winter would increase the system’s payback period as the system would only reduce heating energy consumption for half the year.

Solution Status – Onsite Solar Thermal

- Onsite Solar Thermal is not being carried forward into the final clean energy feasibility study

Renewable Energy Credits (REC) & Carbon Offsets

Concept Overview

A Renewable Energy Credit (REC) is a tradeable certificate that represents the environmental attributes of one megawatt-hour (MWh) of electricity generated by a renewable energy source. One REC is produced for each MWh of renewable electricity generated. By purchasing and retiring (i.e., not reselling) a REC, SSU can offset its GHG emissions associated with electricity the campus purchases and imports from the power grid. RECs that SSU acquires and retires can be generated from renewable generation systems located either on or off campus. Massachusetts current goal of providing 100% renewable electricity by 2050 would eliminate the need for voluntary REC purchases by SSU after 2050.

Carbon offsets, represent a purchased unit of carbon dioxide-equivalent (CO_2e) that is reduced, avoided, or sequestered and claimed to mitigate increases in global GHG emissions by offsetting 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.

Campus Opportunity

SSU has provided direction to avoid the purchase of RECs and Carbon Offsets as part of this clean energy feasibility study and instead focus on reducing carbon emissions for the campus through the expanded use of other solutions identified above. In addition, as this study is for only the North Campus and not the entire university, thus any consideration of offsets would occur at the university level and not sub-campus level.

Solution Status – RECs and Carbon Offsets

- Renewable Energy Credits (REC) & Carbon Offsets are not being carried forward into the final clean energy feasibility study.

Options Selected Summary

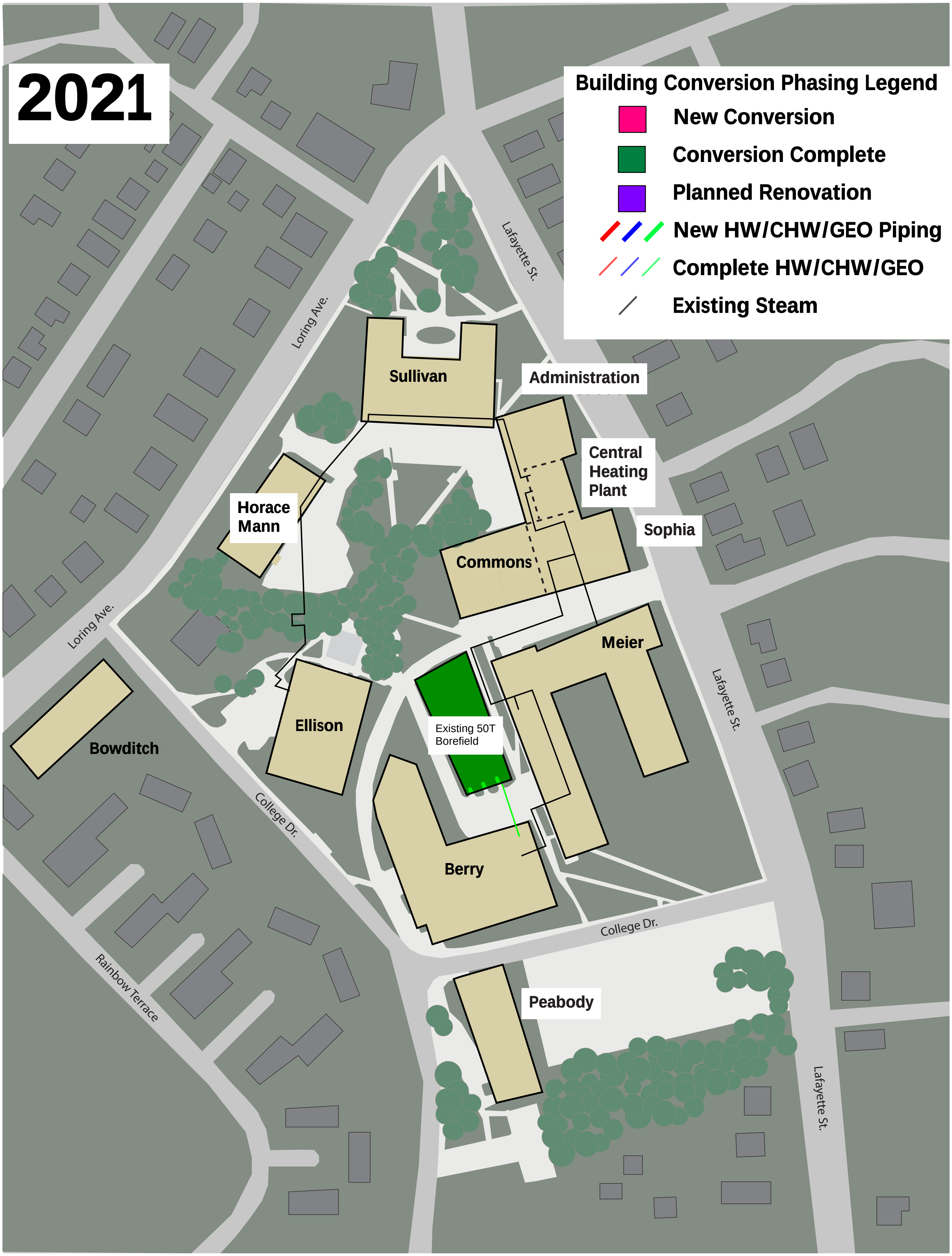
Each of the solutions included in this report were evaluated and either selected to be included in the final clean energy feasibility study or discarded. While all the solutions considered have the potential to reduce GHG emissions and have a positive financial impact, some of the solutions were not as effective as others when applied to the SSU North Campus. The solutions not selected along with reasoning behind the decisions are listed below:

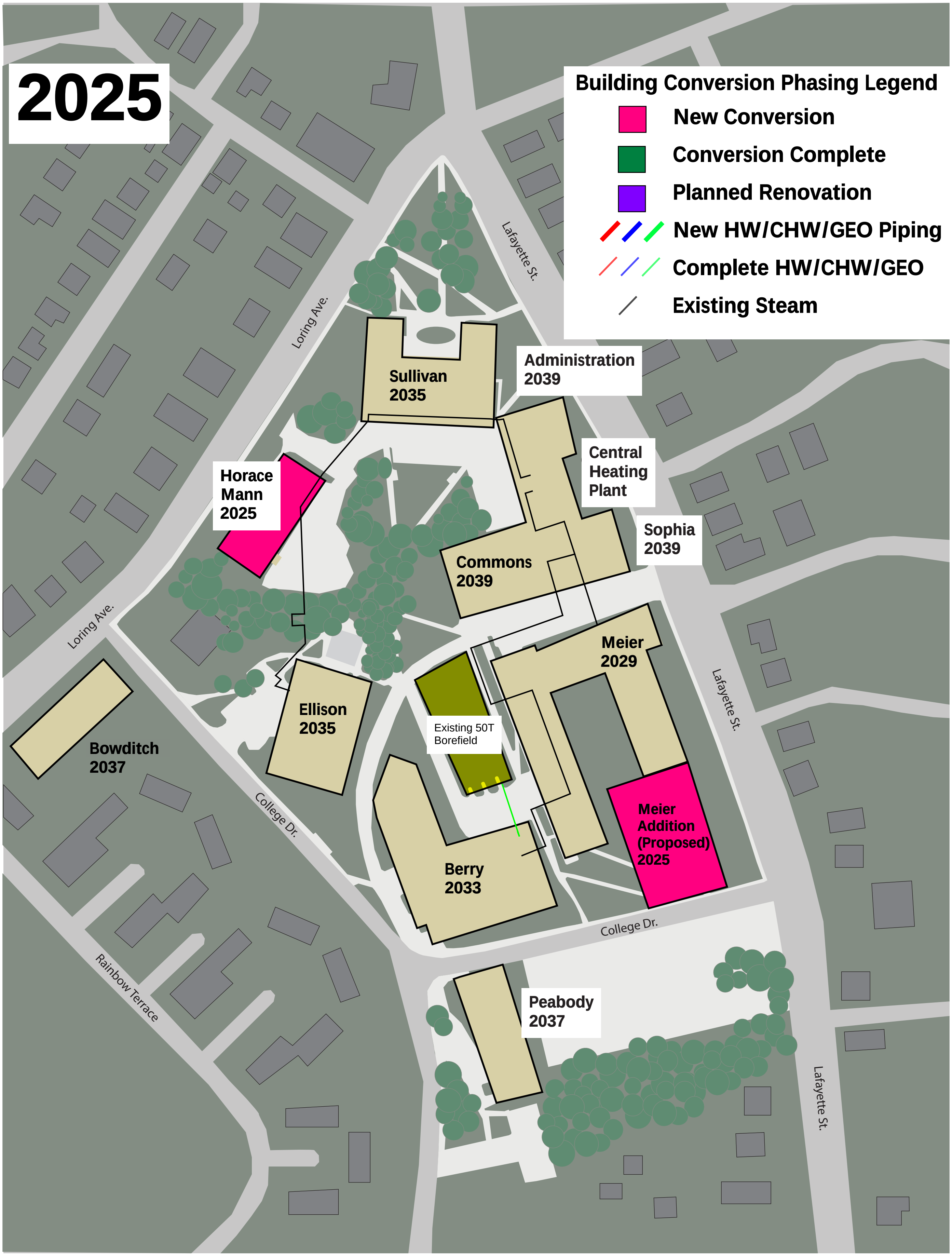
- Onsite PV
  - This solution was not selected due to limited space available on the North Campus and the short-term use of any RECs generated by the PVs. As SSU is not considering REC purchases, onsite REC generation to offset REC purchases is not a priority for this study.
  - Salem State University will continue plans to install PV as roofs are re-done or parking lots are repaved and when projects, via a PPA, are cash-positive for the University. This will continue as a separate scope from this North Campus Clean Energy Feasibility Study and recommended roadmap. While important projects in terms of accelerating the grid's transition to renewable electricity, these initiatives do not address the main goal of this project which is transitioning heating and cooling systems off of fossil fuels.

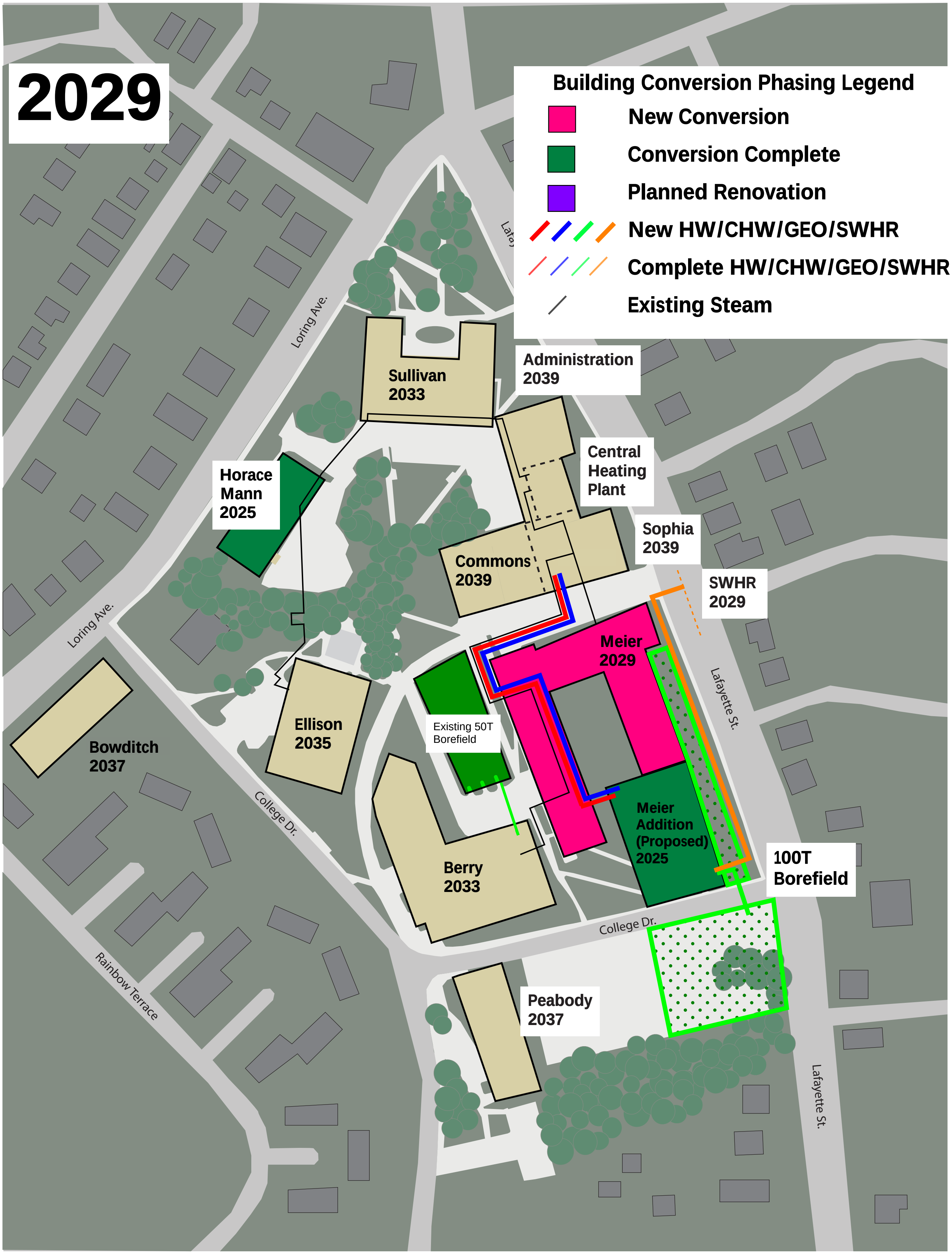
- Onsite Solar Thermal
  - This solution was not selected due to the low summer heating load on the North Campus.

- Renewable Energy Credits and Carbon Offsets
  - These solutions were not selected per the direction of SSU to allow for the increased use of other viable solutions and ensure that financial resources remain available for students.

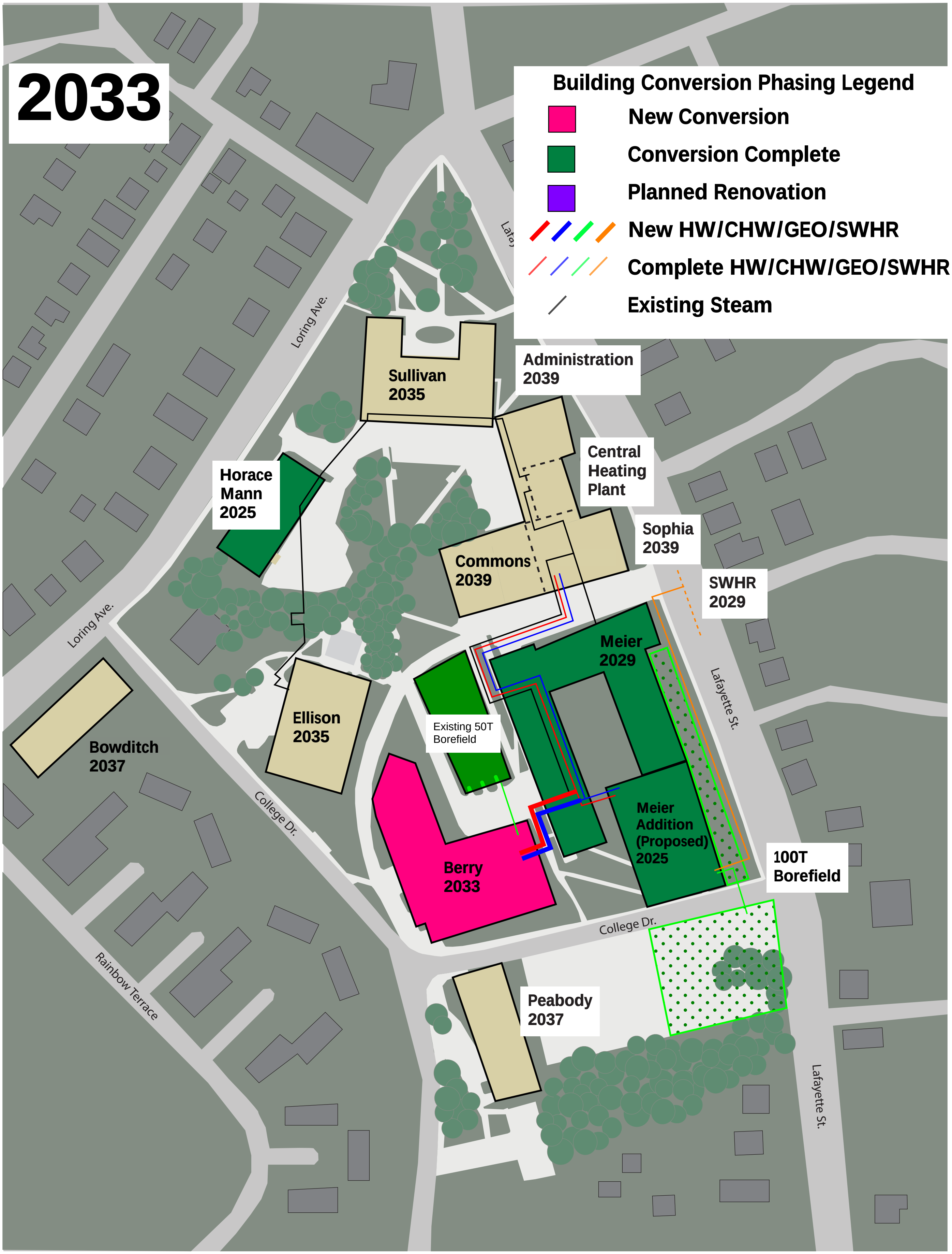
The solutions selected to be included in the final clean energy feasibility study will be further developed and optimized to provide a clear and effective pathway to carbon neutral thermal systems for the North Campus by 2050.

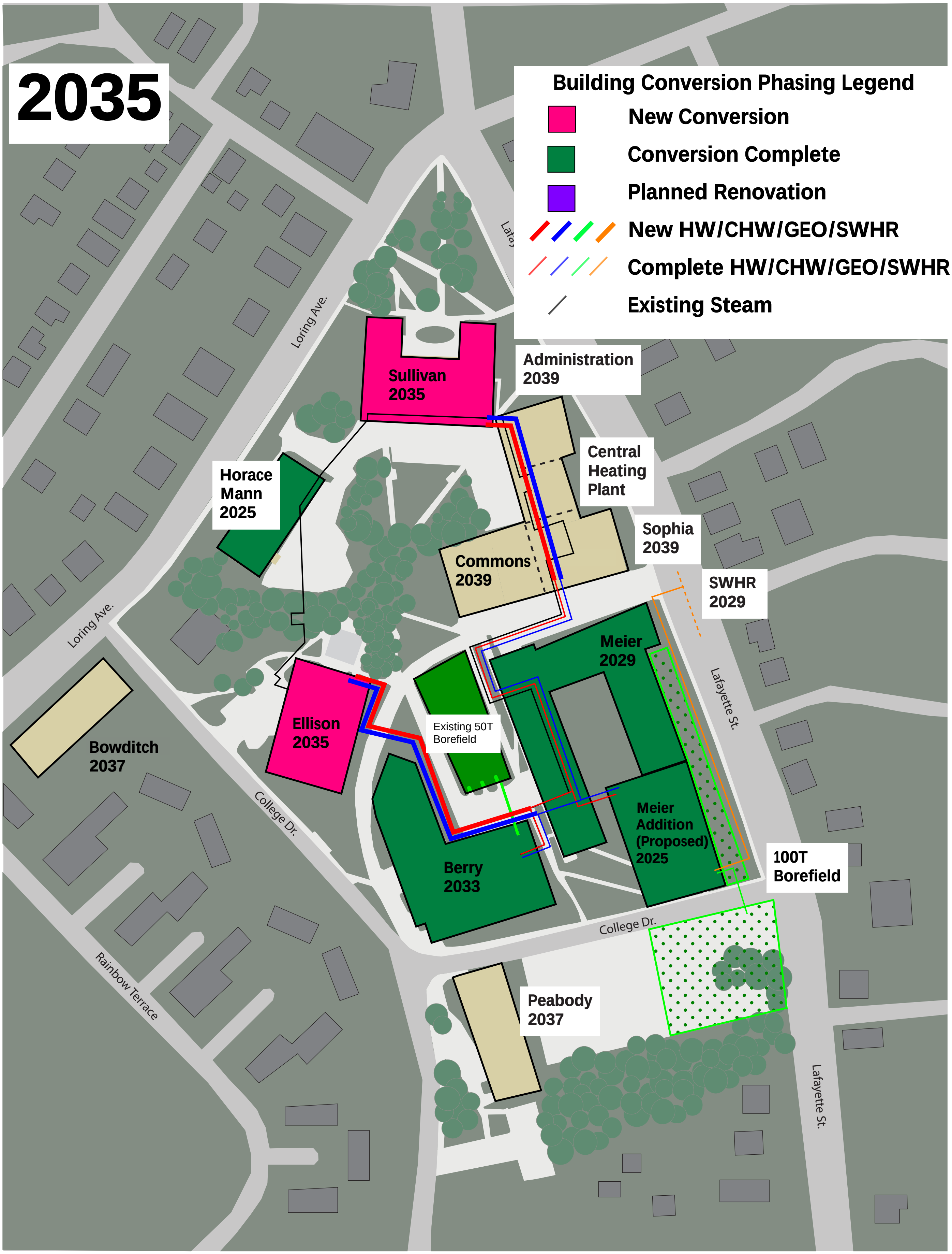

2021
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO Piping
Complete HW/CHW/GEO
Existing Steam
Loring Ave.
Lafayette St.
Sullivan
Administration
Central Heating Plant
Sophia
Horace Mann
Commons
Meier
Ellison
Bowditch
Existing 50T Borefield
College Dr.
Berry
Rainbow Terrace
Peabody


2025
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO Piping
Complete HW/CHW/GEO
Existing Steam
Lafayette St.
Loring Ave.
Sullivan 2035
Administration 2039
Central Heating Plant
Horace Mann 2025
Sophia 2039
Commons 2039
Loring Ave.
Meier 2029
Ellison 2035
Existing 50T Borefield
Lafayette St.
Bowditch 2037
College Dr.
Meier Addition (Proposed) 2025
Berry 2033
College Dr.
Rainbow Terrace
Peabody 2037
Lafayette St.



2029
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Loring Ave.
Sullivan
2033
Administration
2039
Central
Heating
Plant
Horace
Mann
2025
Commons
2039
Sophia
2039
SWHR
2029
Meier
2029
Lafayette St.
Loring Ave.
Bowditch
2037
Ellison
2035
Existing 50T
Borefield
Meier
Addition
(Proposed)
2025
100T
Borefield
College Dr.
Berry
2033
College Dr.
Rainbow Terrace
Peabody
2037
Lafayette St.


2033
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Sullivan 2035
Administration 2039
Central Heating Plant
Horace Mann 2025
Commons 2039
Sophia 2039
SWHR 2029
Meier 2029
Ellison 2035
Bowditch 2037
Existing 50T Borefield
Meier Addition (Proposed) 2025
Berry 2033
100T Borefield
Peabody 2037
Loring Ave.
College Dr.
Lafayette St.
Rainbow Terrace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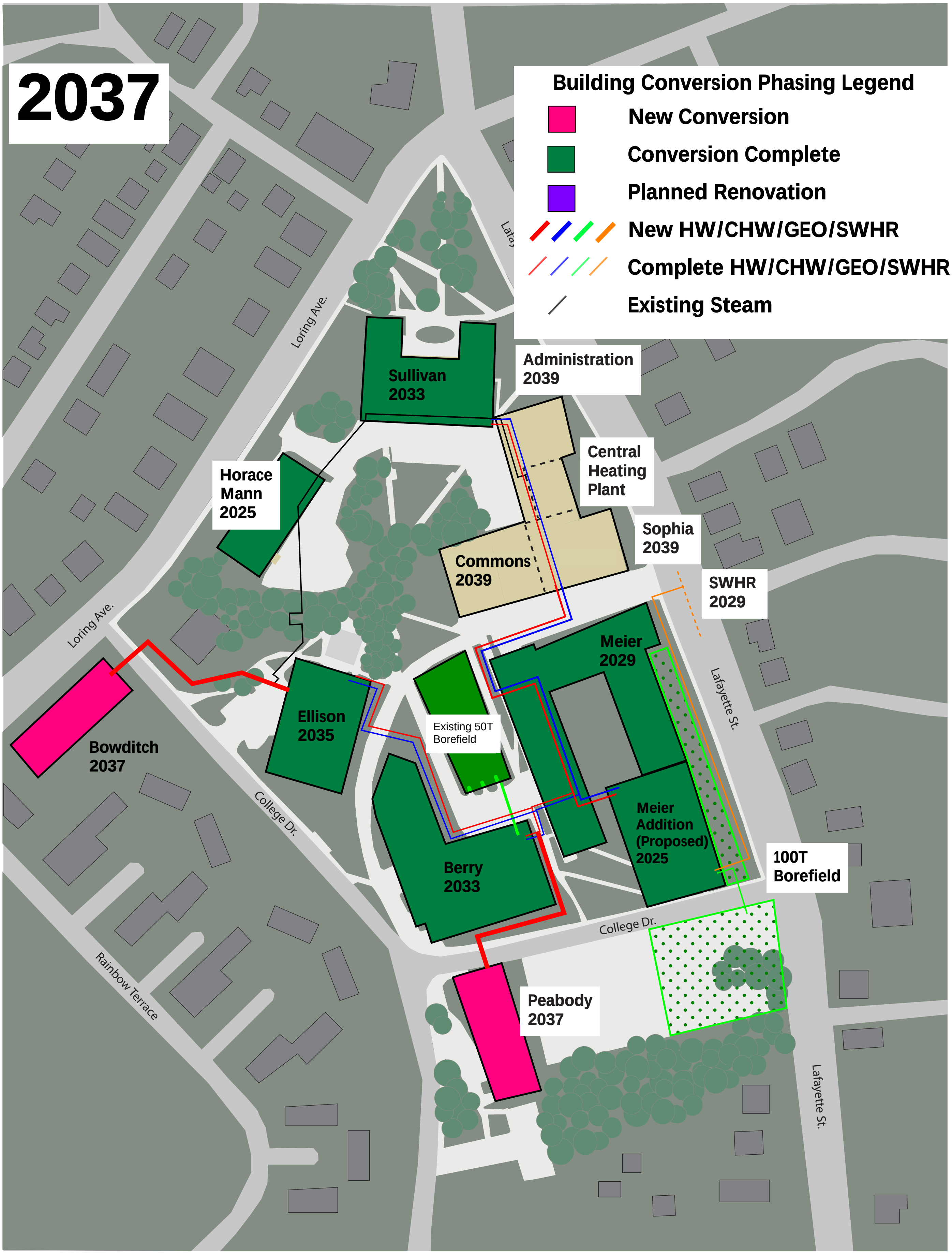
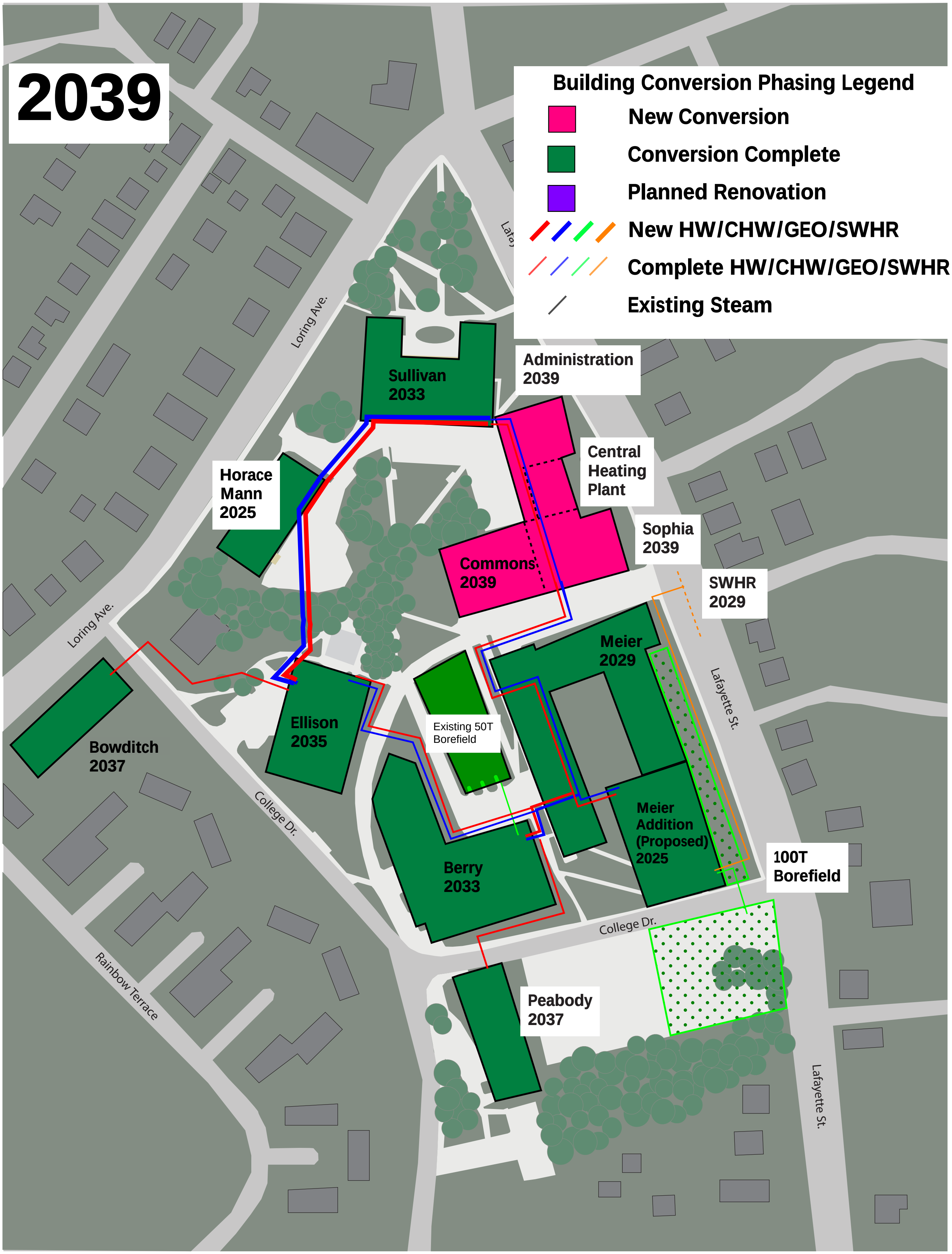
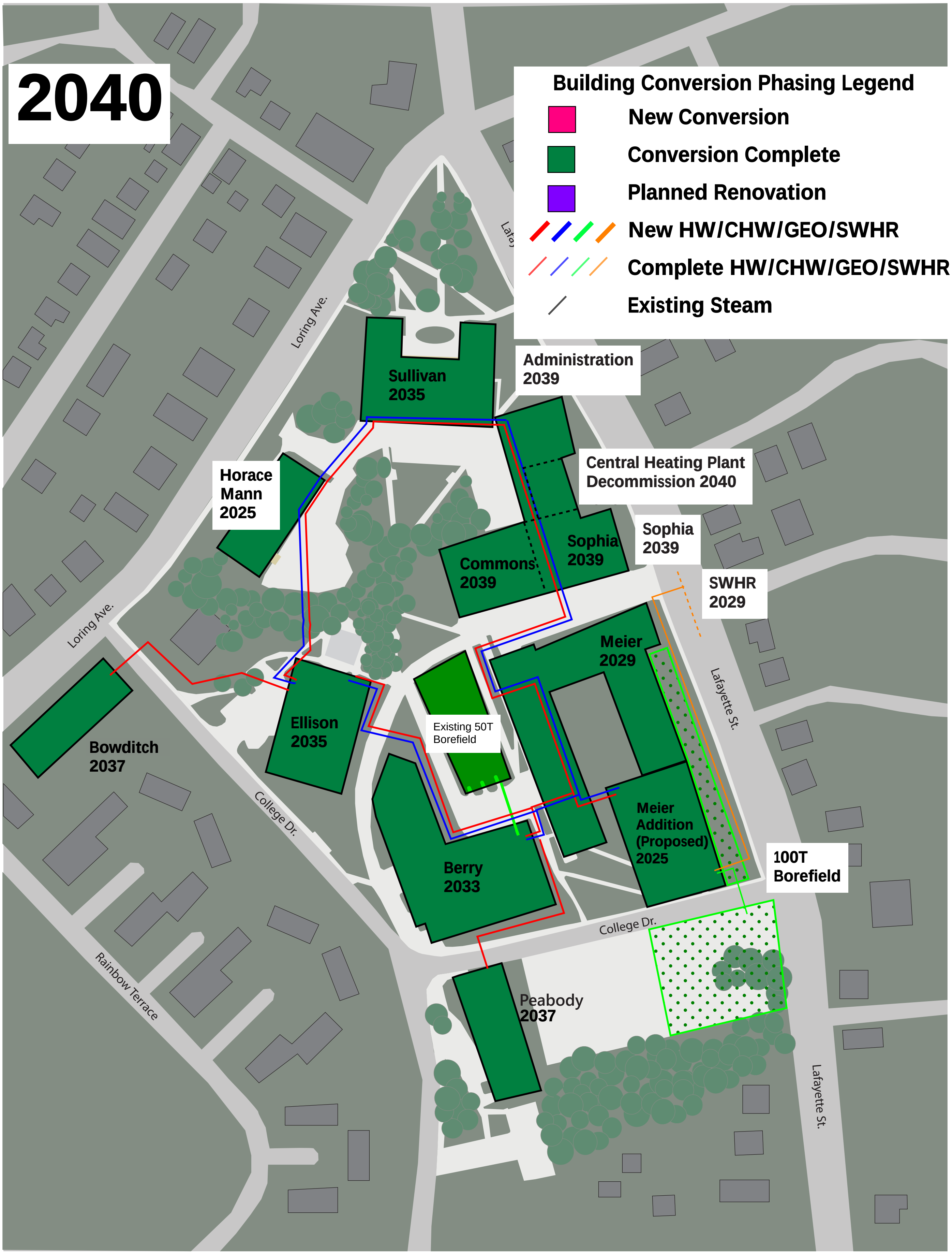
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Sullivan 2035
Administration 2039
Central Heating Plant
Horace Mann 2025
Sophia 2039
Commons 2039
SWHR 2029
Meier 2029
Ellison 2035
Existing 50T Borefield
Bowditch 2037
Meier Addition (Proposed) 2025
Berry 2033
100T Borefield
Peabody 2037
Loring Ave.
Loring Ave.
College Dr.
College Dr.
Lafayette St.
Lafayette St.
Rainbow Terrace


2037
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Loring Ave.
Loring Ave.
Sullivan
2033
Administration
2039
Central
Heating
Plant
Horace
Mann
2025
Sophia
2039
Commons
2039
SWHR
2029
Meier
2029
Ellison
2035
Existing 50T
Borefield
Bowditch
2037
Lafayette St.
College Dr.
Meier
Addition
(Proposed)
2025
Berry
2033
100T
Borefield
College Dr.
Rainbow Terrace
Peabody
2037
Lafayette St.


2039
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Sullivan 2033
Administration 2039
Central Heating Plant
Horace Mann 2025
Commons 2039
Sophia 2039
SWHR 2029
Meier 2029
Ellison 2035
Bowditch 2037
Existing 50T Borefield
Meier Addition (Proposed) 2025
100T Borefield
Berry 2033
Peabody 2037
Loring Ave.
College Dr.
Lafayette St.
Rainbow Terrace



2040
Building Conversion Phasing Legend
New Conversion
Conversion Complete
Planned Renovation
New HW/CHW/GEO/SWHR
Complete HW/CHW/GEO/SWHR
Existing Steam
Sullivan 2035
Administration 2039
Horace Mann 2025
Central Heating Plant Decommission 2040
Sophia 2039
Commons 2039
SWHR 2029
Meier 2029
Bowditch 2037
Ellison 2035
Existing 50T Borefield
Meier Addition (Proposed) 2025
Berry 2033
100T Borefield
Peabody 2037
Loring Ave.
College Dr.
Lafayette St.
Rainbow Terrace

Appendix D1: BAU Capital Investment Summary

	Central Steam Plant Equipment	Building Level Campus Steam Equipment	Steam Utility Piping	Building Level Central Equipment	Terminal Unit Replacement	RTU replacements (Commons, Admin Only)	Total	Notes
2021	$ -	$ -	$ -	$ -			$ -	
2022	$ -	$ -	$ -	$ -			$ -	
2023	$ -	$ -	$ -	$ -			$ -	
2024	$ -	$ -	$ -	$ -			$ -	
2025	$ -	$ 42,454	$ 431,095	$ -			$ 473,549	Replacement of all 1980 steam piping - Phased over 5 years, bldg PRV + Misc. Steam (PRV) equipment
2026	$ -	$ -	$ 431,095	$ -			$ 431,095	Replacement of all 1980 steam piping - Phased over 5 years
2027	$ -	$ -	$ 431,095	$ -			$ 431,095	"
2028	$ -	$ -	$ 431,095	$ -			$ 431,095	"
2029	$ -	$ -	$ 431,095	$ -	$ 843,409		$ 1,274,504	" + Meier Hall Terminal unit replacements
2030	$ -	$ 42,454	$ -	$ -			$ 42,454	bldg PRV + Misc. Steam (PRV) equipment
2031	$ -	$ -	$ -	$ -			$ -	
2032	$ -	$ -	$ -	$ 194,013	$ 568,557		$ 762,571	Bowditch Boiler replacements (per MSCBA Schedule), Bowditch FTR replacement (60 years)
2033	$ -	$ -	$ -	$ -	$ 589,484		$ 589,484	Sullivan Terminal unit replacements
2034	$ -	$ -	$ -	$ -			$ -	
2035	$ -	$ 42,454	$ -	$ 86,850	$ 441,893		$ 571,197	Ellison Terminal Unit Replacements & Condensing Unit Replacements, Sophia FCU replacements, bldg PRV + Misc. Steam (PRV) equipment
2036	$ -	$ -	$ -	$ -		$ 450,256	$ 450,256	Commons + Admin RTU replacements
2037	$ -	$ -	$ -	$ 333,193	$ 568,557		$ 901,751	Peabody Boiler replacements (per MSCBA Schedule), Peabody FTR replacement (60 years), Sophia Theater Air Cooled Chilled replacement
2038	$ -	$ -	$ -	$ -		$ 52,110	$ 52,110	Sophia Equipment Replacement
2039	$ -	$ -	$ -	$ -			$ -	
2040	$ -	$ 42,454	$ -	$ -			$ 42,454	bldg PRV + Misc. Steam (PRV) equipment
2041	$ 1,083,763	$ -	$ -	$ -			$ 1,083,763	CSP Boiler #1 replacement Cost
2042	$ -	$ -	$ -	$ -			$ -	
2043	$ 1,083,763	$ -	$ -	$ -			$ 1,083,763	CSP Boiler #2 replacement cost
2044	$ -	$ -	$ -	$ -			$ -	
2045	$ -	$ 42,454	$ -	$ -			$ 42,454	bldg PRV + Misc. Steam (PRV) equipment
2046	$ -	$ -	$ -	$ -			$ -	
2047	$ -	$ -	$ -	$ -			$ -	
2048	$ -	$ -	$ -	$ -			$ -	
2049	$ -	$ -	$ -	$ -			$ -	
2050	$ -	$ -	$ -	$ -			$ -	
Total	$ 2,167,525	$ 212,270	$ 2,155,475	$ 614,056	$ 3,011,902	$ 502,366	$ 8,663,594	

Appendix D1: Centralized Option Capital Investment Summary

	Energy Conservation Measures	Central Plant Equipment (Peak)	Utility Piping	Building Conversions	Central Plant Equipment (Geothermal)	Geothermal Heat Exchanger	Sewage Heat Recovery System	Total	Nots
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2025	$ 75,000	$ -	$ -	$ -	$ -	$ -	$ -	$ 75,000	Energy Conversation Measures (ECM)
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2029	$ -	$ 581,378	$ 1,736,763	$ 3,206,900	$ 570,000	$ 2,175,210	$ 685,000	$ 8,955,251	WCCH Plant (Peak), New Clean Energy Plant (150 Tons), Meier Hall Conversion, Geothermal Heat Exchanger
2030	$ 75,000	$ -	$ -	$ -	$ -	$ -	$ -	$ 75,000	Energy Conversation Measures (ECM)
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2033	$ -	$ -	$ 459,731	$ 756,400	$ -	$ -	$ -	$ 1,216,131	Berry Library Conversion / Geo Interconnection
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2035	$ 75,000	$ 492,718	$ 2,609,230	$2,329,086	$ 469,762	$ -	$ -	$ 5,975,795	Energy Conversation Measures (ECM), Sullivan Renovation, Ellison Building Conversion, Added WCCH Capacity
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2037	$ -	$ -	$ 516,942	$ 838,964	$ -	$ -	$ -	$ 1,355,906	Sophia Theater Air Cooled Chilled replacement, Bowditch & Peabody Conversion
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2039	$ -	$ 1,040,679	$ 805,041	$ 923,649	$ -	$ -	$ -	$ 2,769,369	WWCH Admin Cluster (Peak), HE Hydronic Boilers (peak)
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2041	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2042	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2043	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2044	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2045	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2046	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2047	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2048	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2049	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
2050	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
Total	$ 225,000	$ 2,114,775	$ 6,127,707	$ 8,054,998	$ 1,039,762	$ 2,175,210	$ 685,000	$ 20,422,452	

Appendix D2: BAU Campus Utility Piping Cost Estimate

Utility Piping	Length	Pipe Cost	Insulation (	Fittings & Valves (+25% Pipe & Insul. Cost)	Excavation / Backfill Costs	Total Cost $ / FT (pipe+insul+fitting+trench)	Total
Demo Existing Steam Pipe							
2"	170	$ 6.87					
3"	1010	$ 6.87	-	-			$ 6,939
4"	850	$ 20.61	-	-			$ 17,519
5"	410	$ 20.61	-	-			$ 8,450
6"	730	$ 20.61	-	-			$ 15,045
8"	520	$ 34.02	-	-			$ 17,690
10"	130	$ 34.02	-	-			$ 4,423
New Steam, Condensate Pipe (DB)							
2"	170	$ 65.32					
3"	1010	$ 65.32	$ 19.87	$ 21.30	$ 88.89	$ 195.38	$ 197,330
4"	750	$ 80.81	$ 24.71	$ 26.38	$ 88.89	$ 220.79	$ 165,592
5"	410	$ 103.53	$ 27.44	$ 32.74	$ 111.11	$ 274.82	$ 112,678
6"	730	$ 134.56	$ 32.46	$ 41.76	$ 111.11	$ 319.89	$ 233,517
8"	420	$ 184.21	$ 42.21	$ 56.61	$ 111.11	$ 394.14	$ 165,537
10"	130	$ 226.73	$ 50.34	$ 69.27	$ 111.11	$ 457.45	$ 59,468
New Steam, Condensate Pipe (Tunnel)					Cost increase for work in existing tunnels / confined spaces (20%)		
2"	0	$ 65.32					
3"	0	$ 65.32	$ 19.87	$ 21.30	$ 21.30	$ 127.79	$ -
4"	100	$ 80.81	$ 24.71	$ 26.38	$ 26.38	$ 158.28	$ 15,828
5"	0	$ 103.53	$ 27.44	$ 32.74	$ 32.74	$ 196.46	$ -
6"	0	$ 134.56	$ 32.46	$ 41.76	$ 41.76	$ 250.53	$ -
8"	100	$ 184.21	$ 42.21	$ 56.61	$ 56.61	$ 339.63	$ 33,963
10"	0	$ 226.73	$ 50.34	$ 69.27	$ 69.27	$ 415.61	$ -
Purge, test, flush							$75,920
				MECHANICAL SUB TOTAL			$1,130,000
ELECTRICAL (tunnel lights, power for temp vent., etc)				1%			$11,300
Civil				20%			$226,000
Structural				10%			$113,000
Difficult Working Conditions				15%			$169,500
Design / Estimating Contingency				15%			$169,500
Construction Contingency				5%			$56,500
General Conditions				10%			$113,000
Inusrance / Bond				3.75%			$42,375
Building Permit				1%			$11,300
Contractor Fee				10%			$113,000
				TOTAL PROJECT COST:			**$2,155,475**

Appendix D2: Centralized Option Campus Utility Piping Cost Estimate

Utility Piping	Length	Pipe Cost	Insulation	Fittings & Valves (+25% Pipe & Insul. Cost)	Excavation / Backfill Costs	Total Cost $ / FT (pipe+insul+fitting+trench)	Total
Demo Existing Steam Pipe							
3"	1910	$ 6.87	-	-			$ 13,122
4"	3750	$ 20.61	-	-			$ 77,288
5"	840	$ 20.61	-	-			$ 17,312
6"	3360	$ 20.61	-	-			$ 69,250
8"	840	$ 34.02	-	-			$ 28,577
10"	0	$ 34.02	-	-			$ -
New CHW, HHW Pipe (DB)							
3"	1910	$ 65.32	$ 19.87	$ 21.30	$ 88.89	$ 195.38	$ 373,169
4"	2300	$ 80.81	$ 24.71	$ 26.38	$ 88.89	$ 220.79	$ 507,814
5"	840	$ 103.53	$ 27.44	$ 32.74	$ 111.11	$ 274.82	$ 230,852
6"	1910	$ 134.56	$ 32.46	$ 41.76	$ 111.11	$ 319.89	$ 610,982
8"	840	$ 184.21	$ 42.21	$ 56.61	$ 111.11	$ 394.14	$ 331,074
10"	0	$ 226.73	$ 50.34	$ 69.27	$ 111.11	$ 457.45	$ -
New CHW, HHW Pipe (Tunnel)					Cost increase for work in existing tunnels / confined spaces (20%)		
3"	0	$ 65.32	$ 19.87	$ 21.30	$ 21.30	$ 127.79	$ -
4"	1450	$ 80.81	$ 24.71	$ 26.38	$ 26.38	$ 158.28	$ 229,506
5"	0	$ 103.53	$ 27.44	$ 32.74	$ 32.74	$ 196.46	$ -
6"	1450	$ 134.56	$ 32.46	$ 41.76	$ 41.76	$ 250.53	$ 363,269
8"	0	$ 184.21	$ 42.21	$ 56.61	$ 56.61	$ 339.63	$ -
10"	0	$ 226.73	$ 50.34	$ 69.27	$ 69.27	$ 415.61	$ -
Purge, test, flush							$142,427
MECHANICAL SUB TOTAL							$2,995,000
ELECTRICAL (tunnel lights, power for temp vent., etc)				1%			$29,950
Civil				20%			$599,000
Structural				10%			$299,500
Difficult Working Conditions				20%			$599,000
Design / Estimating Contingency				15%			$449,250
Construction Contingency				5%			$149,750
General Conditions				10%			$299,500
Inusrance / Bond				3.75%			$112,313
Building Permit				1%			$29,950
Contractor Fee				10%			$556,321
TOTAL PROJECT COST:							**$6,119,534**

Appendix D3: Annual Maintenance Costs, 2021

Central Steam Plant Maintenance Costs		
Item	Cost	Notes
Full Time Employees	$ 560,000	(5) FTE's at $80k each, plus 40% salary for benefits
Training	$ 1,500	
Inspections	$ 1,000	
Contracted Steam System Repairs	$ 72,459	Average of 2yrs 19,20 (JP Campbell, Fraser, F Rounds)
Steam System Trap Survey	$ 8,000	50% of $16k survey done every other year
Steam Trap Maintenance	$ 10,539	Based off 2019 cost
Water Treatment	$ 9,632	Assumption that 50% of Barclay's total SSU campus cost is North Campus
Misc Steam Boiler Maintenance	$ 19,302	Procard charges, Burnell Controls
Steam Utility Piping Repairs	$ 409,170	Average annual North Campus Steam system repair cost from 2014-2018
Central Steam Plant Maintenance Total	$ 1,091,602	

HVAC Department Maintenance Costs		
Item	Cost	Notes
Full Time Employees	$ 420,000	(4) FTE's at $75k each, plus 40% salary for benefits
Boiler Maintenance	$ 25,810	$5,162/boiler (does not include CHP Steam boilers)
Air Cooled Chiller Maintenance	$ 7,000	$50/T and 140T Installed
Split System Maintenance	$ 8,450	$50/T with 169T Installed
Split System Replacement	$ 7,000	2 Units/year
Window AC Maintenance	$ 3,200	Filter change/cleaning
RTU Maintenance	$ 6,400	$25/T and 256T installed
Geo WWHP Maintenance	$ 26,600	$70/T and 380T installed
HVAC Department Maintenance Total	$ 504,460	

Total Annual Maintenance Budget	$ 1,596,062

Appendix D3: Maintenance Costs, BAU & Centralized Option

	BAU			Centralized Option			
	Central Steam Plant	HVAC Department	Total	Central Steam Plant	HVAC Department	Added FTE	Total
2020	$ 1,091,602	$ 504,460	$ 1,596,062	$ 1,091,602	$ 504,460	$ -	$ 1,596,062
2021	$ 1,117,582	$ 516,466	$ 1,634,049	$ 1,117,582	$ 516,466	$ -	$ 1,634,049
2022	$ 1,144,181	$ 528,758	$ 1,672,939	$ 1,144,181	$ 528,758	$ -	$ 1,672,939
2023	$ 1,171,412	$ 541,342	$ 1,712,755	$ 1,171,412	$ 541,342	$ -	$ 1,712,755
2024	$ 1,199,292	$ 554,226	$ 1,753,518	$ 1,199,292	$ 554,226	$ -	$ 1,753,518
2025	$ 1,227,835	$ 567,417	$ 1,795,252	$ 1,227,835	$ 588,917	$ -	$ 1,816,752
2026	$ 1,257,058	$ 580,922	$ 1,837,979	$ 1,257,058	$ 602,422	$ -	$ 1,859,479
2027	$ 1,286,976	$ 594,747	$ 1,881,723	$ 1,286,976	$ 616,247	$ -	$ 1,903,223
2028	$ 1,317,606	$ 608,902	$ 1,926,508	$ 1,317,606	$ 630,402	$ -	$ 1,948,008
2029	$ 1,348,965	$ 623,394	$ 1,972,359	$ 1,348,965	$ 676,044	$ -	$ 2,025,009
2030	$ 1,381,070	$ 638,231	$ 2,019,301	$ 1,381,070	$ 678,356	$ -	$ 2,059,426
2031	$ 1,413,939	$ 653,421	$ 2,067,361	$ 1,413,939	$ 693,546	$ -	$ 2,107,486
2032	$ 1,447,591	$ 668,972	$ 2,116,564	$ 1,447,591	$ 709,097	$ -	$ 2,156,689
2033	$ 1,482,044	$ 684,894	$ 2,166,938	$ 1,482,044	$ 739,719	$ -	$ 2,221,763
2034	$ 1,517,317	$ 701,194	$ 2,218,511	$ 1,517,317	$ 750,469	$ -	$ 2,267,786
2035	$ 1,553,429	$ 717,883	$ 2,271,312	$ 1,553,429	$ 768,958	$ -	$ 2,322,387
2036	$ 1,590,400	$ 734,969	$ 2,325,369	$ 1,590,400	$ 786,044	$ 105,000	$ 2,481,444
2037	$ 1,628,252	$ 752,461	$ 2,380,713	$ 1,302,601	$ 803,536	$ 105,000	$ 2,211,137
2038	$ 1,667,004	$ 770,369	$ 2,437,374	$ 1,000,203	$ 800,796	$ 105,000	$ 1,905,999
2039	$ 1,706,679	$ 788,704	$ 2,495,383	$ 682,672	$ 814,856	$ 105,000	$ 1,602,528
2040	$ 1,747,298	$ 807,475	$ 2,554,773	$ 349,460	$ 833,627	$ 105,000	$ 1,288,087
2041	$ 1,788,884	$ 826,693	$ 2,615,577	$ -	$ 868,331	$ 210,000	$ 1,078,331
2042	$ 1,831,459	$ 846,368	$ 2,677,828	$ -	$ 888,006	$ 210,000	$ 1,098,006
2043	$ 1,875,048	$ 866,512	$ 2,741,560	$ -	$ 908,150	$ 210,000	$ 1,118,150
2044	$ 1,919,674	$ 887,135	$ 2,806,809	$ -	$ 928,773	$ 210,000	$ 1,138,773
2045	$ 1,965,362	$ 908,249	$ 2,873,611	$ -	$ 949,887	$ 210,000	$ 1,159,887
2046	$ 2,012,138	$ 929,865	$ 2,942,003	$ -	$ 971,503	$ 210,000	$ 1,181,503
2047	$ 2,060,027	$ 951,996	$ 3,012,023	$ -	$ 993,634	$ 210,000	$ 1,203,634
2048	$ 2,109,055	$ 974,653	$ 3,083,709	$ -	$ 1,016,291	$ 210,000	$ 1,226,291
2049	$ 2,159,251	$ 997,850	$ 3,157,101	$ -	$ 1,039,488	$ 210,000	$ 1,249,488
2050	$ 2,210,641	$ 1,021,599	$ 3,232,240	$ -	$ 1,063,237	$ 210,000	$ 1,273,237

Appendix D4: Building Conversions for LTHW

Building Name	Bldg. Conversion Effort (H/M/L)	Gross Area (SF)	Conversion Year	Conversion Costs ($)	Estimated $ / GSF		
					Low	Medium	High
Administration	M	23,267	2039	$304,798	$6.10	$13.10	$20.00
Commons Dining Hall	M	35,089	2039	$459,666			
Sophia Theater	L	26,096	2039	$159,186			
Berry Library	L	124,000	2033	$756,400			
Bowditch Hall	L	64,183	2037	$391,516			
Ellison Campus Center	M	49,776	2035	$652,066			
Meier Hall	H	160,345	2029	$3,206,900			
Peabody	L	73,352	2037	$447,447			
Sullivan	H	83,851	2035	$1,677,020			
Total		639,959		$8,054,998			

Building Conversion Effort Notes:

Administration- Rooftop HVAC Units w/ DX Cooling, Natural Gas & Electric Heating, Hydronic Heating Systems
Commons Dining Hall- Rooftop HVAC Units w/ DX Cooling, Natural Gas & Electric Heating, Limited Direct Steam Systems
Sophia Theater- Recently renovated (2015), Hydronic Heating Systems, Rooftop AHUs
Berry Library- Recently built (2012), Hydronic Heating Systems, Geothermal and LTHW compatible systems
Bowditch Hall- Hydronic Systems, Repetitive Design, Simple HVAC Systems
Ellison Campus Center- Recently Renovated (1999), Hydronic Heating Systems, Refrigerant Based Cooling Systems
Meier Hall- Lab Building, Complicated Lab HVAC Systems, Not Recently Renovated
Peabody- Hydronic Systems, Repetitive Design, Simple HVAC Systems
Sullivan- Older Building (1896), Not recently Renovated, Direct Steam Systems

Appendix D5: Central Energy Plant Cost Estimate

Central Energy Plant Cost Estimate				
SIZE	TYPE	QTY	UNIT PRICE	TOTAL PRICE
10"	PIPING	0	$ 277.07	$ -
8"	PIPING	350	$ 226.42	$ 80,000
6"	PIPING	250	$ 167.02	$ 42,000
4"	PIPING	50	$ 105.52	$ 6,000
3"	PIPING	50	$ 85.19	$ 5,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		1	25%	$ 33,250
Heat Recovery Chiller - Equipment Cost		150	$ 750	$ 113,000
Water Cooled Chiller System - Equipment Cost		570	$ 1,850	$ 1,055,000
High Efficiency RFO Boilers, dual fuel		3	$ 131,750	$ 395,250
Pumps (LTHW, Geothermal)		4	$ 25,000	$ 100,000
MISC ACCESSORIES		1	$ 100,000	$ 100,000
Electrical		1	$ 100,000	$ 100,000
Controls		1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK				$ 2,179,500

Design / Estimating / Contingency	15%	$ 326,925
Construction Contingency	5%	$ 108,975
General Conditions	10%	$ 217,950
Insurance / Bond	3.75%	$ 81,731
Building Permit	1%	$ 21,795
Contractor Fee	10%	$ 217,950
TOTAL		$ 3,155,000

Appendix D6: Geothermal Cost Estimate

1.5" U-Bend Bore Field Cost			
# of Bores	Depth of Bores:	Total Length:	# of Acres:
55	**800**	**44,000**	**0.55**
Direct Costs:			**Total:**
Total Bore Hole Cost:			$ 1,144,000
Total Lateral Piping Cost ($/FT):		$ 5.00	$ 220,000
Manifold Vault Cost:		$ 80,000	$ 80,000
Subtotal Direct Costs:			**$ 1,444,000**
Indirect Costs:			**Total:**
# phases	**1**		
Mob/Demob Charge (1 per phase)			$ 25,000
Removal of cuttings/waste			$ 25,000
Site Restoration/clean up			$ 25,000
Environmental/Water Management			$ 25,000
Design / Estimating / Contingency (15%)			$ 216,600
Construction Contingency (5%)			$ 72,200
General Conditions (10%)			$ 144,400
Insurance / Bond (3.75%)			$ 54,150
Building Permit (1%)			$ 14,440
Contractor Fee (10%)			$ 144,400
Subtotal of Indirect Costs:			**$ 746,190**
Grand Total Cost of Borefield:			**$ 2,190,190**
Total Cost per Bore:			$ 39,822
Total Cost per Foot:			$ 50

Geothermal Heat Exchanger Borehole Cost

Type:	**# of Bores:**	**Depth:**	**Total Length:**	**Ft/ Ton:**	**Tons/ Bore**	**GHX $/FT**	**GHX Construction $**
1.5" U-Bend	55	800	44,000	440	1.8	$ 26.00	$ 1,133,647

* U-bend spaced at 20' and approximately 100 bores/acre.

Appendix D7: Wastewater Heat Recovery (HR)

Wasterwater Heat Reocvery System Estimate				
SIZE	TYPE	QTY	UNIT PRICE	TOTAL PRICE
10"	PIPING	0	$ 457.45	$ -
8"	PIPING	0	$ 394.14	$ -
6"	PIPING	0	$ 319.89	$ -
5"	PIPING	0	$ 274.82	$ -
4"	PIPING	0	$ 220.79	$ -
3"	PIPING	430	$ 195.38	$ 85,000
150 GPM PUMP		2	$ 20,297	$ 41,000
MISC ACCESSORIES (ET, AS, CPF)		1	$ 9,688	$ 10,000
SHARC SYSTEM (MODEL 660)		1	$ 210,785	$ 211,000
STORAGE TANK (6,000 Gal)		1	$ 68,926	$ 69,000
			TOTAL DIRECT COST OF WORK	$ 416,000

Electrical	3%	$ 13,000
Controls	6%	$ 25,000
Civil	10%	$ 42,000
Design / Estimating / Contingency	15%	$ 63,000
Construction Contingency	5%	$ 21,000
General Conditions	10%	$ 42,000
Insurance / Bond	3.75%	$ 16,000
Building Permit	1%	$ 5,000
Contractor Fee	10%	$ 42,000

TOTAL	$ 685,000

Appendix D8: City of Salem Department of Public Works
Historic Water Rates

Water	Water Rates per 100 CF		Sewer	Sewer Rates Per 100 CF
Effective July 1, 2002			**Effective July 1, 2002**	
Residential	$1.85		Residential	$3.53
Non-Residential	$2.52		Non-Residential	$5.34
			Non-Residential over 25,000	$6.85
Effective July 1, 2003	10% increase		**Effective July 1, 2003**	5% increase
Residential	$2.04		Residential	$3.70
Non-Residential	$2.77		Non-Residential	$5.61
			Non-Residentail over 25,000	$7.19
			Effective July 1, 2004	5% increase
			Residential	$3.89
			Non-Residential	$5.89
			Non-Residential over 25,000	$7.55
Effective November 1, 2006	7% increase		**Effective November 1, 2006**	9% increase
Residential	$2.18		Residential	$4.24
Non-Residential	$2.96		Non-Residential	$6.42
			Non-Residential over 25,000	$8.23
			Effective August 1, 2008	9% increase
			Residential	$4.62
			Non-Residential	$7.00
			Non-Residential over 25,000	$8.97
Effective July 1, 2009	**4% increase**		**Effective July 1, 2009**	5% increase
Residential	$2.27		Residential	$4.85
Non-Residential	$3.08		Non-Residential	$7.35
			Non-Residential over 25,000	$9.42
Effective July 1, 2010	**4% increase**		**Effective July 1, 2010**	5% increase
Residential	$2.36		Residential	$5.09
Non-Residential	$3.20		Non-Residential	$7.72
			Non-Residential over 25,000	$9.89
Effective August 1, 2011	**3% increase**		**Effective August 1, 2011**	**2% increase**
Residential	$2.43		Residential	$5.19
Non-Residential	$3.29		Non-Residential	$7.87
			Non-Residential over 25,000	$10.09
Effective August 1, 2012	**9% increase**		**Effective August 1, 2012**	**4% increase**
Residential	$2.65		Residential	$5.40
Non-Residential	$3.59		Non-Residential	$8.19
			Non-Residentail over 25,000	$10.49
Effective August 1, 2013	**5% increase**		**Effective August 1, 2013**	**5% increase**
Residential	$2.78		Residential	$5.67
Non-Residential	$3.77		Non-Residential	$8.60
			Non-Residential over 25,000	$11.02
Effective August 1, 2014	**4% increase**		**Effective August 1, 2014**	**4% increase**
Residential	$2.89		Residential	$5.90
Non-Residential	$3.92		Non-Residential	$8.94
			Non-Residential over 25,000	$11.46
Effective August 1, 2015	**1% increase**		**Effective August 1, 2015**	**1% increase**
Residential	$2.92		Residential	$5.96
Non-Residential	$3.96		Non-Residential	$9.03
			Non-Residential over 25,000	$11.56

Effective August 1, 2016	**2% increase**		**Effective August 1, 2016**	**2% increase**
Residential	$2.98		Residential	$6.08
Non-Residential	$4.04		Non-Residential	$9.21
			Non-Residential over 25,000	$11.79
Effective August 1, 2018	**9-11% increase**		**Effective August 1, 2018**	**9-15% increase**
Residential	$3.31		Residential	$6.71
Non-Residential	$4.48		Non-Residential	$10.61
			Non-Residential over 25,000	$13.01
Effective August 1, 2019	**4.5% increase**		**Effective August 1, 2019**	**3% increase**
Residential	$3.46		Residential	$6.91
Non-Residential	$4.68		Non-Residential	$10.46
			Non-Residential over 25,000	$13.40
Effective August 1, 2020	**4.61% increase**		**Effective August 1, 2020**	**3.20% increase**
Residential	$3.62		Residential	$7.13
Non-Residential	$4.90		Non-Residential	$10.80
			Non-Residential over 25,000	$13.83

Appendix E: LCCA Results - Business As Usual

Salem State University - North Campus - BAU												
Year	Year Count	Electric Utility Cost PC ($)	Gas Utility Cost PC ($)	Investment Cost PC ($)	Maintenance Cost PC ($)	City Water Cost PC ($)	Social Carbon NG PC ($)	Social Carbon Electricity PC ($)	Carbon Tax $/Ton	Total PC ($)	Total FC ($)	Total PV ($)
2021	1	$477,825	$449,082	$0	$1,634,049	$9,900	$0	$0	$ -	$2,570,856	$2,570,856	$2,570,856
2022	2	$477,825	$449,082	$0	$1,672,939	$10,254	$0	$0	$ -	$2,610,100	$2,671,455	$2,496,898
2023	3	$477,825	$449,082	$0	$1,712,755	$10,622	$0	$0	$ -	$2,650,283	$2,776,382	$2,425,410
2024	4	$477,825	$449,082	$0	$1,753,518	$11,002	$0	$0	$ -	$2,691,427	$2,885,834	$2,356,299
2025	5	$599,920	$494,611	$473,549	$1,795,252	$11,396	$128,722	$42,192	$ 51.00	$3,545,641	$3,890,769	$2,969,255
2026	6	$599,920	$494,611	$431,095	$1,837,979	$11,804	$131,785	$41,468	$ 52.21	$3,548,661	$3,985,605	$2,842,885
2027	7	$599,920	$494,611	$431,095	$1,881,723	$12,226	$134,922	$40,686	$ 53.46	$3,595,182	$4,132,868	$2,755,304
2028	8	$599,920	$494,611	$431,095	$1,926,508	$12,664	$138,133	$39,844	$ 54.73	$3,642,773	$4,286,161	$2,670,789
2029	9	$610,395	$494,611	$1,274,504	$1,972,359	$13,117	$141,420	$39,618	$ 56.03	$4,546,024	$5,477,163	$3,189,919
2030	10	$610,395	$494,611	$42,454	$2,019,301	$13,587	$144,786	$38,629	$ 57.36	$3,363,763	$4,144,821	$2,256,227
2031	11	$610,395	$494,611	$0	$2,067,361	$14,073	$148,232	$37,571	$ 58.73	$3,372,243	$4,252,901	$2,163,791
2032	12	$610,395	$494,611	$762,571	$2,116,564	$14,577	$151,760	$36,441	$ 60.13	$4,186,918	$5,408,460	$2,571,916
2033	13	$610,395	$494,611	$589,484	$2,166,938	$15,099	$155,372	$35,235	$ 61.56	$4,067,134	$5,376,971	$2,389,867
2034	14	$610,395	$494,611	$0	$2,218,511	$15,639	$159,070	$33,952	$ 63.02	$3,532,178	$4,776,990	$1,984,465
2035	15	$622,052	$494,611	$571,197	$2,271,312	$16,199	$162,856	$36,665	$ 64.52	$4,174,891	$5,782,306	$2,245,139
2036	16	$622,052	$494,611	$450,256	$2,325,369	$16,779	$166,732	$35,035	$ 66.06	$4,110,833	$5,827,312	$2,114,771
2037	17	$622,052	$494,611	$901,751	$2,380,713	$17,380	$170,700	$33,306	$ 67.63	$4,620,512	$6,707,575	$2,275,169
2038	18	$622,052	$494,611	$52,110	$2,437,374	$18,002	$174,762	$31,476	$ 69.24	$3,830,387	$5,686,516	$1,802,799
2039	19	$622,052	$494,611	$0	$2,495,383	$18,647	$178,922	$29,540	$ 70.89	$3,839,154	$5,833,774	$1,728,637
2040	20	$622,052	$494,611	$42,454	$2,554,773	$19,314	$183,180	$27,494	$ 72.58	$3,943,878	$6,134,965	$1,699,101
2041	21	$622,052	$494,611	$1,083,763	$2,615,577	$20,006	$187,540	$25,333	$ 74.30	$5,048,881	$8,049,485	$2,083,667
2042	22	$622,052	$494,611	$0	$2,677,828	$20,722	$192,003	$23,054	$ 76.07	$4,030,270	$6,569,074	$1,589,342
2043	23	$622,052	$494,611	$1,083,763	$2,741,560	$21,464	$196,573	$20,653	$ 77.88	$5,180,674	$8,655,516	$1,957,308
2044	24	$622,052	$494,611	$0	$2,806,809	$22,232	$201,251	$18,124	$ 79.74	$4,165,079	$7,114,097	$1,503,623
2045	25	$622,052	$494,611	$42,454	$2,873,611	$23,028	$206,041	$15,462	$ 81.63	$4,277,259	$7,479,290	$1,477,517
2046	26	$622,052	$494,611	$0	$2,942,003	$23,852	$210,945	$12,664	$ 83.58	$4,306,127	$7,707,736	$1,423,154
2047	27	$622,052	$494,611	$0	$3,012,023	$24,706	$215,965	$9,724	$ 85.57	$4,379,081	$8,024,181	$1,384,774
2048	28	$622,052	$494,611	$0	$3,083,709	$25,591	$221,105	$6,637	$ 87.60	$4,453,705	$8,354,505	$1,347,572
2049	29	$622,052	$494,611	$0	$3,157,101	$26,507	$226,368	$3,398	$ 89.69	$4,530,036	$8,699,341	$1,311,507
2050	30	$622,052	$494,611	$0	$3,232,240	$27,456	$231,755	$0	$ 91.82	$4,608,114	$9,059,348	$1,276,539

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix E: LCCA Results - Centralized System

Salem State University - North Campus - Centralized Option												
Year	Year Count	Electric Utility Cost PC ($)	Gas Utility Cost PC ($)	Investment Cost PC ($)	Maintenance Cost PC ($)	City Water Cost PC ($)	Carbon Tax PC NG ($)	Carbon Tax PC Elec ($)	Carbon Tax $/Ton	Total PC ($)	Total FC ($)	Total PV ($)
2021	1	$477,825	$449,082	$0	$1,634,049	$9,900	$0	$0	$ -	$2,570,856	$2,570,856	$2,570,856
2022	2	$477,825	$449,082	$0	$1,672,939	$10,254	$0	$0	$ -	$2,610,100	$2,671,455	$2,496,898
2023	3	$477,825	$449,082	$0	$1,712,755	$10,622	$0	$0	$ -	$2,650,283	$2,776,382	$2,425,410
2024	4	$477,825	$449,082	$0	$1,753,518	$11,002	$0	$0	$ -	$2,691,427	$2,885,834	$2,356,299
2025	5	$718,453	$449,206	$75,000	$1,816,752	$11,396	$116,885	$55,775	$ 51.00	$3,243,468	$3,556,375	$2,714,061
2026	6	$718,453	$449,206	$0	$1,859,479	$11,804	$119,667	$54,819	$ 52.21	$3,213,428	$3,605,445	$2,571,722
2027	7	$718,453	$449,206	$0	$1,903,223	$12,226	$122,515	$53,785	$ 53.46	$3,259,409	$3,742,410	$2,494,994
2028	8	$718,453	$449,206	$0	$1,948,008	$12,664	$125,431	$52,671	$ 54.73	$3,306,434	$3,885,101	$2,420,881
2029	9	$679,574	$293,147	$8,955,251	$2,025,009	$13,117	$83,803	$48,688	$ 56.03	$12,098,590	$14,589,400	$8,496,919
2030	10	$679,574	$293,147	$75,000	$2,059,426	$13,587	$85,798	$47,473	$ 57.36	$3,254,005	$4,001,524	$2,178,224
2031	11	$679,574	$293,147	$0	$2,107,486	$14,073	$87,840	$46,173	$ 58.73	$3,228,293	$4,062,048	$2,066,689
2032	12	$679,574	$293,147	$0	$2,156,689	$14,577	$89,930	$44,784	$ 60.13	$3,278,701	$4,221,834	$2,007,633
2033	13	$716,710	$242,214	$1,216,131	$2,221,763	$15,099	$76,074	$45,668	$ 61.56	$4,533,659	$5,981,101	$2,658,381
2034	14	$716,710	$242,214	$0	$2,267,786	$15,639	$77,884	$44,005	$ 63.02	$3,364,239	$4,532,460	$1,882,882
2035	15	$862,483	$122,092	$5,975,795	$2,322,387	$16,199	$40,193	$50,827	$ 64.52	$9,389,977	$13,002,207	$5,048,463
2036	16	$862,483	$122,092	$0	$2,481,444	$16,779	$41,150	$48,568	$ 66.06	$3,572,516	$5,025,028	$1,823,617
2037	17	$851,008	$120,706	$1,355,906	$2,211,137	$17,380	$41,651	$45,558	$ 67.63	$4,643,345	$6,702,679	$2,273,508
2038	18	$851,008	$120,706	$0	$1,905,999	$18,002	$42,642	$43,054	$ 69.24	$2,981,411	$4,377,881	$1,387,922
2039	19	$851,008	$120,706	$2,769,369	$1,602,528	$18,647	$43,657	$40,406	$ 70.89	$5,446,320	$8,244,701	$2,443,031
2040	20	$863,678	$92,194	$0	$1,288,087	$19,314	$0	$38,166	$ 72.58	$2,301,439	$3,513,535	$973,087
2041	21	$863,678	$92,194	$0	$1,078,331	$0	$0	$35,167	$ 74.30	$2,069,370	$3,221,051	$833,792
2042	22	$863,678	$92,194	$0	$1,098,006	$0	$0	$32,004	$ 76.07	$2,085,882	$3,320,319	$803,328
2043	23	$863,678	$92,194	$0	$1,118,150	$0	$0	$28,670	$ 77.88	$2,102,692	$3,423,009	$774,059
2044	24	$863,678	$92,194	$0	$1,138,773	$0	$0	$25,159	$ 79.74	$2,119,804	$3,529,248	$745,936
2045	25	$863,678	$92,194	$0	$1,159,887	$0	$0	$21,465	$ 81.63	$2,137,223	$3,639,168	$718,910
2046	26	$863,678	$92,194	$0	$1,181,503	$0	$0	$17,581	$ 83.58	$2,154,955	$3,752,908	$692,936
2047	27	$863,678	$92,194	$0	$1,203,634	$0	$0	$13,499	$ 85.57	$2,173,005	$3,870,608	$667,971
2048	28	$863,678	$92,194	$0	$1,226,291	$0	$0	$9,214	$ 87.60	$2,191,377	$3,992,419	$643,973
2049	29	$863,678	$92,194	$0	$1,249,488	$0	$0	$4,716	$ 89.69	$2,210,076	$4,118,493	$620,901
2050	30	$863,678	$92,194	$0	$1,273,237	$0	$0	$0	$ 91.82	$2,229,109	$4,248,991	$598,719

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix F: Sensitivity Analysis Results

Sensitivity Analysis Results											
#	Scenario Description	Price Changes				BAU		Centralized Option		30 Year Savings (Present Value)
		Elec Change	NG Price Change	Carbon Price Change	Cap Invest Price Change	30 Year NPV	% Difference from Original	30 Year NPV	% Difference from Original	
0	**Original**	0%	0%	0%	0%	$62,864,502	-	$60,392,000	-	$2,472,502
1	**+ Electricity**	20%	0%	0%	0%	$64,765,570	3.0%	$62,704,694	3.8%	$2,060,875
2	**- Electricity**	-20%	0%	0%	0%	$60,963,434	-3.0%	$58,079,306	-3.8%	$2,884,128
3	**+20% Natural Gas**	0%	20%	0%	0%	$64,554,991	2.7%	$61,367,504	1.6%	$3,187,487
4	**-20% Natural Gas**	0%	-20%	0%	0%	$61,174,013	-2.7%	$59,416,497	-1.6%	$1,757,517
5	**+ Capital Investment**	0%	0%	0%	20%	$63,872,260	1.6%	$62,847,772	4.1%	$1,024,488
6	**- Capital Investment**	0%	0%	0%	-20%	$61,856,744	-1.6%	$57,936,228	-4.1%	$3,920,515
7	**+ Carbon**	0%	0%	250%	0%	$69,394,187	10.4%	$63,758,633	5.6%	$5,635,554
8	**- Carbon**	0%	0%	-100%	0%	$60,252,628	-4.2%	$59,045,347	-2.2%	$1,207,281
9	**+ Elec & - Natural Gas**	20%	-20%	0%	0%	$63,075,081	0.3%	$61,729,191	2.2%	$1,345,890
10	**+ Elec & - Nat Gas & +Capital Investment**	20%	-20%	0%	20%	$64,082,840	1.9%	$64,184,963	6.3%	-$102,123
11	**+Elec & - Nat Gas & - Carbon & +Capital Investment**	20%	-20%	-100%	20%	$61,470,966	-2.2%	$62,838,310	4.1%	-$1,367,344
12	**-Elec & + Natural Gas**	-20%	20%	0%	0%	$62,653,923	-0.3%	$59,054,810	-2.2%	$3,599,113
13	**+ Elec & + Natural Gas**	20%	20%	0%	0%	$66,456,059	5.7%	$63,680,198	5.4%	$2,775,861
14	**-Elec & - Natural Gas**	-20%	-20%	0%	0%	$59,272,946	-5.7%	$57,103,803	-5.4%	$2,169,143
15	**+Elec & + Natural Gas & -Carbon**	-20%	20%	-100%	0%	$60,042,049	-4.5%	$57,708,157	-4.4%	$2,333,892
16	**-Elec & + Natural Gas & + Carbon & - Capital Investment**	-20%	20%	250%	-20%	$68,175,849	8.4%	$59,965,671	-0.7%	$8,210,179
17	**-Elec & + Natural Gas & + Carbon**	-20%	20%	250%	0%	$69,183,608	10.1%	$62,421,443	3.4%	$6,762,165