DISTRICT ENERGY MASTER PLAN

March 2020
Summary Report

Smith College

MEP

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Executive Summary

The purpose of this conceptual design phase study was to identify and evaluate multiple options wherein net carbon neutrality would be achieved by 2030. MEP Associates, LLC (MEP) worked with Smith College to develop and recommend an option which includes an implementation plan and a life cycle cost analysis.

A business-as-usual (BAU) case was developed to show both the cost and carbon of the existing campus and thermal energy systems if no major changes are made.

The analysis was guided by principles developed by the Smith College Study Group on Climate Change, along with two additional principles: (1) a transition from steam to low-temperature-hot-water (LTHW) as the thermal district heating network and (2) the electrification of the thermal load profile. These principles are based on the availability of multiple carbon-neutral technologies capable of creating LTHW and electricity. In contrast, the existing steam system is dependent on fossil fuels, a carbon-intense energy source.

The recommended option includes a transition from the existing district steam system to a district LTHW system and an expansion of the current district chilled-water (CHW) system. A geothermal (ground source) heat pump system is proposed to provide the LTHW and CHW while also capturing and recovering some waste-heat on campus. A closed-loop vertical geothermal heat exchanger (GHX) system is proposed to be installed in the athletic fields as the heat source/sink for the heat-pump system, and the existing chiller plant is proposed to be expanded to house the new heat-pump chillers. Traditional boilers and chillers are proposed to be used to provide the peak heating and cooling loads and to balance the annual load on the geothermal field. A sewage heat recovery system and a CHW thermal storage (TES) system is also proposed to be utilized to balance the overall system and offset the size of the GHX field.

This study confirmed that the recommended option could provide a substantial reduction in energy use and carbon emissions and result in significant savings to the College. The analysis showed a "break-even" point in return on investment at year 20 in a 30-year life cycle cost analysis.

The recommended option includes a phased approach to implementation. A phased approach allows for information gathered in the early phases to inform the subsequent phases so that the final system can be "right-sized" for the actual thermal load and system performance, as well as the potential integration of new equipment and technology as advancements are made.

List of Abbreviations

BAU	Business as Usual
CHP	Combined Heat and Power
CHW	Chilled Water
GHG	Greenhouse Gas
GHX	Geothermal Heat Exchanger
GSF	Gross Square Foot
HTHW	High Temperature Hot Water (160-180° F)
kBTU	Thousand British Thermal Units
MWh	Mega Watt Hour
LTHW	Low Temperature Hot Water (120 – 150° F)
REC	Renewable Energy Credit
SGCC	Study Group on Climate Change
SCC	Social Cost of Carbon
TES	Thermal Energy Storage

Introduction

Introduction

This Energy Master Plan Conceptual Design Report was compiled by MEP Associates, LLC with the support of Fovea, LLC and Vanasse Hangen Brustlin (VHB) as an extension of the *Smith College Campus Energy Decarbonization Study* by Integral Group. This report discusses strategies that will inform the College how to meet future utility needs while also meeting its 2030 Carbon Neutrality Goal. The results presented in this report synthesize the results of various investigations, interviews, site visits, and analyses conducted to determine the best course of action.

Acknowledgements

MEP Associates, LLC would like to extend its thanks to Gary Hartwell, Dano Weisbord, Jim Gray, Denise McKahn, Michelle Smith, Chuck Dougherty, Ben Paquette, and their teams from Smith College who assisted in the gathering of information and provided insight into campus operations and systems necessary to complete this study.

Goals

The goal of this conceptual design report is to develop and present a recommended option that would enable the College to achieve net carbon neutrality for thermal heating and cooling by 2030. Options were analyzed and compared to various business-as-usual (BAU) cases to inform decisions made by the College.

Criteria

The recommended option meets the following criteria as defined in the *Energy Decarbonization Study.* It is:

- Cost effective from a long-term, life cycle cost perspective.
- Technically sound and reliable for a long-term low-carbon energy supply.
- Resilient toward multiple external risks, such as those related to climate change, availability, and affordability of low-carbon fuels and energy sources, and variable economic conditions.
- Provides opportunities to engage students and researchers on campus in energy use and energy efficiency research.

Guiding Principles and Sustainability Goals

The guiding principles for this study were developed by the Smith College Study Group on Climate Change (SGCC).

1 – Academic: Create new academic offerings and further infuse climate change and sustainable development concepts across the curriculum, while enhancing experiential and applied learning opportunities for students.

2 – Campus Programming: Expand opportunities for students to learn about climate-action initiatives outside of the classroom and to live more sustainably on campus.

3 – Campus Operations: Aggressively pursue the college's commitment to net-zero greenhouse gas emissions by 2030, including a roughly 40 percent reduction in emissions over the next five years [2023] and continued research and scholarship focused on the optimal path to net zero.

4 – Investments: Address climate change in the context of Smith's endowment investments.

5 – Institutional Change: Develop sustainability and climate-change initiatives that model ideal institutional behavior.

The Energy Master Plan is specifically focused on the goals listed under "Campus Operations" and follows the recommendation of the SGCC for a multi-phased scenario that includes energy efficiency, renewable energy, conversion to a LTHW system, and a ground-sourced heat pump system with geothermal heat exchangers (GHX) to provide the majority of the thermal energy necessary to heat and cool the campus.

Existing Systems

Steam Plant

Smith College heats 79 of the 104 buildings on campus (approximately 2.6 of the 2.8 million GSF) from a central steam plant. The steam plant, located on the south end of the campus, houses three dual-fuel (oil and natural gas) boilers in addition to a single natural-gas-fired cogeneration system. Steam is distributed to the buildings via an underground distribution piping system that is both directly buried and located in tunnels. Steam condensate is returned to the central steam plant via the same system with dedicated condensate pipes.

The oldest boilers in the plant are numbers four and five. Each of these boilers produce approximately 43,000 lbs/hr of steam. The newest and largest boiler, number three, was installed in 2007 and produces approximately 57,000 lbs of steam/hr. Smith College currently stores approximately 90,000 gallons of oil on site in three 30,000-gallon concrete oil bunkers. The power plant also houses a 3.5 MW gas turbine, connected to a heat recovery steam generator (HRSG). The 19,500 lbs/hr capacity HRSG is utilized as much as possible during the heating season. The gas turbine requires a natural gas compression system to increase pressure, as well as the addition of 19% aqueous ammonia to reduce NOx emissions (approximately 20,500 gallons of ammonia per year). The high-pressure steam created from the boilers and HSRG is then distributed to the campus through a network of distribution piping.

Chilled-Water Plant

Smith College cools 28 buildings (approximately 1.4 million GSF) from a central CHW plant. The CHW plant has a capacity of 4,363 tons of cooling. CHW is distributed through a network of direct-buried CHW piping throughout central campus. The existing chillers in the plant use evaporative and/or absorptive technologies that require large amounts of make-up water in order to generate CHW. Neither technology is as efficient or effective as newer chiller technologies.

The chiller plant is also located on the south end of campus and houses six chillers. The oldest chiller (CH-5) is a 1,000-ton *York* electric centrifugal chiller that was installed during the 1990 Chiller Plant Expansion project. This project also added four 3,000 gallons per minute (GPM) cooling towers which are located on the roof of the chiller plant. In 1999, three new 700-ton *Trane* electric centrifugal chillers (CH-1, 2, & 3) were added, replacing the two original 1965, 750-ton chillers. In 2010, two new *York* steam-absorption chillers (CH-4 & 6) were added to replace one of the two 1000-ton units from the 1989 expansion project. One of the *York* chillers has 800 tons of cooling capacity (CH-4) and the other has 210 tons (CH-6). The steam system was expanded during this project, and a free-cooling flat-plate heat exchanger was added. The chiller plant also currently houses 12 base-mounted pumps, a steam pressure reducing (PRV) station, a piping system for the absorption chillers, and all the electrical equipment required for the chillers and cooling towers.

Stand-Alone Systems

Currently, 33 buildings (approximately 400,000 GSF) are cooled via stand-alone systems, including localized air-cooled chillers, direct expansion (DX) units, and residential window air conditioners. 19

buildings (approximately 75,000 GSF) are heated via stand-alone systems, including electric heat, gas-fired boilers, and/or gas-fired rooftop units.

Some buildings served by the campus high-pressure steam-distribution system require heat and domestic hot water year-round. When the central steam plant ramps down production in the summer, these buildings use natural gas or electric boilers, and domestic water heaters to meet the heating demand.

Campus Buildings

Smith College has a broad range of historic and modern building types. The scope of the District Energy Master Plan includes an analysis of 104 buildings on campus (approximately 2.8 million GSF), as shown in Figure 1.

Due to the building types and eras of construction represented, there are a wide variety of heating systems used within the buildings across campus. The three main types are:

1) **Steam-to-HTHW Heat Exchange**. The majority of buildings on campus have steam-to-High-Temperature-Hot-Water heat exchangers, also known as steam converters, with a HTHW distribution system throughout the building. This is typical of larger buildings that were built or renovated after approximately 1960. These heating systems typically consist of steam preheat air-handling coils and steam-to-hot-water shell and tube heat exchangers for both domestic hot water and HTHW. The systems have dedicated pumps to distribute HTHW to terminal heating units throughout the building. The buildings with HTHW systems typically circulate water at temperatures between 160° and 180° F.

2) **All Steam Heating**. Several of the older buildings on campus have steam piping that deliver steam directly to the heating equipment, e.g. domestic water heaters, radiators, and coils. Steam condensate piping returns the condensate to the central heat plant.

3) **Stand-Alone Heating**. Heating in many of the smaller residential buildings is accomplished within the buildings by boilers or air handling units which are fired by natural gas, oil, or direct electricity.

Cooling. Twenty-eight buildings (approximately 1.4 million GSF) on campus are cooled by the district CHW system and 22 buildings (approximately 400,000 GSF) have stand-alone cooling systems. The remaining buildings (approximately 1 million GSF) are not cooled. The stand-alone systems include local chillers, mini-split systems, DX units, and window air-conditioning units. Every year, the maintenance staff installs and uninstalls up to 300 window air-conditioning units across campus.

Figure 1: Example building-based annual load profile for heating and cooling demands for Sabin Reed Hall.

Campus Electrical System

Smith College currently consumes approximately 22,000 megawatt-hours (MWh) per year. Approximately 8,000 MWh of that energy is purchased from the electric utility, National Grid, by means of two primary 13.8 kV feeder lines. These lines are routed to the main 13.8 kV switchgear, which has a main-tie-main arrangement to allow for redundancy via connection to either of the electric utility lines. The switchgear is owned and maintained by Smith College. Based on information provided by Smith College, each feeder from the electric utility is able to provide the necessary power for present and future loads of the campus, up to approximately 8 MW of power. The switchgear connects to several campus 13.8 kV feeder lines which reduce the voltage through transformers across campus to 2400V. This 2400V network could supply the additional projected required electricity needs.

Master Plan Cases

In order to evaluate performance metrics across varying cases, several options were analyzed. Ultimately, the final recommended option was compared to the projected BAU reference case.

- *Reference Case:* Represents the current BAU. This case assumes Smith College will meet carbon neutrality in 2030, including the purchase of carbon offsets.
- *Recommended Option:* Represents a recommended solution to achieve carbon neutrality. It includes a complete transition from steam to low-temperature-hot-water (LTHW) and low-carbon solutions to provide LTHW and CHW to the campus via ground-source heat pumps, thermal energy storage (TES), and sewage-heat-recovery.

Reference Case - Business as Usual (BAU or Ref Case)

Since 2005, Smith College has decreased reliance on purchased electricity through the increase of on-site electricity production via the installation of an efficient combined-heat-and-power (CHP) system. This shift, coupled with investment in building energy conservation, has enabled Smith College to continue to reduce Scope 1 and Scope 2 GHG emissions by 13% since 2005 despite an increase in GSF due to Ford Hall. Figure 2 illustrates the shift in the source of emissions and the resulting reductions during that period.

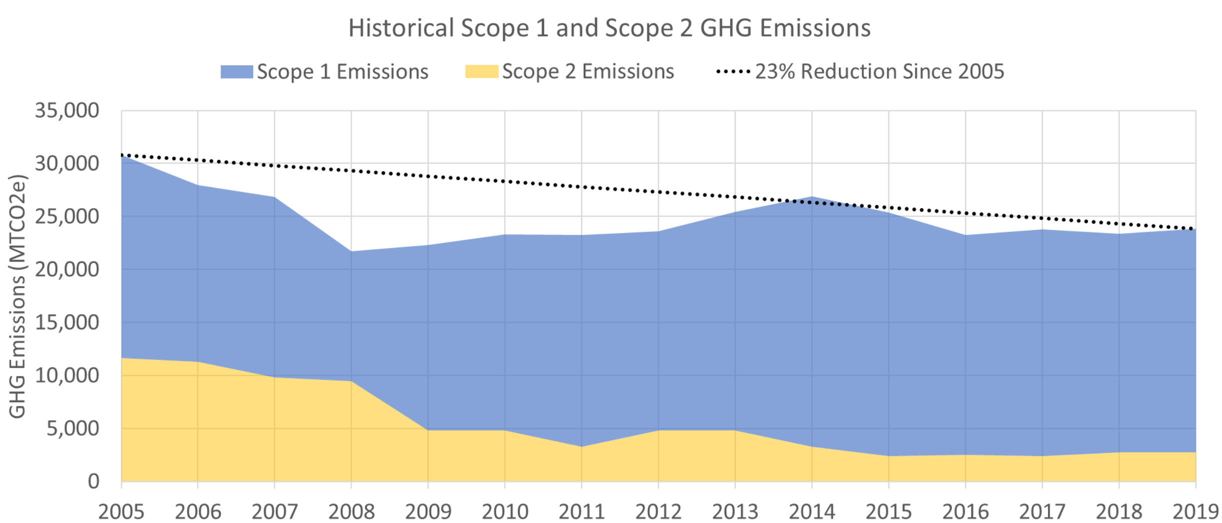

Figure 2: Scope 1 and Scope 2 GHG Emissions starting in 2005 at approximately 30,000 metric tons of carbon dioxide equivalent steadily decreasing to approximately 24,000 metric tons in 2019.

To forecast BAU Scope 1 and Scope 2 GHG emissions through 2050, as the SCAMP report does, this study assumes a "do-nothing" scenario where Smith will not construct any new buildings or achieve any additional energy conservation measures in their buildings." Specifically, the following assumptions have been made:

1) *Campus Growth* – It is assumed that Smith College will have a no-net-growth policy resulting in no-net increase of square footage on campus.
2) *Energy Use Intensity* – It is assumed that the energy use intensity of the buildings on campus will remain the same through 2050. Potential reductions from Energy Conservation Measures (ECMs) have not been included in the BAU.
3) *GHG Intensity of the Grid* – It is assumed that a 2% annual reduction in grid GHG intensity will take place from 2020 through 2050, which differs from the SCAMP study. This results in the assumed grid GHG intensity dropping from current levels of 292 kg CO_2e to 156 kg CO_2e by 2050 (see Figure 3 below). This forecast is in-line with general industry expectations.

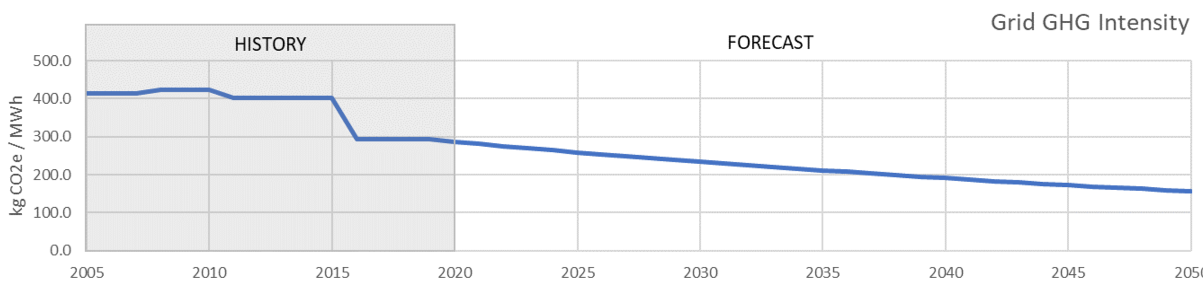

Figure 3: Historic and projected carbon emissions intensity of the electric grid serving Smith College starting in 2005 at approximately 400 kg of carbon dioxide equivalent per megawatt hour in 2005 and decreasing to approximately 175 kg by 2050

4) *GHG Goal* – It is assumed that the GHG goal is to be carbon neutral by 2030. No other interim milestones are included prior to 2030 (see GHG Reduction Target in Figure 4 below). In the Reference Case it is assumed that Smith College will purchase carbon offsets to meet the stated GHG Goal of carbon neutrality post 2030. No offsets purchases are included in the BAU prior to 2030.

This set of assumptions results in a decrease in the forecasted levels of Scope 1 and Scope 2 emissions from current levels of 23,328 metric tons of carbon dioxide equivalent (MT CO_2e) to 22,284 MT CO_2e by 2050 in the BAU case (see Figure 4). For reference purposes, the 2005 Baseline case described above may also be seen below in Figure 4.

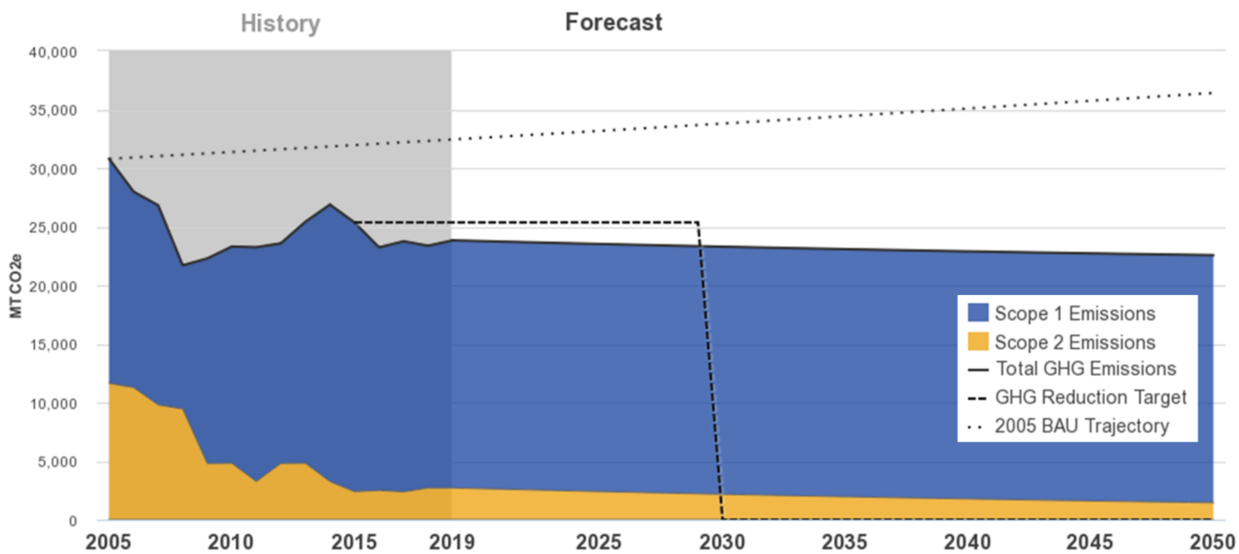

Figure 4: Depiction of business as usual carbon emissions from measured historic totals in 2005 through 2019 and projected through 2050 for scopes 1 and 2.

Recommended Option – Conversion to LTHW with GHX

In order to reduce the overall carbon emissions produced by the College, the systems used for heating and cooling must be electrified.

In lieu of steam for heating (and absorption-cooling), the campus will transition to a centralized, low-temperature-hot-water (LTHW) system. While the final temperature remains to be determined, LTHW will likely be distributed to the campus buildings at a temperature of 130°F. Significant modifications to some of the existing heating systems will need to be made for the required space conditioning to occur using this new, lower temperature. The chilled-water (CHW) network will also be expanded to provide air conditioning to more of the buildings on campus.

Ground-source heat pump technology will be used to produce the majority of the LTHW and CHW on campus (Figure 5). A ground-source heat pump is a device that utilizes the refrigeration cycle to transfer heat from a heat "source" to a heat "sink", alternately using the buildings and the ground for either purpose depending on the season. During the summer, the heat pump will transfer heat from the buildings (the source) to the ground (the sink), while in the winter the heat pump will transfer the heat from the ground (the source) to the buildings (the sink). In the spring or fall, when the campus has both heating *and* cooling requirements, the heat pump will then be able to transfer heat from the spaces that require cooling to the spaces that require heating. This is referred to as "simultaneous heating and cooling" (Figure 6).

An array of geothermal heat exchangers (GHXs) will be coupled with the heat pump to be used as an energy sink and source. A GHX is a vertical closed-loop heat-exchanger that is installed to depths typically between 300' and 1500' that is used to transfer heat between the fluid in the system to the surrounding earth. In the summer (cooling season), the heat pumps will produce chilled water for the campus, and the heat rejected off of the heat pumps will be transferred into the ground via the GHX. Over the course of the cooling season, the earth will act as a storage medium and slowly increase in temperature. Throughout the heating season, the GHX will extract heat from the ground to be used by the heat pumps to supply heated water to the campus (Figure 7).

The ground-source heat pump system will *not* provide 100% of the LTHW and CHW on campus. Some supplemental heating and cooling will be provided by the conventional systems during peak demand, which is called "hybrid heating and cooling".

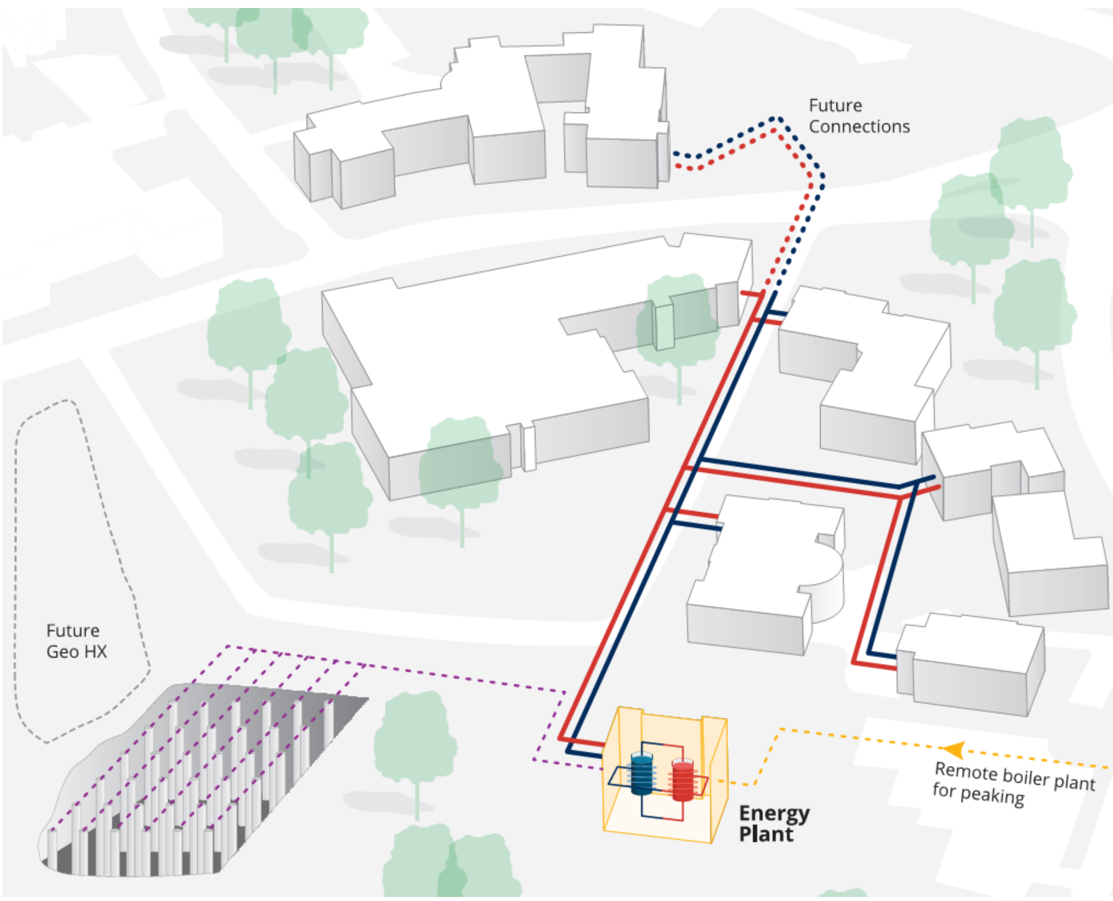

Figure 5: Artist conceptual depiction of a campus scale geothermal system with a ground source heat exchanger connected to a central energy plant with thermal distribution providing heating and cooling to campus buildings.

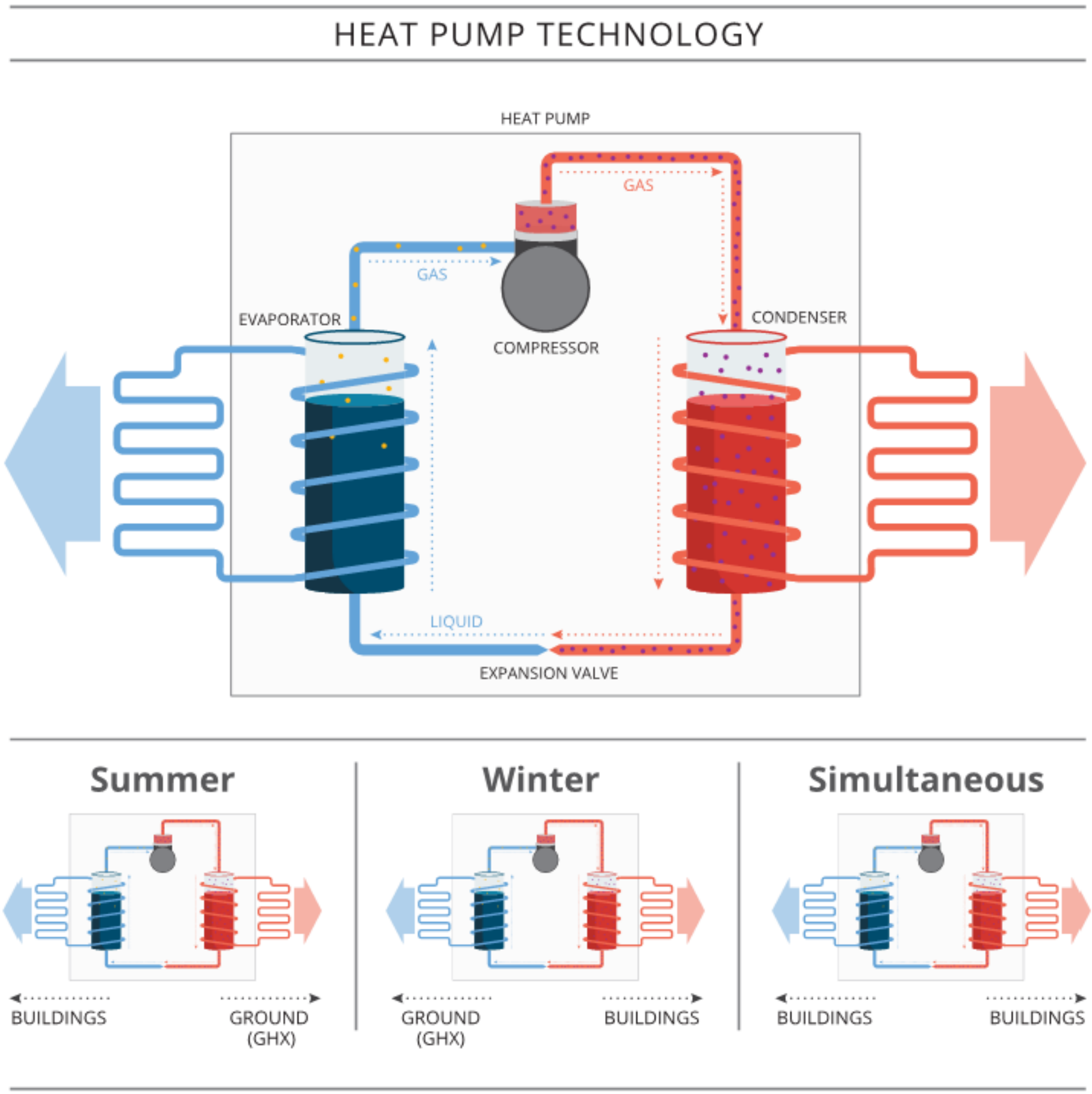

Figure 6: Artist conceptual depiction of the refrigeration cycle used by heat pump technology and heat pump functionality in summer, winter, and simultaneous heating and cooling conditions.

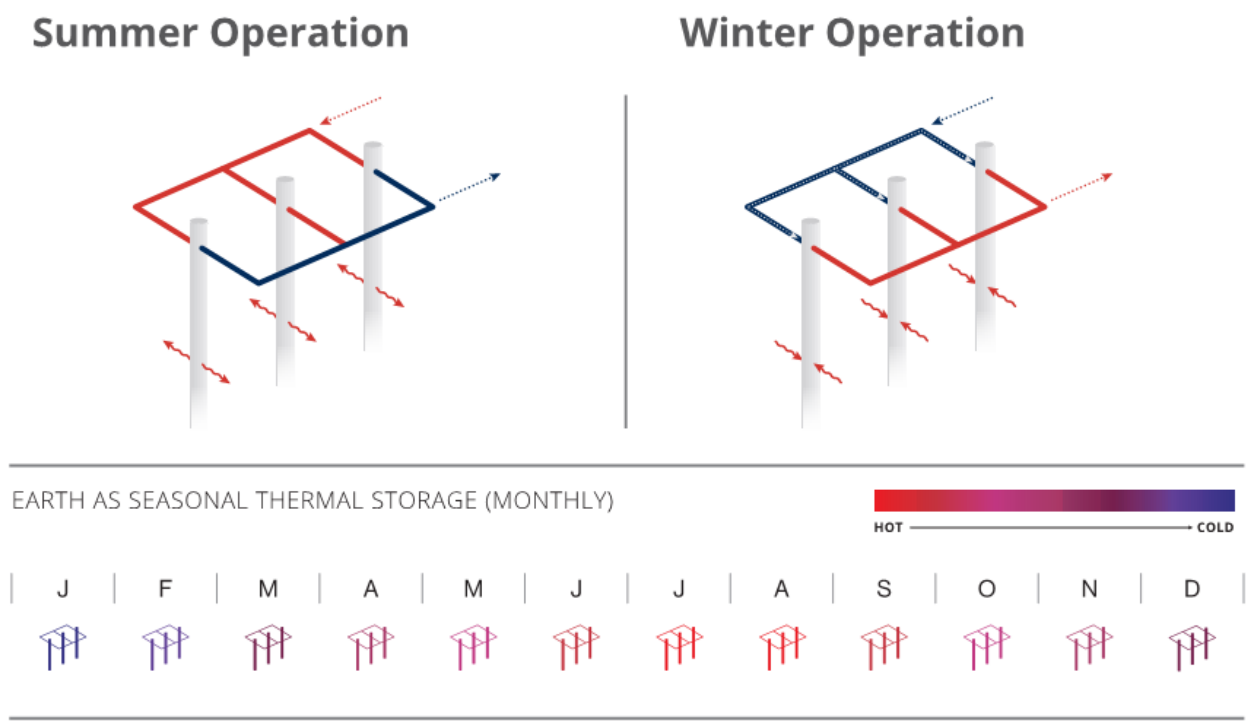

Figure 7: Artist depiction of annual operation of a ground source heat exchanger cooling down in winter months as heat is extracted from the ground and warming up during the summer as heat is rejected from buildings to the ground.

Phased Approach

A phased approach to the implementation plan is desirable for multiple reasons. First, the project requires significant capital investment and construction activity on campus. A phased approach allows the financial investment and construction period to be spread across a longer timeline. A second benefit is the ability to gather data from early phases, in order to "right-size" the later phases. The existing building-by-building meter data is limited. As such, the thermal load profile for the campus was developed based on available campus-wide data, interviews with facility personnel, and reasonable assumptions. A phased approach to implementation will allow meter readings and other data from the first phases to inform the design of subsequent phases so the final system is the appropriately sized to accommodate actual energy use. The first phase includes built-in redundancy and modulation to allow for fluctuations in the actual system performance as compared to the system model.

Distribution Piping

Three new types of distribution piping will be required: LTHW, CHW, and geothermal. The LTHW piping will replace the steam/condensate piping that is currently in place. The existing CHW piping will continue to be used and new CHW piping will be installed to provide additional CHW to buildings as they are connected to the district system. Geothermal distribution piping will be installed to connect the energy plant and the GHX. All new distribution piping will be direct buried in an open-cut trench. The one exception to this method of installation will be the geothermal piping where it crosses Mill River; this methodology will be determined in the Schematic Design phase. All new piping will be HDPE construction and its wall thickness will be determined based on local system pressure and temperature. Branch valves and flanges will be added to enable future connections, as buildings will be added in a phased approach.

The campus has an existing high-pressure steam piping tunnel system, including pumped condensate piping, and communications utilities. Adding new LTHW and CHW piping in the existing tunnel system is therefore not possible due to space restrictions. Once the majority of the campus has been converted to LTHW, the existing steam and condensate piping will be decommissioned (abandoned in-place or removed).

Energy Plant

The chiller plant will be converted into the new “Energy Plant.” The new Energy Plant will produce LTHW and CHW for the campus. The existing chillers will be converted to a ground-source heat pump system. Natural gas-fired boilers, cooling-only chillers and cooling towers are recommended to meet peak demands in summer and winter and to ensure a balanced annual load on the geothermal system.

The footprint of the chiller plant is not large enough for the new equipment, so a 4,500 square foot addition is required to accommodate the new equipment and piping.

Campus Load Profile

The current campus thermal energy load profile is heating dominant, meaning that the campus uses more energy for heating than cooling over the course of a year. The future load profile will be less heating dominant than the current load profile after the transition from a steam system to a LTHW system, including connecting more buildings to chilled water. The projected thermal load profile assumes a 50% reduction in the heat load due to the conversion from steam to LTHW (30% in the steam distribution system and 20% in the buildings). Figure 8 shows the annual profiles for the cooling load (shown in blue) and the heating load (shown in red). The purple band in the middle represents the simultaneous heating and cooling load. The simultaneous load demand is important to the right-sizing of the system because the heat pumps are able to produce both LTHW and CHW most efficiently during these periods.

Ground-source heat pump systems perform most efficiently with a balanced yearly load profile, that is, heat is stored in the ground during the summer and is equivalent to the heat removed from the ground in the winter. The following three measures could help balance the system: (1) Hybrid Heating: a reduction of the peak and annual heat load by means of peaking/balancing boilers; (2) Hybrid Cooling: a reduction of the peak cooling load through the use of cooling towers; and 3) an increase in the annual cooling load through the addition of buildings (square footage of cooling demand).

Multiple options were analyzed to compare the benefits of a balanced geothermal system with the inclusion of additional cooling to the thermal profile. The recommended option includes the addition of district cooling to approximately one-third of the GSF on campus.

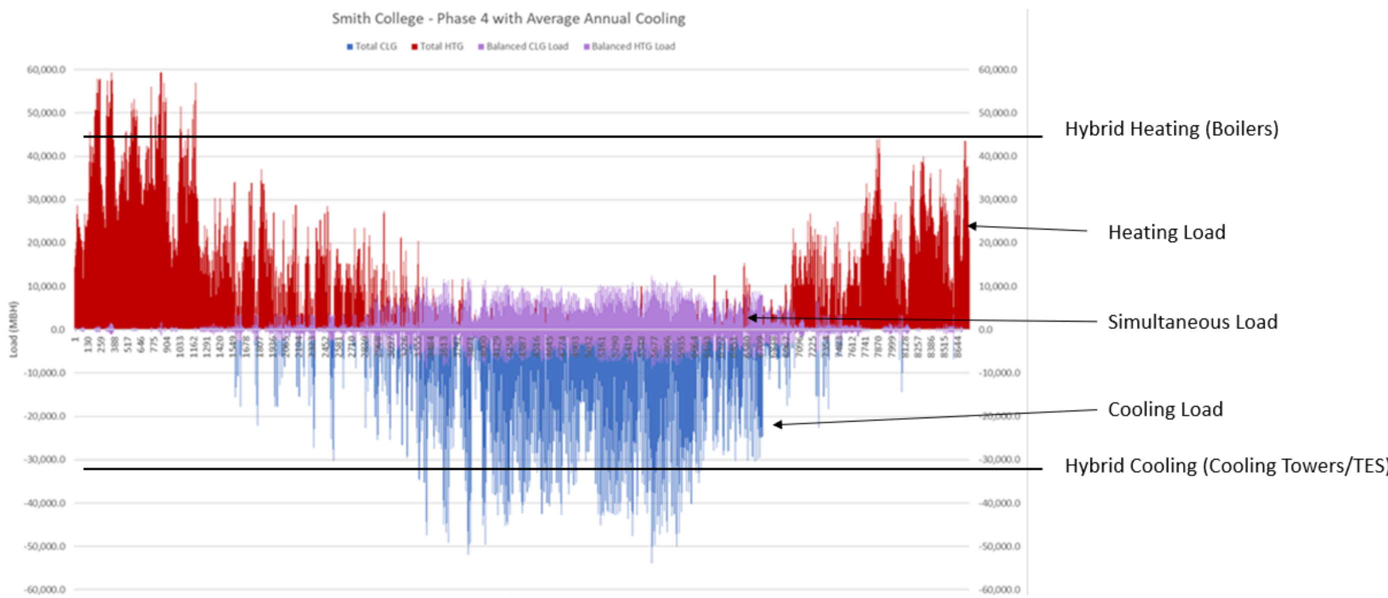

Figure 8: Figure 8 annual, hourly graph of the thermal load profile of the campus showing heating load, cooling load, and the presence of simultaneous load conditions, where both heating and cooling are needed at the same time.

Approximately one-third of the campus is currently air-conditioned by means of the campus CHW system. The ground-sourced heat pump system size was determined based on an expectation that buildings will be added to the CHW system that currently either have existing infrastructure for air conditioning (e.g. local chillers), or will require major renovations to their mechanical systems for a conversion to LTHW. Such buildings comprise approximately fifty percent of the building gross square footage that is not currently connected to the campus CHW system. The costs associated with the addition of these buildings to the district CHW system are included in the District Energy Master Plan report. The CHW distribution piping will be sized to accommodate all buildings on campus, allowing for future connections.

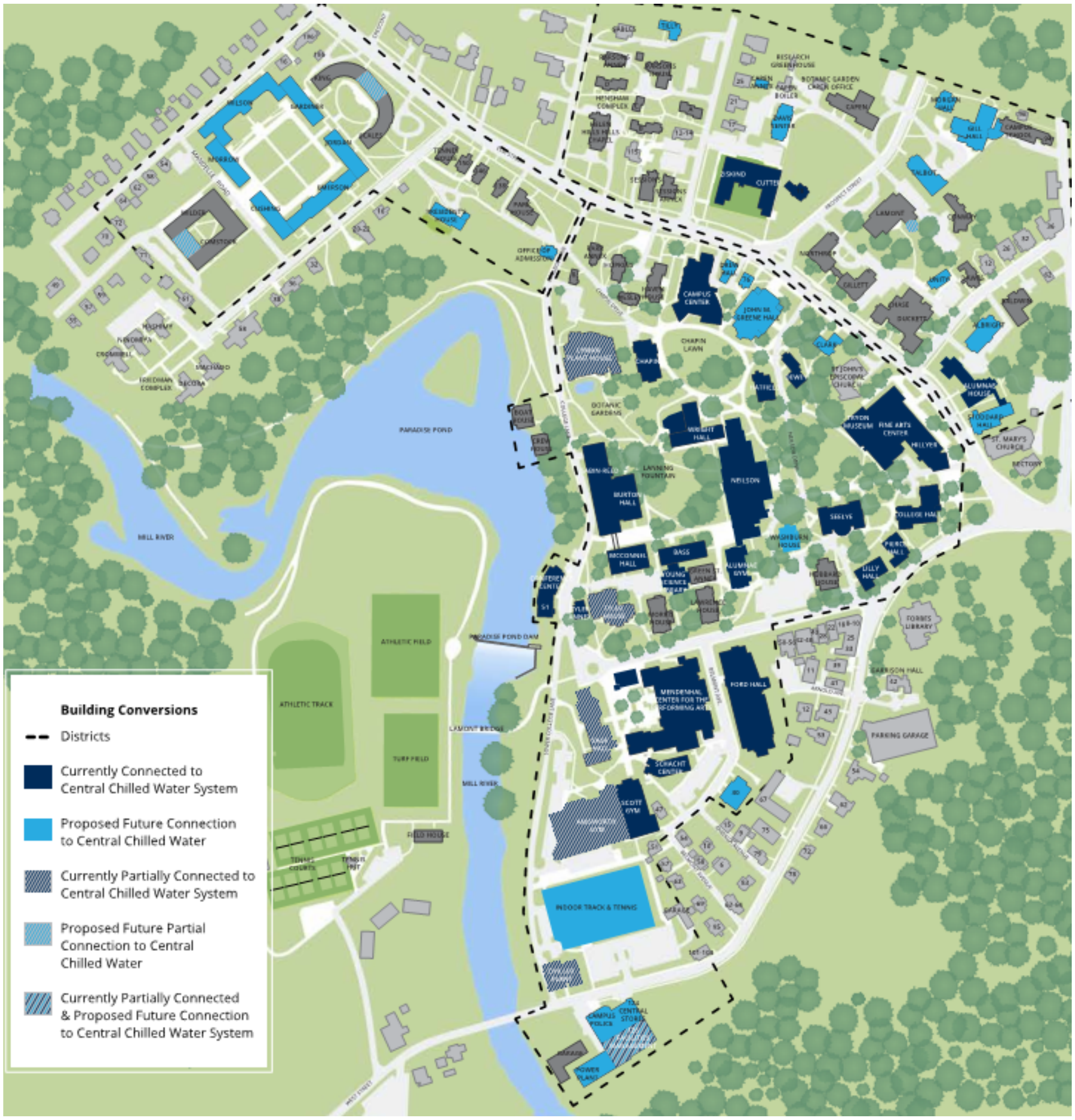

Figure 9: Campus map indicating buildings currently connected to a central chilled water system, proposed buildings to be connected to central systems in the future.

Hybrid Heating and Cooling

To achieve a balanced thermal profile and reduce the size of the geothermal heat exchangers, this report assumes that a portion of the heating load will be provided by hot water boilers. This supplemental heating source is known as "hybrid heating." Similarly, a portion of the cooling load will be provided by electric chillers and cooling towers. This supplemental cooling source is known as "hybrid cooling". See Figure 10 below.

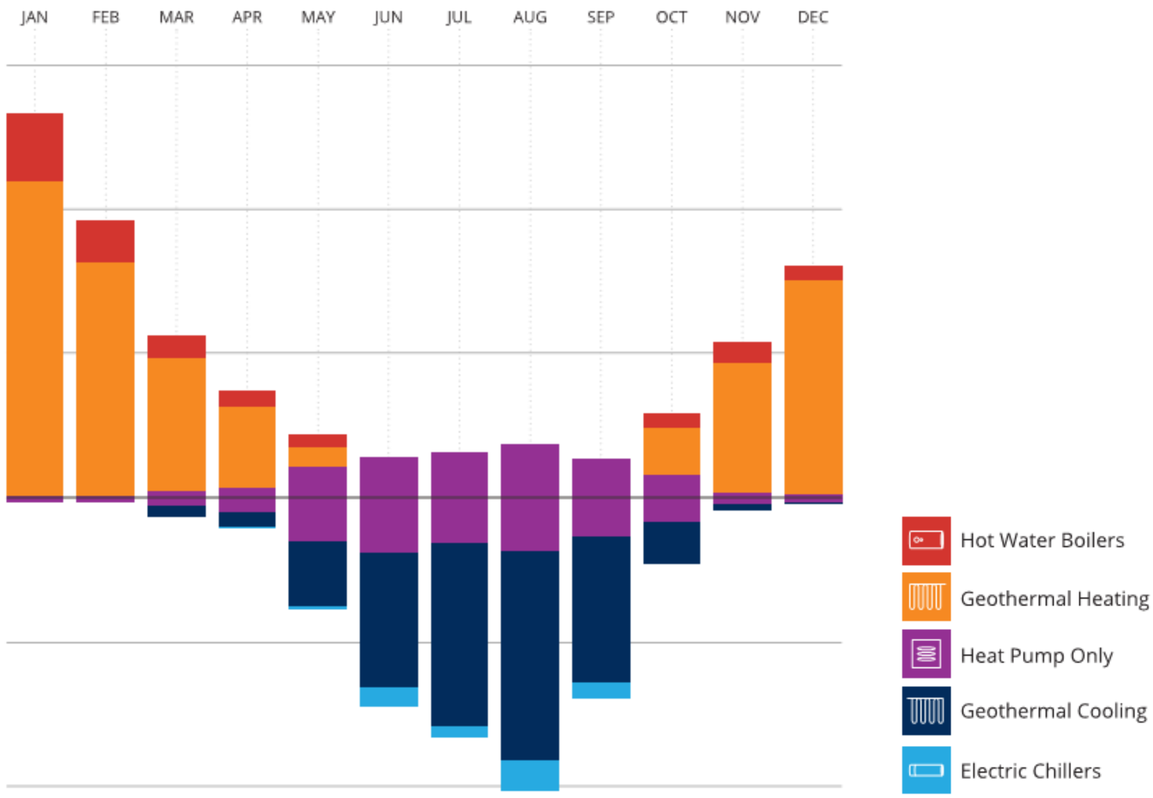

Figure 10: Graph showing how campus thermal loads will be supplied on a monthly bases by hot water boilers, geothermal heating, simultaneous heat pumps, geothermal cooling, and electric chillers.

During the initial phases of the integration of the GHX system, hybrid heating will be provided by the existing steam boilers, HRSG, and a steam-to-LTHW heat exchanger. These systems will provide the additional heating on peak demand days, as well as balance the annual load on the geo-field.

As part of the last proposed phase of the project, the existing steam boilers and HRSG are recommended for decommissioning. At that time, conventional boilers are proposed to be utilized to meet the peak heating demand. It is recommended that (4) 6,000 MBH conventional boilers be installed in the boiler plant that is adjacent to the new Energy Plant.

Geothermal Heat Exchanger (GHX)

Geothermal heat exchanger (GHX) sizing and material selection have been based on a number of factors, including land availability, equipment and installation costs, and the campus thermal profile, as shown in Figure 12 below. Multiple types and depths of closed-loop vertical GHXs were analyzed. The most cost-effective solutions for Smith College are a 600 ft depth coaxial *Rygan* or U-bend GHX. Both options have a similar cost and acreage requirements. The U-bend GHX is less efficient in terms of tons of heat transferred per linear foot but is less expensive overall and can be installed more densely. This allows the system cost and acreage requirements to be similar to a typically more efficient coaxial *Rygan*

GHX. As there are no major cost or space differences, the U-bend system is the preferred option as it is simple technology that has been proven to be reliable for over thirty years in the geothermal industry.

Type:	# of Bores:	Depth:	Total Length:	Ft/ Ton:	Tons/ Bore	Total Geo $	Total Geo $/ft	$/Ton	Acres	Tons/ Acre*
1.5" U-Bend	960	600	576,000	212	2.8	$ 18,109,271	$ 31.44	$ 5,456	8.7	312
1.5" U-Bend	678	850	576,000	212	4.0	$ 18,800,471	$ 32.64	$ 5,456	6.2	442
Coaxial 'Rygan' (3.5")	640	600	384,000	141	4.3	$ 18,323,520	$ 47.72	$ 5,775	9.1	298
Coaxial 'Rygan' (4.5")	384	1000	384,000	141	7.1	$ 21,283,696	$ 55.43	$ 7,023	5.5	496

* U-bend spaced at 20' and approximately 110 bores/acre. Rygan spaced at 25' and assumed 70 bores per acre

Figure 11: Table comparing potential ground source heat exchanger types, depths, performance, and cost.

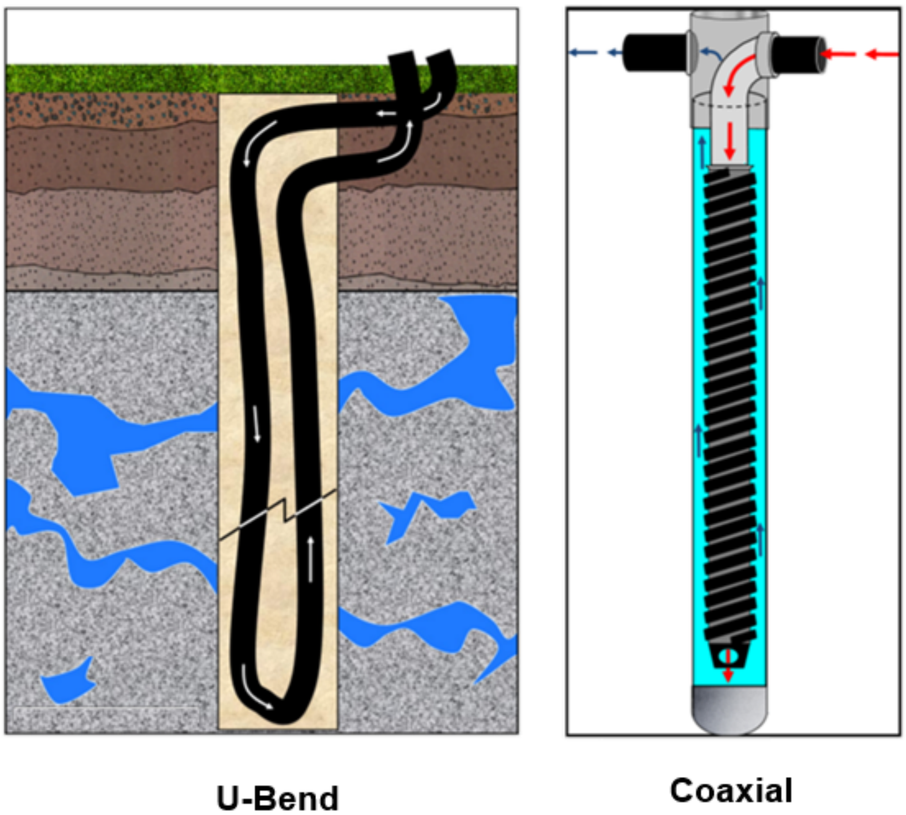

Figure 12: Artist depiction of ground source heat exchanger types including u-bend and coaxial heat exchangers.

The Athletic Field was chosen as the preferred location for the installation of GHX field. See Figure 13 below.

The advantages of this location are:

- It is an open area, ideal for large construction equipment and water management.
- Any noise produced by construction activity and environmental reclamation will take place away from the core of the campus.

- There will be minimal disturbance to trees or any major landscaping during the project.

The challenges to this location are:

- Running a direction bore under the adjacent river will be costlier than an above-ground run of piping and will require additional permits to receive installation approval.
- The regular use of the Athletic Field will be disrupted.

Figure 13: Map of Smith College athletic fields indicating acreage identified for geothermal heat exchanger installation.

Other locations considered for the location of the geothermal field included, but were not limited to: the open space in the central quadrangle, the Chapin Lawn, and the road along Lower College Lane. None of these areas were large enough to properly accommodate the required number of geothermal heat exchangers. It would therefore have been necessary to install a portion of the geothermal field in the athletic fields anyway. Due to the significant cost of running pipes across Mill River in some way, the best solution is to install the entire geothermal system in the athletic fields and minimize the geothermal piping associated with connect the well fields. This solution also helps to ensure that any disturbance to trees or landscaping on campus would be minimized.

Redundancy

The new Energy Plant design includes complete redundancy on all critical equipment.

The equipment relies on a series of pumps to ensure that appropriate flow rates are always maintained. The importance of a redundant set of pumps cannot be understated. The heat pumps will be arranged in a "lead-lag-standby" configuration, meaning that if one pump fails, the two remaining pumps will maintain flow requirements. The distribution pumps for the geothermal, LTHW, and CHW systems are also arranged in a "lead-lag-standby" configuration. There will be two pumps each for the boilers, the cooling-only chiller, and the temporary steam-to-LTHW heat-exchanger. Each of these pumps will be capable of sustaining 100% of their respective loads in the case one fails or requires maintenance.

Building conversion

The majority of buildings on campus are currently heated by a district steam system. Buildings are either heated directly by steam, or via high-temperature-hot-water (HTHW) which is generated via a steam-to-HTHW heat exchanger (steam-converter) located in the mechanical rooms of individual buildings. The mechanical systems within each of the buildings on campus will generally need substantial modification to accept the new GHX system heat in the form of LTHW (130° F). The buildings currently heated entirely by steam only will need to have all the existing heating system removed entirely. The buildings currently heated by HTHW (150° to 180° F) will be evaluated on an individual basis to determine the compatibility of existing systems with the new LTHW system.

It is recommended that a hot-water-reset-temperature test be performed on each building currently heated by HTHW. The temperature of the hot water delivered to the building is reduced at a time when the outside temperature is at or near the design conditions (0 ° F). The water temperature is decreased incrementally until it reaches 130° F. The test determines if the building equipment and mechanical systems are able to maintain thermal space requirements with lower temperatures, or if systems need to be modified. Energy conservations measures will be recommended for buildings and/or spaces within a particular building that are unable to maintain temperature setpoints.

Any building that requires steam from the heating plant will be converted to local steam systems that utilize natural gas or electricity. Conversions will include the removal and replacement of steam humidifiers with units that are powered by electricity or natural gas.

During the winter of 2018/2019, a hot-water-reset-temperature test was performed on a small portion of the buildings on campus, and informational interviews were conducted with facilities staff. The results of the tests and interviews were used to inform the scope of the building conversions and projected cost analysis. Based on these considerations, each building was labeled as one of the following conversion types:

- **Type A**: *Replace all* steam equipment and reuse *all* hot water distribution equipment. This conversion type has the lowest cost per square foot.
- **Type B**: *Replace all* steam equipment and reuse *a portion of* the hot water distribution equipment.
- **Type C**: *Replace all* steam equipment and *all* hot water distribution equipment.
- **Type D** (steam-only building): *Replace all* steam distribution equipment *and* steam/condensate piping. This conversion type has the highest cost per square foot.
- **Type E**: A building which has or will be undergoing major renovation and will be designed to accommodate LTHW.

The map in Figure 14 below shows the conversion type for each building.

To estimate the projected cost of campus building modifications to accept LTHW, seven representative buildings and types were analyzed. A low and a high cost estimate was developed for each building. A low estimate indicates all terminal units are compatible with accepting LTHW (type A) and a high estimate indicates all the terminal units need to be replaced (type C). Buildings heated directly with steam (type D) requires additional cost to the high cost estimate which includes the replacement cost for steam piping. The cost per GSF for each representative building type was applied to the remaining buildings on campus to estimate the total cost to convert and modify all buildings on campus.

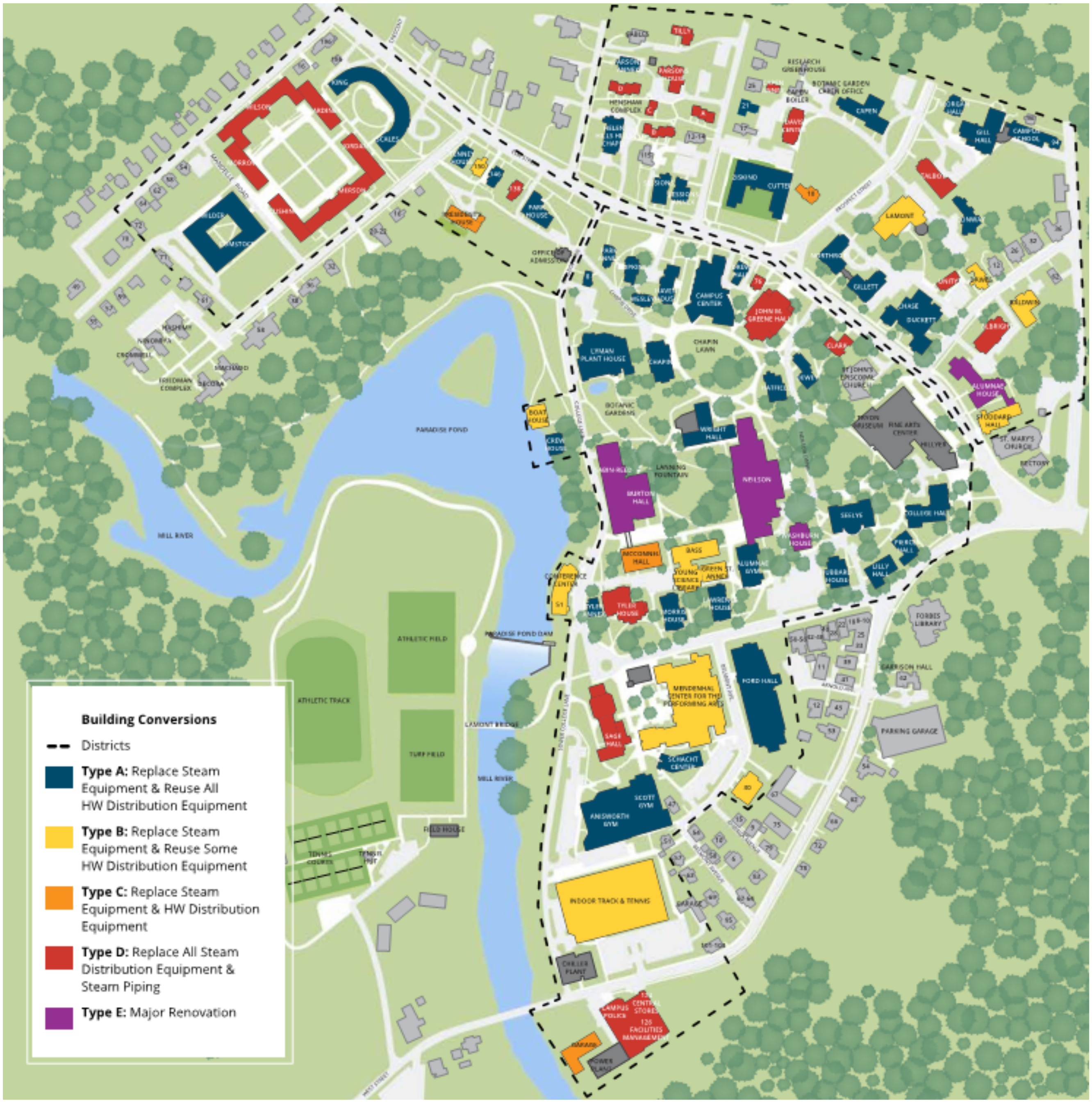

Figure 14: Campus map indicating heating system modifications necessary, by building, to transition heating distribution from steam to low temperature hot water.

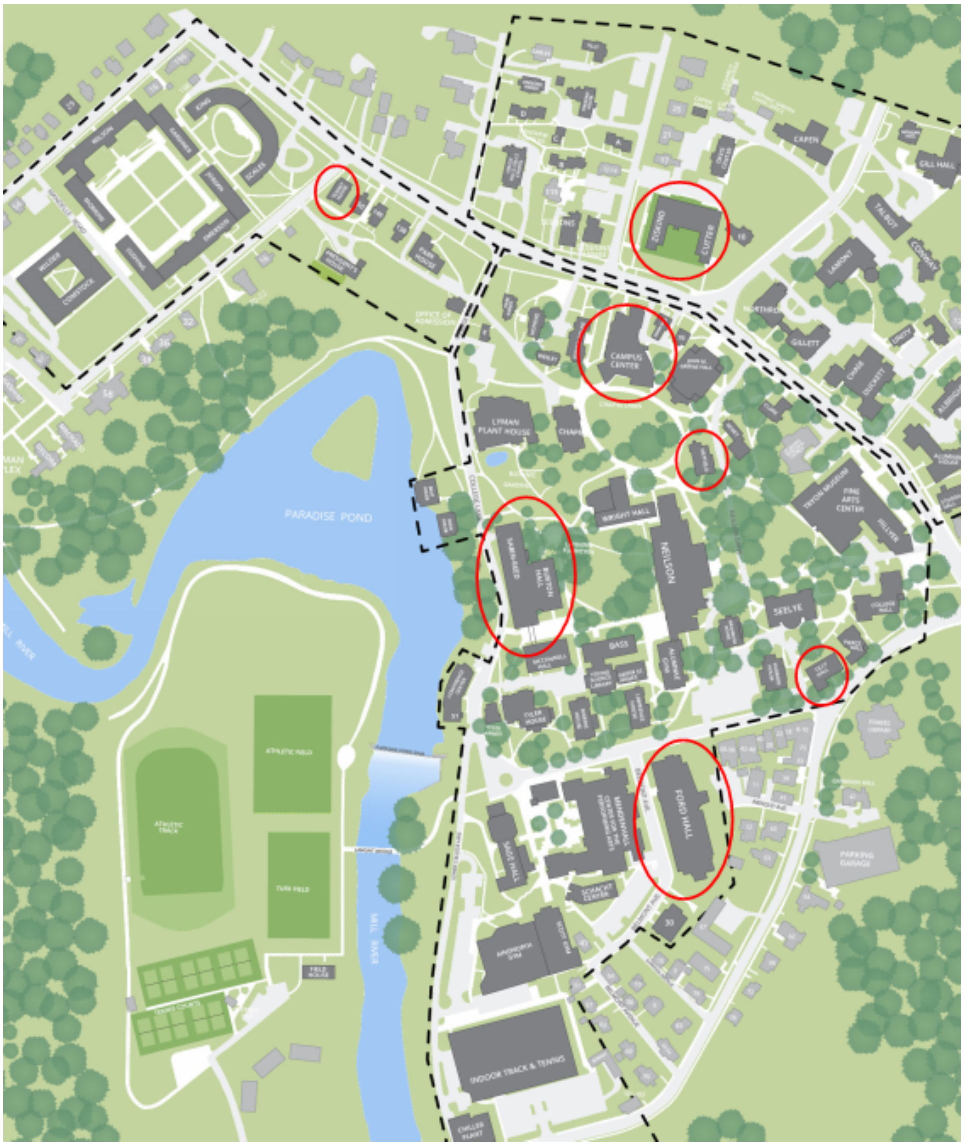

Figure 15: Campus map highlighting buildings that were investigated to assess heating system conversion costs for representative buildings, including: Tenney House, Ziskind and Cutter Houses, Campus Center, Hatfield Hall, Sabin-Reed and Burton Hall, Lilly Hall, and Ford Hall.

Backup Electricity

The campus has two existing primary backup electrical power options: distributed emergency power, and centralized electricity production by the co-generation system. The distributed emergency power system consists of both diesel and natural gas fueled emergency generators, located throughout campus to provide life safety and critical power support during a power outage. The co-generation system can be operated in the event of a grid-power outage and is capable of producing enough electricity to meet the electrical demand of the campus.

It is anticipated that the co-generation system will reach its end-of-life in 2030, at which time a decision will need to be made regarding how backup electricity for the new energy plant and campus will be provided. Backup power will always need to be provided to the campus to meet its heating load. That power could be provided via a new 1MW, 480V, 3-phase diesel generator. It is possible that the existing 750 KW Black Start generator could be used to provide the required backup power for the heating load during a power outage.

Backup electricity for the chilled-water system will require much more electricity, currently estimated at 4 MW of 4160V power. Additionally, backup electricity is required to power the pumps that supply CHW to campus, the heat pumps, and the chillers. Total backup power and electricity calculations do not include the electricity that is required at each building in order to utilize the CHW to cool them.

There are two proposed options to provide backup power for cooling: (1) installation of new diesel generators or (2) reallocation of the current co-generation power. An estimated two to four large-scale diesel generators could be installed adjacent to the new Energy Plant, along with the accompanied large diesel storage tanks.

Options to Reduce total GHX

Sewage Heat Recovery

A major municipality waste-water line runs directly through the Smith College campus. The main 36" waste-water line carries approximately 1.5-2.5 million gallons of 60-70° F waste-water per day from an area northwest of campus to a Northampton sewage treatment plant. One option to reduce the cost of geothermal heat exchangers is to install a sewage heat recovery system, and then extract or add heat to the waste-water depending on the season. Heat from the sewage system may also be injected into the new Energy Plant to assist in the heating and cooling of the campus. A model of this system showed that it could offset as many as 150 U-Bend GHXs installed at a depth of 600 ft. This estimate was based on the following assumptions:

- The municipality will allow for Smith College to reduce or increase the waste-water temperature by approximately 10° F. (Note: Although it is possible to design a system to reduce/increase the temperature by as much as 20°F, a figure of 10° F degrees was used.)
- The system would divert a minimum flow of 1.5 million gallons per day at a rate of approximately 1000 gallons per minute. All flow over 1.5 million gallons would not be diverted through the system.
- The flow rate remains steady over the course of a given day or year. The 1.5 million gallons were divided evenly the 24 hours per day in the model.

SHARC Energy Solutions manufactures a prefabricated sewage heat recovery skid system, known as the "SHARC 880" system. The system footprint varies according to the desired heat exchanger, but the base system requires a footprint of approximately 22 ft by 12 ft. The system includes the control panel skid, the SHARC 880 skid, the piping/valve tree skid, the heat exchanger, and a 10,000 gallon below-grade sealed storage tank. The system would need to be located adjacent to the existing sewage line, as shown in the Figure 16.

Sewage heat recovery is a recommended solution as part of the Energy Master Plan and may be installed during any phase of implementation. The line is City-owned, and as such, permission to use thermal energy will need to be granted by the city to the College.

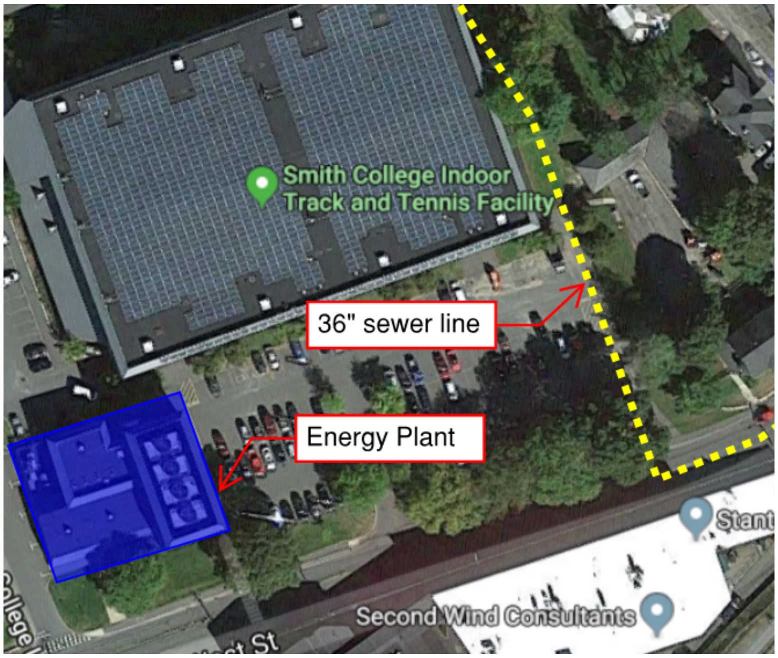

Figure 16: Aerial Image of proposed location of sewage heat recovery system.

Mill River/Pond Heat Extraction

Professor McKahn of Smith College and her students investigated the viability of the thermal contribution from Mill River to the LTHW and CHW systems on campus as an offset to geothermal heat exchanger capacity. Current regulations limit any thermal changes to the Mill River to a maximum of 1° F. Ultimately, this means that no significant heat may be added to either the river or pond; it may only be extracted. During the time of year that the campus requires heating, the temperature of Mill River is below the allowable water temperature for the heat pumps and the chillers. Therefore, Mill River/Pond heat extraction was determined to be infeasible.

Solar Thermal Renewable Energy

Solar thermal renewable energy can be effective for the production of LTHW. Solar thermal collectors gather heat from the sun to heat a fluid inside the pipes/tubes of the collectors. The heated fluid can then be used as supplemental thermal heating during the winter, and/or for summer load balancing. Winter heating uses solar thermal heat to supplement GHX heat on peak cold winter days. Load balancing uses solar thermal energy to help balance the annual load of heating/cooling added to the geothermal field by raising the ground temperature around the geothermal heat exchangers.

There are several reasons why solar thermal technology is not a recommended solution in the case of Smith College:

- Intermittent nature of solar radiation in the northeast prevents solar thermal from being a reliable heating source during the winter months.
- There is limited ground or roof space for solar thermal collectors. The large roofs on the buildings immediately adjacent to the energy plant already host solar PV panels.

The projected thermal load profile for Smith College is heating dominant. However, due to the heat of compression from the heat-pump chillers, the load on the geothermal field is different than the load on the campus. This means that the thermal load on the geothermal field is relatively balanced and solar thermal heat would not provide any additional benefit. For these reasons, solar thermal technology is not recommended. This conclusion can be reassessed after the first phase of implementation of the Energy Master Plan.

Thermal Energy Storage Tanks

CHW and LTHW thermal energy storage (TES) can optimize the economic performance of campus energy systems. CHW TES would allow high-efficiency chillers to cool water to 39°F at night, during off-peak electric hours. This stored chilled water can be dispatched throughout the peak hours of the day to reduce electric demand and avoid high electric costs known as capacity charges.

A potential reduction of nearly 700kW is achievable with an average high-efficiency chiller operation of .5kW/ton and the uniform dispatch of a 1-million-gallon storage tank (approximately 13,000 ton-hours of cooling capacity). The dispatch period of the tank capacity may be further optimized to provide up to 1MW of demand savings.

The cost of a 1-million-gallon CHW storage tank is approximately $1.1 million in 2020 dollars and could produce an approximate annual savings of $75,000 (in 2020 dollars). This system has a simple payback of approximately 15 years. For hybrid cooling, a CHW storage tank may eliminate the requirement for a cooling tower, as the thermal storage tank would provide the peak cooling load. Therefore, CHW TES is recommended.

LTHW TES can be used to store 140° F water that can be used during peak heating demand. A separate storage tank for LTHW allows for the recovery of heat that is produced during CHW production; this is known as “waste heat”. Waste heat can be used to level daily loads on the central plant equipment. Doing so reduces the amount of required heating capacity of the equipment that needs to be installed, and contributes to overall system resiliency. However, LTHW TES would require a high capital expenditure and has a very long-term return on investment. It is therefore not recommended.

Other System Options Considered

Distributed systems

A distributed system is an alternative to the centralized system as proposed for Smith College. A distributed system has multiple ground-source heat pump systems dedicated to a single building or a small group of buildings. The main advantages of a distributed system are: (a) it does not require a central energy plant and (b) it would significantly reduce the amount of distribution piping on campus. A distributed system was deemed unsuitable for two reasons:

1. **The overall efficiency of a distributed system is lower than that of a centralized system.** A distributed system typically has a lower simultaneous load capacity and is therefore less efficient.
2. **The overall capital cost of a distributed system is higher than the cost of a centralized system**. The typical per-ton cost of a distributed system is higher because it utilizes smaller heat pump chillers. It also has a larger overall tonnage capacity due to its inability to take advantage of diversity in the system.

Multiple Energy Plants

An alternative to the expansion of the energy plant is to build an additional energy plant within the core of the campus. This option would add significant costs to the overall Energy Master Plan and would not provide significant benefits Smith College, so this option is therefore not recommended.

Implementation Plan with Phases

The implementation plan for the recommended option has been divided into four sub-phases.

Phase 1 – Initial Central Area of Campus

Overview of Phase 1

- The conversion to LTHW of 17 buildings in the central area of campus.
- The installation of new LTHW distribution piping to these buildings, as well as new chilled-water piping as appropriate.
- An expansion of the central chiller plant to house additional heat pump chillers and pumps.
- The installation of a steam-to-LTHW heat exchanger in the central steam plant.
- The installation of GHX in the athletic field and associated piping across Mill River to the new energy plant.
- It is recommended that the permit application process for the sewage-heat-recovery system begin during the initial implementation phase. If possible, the system should also be installed in this the first phase, as permit approvals often have a long lead time.

Building Conversions

The 17 buildings selected for conversion are located in the central core of the campus and will require minimal renovation to their mechanical systems; the existing terminal heating equipment is already compatible with LTHW. The estimated cost of conversion includes all labor and equipment required for the elimination of the steam-to-HTHW heat-exchangers and steam coils, as well as the addition of new hot water piping in each building. It also includes the connection of the new piping to the existing hot water system and newly installed hot water equipment. The existing chilled-water system will remain in place. See Figures 17 and 18.

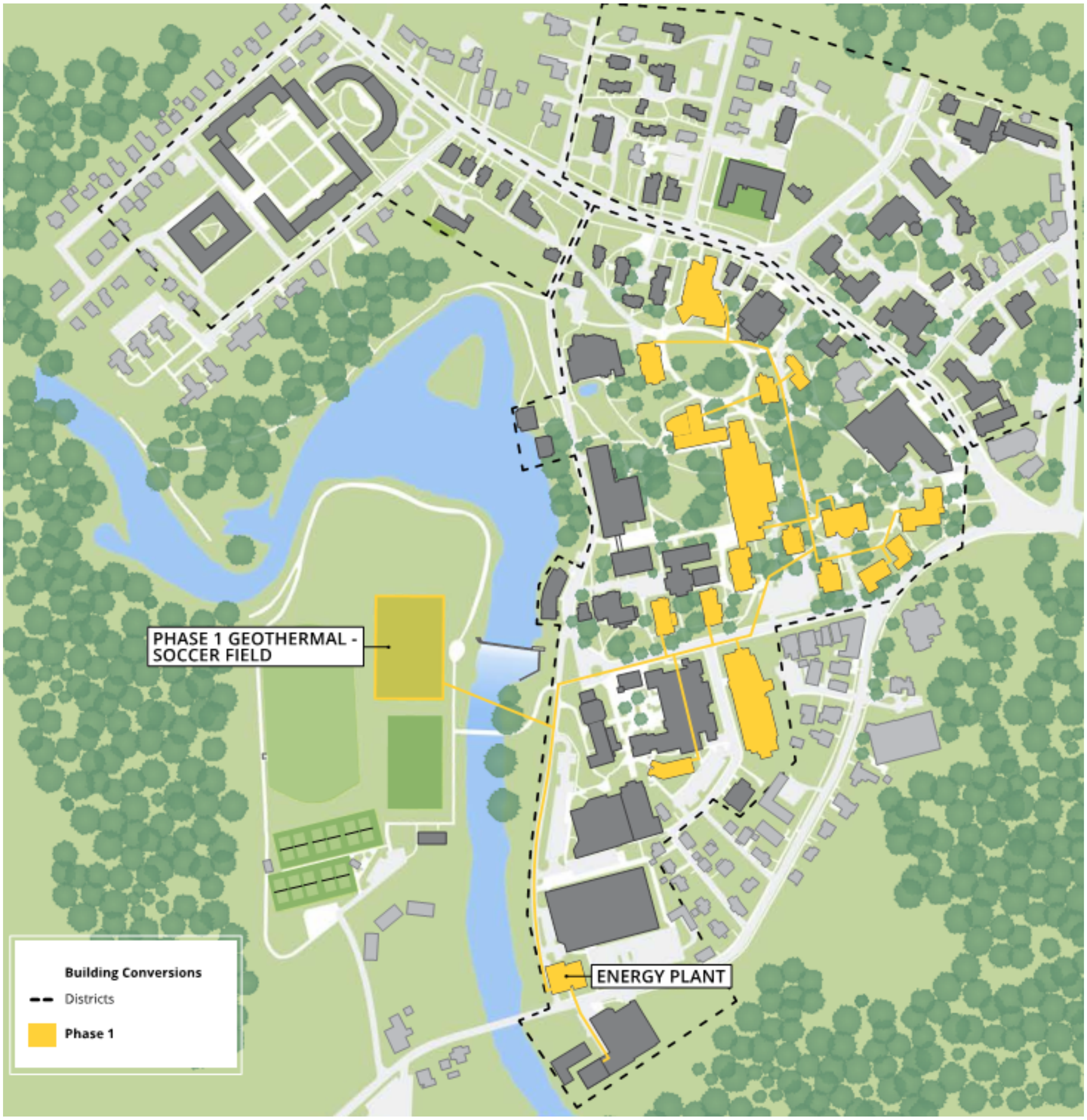

Figure 17: Campus map identifying which buildings are included in Phase 1 implementation, including the Energy Plant and its addition, distribution piping, and the Phase 1 Geothermal field located beneath the existing soccer field.

Figure 18: Campus map focusing on core campus buildings and grounds impacted by Phase 1 implementation.

Energy Plant

The existing chilled water plant will receive a 4,500 ft^2 addition that will house all new required equipment. The addition will include essential infrastructure for future phases of implementation and will turn the “chiller plant” into a new “Energy Plant.”

Four 275-ton modular heat pump chillers are proposed to be installed and will be connected to the existing CHW system. The existing chillers and their respective cooling towers will supplement the new heat pumps when the cooling demand exceeds their capacity and will serve as a primary source for hot water during the heating season. Additional pumps will be installed for the heat pumps, the LTHW distribution system, and the GHX distribution system. This phase includes the removal of the existing 1,000-ton electrical centrifugal chiller (#5).

Hybrid Heating

A new steam-to-LTHW heat exchanger and required pumps will be installed to supplement the new LTHW system during peak heating conditions, as well as to balance the annual load. The existing steam system (HRSG and/or natural gas boilers) will deliver approximately 18,000 MBH of steam to the new heat exchanger.

Sewage Heat Recovery

If feasible and approved, it is recommended that the sewage-heat-recovery system be installed as part of Phase 1.

Electrical

To support the expansion of the Energy Plant, it will be necessary to remove the existing 200A/2400V switch and replace it with a 400A/2400V switch for the new heat pumps. A new switchboard with a 1750 kVA, 2400V to 480V transformer and motor control centers for new 480V loads will need to be provided.

GHX

In Phase 1, approximately 180 U-bend GHXs will be installed to a depth of 600 ft in the soccer field. A supply-and-return pipe will be designed to span Mill River at the most favorable location to connect the GHX and the Energy Plant. Cost analysis for this connection was based on directionally boring the geothermal pipes underneath Mill River. Other potentially less expensive, but logistically more complex, options would necessitate the pipe passing through land that is not owned by the College. The soccer field was selected as the location for the initial geothermal field installation due to considerations related to its proximity to the new Energy Plant and the optimal end point of the directional bore.

Phase 2 – North of Elm Street

Overview

- The conversion to LTHW of 31 buildings north of Elm Street.
- The installation of new LTHW distribution piping to these buildings, as well as new chilled-water piping as appropriate.
- A 1,200-ton heat pump addition to the Energy Plant.
- Additional GHXs connected to the existing supply and return piping across Mill River. See Figure 19.

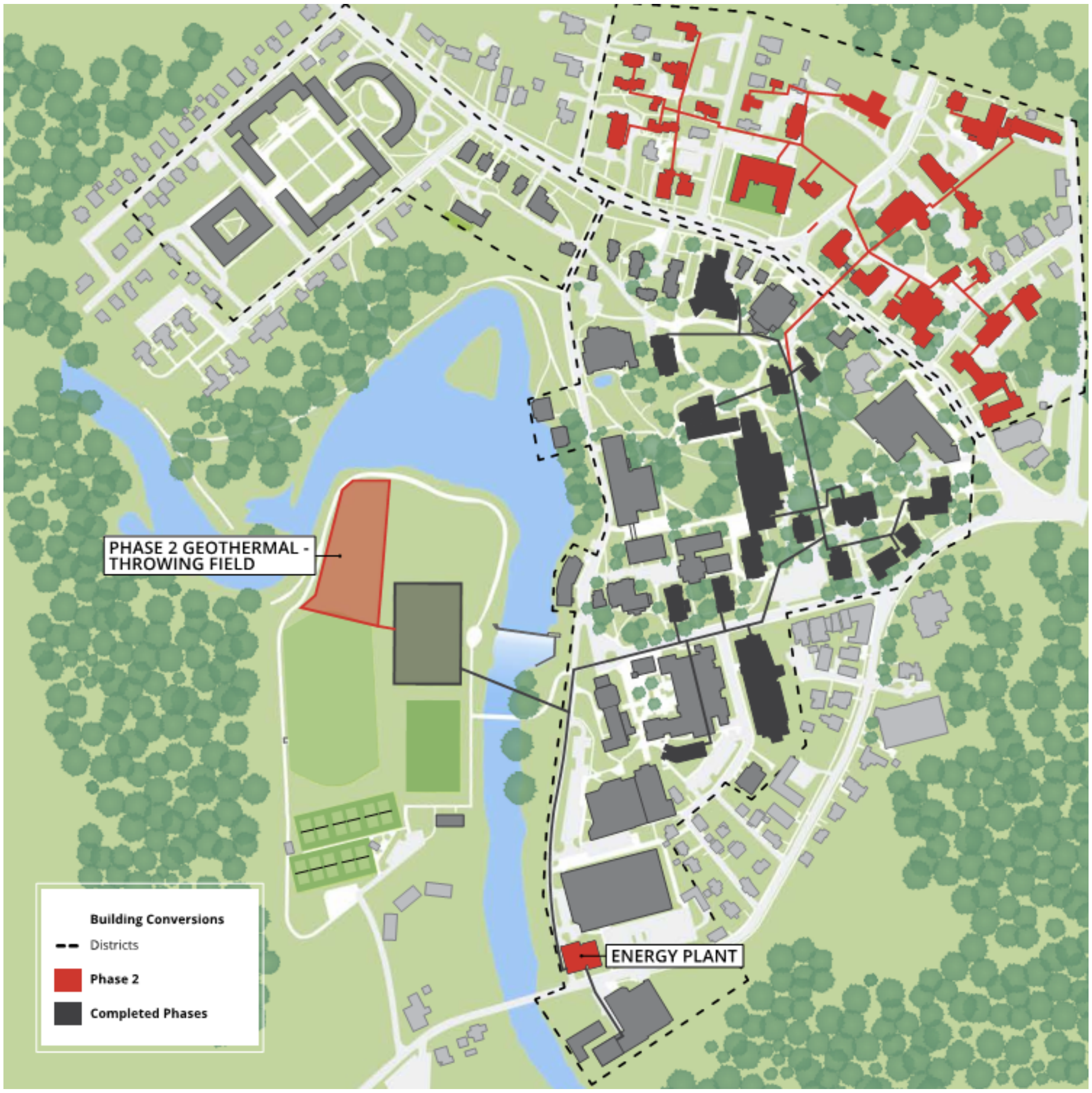

Figure 19: Campus map identifying which buildings are included in Phase 2 implementation, including the Energy Plant, distribution piping, and the Phase 2 Geothermal field located beneath the existing throwing field.

Building Conversions:

A total of 31 buildings will be added to the LTHW and CHW distribution systems on campus (See Figure 20). These buildings vary in the degree of mechanical upgrades that are needed in order to accept LTHW. Some will only require the removal of the steam-to-HTHW heat exchanger in the mechanical room, while other buildings will require a full renovation of their mechanical systems. The cost of building conversions will be driven by the elimination of existing equipment and by the installation of LTHW distribution equipment.

Figure 20: Campus map focusing on campus buildings north of Elm Street and grounds impacted by Phase 2 implementation.

Energy Plant:

The installation of a new 1,200-ton heat pump is required for the additional load of the Phase 2 buildings. New pumps and piping will be added and connected to the piping headers from Phase 1.

Hybrid Heating

The steam-to-LTHW heat exchanger added in Phase 1 will continue to be the supplemental source of heating. No additional hybrid heating capacity is required.

Electrical:

It will be necessary to install a new 2400V switchgear with a new feed to the medium voltage network. This switchgear will contain the main overcurrent protective device and six 400A fused feeder sections. A new 480V switchgear that includes a 2000A switchboard with feeder sections and motor control centers for new loads of 480V will also need to be installed.

GHX:

Approximately 200 U-bend GHXs will be installed to a depth of 600 ft in the throwing field. These GHXs will be connected to the supply-and-return piping that will span Mill River and connect to the Energy Plant.

Phase 3 –Quad Area

Overview

- The conversion to LTHW of 17 buildings in the Quad Area.
- The installation of new LTHW distribution piping to these buildings.
- A 1,200-ton heat pump will be added to the Energy Plant.
- Additional GHX wells connected to the existing supply and return piping across Mill River. See Figure 21.

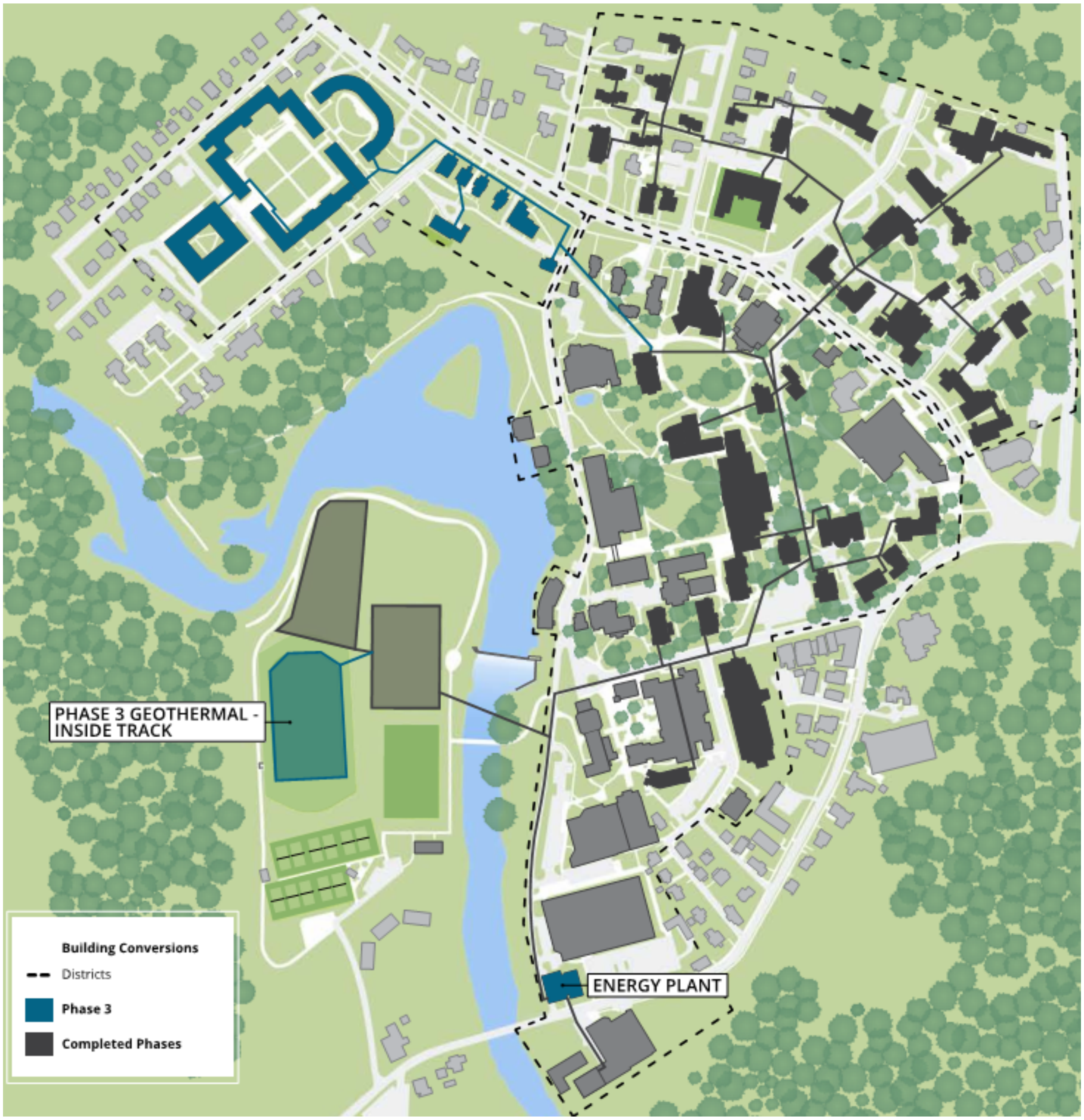

Figure 21: Campus map identifying which buildings are included in Phase 3 implementation, including the Energy Plant, distribution piping, and the Phase 3 Geothermal field located beneath the field inside the existing track.

Building Conversion

The 17 buildings that will be added to the new campus LTHW and CHW distribution systems vary in their need for mechanical upgrades in order to accept LTHW (See Figure 22). Some will only require the removal of the steam-to-HTHW heat exchanger in the mechanical room while other buildings will require a full renovation of their mechanical systems. The cost of building conversion will be driven by the elimination of steam-to-HTHW heat exchangers and steam coils, and by the addition of LTHW distribution equipment.

Figure 22: Campus map focusing on the Quadrangle and grounds impacted by Phase 3 implementation.

Energy Plant

The installation of a new 1,200-ton heat pump is required for the additional load of the Phase 3 buildings. New pumps and piping will also be added and connected to the piping headers from Phase 1. The new heat pump and its associated equipment will be housed in the expansion that was constructed during Phase 1. The existing CHW pumps will need to be removed and replaced with larger pumps to accommodate the increase in connected load.

Hybrid Heating

The steam-to-LTHW heat exchanger added during Phase 1 will continue to serve as the supplemental source of heating. The load on the existing high-pressure steam distribution system will be reduced to a point that an existing boiler from the boiler plant may be decommissioned. The boiler to be decommissioned will be assessed and determined during later design phases.

Electrical

Certain electrical changes will need to be made during Phase 3, including the installation of new 2400V feeders to new 1200-ton heat pumps, and the removal of the feeders to existing centrifugal chillers and other mechanical support loads. Feeders from the switchgear for the pumps, which include a smaller unit motor control center, will also need to be installed.

GHX:

Approximately 160 U-bend GHXs will be installed to a depth of 600 ft in the throwing field, similar to Phase 2. These GHXs will be connected to the supply-and-return piping that will span Mill River and connect to the Energy Plant.

Phase 4 – Remaining Central Campus Area

Overview

- The conversion to LTHW of 28 buildings in the Central Campus Area.
- The installation of new LTHW distribution piping to these buildings.
- A 1,200-ton heat pump and a 900-ton cooling-only chiller will be added to the Energy Plant.
- All remaining existing steam boilers will be removed from central steam plant.
- A high-efficiency natural gas boiler will be added to the Energy Plant for hybrid heating since the existing steam-to-LTHW heat exchanger used during Phases 1-3 will have been decommissioned.
- All remaining steam systems and distribution piping will be decommissioned.
- Additional GHX wells connected to the existing supply and return piping across Mill River. See Figure 23.

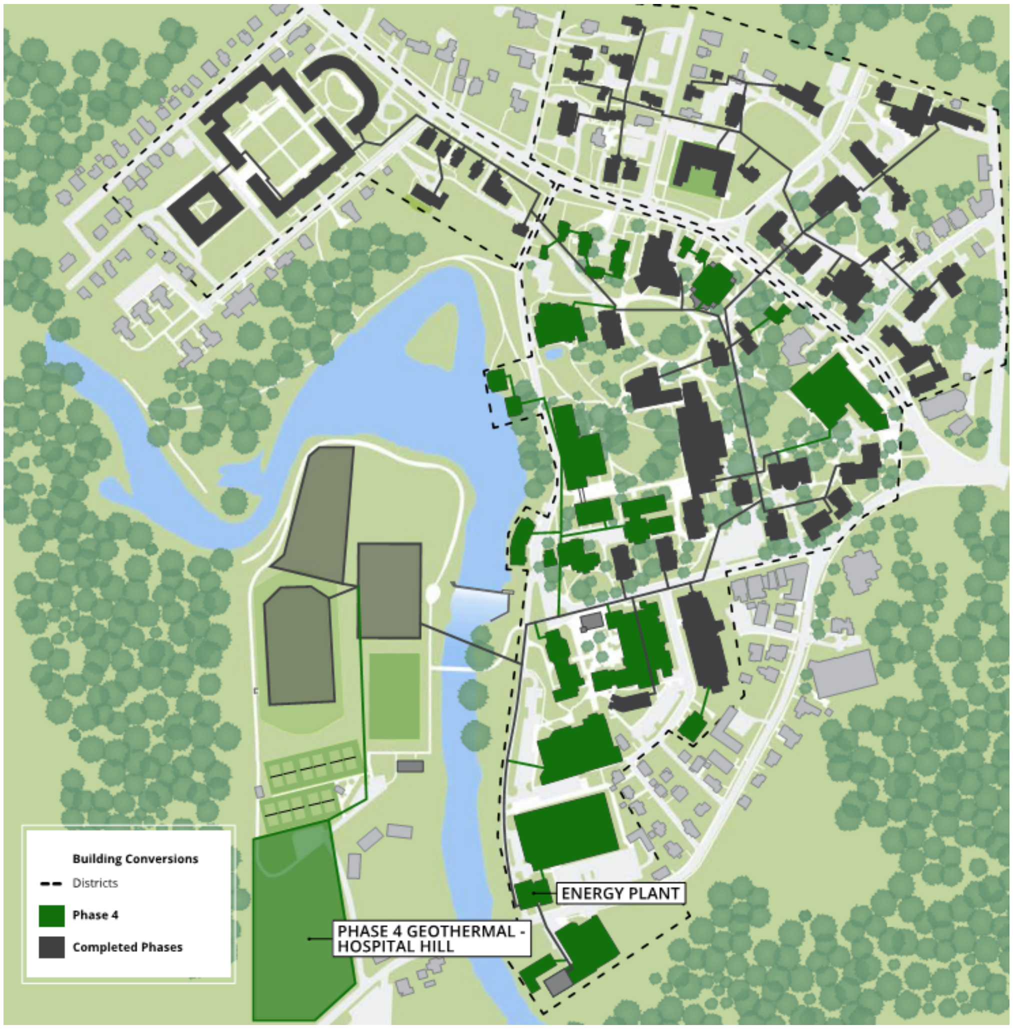

Figure 23: Campus map identifying which buildings are included in Phase 4 implementation, including the Energy Plant, distribution piping, and the Phase 4 Geothermal field located beneath hospital hill.

Building Conversions

The 28 buildings that will be added to the new campus LTHW and CHW distribution systems vary in their need for mechanical upgrades in order to accept LTHW (See Figure 24). These buildings all require a more intensive mechanical system renovation to accept LTHW due to the fact that the lower cost buildings were connected during phase 1. The cost of building conversion will be driven by the elimination of steam-to-HTHW heat exchangers and steam coils, and by the addition of LTHW distribution equipment.

Sabin-Reed / Burton Halls and the Brown Fine Arts Center are two exceptions to the conversion of the buildings in Phase 3.

The cost to convert Sabin-Reed-Burton to LTHW will be considerably higher than that of the other buildings because it currently requires 180° F water to meet thermal space heating requirements. Nearly all of the mechanical systems would need to be replaced to be compatible with LTHW. Since the building is due for major renovation within the next 10+ years, it is recommended that the cost of upgrades to the existing building be excluded from this Master Plan. However, the energy load of a future energy-efficient science building of equal size has been included in the total campus load calculation of this Master Plan.

The temperature and humidity requirements, and high cost of conversion to LTHW of the Brown Fine Arts Center, resulted in a decision to exclude this building from being connected to the new Energy Plant. The Center will still be provided with CHW from the central system, but a local high-efficiency boiler is proposed to be installed to provide hot water and steam to the existing mechanical systems.

Energy Plant:

Phase 4 will include the installation of a third 1,200-ton heat pump, a 900-ton cooling-only centrifugal chiller, and associated equipment. The new equipment will be housed in the expansion space constructed during Phase 1. Demolition includes the removal of the remaining original chillers and associated equipment and the remaining steam piping.

Decommissioning of the existing high-pressure steam distribution system will allow for the complete removal of the two remaining original boilers and the associated steam equipment from the central steam plant. The temporary steam-to-LTHW heat exchanger installed as part of Phase 1 for hybrid heating will also be removed, and a high-efficiency boiler, or potentially a biofuel boiler, could be added to the existing boiler plant for hybrid heating.

Figure 24: Campus map focusing on buildings and grounds impacted by the final phase, Phase 4, implementation.

Electrical

The required electrical work in Phase 4 includes the final installation of new wiring to support the heat pump, the chiller, and the other pumps.

The building-level electrical generators will be reviewed for overall capacity, capability, and support for loads. A decision will need to be made to either reallocate the Cogeneration System or install a generator for backup power. The cost estimate in this Master Plan assumes the reallocation of the Cogeneration system.

GHX:

Approximately 425 U-bend GHXs will be installed to a depth of 600 ft in Hospital Hill. These GHXs will be connected to the supply-and-return piping that will span Mill River and connect to the Energy Plant.

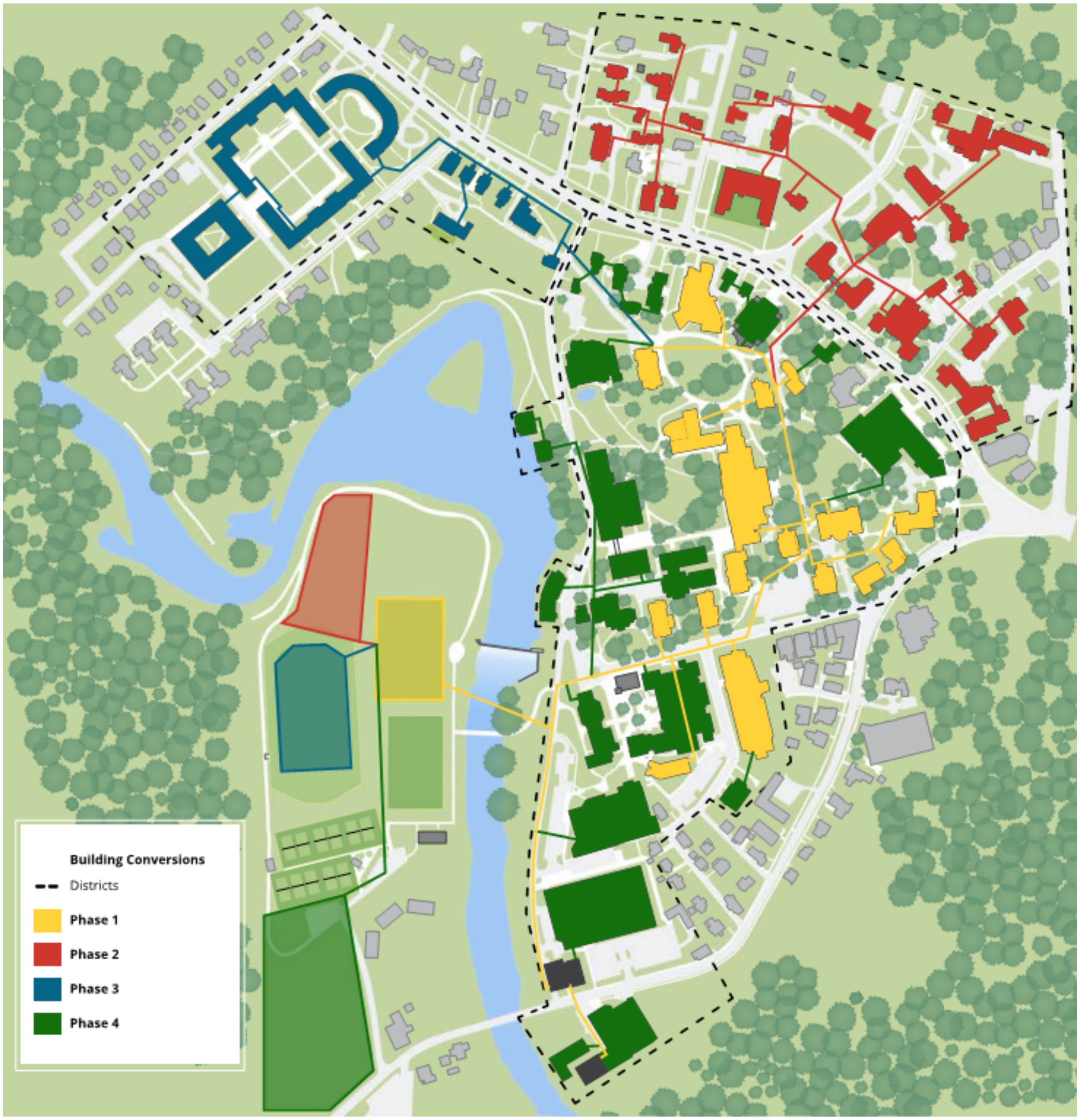

Figure 25: Campus map identifying which buildings are included in each phase, including the Energy Plant, distribution piping, and the Geothermal fields.

Overview of Analysis Method

A central strategy outlined in this master plan is to improve campus energy efficiency through conversion of the district-energy system from fossil fuel generated steam to ground-source low temperature hot water and cooling distribution. To inform the geo-field and equipment sizing, the project team needed to calculate the expected heating and cooling demand for the buildings within the scope of the Energy Master Plan. The buildings were then grouped into four phases of implementation.

1) Three significant challenges that the project team experienced were: The existing building stock uses a variety of heating and cooling systems, which increases the complexity of comparing building energy use intensity. For example, if a building is cooled by a local chiller there may be a measure of the electricity supplied to the building, but not a measure of the cooling energy used in the building. For planning purposes, it was necessary to know and/or estimate the cooling energy that will be required in each building.
2) The available metering data for campus buildings was inconsistent. Some buildings had 1-2 years of high-quality data for one utility, but perhaps no available data for any other utility. Some buildings had significant metering anomalies, making the building-level meter data unreliable and therefore unusable for this analysis. Other buildings had little-to-no information available beyond what utilities served the building; this was especially true for the thermal energy sources.
3) Many existing buildings are not currently cooled, but they have potential to be in the future if connection to the district energy system proves to be financially feasible. It will be necessary to estimate the cooling energy that will be required in the currently uncooled buildings to ensure that successive phases of the GHX installations are right-sized.

To overcome these challenges, the project team created estimated thermal energy profiles for each building based on information that was available. The goal was to represent the specific heating and cooling demands for each building, at an hourly resolution, regardless of how the heating and cooling energy might be supplied today.

The project team followed the following five steps in this process:

- *Step 1*: Establish the list of building in scope
- *Step 2*: Identify the total thermal energy needs for the group of buildings in scope.
- *Step 3*: Allocate total energy to each building
- *Step 4*: Allocate total building energy across the typical year
- *Step 5*: Aggregate loads by implementation phase

Step 1: Establish the list of buildings in scope

Goal: Gather information about which buildings are, or might be, connected to a central heating or cooling system and establish how the thermal energy demands for that building would be reflected as an 8760 Hourly Building Thermal Profile.

The project team used the following inputs to establish which buildings should be included in the thermal load analysis:

1) **A buildings list** with information such as building name, GSF, year built, and location.
2) **A technical building questionnaire.** The questionnaire included information from the building list and from the facilities staff.
3) **Building metering data** made available through SkySpark, a building analytics software.

Step 2: Existing Campus Energy Profile

Goal: Identify the total the thermal needs for the buildings that will be part of the campus LTHW and CHW scope.

During this step the project team worked through a series of sub-steps to translate the varied sources of thermal energy in the buildings into the specific thermal demands, irrespective of how that thermal energy was produced.

Gather Energy Invoices to Determine Total Energy Purchases

One reliable source of energy consumption information is the total amount of energy purchased, as documented on invoices and via central meters. This information served as a reliable starting point, as well as an upper bound for a determination of the annual thermal energy load.

The project team took the following sub-steps:

Step		Central Steam	Central Chilled Water	Natural Gas	Campus Electric	Notes
1	GSF	2,596,398	1,118,554	2,847,524	2,847,524	Source: GH per Energy Master Spreadsheet_Smith College.xlsx
2	Send-out energy from central meter point	206,566,130 lbs	4,363,107 ton-hrs	265,475 therms	21,748,100 kWh	Source: Smith Plant management reports
3	Btu conversion factor	1,100 Btu/lb	12,000 Btu/ton	103,700 Btu/therm	3,412 Btu/kWh	Steam factor assumes net enthalpy (sendout steam minus condensate return)
	Total Btu	227,222,742,523	52,357,288,000	27,529,798,980	74,204,517,200	
	Pre-loss EUI	87.5 kBtu/GSF	46.8 kBtu/GSF		26.1 kBtu/GSF	
	Building Energy Adjustments					
4	Distribution losses	30%	2%	0%	1%	Losses form point of metering
	Building Conversion Losses	20%	0%	10%	0%	Boilers, heat exchangers, etc.
	Not for thermal needs	0%		40%		
	Average Campus Building EUI	43.8 kBtu/GSF	45.9 kBtu/GSF	0.0 kBtu/GSF	25.8 kBtu/GSF	115.4 kBtu/GSF
	Total Btu	**113,611,371,261**	**51,310,142,240**	**13,764,899,490**	**73,462,472,028**	**252,148,885,019 Btu**

Assumption

1. Using information from the Building Questionnaire, the number of GSF served by each source of thermal energy was calculated.
2. Electric and natural gas invoices were gathered to determine the total energy purchases in the baseline year. Energy data from the central steam and chilled water plants was gathered.
3. All energy units were converted into BTUs.

4. Assumptions[1] for distribution and building conversion losses were made.

Allocation of Campus Electricity Used for Distributed Heating and Cooling

Based on the Building Questionnaire, it was known that some buildings were heated and cooled via electricity.

1) Analysis of the electricity data for the buildings Cromwell House and Decora suggest that approximately 25% of the electricity used in buildings with electric heating can be attributed to heating. Assuming 100% of that electricity is turned into usable heat and 2.2% of buildings are known to have electric heating, it may be further assumed that 25% of 2.2% of the total campus electricity may be attributed to distributed electric heating.
2) Analysis of the electricity data for the buildings King House and Morgan Hall suggest that approximately 13% of electricity in those buildings is attributable to cooling. Assuming that chilled water is produced at 1.1 kw/ton of cooling, it may be further assumed that 13% of the 15.6% of total campus electricity is attributable to distributed cooling.

	Central Steam	Central Chilled Water	Natural Gas	Campus Electric	Hot Water	Chilled Water	Notes
GSF	2,596,398	1,118,554	2,847,524	2,847,524			Source: GH per Energy Master Spreadsheet_Smith College.xlsx
Total Btu	**113,611,371,261**	**51,310,142,240**	**13,764,899,490**	**73,462,472,028**			**252,148,885,019 Btu**
Distributed Equipment Adjustments							
GSF with Electric Heating				61,845	61,845		Source: Questionnaire
% of Total Connected GSF			1	2.2%			
Allocation of Campus Electric for Distributed Heating				-124,586 kWh	425,087,390 Btu		GSF is heated with electric heating. Electric profiles show about 25% of electricity in those buildings is used for cooling (see CromwellHouse and Decora tabs). Assume 100% of electric Btus are turned into useable heat.
GSF with Electric Cooling				444,330		444,330	Source: Questionnaire
% of Total Connected GSF			2	15.6%			
Allocation of Campus Electric for Distributed Cooling				-644,844 kWh		8,511,939,505 Btu	GSF is cooled with some mode of distributed chilling. Electric profiles show about 13% of electricity in those buildings is used for cooling (see KingHouse and MorganHall tabs). Assume 1.1 kw/ton.

Allocation of Campus Energy to Hot and Chilled Water

Energy from the known thermal energy sources needed to be reallocated to hot water or chilled water. Sub-steps included:

1) Allocation of Central Steam, Natural Gas, and Electric Heating BTUs to Hot Water Demand.
2) Allocation of Central Chilled Water and Electric Cooling to Chilled Water Demand.
3) Adjustment of Campus Electricity to remove Electricity used for space heating in Steps 1 and 2.

[1] Since metered data was not available to calculate distribution and building conversion loss percentages, the assumptions used were based on MEP's experience working on other campuses with similar systems.

4) Summation of Hot Water and Chilled Water Demands to calculate the starting annual energy to be allocated.

	Central Steam	Central Chilled Water	Natural Gas	Campus Electric	Hot Water	Chilled Water	Notes
GSF	2,596,398	1,118,554	2,847,524	2,847,524			Source: GH per Energy Master Spreadsheet_Smith College.xlsx
Send-out energy from central meter point	206,566,130 lbs	4,363,107 ton-hrs	265,475 therms	21,748,100 kWh			Source: Smith Plant management reports
Adjusted Total Btu	**113,611,371,261**	**51,310,142,240**	**13,764,899,490**	**73,462,472,028**			**252,148,885,019 Btu**
Allocation of Campus Energy to Hot Water	-103,283,065 lb		-132,738 therms	-124,586 kWh			
Allocation of Campus Energy to Hot Water (Btu)	-113,611,371,261	1	-13,764,899,490	-425,087,390	127,801,358,141		
GSF connected	2,596,398		251,126	61,845	2,909,369		
Average Campus Building EUI - Hot Water	-43.8 kBtu/GSF		-54.8 kBtu/GSF	-6.9 kBtu/GSF	43.9 kBtu/GSF		
Allocation of Campus Energy to Chilled Water		-4,275,845 tons		-644,844 kWh			
Allocation of Campus Energy to Chilled Water (Btu)		-51,310,142,240 Btu	2	-8,511,939,505		59,822,081,745	
GSF connected		1,118,554		444,330		1,562,884	Assumes that 1,346,485 GSF is uncooled
Average Campus Building EUI - Chilled Water		-45.9 kBtu/GSF		-19.2 kBtu/GSF		38.3 kBtu/GSF	
Non-thermal Campus Electric				20,978,670 kWh			
Non-thermal Campus Electric (Btu)			3	71,579,222,417			259,202,662,303
GSF				2,847,524			
Average Campus Building EUI - Electricity				25.1 kBtu/GSF			107.3 kBtu/GSF
			4	**Campus Electric**	**Hot Water**	**Chilled Water**	
Starting Annual Energy to be Allocated				**71,579,222,417**	**127,801,358,141**	**59,822,081,745**	

Step 3: Allocate total energy to each building

Goal: Calculate the **Building Annual Thermal Energy Demands:** how much thermal energy each building will require over the course of a year.

Step 2 calculated the total amount of energy that can be attributed to the thermal energy demands for each group of buildings. However, this was a single annual number for each type of energy. In this step. totals were allocated for each energy type to the buildings in the building list.

1) The BTUs for the buildings were removed where high-quality data was available: Ford Hall and Sabin Reed Hall. These two buildings represent roughly 25% of all thermal energy consumed by the campus in the baseline year.
2) The anticipated amount of energy needed for cooling the buildings that are not currently cooled was re-added under the assumption that future spaces will have a similar cooling intensity as the existing spaces.

	Campus Electric	Hot Water	Chilled Water	Notes
Starting Annual Energy to be Allocated	**71,579,222,417**	**127,801,358,141**	**59,822,081,745**	
Less: Specific Building Energy Allocation				
Ford Hall	9,216,939,564	14,139,148,300	4,939,971,541	1 — 201.7 kBtu/GSF
Sabin Reed Hall	7,067,152,870	20,296,605,605	8,598,988,048	294.5 kBtu/GSF
Remaining for Allocation	**55,295,129,983**	**93,365,604,237**	**46,283,122,156**	35.6 kBtu/GSF
Plus: Btus for Buildings not Cooled			47,921,585,281	2
Total Btus to be Allocated to Non-Specific Buildings	**55,295,129,983**	**93,365,604,237**	**94,204,707,437**	
Total Btus to be Allocated to All Buildings	**71,579,222,417**	**127,801,358,141**	**107,743,667,027**	

The outstanding energy demand was then allocated to the remaining buildings. Rather than using a simple allocation by GSF, the allocation was weighted based on information that was gathered in the Building Questionnaire. Specifically, the following weighting factors were used:

	Heating	**Cooling**	**Electric**
What is the building's Programmatic Function?	**Relative to avg GSF**	**Relative to avg GSF**	**Relative to avg GSF**
Residential	0.5	0.5	0.5
Academic / Classroom	0.75	0.75	0.75
Administration / Office	0.65	0.65	0.65
Recreation	1.1	1.1	1.1
Laboratory	2.25	2.25	2.25
N/A	1	1	1
	Heating	**Cooling**	**Electric**
Is the building ventilated?	**Relative to avg GSF**	**Relative to avg GSF**	**Relative to avg GSF**
Yes, with Heat Recovery	0.5	0.5	0.5
Yes, with Energy Recovery	0.5	0.5	0.5
Yes. Return air system.	0.75	0.75	0.75
Yes. 100% outside air system.	1.5	1.5	1.5
Operable windows or no mechanical ventilation	1.2	1.2	1.2
N/A	1	1	1

What is the quality of the building envelope?	Heating Relative to avg GSF	Cooling Relative to avg GSF	Electric Relative to avg GSF
1 - high-quality; new or fully updated	0.6	0.6	0.6
2 - high-quality; original insulation but updated fenestration	0.7	0.7	0.7
3 - acceptable; new insulated with new fenestration	0.85	0.85	0.85
4 - acceptable; new insulated but original fenestration	0.9	0.9	0.9
5 - low-quality; minor upgrades	1.1	1.1	1.1
6 - poor quality; no insulation and/or original fenestration	1.5	1.5	1.5
N/A	1	1	1

Modeled Building EUIs

Using the total BTUs to allocate the weighting factors, the utility connection information from the questionnaire, and the GSF of each building, the project team was able to calculate an EUI for each building with and without future cooling. If it is assumed that cooling will not be added to any existing building, the average EUI is 96 kBTU/GSF/Year. The average EUI with additional cooling is 112 kBTU/GSF/Year.

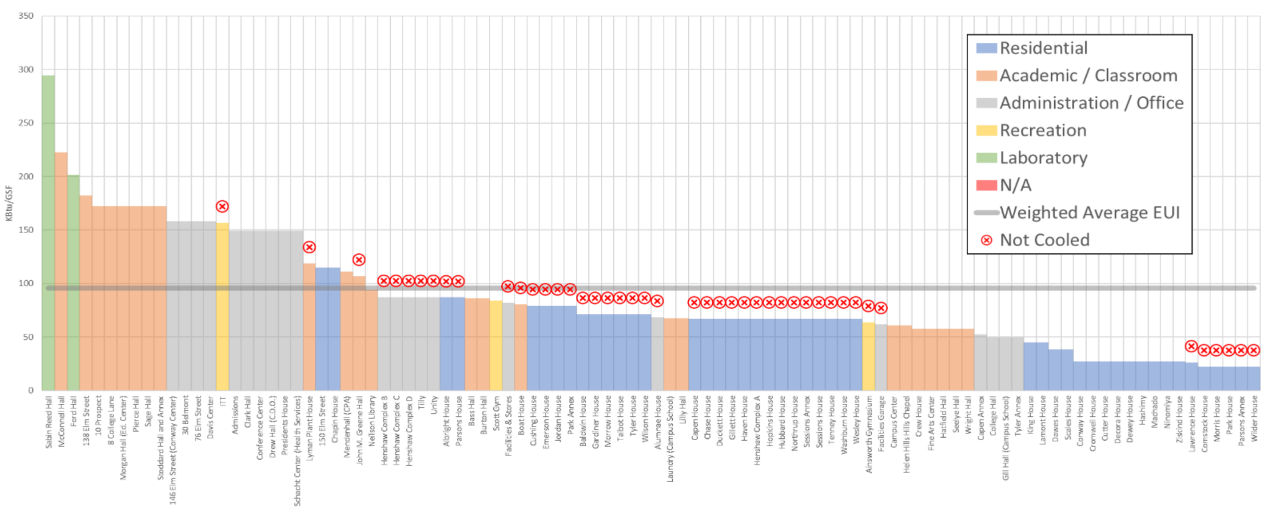

Figure 26: Graphic of all campus buildings and their associated energy use intensity, assuming no additional cooling is added to existing buildings.

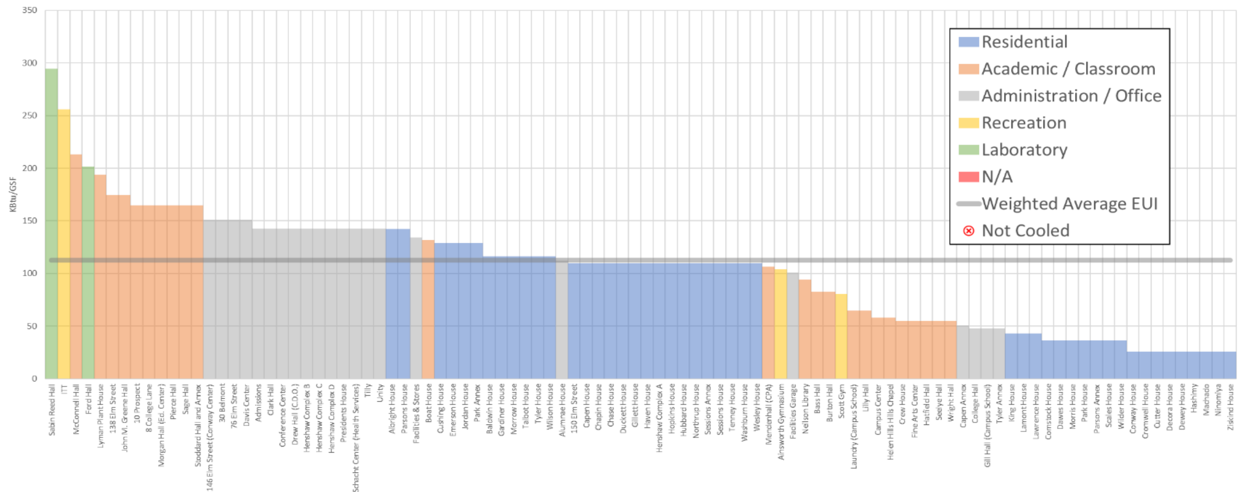

Figure 27: Graphic of all campus buildings and their associated energy use intensity, with additional cooling.

Step 4: Allocate total building energy across a typical year

Goal: Distribute the typical annual thermal heating and cooling energy demand for each building across the hours of a typical year.

At the end of Step 3, every building in the scope had an annual total value to represent its heating and cooling demand in BTUs. The goal of Step 4 was to distribute those BTUs across the 8,760 hours of a typical year to create an hourly, building-specific thermal profile (Figure 28).

The following allocation methods were used in accordance with the available data for each building:

- Annual allocation profile - specific buildings
    - Where specific metered building information was available a building-specific profile was created and used in the campus-wide thermal profile. The building-specific profiles use were for Ford Hall and Sabin-Reed Hall.
    - These building-specific profiles were weather normalized using a typical meteorological year (TMY3) weather file.
- Annual allocation profile - profile based on an energy model
    - Where building-specific energy information was not available, an hourly building energy profile was created using an energy model. An energy model for the following space types were created using the Northampton, MA weather zone:
        - Academic / Classroom
        - Administration / Office
        - Recreation
        - Residential

- The hourly energy profile was then assigned to each building based on the Programmatic Function of the building and adjusted for the energy assigned to each building in Step 3 above.

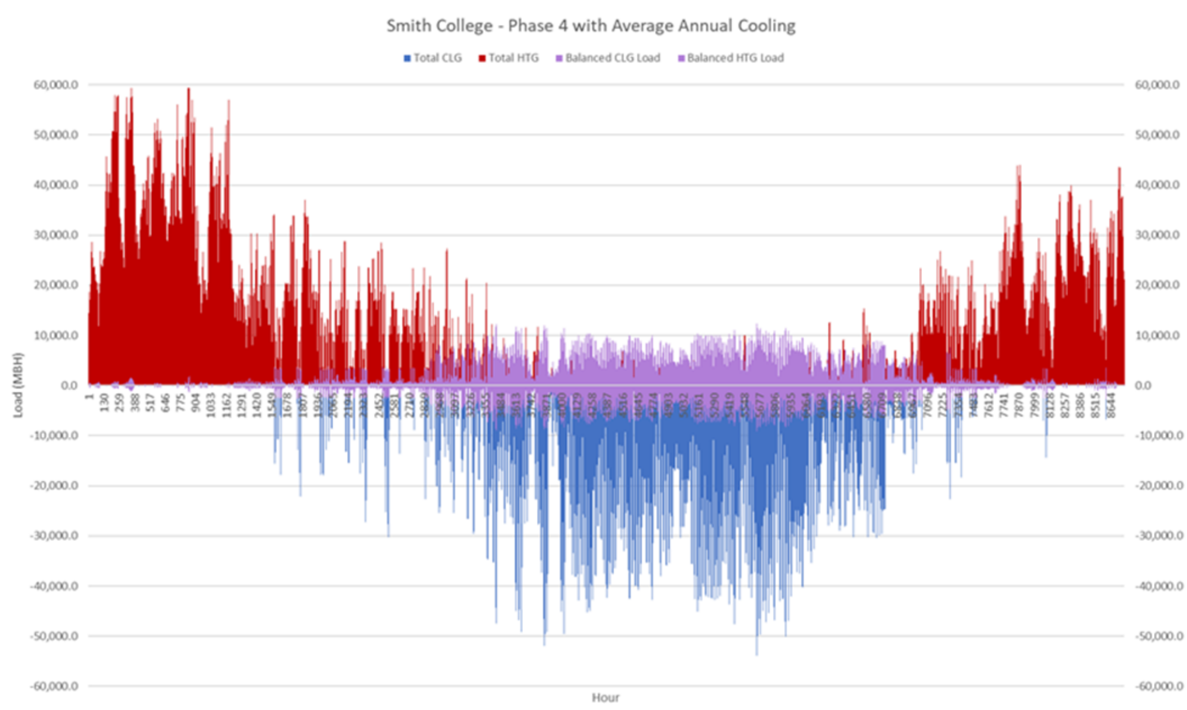

Figure 28: Annual load profile of heating and cooling demands for the campus on an hourly basis.

Building Profile Examples

Figures 26 through 33 are visualizations of the hourly profiles which were used to allocate the annual energy across the typical year.

Ford Hall

Figure 29: Example building-based annual load profile for heating and cooling demands for Ford Hall.

Sabin Reed Hall

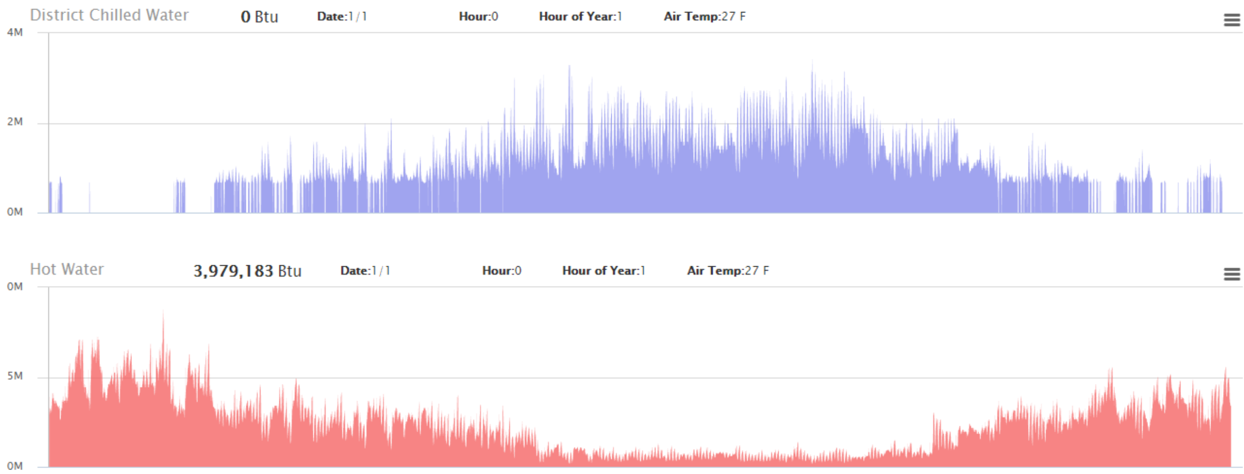

Figure 30: Example building-based annual load profile for heating and cooling demands for Sabin Reed Hall.

Energy Model: Academic / Classroom

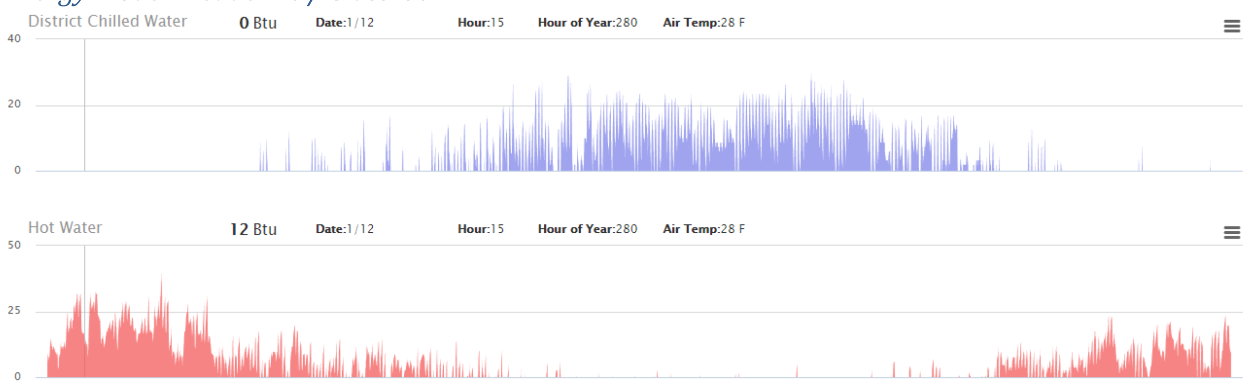

Figure 31: Annual load profile developed via energy modeling for a representative Academic/Classroom building.

Energy Model: Administration / Office

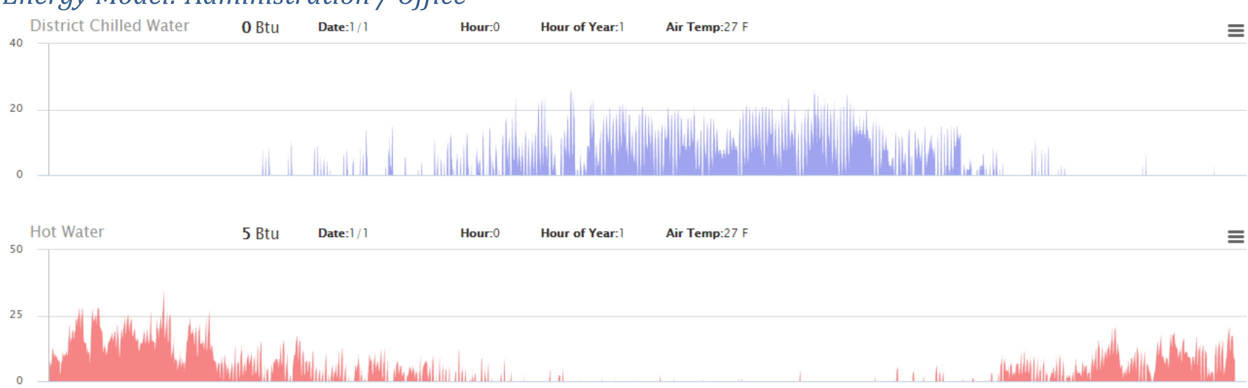

Figure 32: Annual load profile developed via energy modeling for a representative Administration / Office building.

Energy Model: Recreation

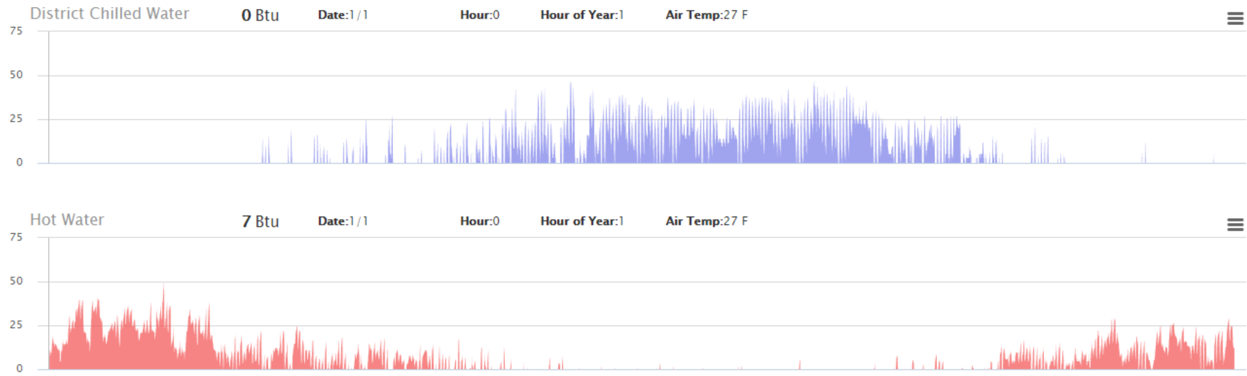

Figure 33: Annual load profile developed via energy modeling for a recreational building.

Energy Model: Residential

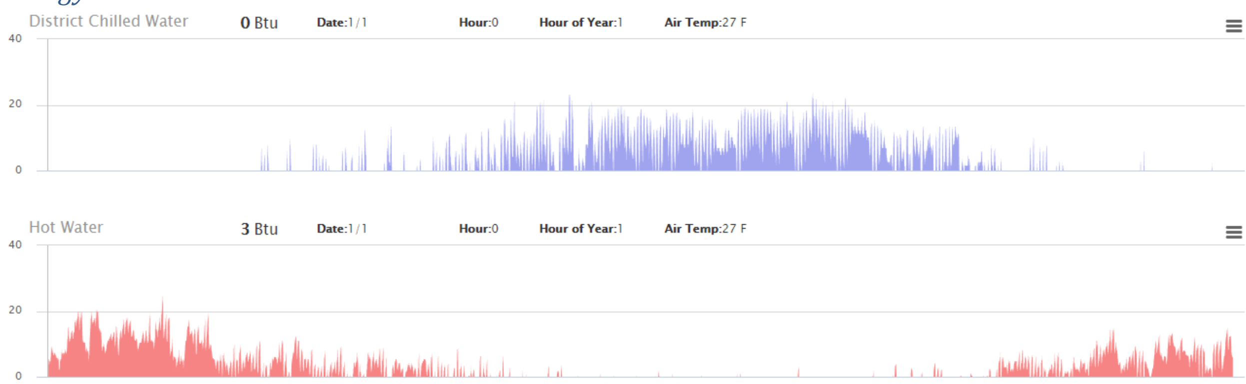

Figure 34: Annual load profile developed via energy modeling for a representative residential building.

Rebates and Incentives

There are multiple potential rebates and incentives that are available at the local and state levels for this project. Due to the complexity, uniqueness, and lengthy implementation schedule, there are currently no prescriptive rebates or incentives available. However, through the Massachusetts Alternative Energy Portfolio Standard (APS) program, any entity who wants a Generation Unit to be qualified for participation in the APS Renewable Thermal program must apply for a Statement of Qualification (SQA). As the project continues into schematic design and generation and project sizing is refined, Smith College will continue to collaborate with the state and local utilities to determine potential custom rebates/incentives. There is interest from all parties in supporting Smith College with their decarbonization goals.