Western Washington University

Heating System Conversion Feasibility Study

SP084

Submitted By: Säzän Group & Integral Group

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Acknowledgements

The project team would like to begin by acknowledging that the Western Washington University campus is the ancestral homelands of the Coast Salish Peoples, who have lived in the Salish Sea basin, throughout the San Juan Islands and the North Cascades watershed, from time immemorial. We express our deepest respect and gratitude for our Indigenous neighbors, the Lummi Nation and Nooksack Tribe, for their enduring care and protection of our shared lands and waterways.

The project team would also like to acknowledge the highly collaborative partnership we had with members of a specially formed Western Washington University (WWU) Working Group that oversaw and supported our work. These individuals offered invaluable insights based on their experience and understanding of campus operations, represented WWU's interests and perspectives to guide decisions, as well as worked tirelessly to ensure that the project team got the data and information we requested in a timely manner to enable completion of this study. Among those specifically we would like to thank are:

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Introduction

On July 13, 2021, Western Washington University issued a Request for Qualifications for a consultant team to assess the feasibility of replacing their existing aging campus steam-based heating system. A primary objective of WWU is to reduce and ultimately eliminate WWU heating system greenhouse gas emissions (GHG) and the university's overall environmental impact. This report, generated by the selected consultant team led by Säzän Group and Integral Group, provides the results of the feasibility study.

In response to a request from WWU, funding for the study was appropriated by the Washington State Legislature through the Department of Commerce. The deliverables of this study – this report, including results from technical and financial analyses – will be used in development of a capital funding request to the Washington State Office of Financial Management (OFM) to develop Schematic Design (SD) documentation for the Preferred Alternative heating system conversion option, as described herein. The future SD documentation in turn would be used to support contracting for further design and development and ultimate delivery of needed upgrades, that are cumulatively viewed as a long-term capital program at WWU.

Though the work reported here is not a predesign as defined by OFM, the Predesign Manual issued by OFM for capital projects provided a general guide for how this report is organized. Major report sections include an executive summary, a problem statement, a review of the analysis methodologies used, an overview of the impacted campus infrastructure, development of heating and cooling demand profiles for the campus, initial screening of potential alternatives, the technical and financial analysis of most promising low-carbon emitting options, a presentation of a Preferred Alternative, with cost analysis that includes anticipated capital expenditures and impacts on operating costs. Appendices are included that provide supporting information.

Table of Contents

Executive Summary

Problem and Purpose

Western Washington University (Western) currently relies on an aging, natural gas fired central steam plant and distribution system to provide heating and hot water to the main campus. The system accounts for nearly 97% of Western's annual greenhouse gas emission (GHG) and about 57% of Western's FY23 utility budget. While the plant is well maintained and operates as efficiently as possible, its economic and operational efficiency are ultimately limited by a mid-twentieth century design. In addition, qualified operators must be on site twenty-four hours a day, and as the industry slowly transitions away from steam heating it is becoming increasingly difficult to find and retain these personnel.

From an engineering standpoint, the transition from steam to hot water distribution and natural gas combustion to electric heat pumps would increase energy efficiency by over 300%. When added to the existing purchase agreement for fully renewable clean electric power, the change would nearly eliminate fossil fuel burning for campus heating and hot water production and dramatically reduce annual CO_2 emissions. Western's strong commitment to being a regional leader in mitigating climate change includes exceeding state requirements and reaching carbon neutrality by 2035, as outlined in the Sustainability Action Plan, and being a signatory on the Presidents' Climate Commitment. This alternative approach to heating infrastructure would align with those commitments.

Within this context, Western commissioned a consultant team to analyze the economic and engineering requirements of such a conversion. Feasible low carbon options for new central plant configurations were developed and their relative advantages identified. Energy and carbon savings and other operational costs were estimated and balanced against the initial costs of construction using a total cost of ownership (life cycle cost) model. The financial analysis also considered the increasing need for major renewal and replacement of the steam system over the coming years, as well as the eventual renewal and modernization of heating and cooling systems in all buildings. Based on the financial and technical analyses completed, a Preferred Alternative was identified.

Methodology and Options Analyzed

The study was organized into four overlapping phases. In the initial Discover phase, investigators reviewed existing documentation and utility information and visited the campus to better understand the existing infrastructure. The information was analyzed to derive Western's aggregated annual heating and hot water demand profile for all buildings served by the steam infrastructure. As it became clear that heat pump technology would be one of the options considered for the central plant, the decision was made to add cooling to select buildings as part of the analysis. This is a need that building occupants have repeatedly communicated and would have the secondary benefit of potentially providing a source of heat recovery. The options ultimately developed therefore included provisions for centralized chilled water generation.

The heating and cooling thermal demand profiles were further refined to account for anticipated future development and incorporation of energy efficiency retrofits in existing buildings. The retrofits were either already a part of Western's capital plans or were cost effective enough to likely be done in the future as part of normal renewal of aging assets.

The Define phase of the project focused on identifying a broad list of potential strategies for new centralized heating and cooling infrastructure and then filtering it down to a short list of the four most promising options for detailed analysis in the subsequent phase. Meetings with the WWU Working Group further clarified objectives to help inform the process. The consultant team worked with Western to define Evaluation Criteria used to assess the shortlisted options. Categories in the Evaluation Criteria include carbon, financial, technical, implementation, and political/social/environmental (PSE) performance. These criteria were weighed based on factors determined by the WWU Working Group and Steering Committee.

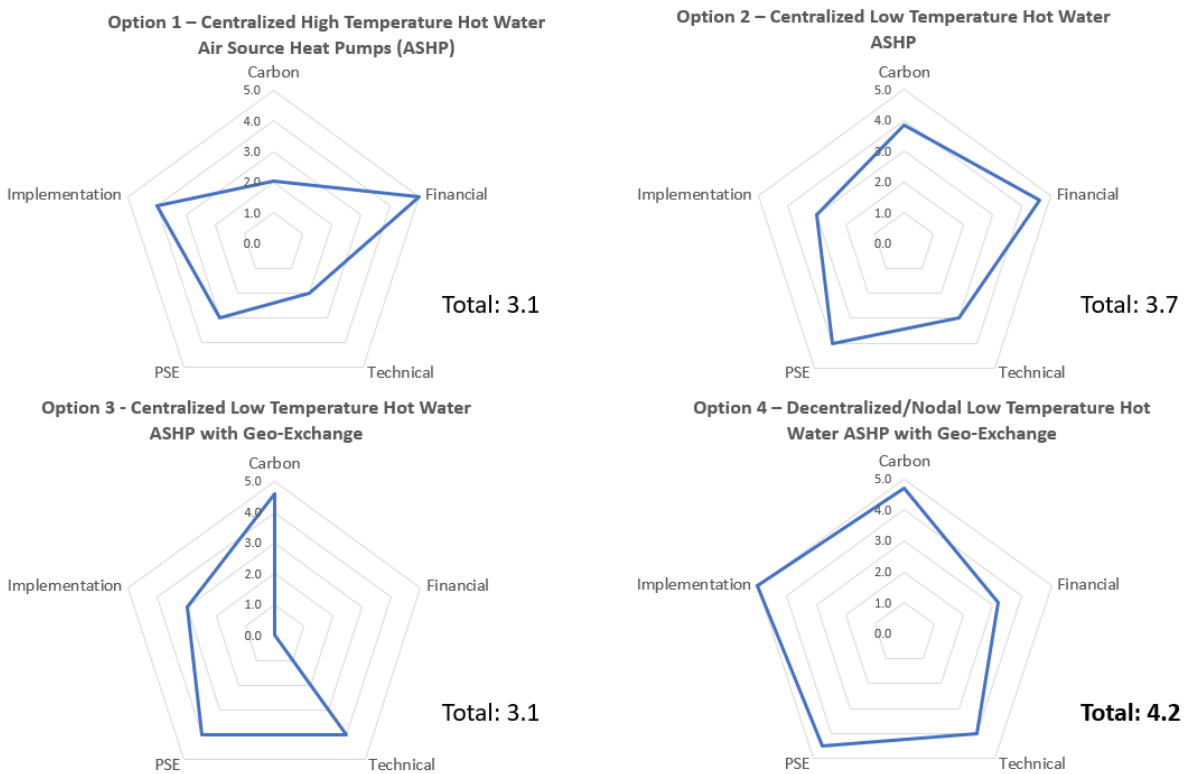
In the "Refine" phase a detailed evaluation of options was completed. Thermal and mechanical modeling tools enabled the consultant team to develop preliminary system configurations and estimate energy use, carbon emissions, and operating costs. Capital costs for required upgrades were estimated, along with 50-year life cycle costs. Using the results of these analyses and an Evaluation Criteria matrix, a Preferred Alternative was selected.

Of the four options selected for detailed evaluation, three assume a single central plant would be provided to deliver heating and chilled water to the WWU campus. The fourth option is a de-centralized or nodal option where multiple heating and cooling plants would be provided, each serving a different portion of the campus. All options include various combinations of complementary heat pump technologies, including air-source heat pumps, water source heat pumps, heat recovery chillers, and air-cooled chillers. For times when both heating and cooling are needed simultaneously, instantaneous heat recovery from return chilled water would be provided. Natural gas boilers are included as a winter peaking strategy that also provides resilience. Each option includes separate supply and return piping for both heating and chilled water that is distributed to serve Energy Transfer Stations in each building. Options 3 and 4 also include a geo-exchange field to efficiently capture and reject heat into the earth using water-to-water heat pumps and heat recovery chillers.

Results

The evaluation criteria represented in the chart below provides a summary view as to how each option compares to the others. As indicated, each option has its strengths, with Option 4 receiving the best overall score. It excels in the Carbon, Technical and PSE categories due to the best overall performance of the system and the use of geo-exchange.

Option 4 also provides increased resiliency to campus heating operations. This is accomplished by complementing a heat pump system coupled with geo-exchange in a nodal configuration with peaking/backup gas-fired boilers. The nodal plant and distribution network configuration of Option 4 also provides more implementation flexibility. Each node can be implemented independently of the others, providing more manageable projects that may match up better to available funding. Western can also strategically choose the order in which the individual nodal systems are constructed. Overall campus disruption during construction is also limited at any one time to the area of campus served by the node and distribution piping being installed.



Evaluation Criteria: Weighted scoring of each option as determined by the WWU Working Group and Steering Committee

The quantitative findings of the financial and technical analysis, detailed in the tables below, provide additional insight both when comparing the four options to each other and when referenced against a business as usual (BAU) case. Over an assumed phased implementation period of 15 years, the total capital expenditures for new campus heating/cooling infrastructure to replace the steam system ranges from a low of $126M for Option 1 to $189M for Option 3. A striking finding is that the estimated capital costs to replace the existing steam system infrastructure for each option are considerably lower than the estimated construction costs to complete upgrades required within buildings that enable them to heat using low temperature (140F) heating water.

15 Year Capital Expenditures (Millions of dollars)	BAU[1]	Option 1	Option 2	Option 3	Option 4
Capital Costs - Central Heating/Cooling Infrastructure (Generation and distribution)	$13	$126	$130	$189	$149
Capital Costs - Building Upgrades	N/A	$314	$314	$314	$314
Total Capital Costs over 15 Years	$13	$440	$444	$503	$463

[1]Business as usual (BAU) is estimated capital cost to maintain existing system for the next 15 years, with no additional investments to replace/upgrade aging heating systems within buildings served by campus steam or the addition of cooling for buildings designated by Western as requiring it.

The results of the 50-year life cycle cost and performance analysis are indicated in the table below. All four options, as expected, dramatically reduce GHG emissions (up to 98% with Option 4) and increase energy efficiency over the BAU.

The life cycle cost results show that, over the 50-year life cycle, total energy costs for the BAU will be nearly the same as the energy costs of the best performing low carbon options, despite their much lower energy use and cost. This result is attributed to the current much lower price of natural gas relative to electricity. However, when carbon pricing is considered, the combined cost of energy and carbon is significantly higher in the BAU case. When capital, energy, carbon, and O&M costs are combined into a total cost of ownership model, options 1 and 2 are comparable to the BAU. Option 4 is slightly higher, but still within a similar range. Option 3 is markedly higher.

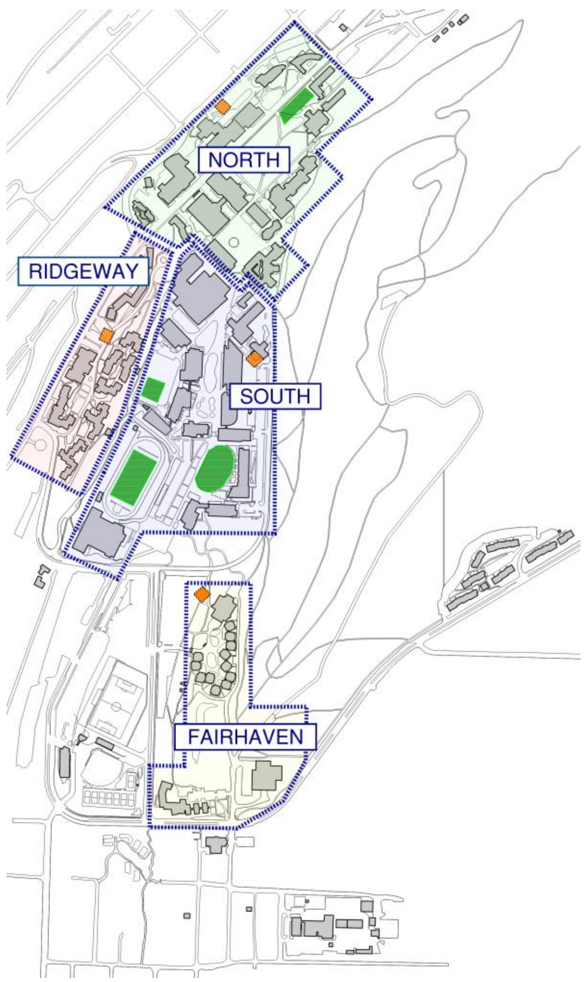
50 Year Life Cycle Costs (Millions of dollars)	BAU[1]	Option 1	Option 2	Option 3	Option 4
Total Nominal O&M Costs	$119	$81	$81	$81	$81
Total Nominal Energy Costs	$100	$105	$116	$104	$104
Total Nominal Carbon Costs	$54	$8	$3	$1	$1
Total Nominal Energy & Carbon Costs	$154	$113	$119	$105	$105
Total Cost of Ownership	$745	$720	$731	$784	$747
Net Present Value (NPV)	$566	$561	$568	$620	$585
GHG Emissions, CO_2 (thousands of tons)					
Total GHG emissions over 50 Years	326	48	19	7	5

[1]For the 50-year life cycle cost analysis the BAU case includes cost to incorporate standalone cooling systems in existing buildings as identified by Western, along with other costs to complete condition-based replacement of aging heating systems in existing buildings. These costs together provide a more equivalent BAU baseline case from which to compare the Options.

Overall, while Option 4 did not have the lowest estimated capital cost or life cycle cost within the sensitivity of the analysis due to inclusion of the geo-exchange, it notably outperformed the other three options in all remaining evaluation criteria categories. Option 4 provides the best overall performance; therefore, it is recommended to be further developed and optimized as the Preferred Alternative.

As envisioned, this project could move forward *without* the building upgrades within the buildings served. This would make the capital costs an estimated cost of $149 million, only 32% of the total project cost. This scope of work is envisioned to be done in phases and, when complete, will eliminate the need for the Steam Plant and aging distribution system. This would also still greatly reduce Western's total greenhouse gas emissions (GHG) but would require heavier usage of the backup natural gas boilers in each plant during colder weather. Therefore, the project's goal of reducing the GHG emissions by 90% would not be realized until all the improvements within the buildings are completed in the future.

The map below shows a conceptual image of how the campus would be divided into the proposed nodes.



Campus map: Areas served by proposed nodal systems in Option 4. Potential geo-exchange fields are shown in green and potential plant locations in orange. All locations and sizing shown are for reference only and will be further refined during schematic design.

Proposed Next Steps

Given the breadth, complexity, and cost of infrastructure upgrades required for the conversion from central steam heating to a low GHG emission heating system, the implementation of the Preferred Alternative is probably best considered as a multi-year phased program rather than as a project or series of projects.

Western will request funding in the 2023 – 2025 capital budget for Schematic Design (SD) of the Preferred Alternative. The SD documentation will provide additional scope clarity, phased implementation scenarios, and a more refined financial analysis.

Funding mechanisms, as well as project delivery and future operations, may not follow traditional paths. Capital funding from the state via a biennial capital funding request will find conflicting priorities given the magnitude of the conversion, both at the Western campus and when considering competing interests at the State level. The evaluation of alternative delivery models is therefore recommended.

Prior to the start of SD data collection and testing, Western is advised to determine the lowest supply heating water temperatures needed in each building to adequately heat them on winter heating days. This will help establish very clearly the initial operational requirement for the new system being designed and may help identify future building upgrades to maximize GHG reductions as quickly as possible.

Finally, as technical concepts and implementation scenarios are developed during SD, and financing and delivery options are identified and evaluated, the transparent engagement and inclusion of Western stakeholder groups is strongly recommended. Stakeholder participation would create a robust, collaborative process that would ensure alignment with Western's strategic and sustainability goals and generate new ideas for implementation and important feedback about how the infrastructure upgrades will affect the campus community.

Background Information

Western currently operates a central heating plant and distribution system based on high pressure steam. The system accounts for nearly 97% of Western's annual greenhouse gas emission (GHG) and about 57% of Western's FY23 utility budget. Nearly every building on campus receives steam for heating and building hot water through this central system, served by boilers at a central steam plant and roughly 4.5 miles of high-pressure steam and condensate return lines distributing steam throughout the campus.

Most of the steam distribution system was installed between 1950 and 1980, meaning most of the system is from over 40 to over 70 years old. Roughly 1/3 of the system has been renewed through minor capital preservation investment over the past several biennia; however, there remains a significant backlog of maintenance and repairs for the steam system and steam plant. In addition, 4 of the 5 boilers are due soon for replacement or major overhaul. A cost burden on the existing systems is it requires dedicated, highly trained full-time staff to monitor, manage and maintain steam production 24/7.

While the existing system has been reliable and is operated as efficiently as possible, its economic and operational efficiency is limited by a design that largely dates from the early- to mid-20th century. From an engineering standpoint, simply transitioning to centralized direct hot water heating that is still generated through burning of natural gas is roughly 30% more energy efficient than the existing steam system. But, by focusing instead on maximizing use of heat-pump based all-electric technologies using waste and renewable/natural heat sources in lieu of natural gas the energy efficiency and energy reduction potential is multiple times greater. This benefits Western by nearly eliminating direct fossil fuel burning at the campus for heating and hot water and reduces annual GHG emissions. Ultimately, all electric heating solutions enable decarbonization through the purchase of increasingly available, fully renewable clean electric power from the grid.

The benefits of this modern and progressive approach to campus heating infrastructure aligns with the Presidents Climate Commitment for which Western is a signatory. Depending on implementation timelines, this conversion would also align with the WWU Sustainability Action Plan that seeks to make Western a regional leader in the drive for a stable climate by exceeding state requirements and reaching carbon neutrality by 2035. The GHG reduction benefit of completing a heating system conversion like this would also enable Western to be a recognized regional leader among peer institutions. And practically, it could provide a hedge against future energy and carbon price risk.

The relative inefficiency and GHG emissions of the existing steam plant as well as the lack of centralized cooling as an available resource is also currently driving new building projects at Western to choose to deploy standalone heating and cooling systems that are not connected to the central steam plant in order to meet high performance targets around energy and carbon reduction. Extrapolated into the future, as more new facilities come online this decoupled, decentralized strategy results in overall higher O&M costs for the campus given a greater amount of heating and cooling equipment is deployed.

In response, the study reported here was commissioned by Western. A multi-disciplinary engineering consultant team with relevant engineering design and analytic experience was selected. Within Western a Working Group was organized to guide the consultant team, providing support and input where needed, and serving as proxy for Western's interests. The WWU Working Group reported to a WWU steering committee.

The consultant team was asked to analyze the economic and engineering requirements of such a conversion, defining expected energy and carbon savings and other operational cost savings that together balance against the initial costs of construction when considered on a total cost of ownership (life cycle cost) basis. The financial analysis considers the increasing need for major renewal and replacement to the steam system over the coming years, as well as the eventual renewal and modernization of heating and cooling systems in all buildings that will need to be addressed in the future based on age and condition. A menu of options was ultimately requested with enough information to enable Western to weigh the relative advantages of each option, considering also available funding, and select a Preferred Alternative that would then be the starting point for funding requests, starting with design.

Analysis of Alternatives

Analysis Method

Options Screening and Evaluation Criteria

To define a path towards decarbonizing campus thermal energy generation that also responds to Western's requirements and constraints the consultant team followed a systematic and phased approach. The objective was to first identify a larger group of potential strategies, then to narrow down the list to multiple decarbonization options for deeper study. The process is illustrated graphically in the figure below.

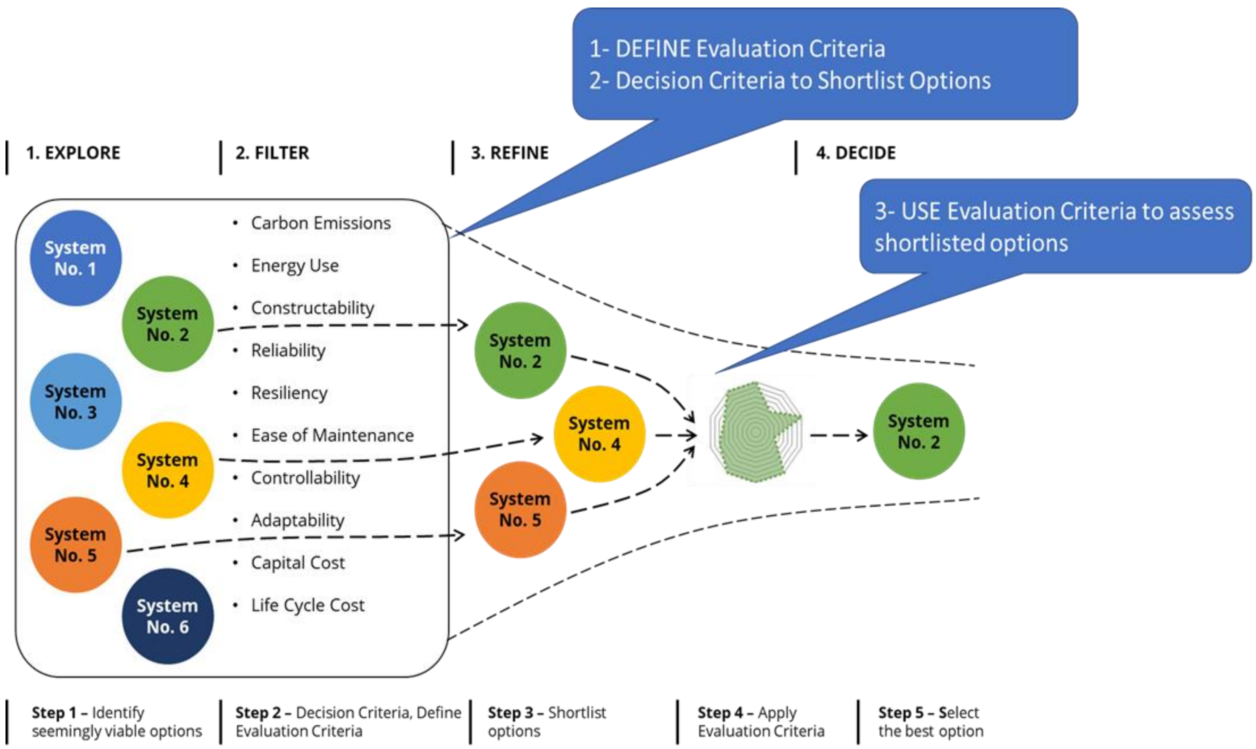


Figure 1 – Analysis method overview

The consultant team first reviewed a range of documents and data to develop an understanding of Western's campus existing infrastructure, site conditions, and thermal energy demands. With this understanding, they then identified and assessed the benefits and challenges of a range of low-carbon strategies that could be viable for Western's campus. These initial decarbonization options and high-level assessments were presented to Western as part of a "*Opportunity Evaluation Workshop.*" Western's input from a subsequent "*Strategy Workshop*" was used as the basis to narrow down the options.

The shortlisted options were further developed and quantitatively evaluated in the "Refine" phase. The consultant team worked with Western to define the Evaluation Criteria that were used to assess the shortlisted options. Evaluation Criteria provide a holistic framework for assessment that goes beyond quantifiable technical and financial performance. Categories in the Evaluation Criteria include carbon, financial, technical, implementation and political/social/environmental (PSE) performance. These criteria were weighed by the WWU Working Group and used to help inform the selection of a Preferred Alternative among the short list of identified options. The Evaluation Criteria and the relative importance (weight) used is provided in the figure below:

	Category	Weight (%)
	Carbon (GHG emissions) performance	34%
	Financial performance	25%
	Technical performance	20%
	Political, Social and Environmental (PSE)	8%
	Implementation	13%

Figure 2 – Evaluation Criteria Weighting as recommended by WWU Steering Committee

Energy Modelling

The operating energy use of each considered short listed option was calculated to provide metrics for use in the decision-making process.

Hourly thermal energy demand profiles were developed to estimate the thermal energy that needs to be provided for heating, cooling, and domestic hot water heating, along with representative hourly variations of those loads. The profiles were based on historical trend data provided by the campus (see below).

The hourly thermal demand profiles were input into the thermal plant model, which is a custom developed spreadsheet-based calculation of the hourly thermal processes of the plant components. Thermal loads are allocated to the different plant components, and the hourly performance is calculated for each to determine utility energy use and, when assessing low grade thermal energy sources and sinks, the heat of extraction and heat of rejection. Heat pump performance is calculated on an hourly basis using part load performance curves calibrated to sample equipment, the Carnot equation for heat pumps, and hourly variations in system fluid temperatures. As described below, some options included a ground source heat exchange, or "geo-exchange" field. In those cases, Earth Energy Designer software was used to model the field thermal response to the imposed loads and provide the resulting fluid temperatures for input to heat pump performance calculations. The model was iterated until all temperatures are within equipment limitations and all thermal demands were met. All plant configurations provide first stage lift for DHW heating, supplying the heated water to each building, where the second stage of heating is provided by distributed water to water heat pumps as needed to meet DHW supply temperature setpoints.

The results of the plant energy analysis include annual energy use, from which annual energy cost and carbon equivalent emissions can be calculated. The analysis results also include the capacity requirements of the major pieces of equipment and, where applied, low grade thermal energy sources and sinks.

Financial Assessment Method and Assumptions

Financial performance of options shortlisted was assessed on a 50-year lifecycle cost analysis (LCCA) basis. The LCCA is based on a large set of financial assumptions (e.g., discount rates, escalation rates, carbon pricing), technical assumptions (e.g., equipment life expectancies, efficiencies, maintenance costs, capital costs), as well as energy source assumptions (e.g., energy rates, GHGIs). The LCCA models were set up for this study to allow sensitivity studies to be performed on all modeling inputs.

The LCCA models are designed to compare the financial performances of options against a Baseline scenario. The LCCA accounts for:

- Capital costs of equipment
    - New investments and end-of-life replacement costs within the 50-year analysis period.
    - Future capital costs, adjusted for inflation with escalation rate.
    - Residual value of equipment, assigned as negative cost in year 50, at the end of analysis period.
- Energy costs for fuels and energy carriers
    - Electricity and fuels.
    - Cost premiums for renewable power purchase agreements.
    - Energy costs - adjusted over time as a function of energy use and escalation rates.
- Carbon costs
    - Carbon tax and carbon offsets.
    - Carbon costs are adjusted over time as a function of escalation of the carbon price factors.
- Operation and Maintenance (O&M) costs
    - O&M costs were determined based on WWU data and adjusted for inflation over time.

The following general financial assumptions and sources were used in the LCCA.

- Analysis period: 50 years (State of Washington requirement)
- Discount rate: 3%
- Escalation (general inflation, electricity, natural gas): based on “EvalLifeCycleCostTool” (State of Washington). General escalation is 2.42%
- Baseline rate of energy carriers (electricity and fuels): based on current values charged to Western and market research

  - Electricity rate (current): 9.21 cents/kWh. Includes renewable PPA premium
  - Natural Gas rate (current): $4.5/MMBTU (commodity) + $1.1/MMBTU (distribution and taxes) = $5.6/MMBTU. Natural Gas rate is highly volatile and has a very significant impact on overall project financial performance. Therefore, a sensitivity analysis conducted in the options evaluation section will test how potential changes in Natural Gas rate impact project conclusions
- Escalation rate of energy carriers (electricity and natural gas), excluding carbon cost: based on EvalLifeCycleCostTool (State of Washington)
- Cost of carbon: based on EvalLifeCycleCostTool (State of Washington). Increases from $75/ton to $136/ton
- GHG intensity of electricity: assumed zero, per renewable PPA
- O&M – Personnel: Based on workbooks provided by Western. BAU: $880K/yr, Options: $660K/yr
- O&M – Small projects: Based on workbooks provided by Western. BAU: $323K, Options: $161K (excludes steam-specific projects)
- Life expectancies: based on ASHRAE charts

For the purposes of comparing financial performance, the LCCAs of all low carbon Options and the Baseline, BAU scenario, assumes Options will be fully implemented on day 1 of the 50-year analysis period, both in terms of initial capital costs as well as energy and carbon performance. This simplifying assumption when applied to all options being evaluated does allow the LCCA to provide a fairer “apples to apples” comparison and subsequently informed the selection of the recommended Option (the Preferred Alternative) using the Evaluation Criteria. This approach avoids the need for assuming very speculative implementation plans for all the options. Looking ahead, different implementation scenarios for the Preferred Alternative can be developed and tested in the LCCA tool to help assess implications on cash flow and Net Present Value of those scenarios.

Existing Campus Infrastructure

Current Steam System

A “Utilities Master Plan Update” report commissioned by Western was issued on June 5, 2017. That report describes and characterizes the existing steam plant equipment as well as the distribution infrastructure used to provide steam to and return condensate from the buildings served by this system. Buildings connected to campus steam are illustrated in the campus map below.

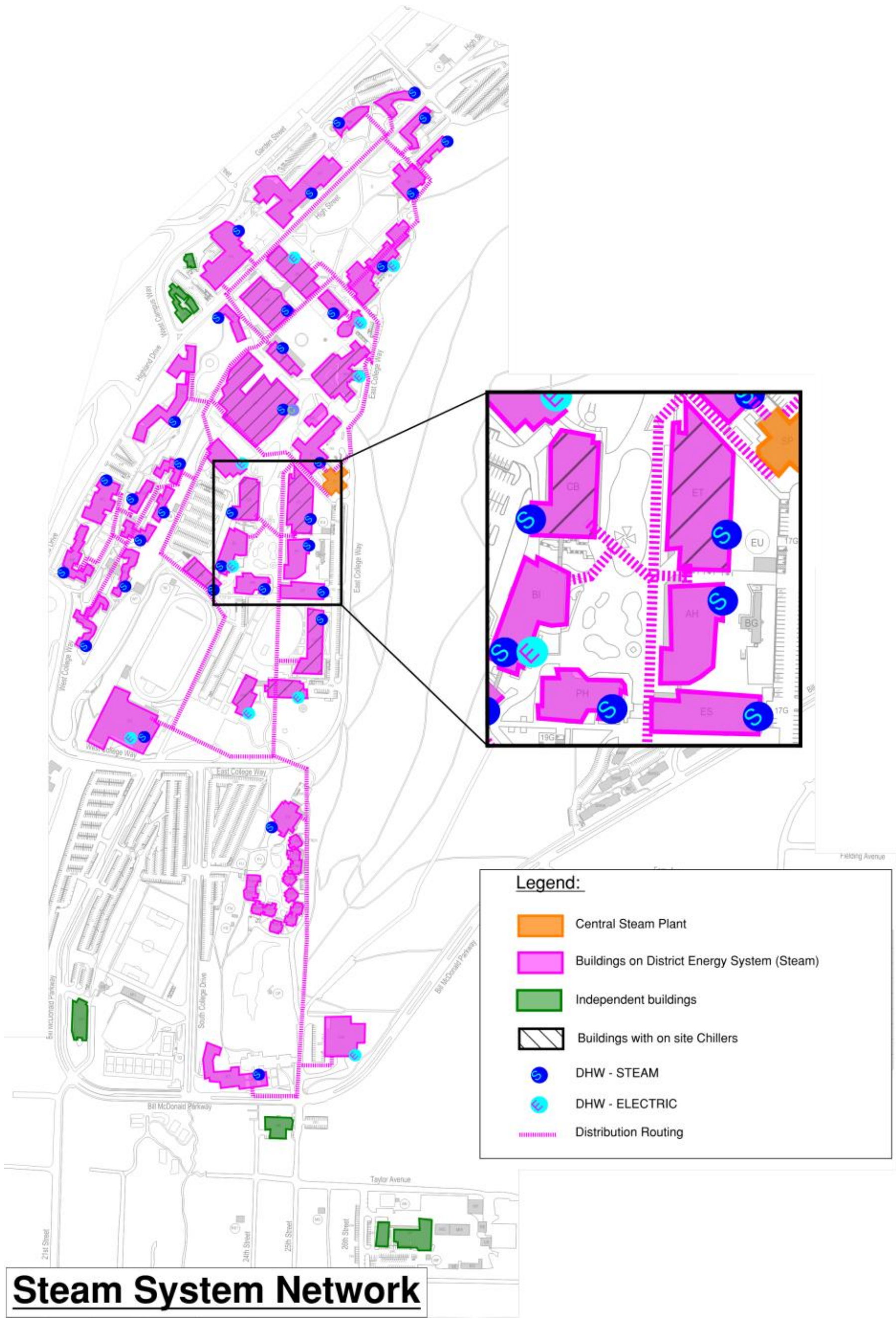


Figure 3 – Steam Distribution Map

Buildings on campus currently utilize steam in different ways, including:

- Direct steam for all heating
- Direct steam for heating air in central air handlers plus steam that is converted to hot water for a water-based distribution system to terminal heating units in spaces
- Steam conversion to hot water, where the heated water is used for all building heating
- Steam conversion to indirectly heat domestic hot water
- Steam for miscellaneous loads (e.g. labs, cooking)

The campus map below identifies in-building heating systems, including standalone buildings that do not rely on campus steam.

Figure 4 – Building Heating Systems

The consultant team on this study reviewed the utilities master plan, met with steam plant operations staff and completed a visual walk through the steam plant and steam tunnels where distribution piping feeding buildings is located. This helped inform conceptualizing strategies for deployment of new heating and chilled water infrastructure as part of a potential campus conversion from steam.

From the review of existing conditions it appeared to the consultant team that things are largely still as reported in the master plan, with aging but well-maintained boilers and other equipment. Age of equipment and piping is understood to be a concern given much of it is well past typical service life. However, the actual deferred maintenance appears to be largely minimized at present through the skill of Western's operations staff, the attention paid to monitoring the system and the continuing diligence that goes into planning and budgeting for future capital and maintenance expenses for that system.

Retaining the steam plant and infrastructure does not, however, align with Western's long-term goals for dramatically reducing carbon emissions and eliminating burning of fossil fuels on the campus. In addition, it may not be feasible to operate the system in the long term due to the increasing scarcity of qualified steam plant operators. Still, the inclusion of the BAU baseline of retaining the steam system for comparison to options identified and evaluated as part of this study was requested by Western. This was justified based on current confidence that, operationally at least, the existing steam plant can still be relied upon, presumably into at least the near future. That is, provided continued investments are made to renew elements of the system when needed, and (longer term) qualified steam plant operators can be found.

Cooling Infrastructure

The existing Utilities Master Plan Update report describes and characterizes in detail those existing buildings that currently have chilled water systems to serve all or portions of their conditioned spaces.

Early in the study the WWU Working Group identified a growing need to deploy cooling (or, additional cooling) in academic buildings. These additional future cooling loads were estimated and combined with existing building cooling loads, to create a profile for the analysis.

A table summarizing existing and desired buildings requiring cooling and their estimated connected peak cooling loads is provided in the "Future Profile" section, found later in this report.

There are O&M cost advantages associated with centralizing the chilled water service. The consultant team also identified additional energy and carbon efficiency benefits by running both heating and cooling from a central plant. For this reason, a common-to-all strategy for the options developed and studied included the assumption that existing chillers serving buildings would be replaced, with those buildings then being interconnected to a new central chilled water system. The additional buildings identified above as needing cooling in future were also assumed to be upgraded to have cooling via the central system.

A campus map showing the geographic locations for buildings requiring cooling is shown below. All buildings colorized (non-gray) were identified by Western as ones that ideally would be interconnected to a future central plant. Those with cross hatching have existing chillers. Color differentiations between buildings represent WWU Working Group categorizations for priority, if choices need to be made in future as far as timing for the interconnections and required building upgrades.

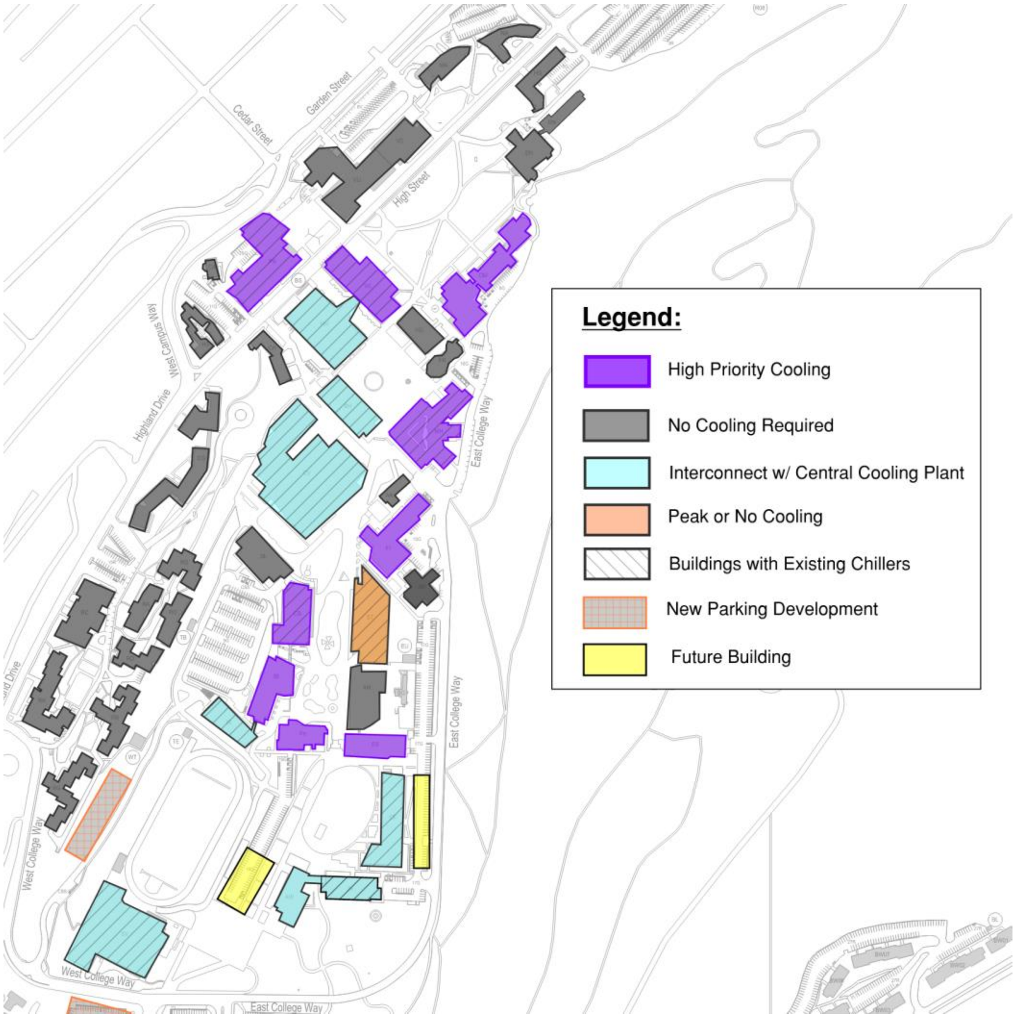


Figure 5 – Campus Cooling Map

To compare the Options being developed to the BAU scenario, it was assumed in the analysis of options that additional chiller capacity would be added in the BAU case for each building requiring cooling. So chilled water production for the BAU was fully decentralized with separate chilled water systems assumed on a building-by-building basis, whereas for the low carbon Options water chillers were all centralized.

Electricity Supply Capacity

As reported in the Utilities Master Plan document, Western's Campus is fed by 3 12,470 volt, 3 phase, 3 wire circuits, each originating from one of the service switchgear cabinets and each nominally rated for 450 amps. Each circuit is shown on the record one-line drawing as one set of 500kcmil copper conductors. At the time when the Utilities Master Plan was completed in 2017 records of highest loads on the 3 feeders for the prior 12 months, as measured by Western, indicated each is well below the nominal capacity, with, in the worst case one feeder at just under 30% of nominal capacity.

- Circuit A 2305 KVA (107 amps)
- Circuit B 1704 KVA (79 amps)
- Circuit C 2689 KVA (124 amps)

The Master Plan overstates the permissible loading of a feeder when other feeders are in service. Washington State has adopted the National Electrical Code (NEC) as the standard for installation of electrical systems. NEC Table 311.60(C)(77) lists 465A for one circuit and 370A for three circuits, at nominal environmental conditions documented in Section 311.60(F). The NEC does permit alternate calculations which can be more closely tuned to the actual soil conditions and construction geometries on site. Alternate calculations using software provide the following current limits with corresponding minimum power delivery.

System constraints will be most evident at duct bank runs, specifically between the PSE service substation and the first feeder route division at Vault TR9. Even with adjacent heat sources in the tunnels, air convection is much more efficient for removing heat from cables than concrete or soil conduction. Soil resistivity testing (recommended in Appendix F) would be taken at the substation perimeter and at one or two places between there and TR9, at minimum.

With that understanding, a representative duct bank cross-section was modeled to examine three-feeder and four-feeder utilization of existing duct banks showing a range of current limits based on soil conditions and actual duct bank arrangement. The power ducts are arranged in two rows of three, with Positions 1–3 in the upper row and Positions 4–6 in the lower row. The existing configuration is three feeders occupying the lower row ducts only. Soil thermal resistivity (rho) is assumed at 90°C-cm/watt when using NEC tables, but many locations in Western Washington have been measured at lower values, which allows higher current limits, as results show for rho = 60°C-cm/watt.

Table 1 – Three-feeder and four-feeder utilization

Case	Qty	Rho	Pos 2	Pos 4	Pos 5	Pos 6	Minimum Feeder Power
1	3	90	0.0 A	377.5 A	352.7 A	377.5 A	7,618 kW
2	3	60	0.0 A	407.7 A	381.0 A	407.7 A	8,229 kW
3	4	90	352.8 A	350.3 A	314.9 A	350.3 A	6,802 kW
4	4	60	386.0 A	383.3 A	344.7 A	383.3 A	7,445 kW

Note: Positions 1 and 3 are assumed vacant for three- and four-feeder analysis.

As part of this study utility data for 2019 (pre-pandemic) was analyzed. Hourly loads are provided in the chart below. As indicated, the peak demand in 2019 for the campus was 5,577 kW. This peak is well below the capacity of a single feeder even with the most conservative limit determined from the preceding analysis. Knowing the peak demand, and feeder capacity, provided the basis for understanding the likely design implications, operational constraints and recommendations for the electrical service when evaluating different replacement options for the steam system (see Appendix F).

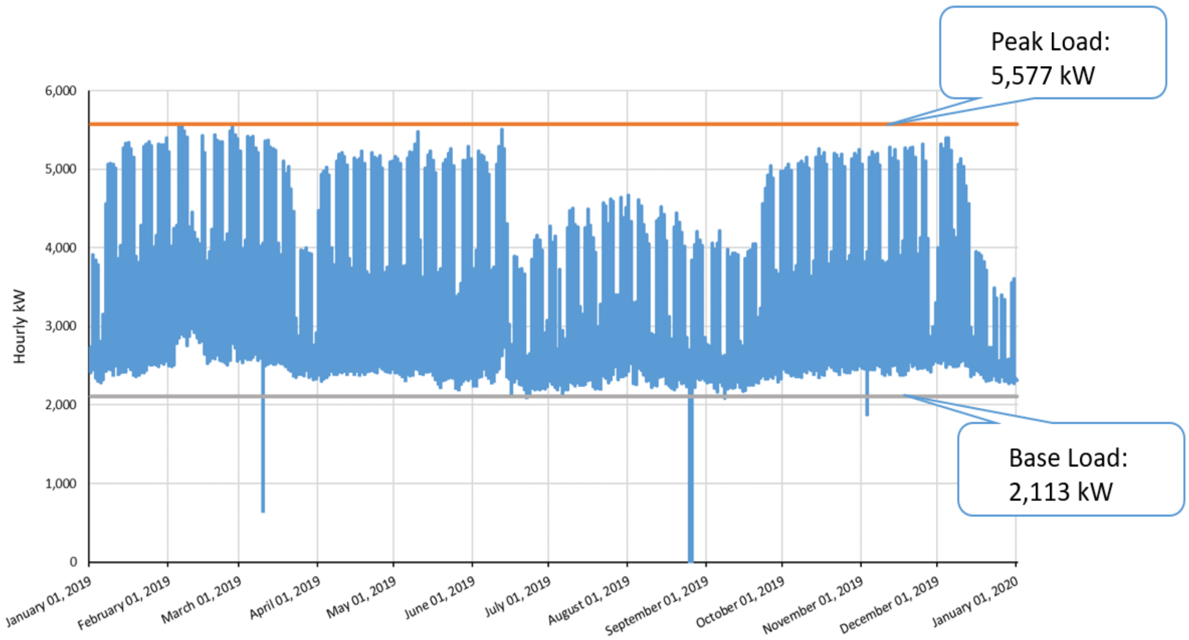


Figure 6 - Peak and base loads

Thermal Demand Profiles

Current Profile

To assist in the analysis of different options for this study, aggregated, campus-level space heating, space cooling and domestic hot water demand profiles for the Western Washington University campus were developed. The following sections outline the key assumptions and methodology used to develop the preliminary campus thermal demand profiles, and additional campus thermal demand considerations critical to developing decarbonization options for Western's campus district energy system (DES).

Existing Utility & Design Information Review

To develop the current heating thermal energy demand profiles for Western served by campus steam, the consultant team reviewed multiple key documents and historical data sets provided by the WWU Working Group. These include but are not limited to:

- Western's Energy Management Database – This provided monthly steam consumption by building. While very helpful, monthly resolution is insufficient for the understanding of short-term load variations or to determine meaningful correlations between steam usage and the corresponding ambient outdoor air temperature or occupancy patterns.
- "Daily Boiler Log Month & Year" spreadsheet. This provided daily steam production along with corresponding daily average outdoor air temperature for the central boiler plant. This dataset provides more granular time resolution (daily) to observe load dynamics. However, plant output is not a direct measurement of building thermal energy demand, since plant output is inclusive of thermal losses in the distribution system (which are significant in a central steam system).

- "Condensate_Interval_Data-2019.03.01-2020.02.28" spreadsheet. Provided 15-min resolution for building level condensate return. This dataset provides the best (shortest) time resolution, and directly measures the variable of interest (thermal energy use in buildings). However, valid data was only available for some of the energy nodes, which precludes its use for directly generating an aggregated load profile for the entire central system.

While none of the above datasets alone was sufficient, they together were critical pieces needed for generating estimated annual thermal heating energy demand profiles for Western's campus buildings currently connected to the existing steam system.

Current Campus Thermal Heating Demand

As the first step in developing the thermal demand profile buildings currently connected to the Central Steam system were identified. These provide the baseline for current operations. To discount any effects the Covid-19 pandemic has on typical campus operations and the corresponding thermal energy demand, the consultant group chose to use years 2018 and 2019 as a basis for developing typical current campus thermal energy demand profile. Shown in the figure below is a campus map developed to identify current steam infrastructure along with existing buildings connected to the campus steam DES.

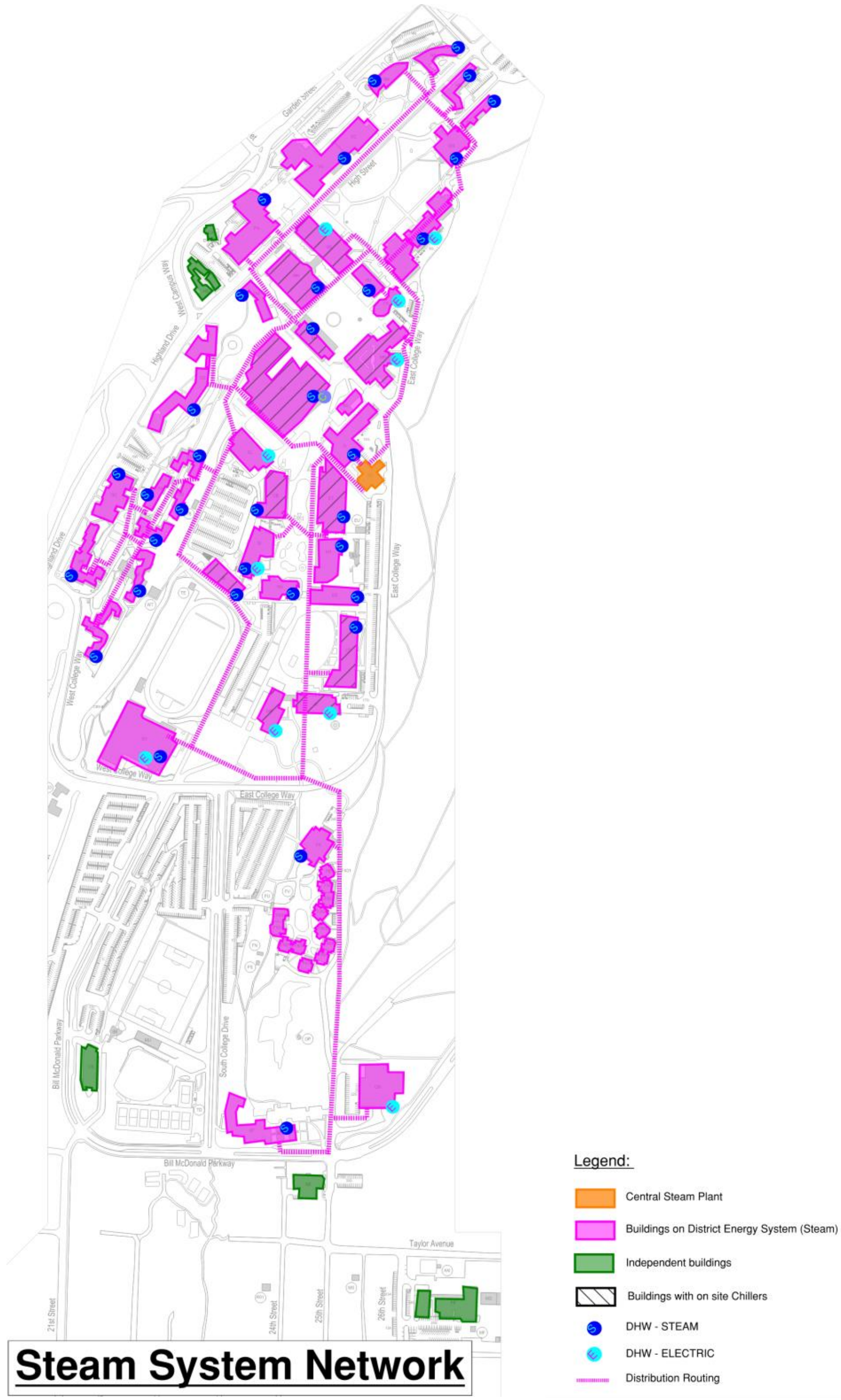


Figure 7 - Existing WWU Steam Infrastructure

Using the daily steam production data recorded at the Central Steam Plant along with the daily average outdoor air temperature ("Daily Boiler Log Month & Year" spreadsheet) aided in visualizing the steam production versus the average outdoor air temperature. Shown below is the steam produced at the central steam plant at a daily resolution for Western's campus with corresponding average outdoor air temperature across the year of 2018 and 2019.

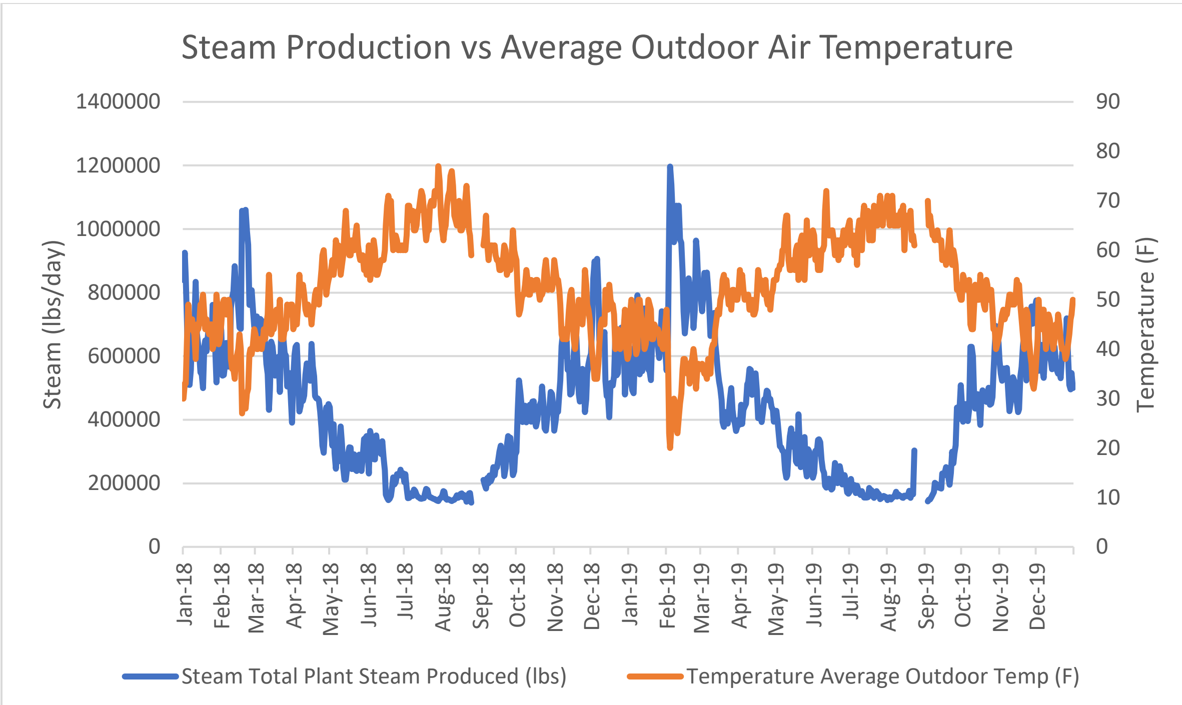


Figure 8 - Daily steam production at Central Plant and Daily Average Outdoor Air Temperature

Figure 8 shows how steam production (dark blue) increases when ambient outdoor air temperature is low – which is the dynamic that would be expected. In particular, the sharp increase in steam production during the February-March 2019 cold snap illustrates how steam production responds to increased heating demand. There are few events worth noting in the figure. As noted by the WWU Working Group, the steam plant is shut down for two-weeks in the month of August each year. This is plainly indicated by the data gap in the steam data set plotted in the figure. Additionally, there is a baseline minimum production of steam during the summer months of approximately 5400 pounds per hour. Assuming no demand, this minimum steam production is based on the maximum turn down of the steam boilers that can still maintain operation and maintain pressure of the steam network. In fact, as noted by the WWU Working Group, the Central Steam Plant is kept operational during the warmer months to serve domestic hot water loads for a base student population that uses the residential buildings during the summer months as well as for humidification for the Western Art Gallery and to provide heat on cool mornings for lab exhaust makeup ventilation air. The WWU Working Group noted that there are also small steam process loads around campus (e.g., the steam sculpture); however, they are not significant relative to the thermal uses of steam listed above.

To determine steam use by buildings currently connected to the steam system, campus-wide steam billing data at monthly resolution was exported from Western's Energy Management database. The difference between the total steam produced at the Central Steam Plant and the steam used by buildings corresponds to thermal losses in the steam and condensate distribution network. Shown in the figure below is the steam production at the Central Steam Plant and the amount of steam delivered to the connected buildings. The difference between the two represent system thermal losses.

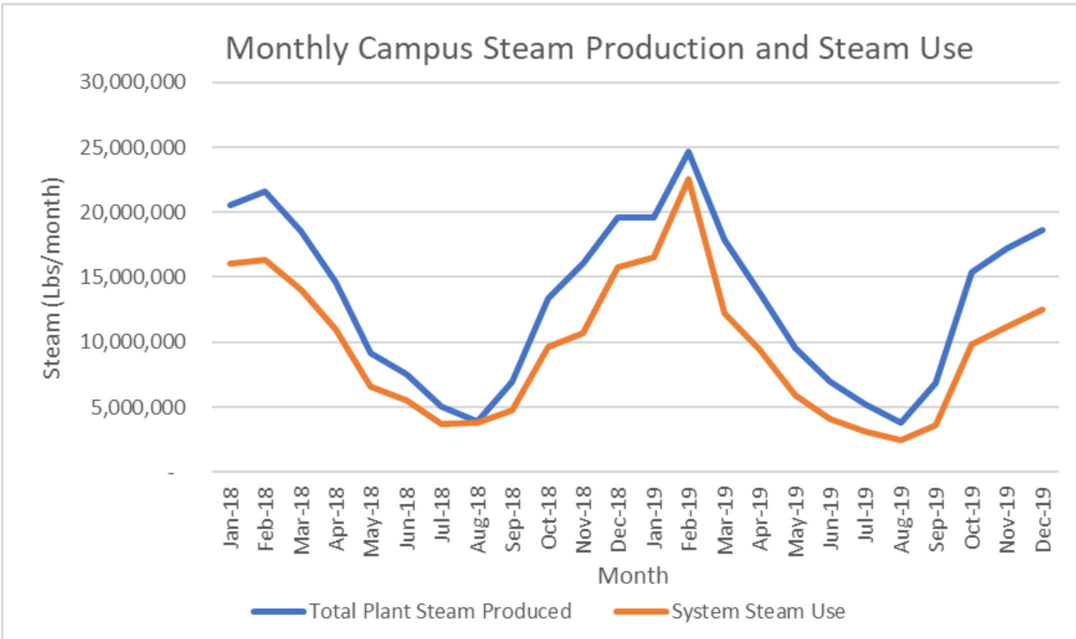


Figure 9 - Monthly Steam Production and Steam Delivered to WWU Campus Buildings.

The losses in the Steam distribution network are largely standby losses, condensate losses, and losses at steam traps and from steam venting. The magnitude of the distribution losses varies over the year as a function of ambient temperature as well as the magnitude of the heating load (e.g., losses in periods of low heating load, such as summer, are higher on a relative % basis). The average calculated steam network system losses over the 2018-2019 period were approximately 30% which is typical for larger campus-scale steam systems. Refer to Appendix A for monthly steam system losses (%) across 2018 and 2019. August data is excluded from the distribution losses calculations, since it is heavily impacted by the central plant shut down for annual maintenance.

To generate a daily baseline heating demand profile for the existing buildings connected to the Central Steam System, the calculated loss factor (%) for each month was applied to the daily output of the of the Central Steam Plant to estimate the daily thermal heating energy delivered to connected buildings on Western's campus. Shown in Figure 10 below is estimated daily steam delivered compared to the daily steam produced at the Central Steam Plant, along with average ambient outdoor air temperatures.

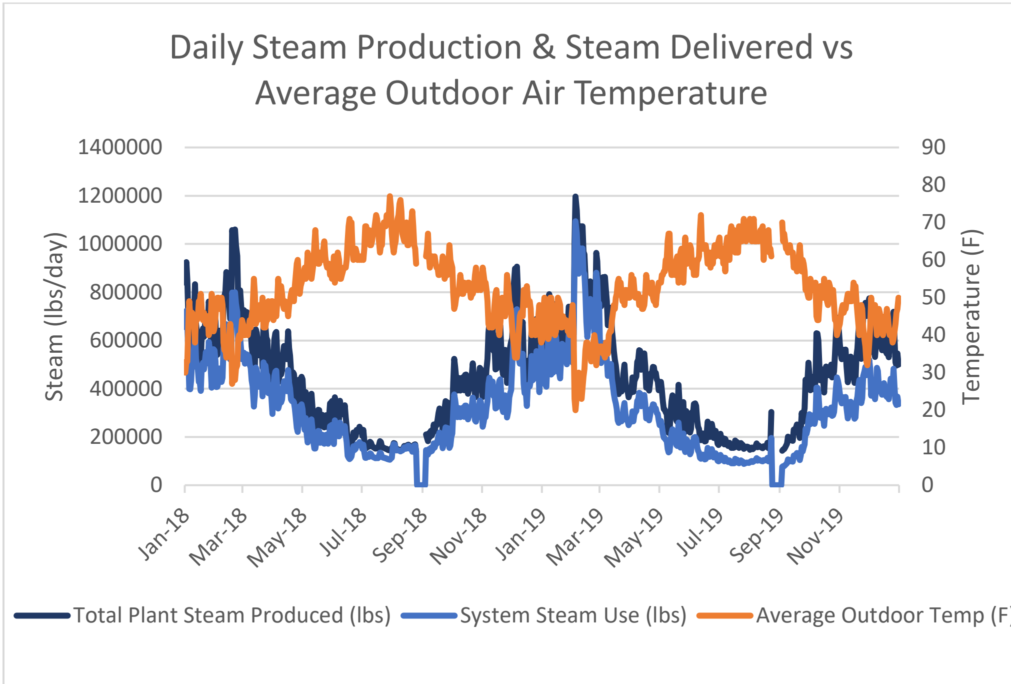


Figure 10 - Daily Steam Production and Delivered at WWU Campus over 2018-2019

To facilitate the evaluation of the low-carbon heating system conversion options, an hourly heating demand profile for a full year timeframe was needed. Hourly resolution of load data is required to accurately estimate performance of system strategies, including heat recovery during times when there is simultaneous heating and cooling demands, or systems whose performance varies depending on variables with "quick dynamics." As an example, the performance of Air Source Heat Pumps (ASHPs) strongly depends on outdoor air temperature, which significantly fluctuates over the 24 hours in a day.

Using the estimated daily totals of the steam used by the connected buildings on Western's campus, a load distribution profile was developed based on past university district steam system evaluations completed by members of the project team. Shown below is a modelled hourly thermal heating demand profile of the Western campus (for 2018). It must be noted that design and evaluation was done using the Future Profile explained in the sections below (rather than the 2018 profile reported here). The Future Profile captures design conditions (peak) in addition to "typical" future weather outdoor air temperature distribution.

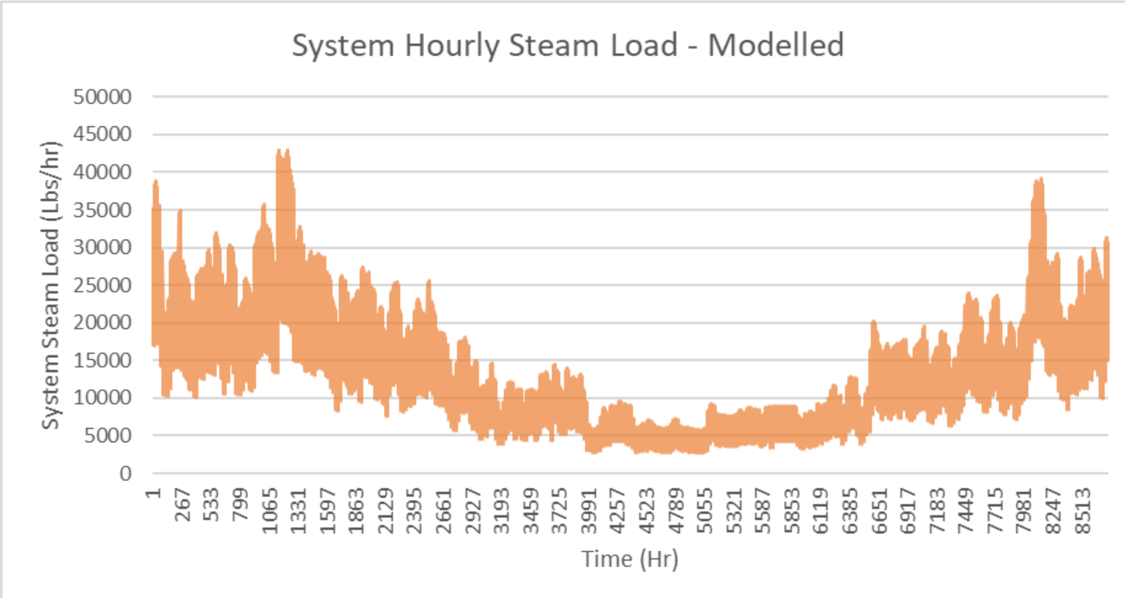


Figure 11 - Hourly thermal demand profile of WWU campus for the year of 2018.

Building Demand Reduction

Building demand reduction is essential part of the thermal infrastructure upgrade and is required regardless of conversion strategy. Many of the conversion strategies being considered include the following: full electrification, integration with geo-exchange or other renewable energy or waste heat resource, or even use of biofuels and renewable natural gas (RNG). Implementing any of these solutions to renew infrastructure to help achieve carbon neutrality for Western will be more expensive if the building have high heating demand due to inefficiency. The energy and carbon costs of all technical options evaluated in this study can be substantially mitigated by reducing campus energy demand by improving the energy efficiency of individual buildings. A lower campus thermal energy demand means central plant infrastructure can be downsized resulting in conversion cost savings, and eventually utility bills and emissions reduced.

The deepest savings from retrofits can be most effectively achieved when aligned with planned modernizations and upgrades such as the replacement of primary heating and cooling system equipment happens at the end of useful life. Some retrofit opportunities in the buildings on campus, as well as housing replacement projects have already been identified by the WWU Working Group. Opportunities in some of the buildings were also identified by the consultant team after a campus walk-through audit. Incorporating these retrofits and utilizing Passive House Standards for the housing replacement projects together result in significant heating demand reduction.

Focusing on buildings with the highest steam consumption is a natural priority. There are nine buildings on campus that currently account for ~50% of the steam demand on the campus. Prioritizing these nine buildings along with maximizing efficiency of housing replacement projects could result in a 10% to 22% heating demand reduction. Given these existing buildings will ultimately need to modernize their systems as part of end-of-life capital renewal projects, an almost inevitable outcome will be some level of demand reduction. Recognizing this fact, for the purposes of developing a future profile of heating demand for this study we – believe conservatively – applied a 10% heating demand reduction.

The chart below shows the identified nine buildings on campus and their percentage of annual steam demand relative to the total steam demand on the campus.

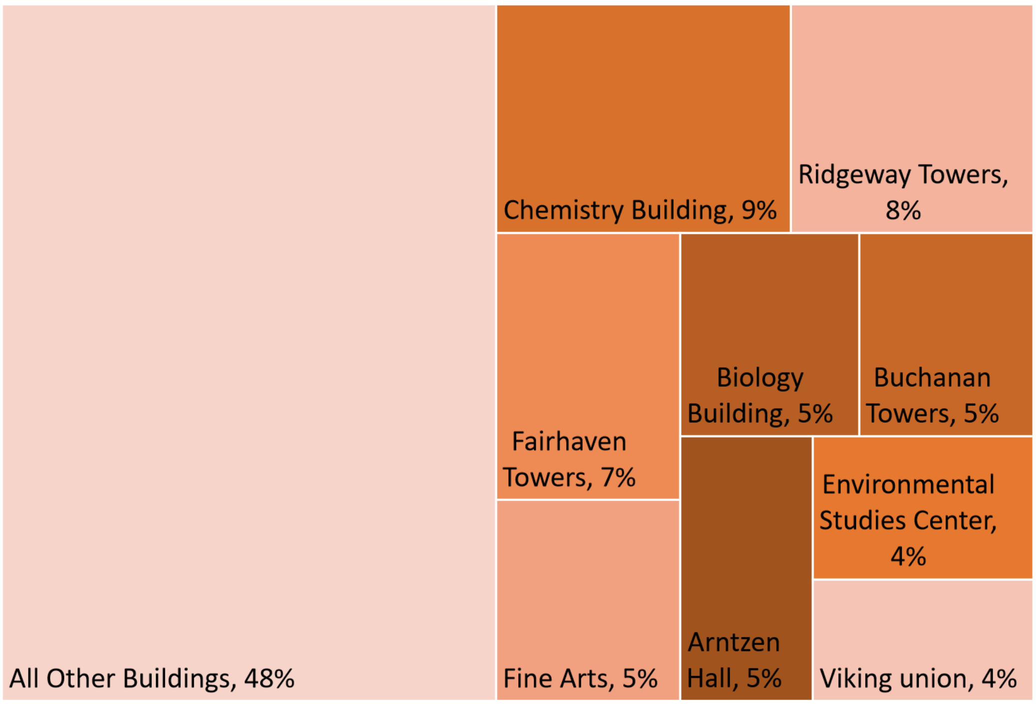


Figure 12 – Percent of Annual Steam Usage of Highest Thermal Demand Buildings versus All Other Buildings

The table below shows the Energy Efficiency Measures (EEMs) identified for these buildings with priorities labeled as: A (Green) for high priority or relative low cost to implement, C (Red) for low priority or relative high cost to implement.

Table 2 – Potential Building Energy Efficiency Measures

Facility	Facility Number	Facility Type	Replace all single pane glazing to current code	Replace existing double pane glazing to current code	Add Interior Insulation to Exterior Walls	Add DCV in remaining Classrooms	Add Air-side Heat Recovery	Fin-Tube Radiator Controls to turn off based on setpoint	Night Set-back Fume Hoods and AHUs	Replace CV Fume Hoods with VAV Fume Hoods	Replace existing HVAC with Decoupled System	Deep Retrofit with Passive House Standards	Repalce facility with Passive House grade facility
Arntzen Hall	AH	Education	A			A					C		
Biology Building	BI	Laboratory					A		A		C		
Buchanan Towers	BT	Residence Hall/Dormitory										C	
Chemistry Building	CB	Laboratory					A		A		C		
Environmental Studies Center	ES	Laboratory	A	A	A			A	A	B	C		
Fairhaven Towers	FX	Residence Hall/Dormitory											A
Fine Arts	FI	Education	A		C	A		A			C		
Ridgeway Towers	RX	Residence Hall/Dormitory											A
Viking union	VU	Mixed Use		B				A					

Note:

High Priority	A
Mid Priority	B
Low Priority	C

The table below shows the percentage reduction of total campus heating/steam load that could result if all EEMs listed for each building above were implemented (total 22% reduction) and if only EEMs A and B were implemented (total 10% reduction).

Table 3 – Total Campus Heating Load Reduction from Implementation of Select Building EEMs

Facility	Facility Number	Facility Type	Total Campus Heating Load Reduction for all EEMs	Total Campus Heating Load Reduction for A and B EEMs
Arntzen Hall	AH	Education	2.0%	0.5%
Biology Building	BI	Laboratory	2.5%	0.9%
Buchanan Towers	BT	Residence Hall/Dormitory	1.2%	0.0%
Chemistry Building	CB	Laboratory	5.2%	1.6%
Environmental Studies Center	ES	Laboratory	3.1%	1.5%
Fairhaven Towers	FX	Residence Hall/Dormitory	2.1%	2.1%
Fine Arts	FI	Education	2.7%	1.2%
Ridgeway Towers	RX	Residence Hall/Dormitory	2.3%	2.3%
Viking union	VU	Mixed Use	0.4%	0.4%
TOTAL			**22%**	**10%**

As a recommendation going forward, the consultant team believes that, based on this preliminary analysis, that assuming significant energy demand reduction in buildings is reasonable to expect as a natural outcome of either planned modernizations and capital renewal projects or as targeted energy retrofits. As such, incorporating a conservative level of heating demand reduction into the analysis was justified.

Future Profile

The goal of this feasibility study is to inform on low carbon options for campus heating (and cooling) systems that support Western's vision of achieving carbon neutrality in the long term. Changing the overall heating and cooling strategy at the campus is a major decision, one that requires a phased implementation over 10 to 15 years, or beyond. For this reason, the analysis completed for this study accounted for both current and anticipated future heating and cooling loads.

The main factors that impact future heating and cooling load profiles in the future are climate change and campus development (new buildings, modernizations and energy upgrades to existing buildings, and demolitions).

The direct impact of climate change on Western's future district heating and cooling plant(s) is anticipated to result in decreased heating demand and increased cooling demand. For this analysis, forecasted future heating and cooling demand profiles were adjusted based on a future weather file that corresponds to a Representative Concentration Pathway (RCP) 4.5 scenario and a 2050s-time horizon. Please refer to Appendix B for further explanation on RCP scenarios.

The procedure used to adjust the current heating load profile to shift to a forecasted future climate scenario involved using regression analysis techniques. Based on 2018-2019 data (daily steam use values estimated above) the consultant team generated a regression model that predicts heating load correlated with daily average outdoor air temperature. The figure below compares "measured" daily steam use (i.e., measured plant steam output, adjusted for distribution loses) vs. outputs of the regression model. Each dot in the figure corresponds to a day from years 2018 and 2019.

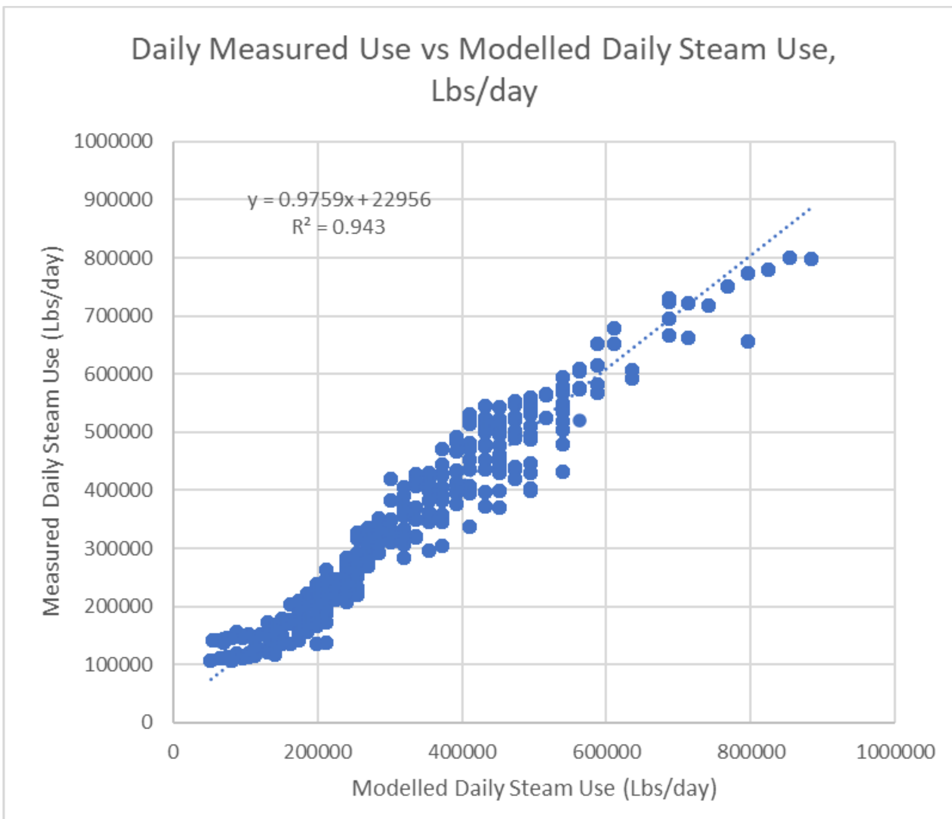


Figure 13 – Regression Analysis for Measured and Modelled Daily Steam Use, Lbs/day

Figure 13 shows there is a very strong correlation between the measured steam use data and the modeled steam use results, with a R^2 value is 0.94. Further, the slope of the correlation is effectively 1 (0.98). This indicates there is no drift in the projections of the model. These strong correlation factors suggest that the model can predict daily heating load with a high degree of accuracy, providing confidence for further analysis on decarbonization options for Western.

To generate a weather-shifted heating load profile for Western, we used the morphed weather file that corresponds to an RCP 4.5 scenario and a 2050s-time horizon as an input into the regression model and obtained the corresponding future-shifted daily load profiles. The weather file was further modified to include outdoor air temperature design conditions so it can more effectively inform sizing (see early January heating load peak in Figure 14). Similar to the current heating load profile, we applied a load distribution profile developed based on past university district steam system evaluations to divide the predicted daily totals (model outputs) into hourly loads.

To capture the anticipated future campus growth within the modeled heating and cooling demand profiles, the WWU Working Group outlined the anticipated growth of the campus for a 10-year time horizon. Shown in the table below are buildings planned to be constructed in the next 10 years with their corresponding estimated gross square footage. The future buildings were assigned a thermal energy demand intensity (TEDI) based on building type, assuming good building practices for new construction. The thermal load of the new buildings was added to the load of the existing buildings.

Table 4 – WWU future building developments (2021-2031)

WWU Campus Growth				
Project/ Event	**Description**	**Building type**	**GSF**	**Est. Occupancy Date**
Interdisciplinary Science Building	New Science Building	Science Lab	56,600	2022-04-01
Kaiser Bosari Hall (KB)	NetZero Elec Eng. / Computer Science	Engineering Lab	55,345	2024-09-01
Student Success Center	New administrative building	Office	30,000	2027-09-01
Coast Salish Longhouse (CL)	Longhouse on south side Sehome Hill Road	Education College/University	7,000	2023-09-01

With the morphed weather data for a 2050-time horizon and future campus building's captured, a thermal heating demand profile of Western's campus was generated. Shown in the Figure 14 is the projected thermal heating demand profile for Western's campus at the year 2050.

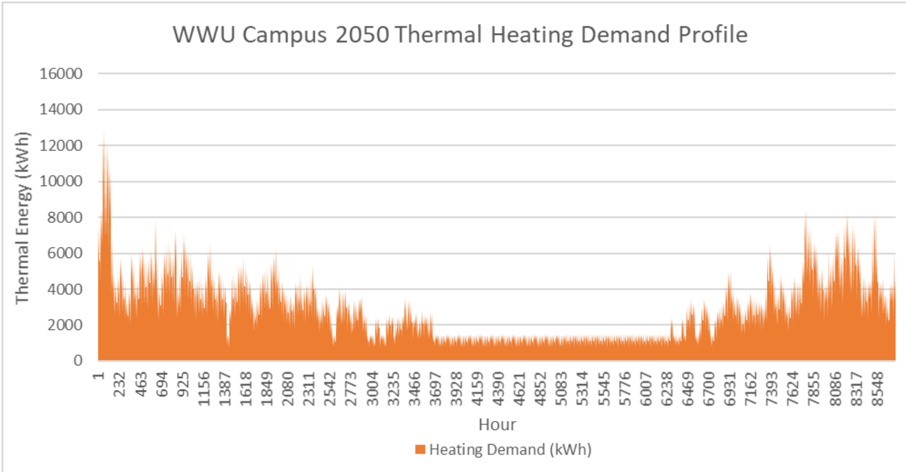


Figure 14: Thermal heating demand profile of WWU campus for the year 2050, kWh

During the "Refine" phase, the WWU Working Group identified additional Western campus buildings that were desired to have cooling beyond those that already have standalone cooling, and asked that all be earmarked for service by central chilled water in the future. Unlike heating, there was no metered information on cooling load or cooling energy use available. Therefore, cooling energy demand and peak load was estimated by building type using benchmark data from other campuses with similar buildings and was calibrated to the project climate location where necessary. The benchmark data was reviewed in terms of Cooling Energy Demand Intensity (CEDI). This was then applied to the respective building floor areas to estimate the total cooling energy demand per year and peak cooling load. The annual energy and peak cooling loads were then used to develop an hourly profile as a function of the outdoor air temperature and occupancy factors. The following table summarizes the cooling load estimates for each building, as well as the total for the campus.

Table 5 – Cooling load estimates

Facility	Building Activity	Cooling Demand Intensity (kWh/m2)	Facility Number	Area [sf]	Area [sqm]	Cooling Demand [kWh]
Academic Instruction/West	Education College/University	33	AI/W	130,649	12,138	400,544
Arntzen Hall	Education College/University	33	AH	98,337	9,136	301,482
Biology Building	Laboratory	72	BI	81,120	7,536	540,935
Bond Hall	Education College/University	33	BH	91,168	8,470	279,503
Carver Gymnasium	Entertainment/ Public Assembly - Fitness Center	33	CV	167,346	15,547	513,050
Chemistry Building	Laboratory	72	CB	77,226	7,175	514,969

Coast Salish Longhouse (Future)	Education College/University	33	CL	7,000	650	21,461
Communications	Education College/University	33	CF	131,365	12,204	402,739
Engineering Technology (Ross)	Education College/University	33	ET	77,592	7,209	237,882
Environmental Studies Center	Laboratory	72	ES	111,145	10,326	741,152
Fine Arts	Education College/University	33	FI	59,300	5,509	181,802
Fraser Hall	Lecture Halls	29	FR	13,562	1,260	36,539
Haggard Hall	Education College/University	33	HH	107,971	10,031	331,018
Humanities	Education College/University	33	HU	33,342	3,098	102,220
Interdisciplinary Science Building (New)	Laboratory	72	IS	55,000	5,110	366,758
Miller Hall	Education College/University	33	MH	135,369	12,576	415,015
Old Main	Office - Other	35	OM	145,474	13,515	473,025
Parks Hall	Education College/University	33	PH	56,109	5,213	172,019
Performing Arts Center	Entertainment/Public Assembly - Fitness Center	33	PA	128,649	11,952	394,413
Student Recreation Center	Entertainment/Public Assembly - Fitness Center	33	SV	98,300	9,132	301,368
Student Success Centre (Future)	Office - Other	35	TBD	40,000	3,716	130,064
Viking Union	Entertainment/Public Assembly - Fitness Center	33	VU	122,494	11,380	375,543
Wilson Library	Public Services - Library	33	WL	141,243	13,122	433,023
			Total	**2,109,761**	**196,003**	**7,666,523**

From the peak cooling demand estimates, an annual aggregated thermal cooling demand profile was generated for the campus by using the neutral temperature method, and adjusted using the future weather file for 2050. This demand profile is shown in Figure 15.

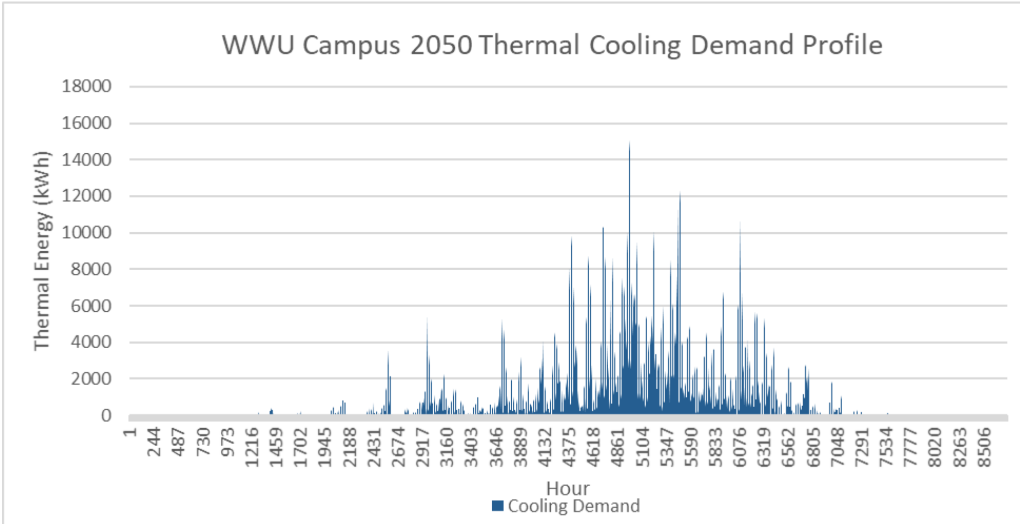


Figure 15 - Thermal cooling demand profile of WWU campus for the year 2050, kWh

Options Screening

Multiple workshops with WWU's Working Group were conducted during the Define Phase to identify and screen a wide range of technically feasible options. As a starting point WWU's Working Group was asked to affirm and further clarify Western's objectives. This was necessary to help inform the winnowing process as well as the subsequent analysis approach used for evaluation of the shortlisted options. Key directions provided by Western included:

- Western places a paramount importance on reducing the carbon intensity of university energy supply sources, with a long-term target of being carbon-neutral by 2035.
- Any recommended low-carbon system options coming out of the study should not rely on combustion fuels and technologies as the primary source of heating; however, shortlisted options should be compared in a financial and technical analysis to the Business-As-Usual (BAU) case of retaining the existing natural gas-fired Central Steam heating system.
- Carbon offsets can be leveraged to optimize sizing and emissions abatement costs of the implemented system, so natural gas is therefore considered a viable option for serving peak load and back-up heating conditions. This would also provide a minimum level of resiliency to help ensure Western's campus could operate in extreme conditions for short periods.

Western also stated at the onset that using biofuels (namely Renewable Natural Gas, or RNG) as a primary energy source for heat generation was not preferred. Reasons for this preference – shared also by the consultant team -- include:

- The long-term availability of low-cost biofuels including RNG is uncertain, given general biofuel scarcity in a carbon-constrained future
- O&M for a biofuel operation could be quite significant, depending on the quality of the biofuel product that is sourced.
- Biomass, as another type of biofuel often considered, can require complex and expensive energy conversion technology to assure minimum emissions with a limited track record, in

addition to requiring on-site biomass storage and handling facilities. There is a risk of potential extended downtimes of biomass system for maintenance.

- GHGs are still emitted by biofuels when burned and these emissions would also be local (on the campus), creating air pollution.
- Future consideration of biofuels as potential carbon-neutral sources is subject to change due to major uncertainty in their GHG reduction benefits

To guide the screening process, the consultant team organized the low carbon options using a systematic process illustrated in the form of a "selection tree" below. The selection tree uses key system configuration questions to group the various complementary energy sources and technologies forming the available low carbon options. In the case of Western's heating system, the key questions were:

- Is the heat carrying fluid steam or hot water? This question is relevant to identify the opportunities and limitations if Western decides to maintain the current steam distribution system.
- In case of hot water, what is the temperature regime of the hot water system? This question is relevant because existing heating terminal units in campus buildings are sized for high temperature hot water distribution (most buildings have a steam to water converter, and use high temperature hot water for building distribution, typically around 180F at design).

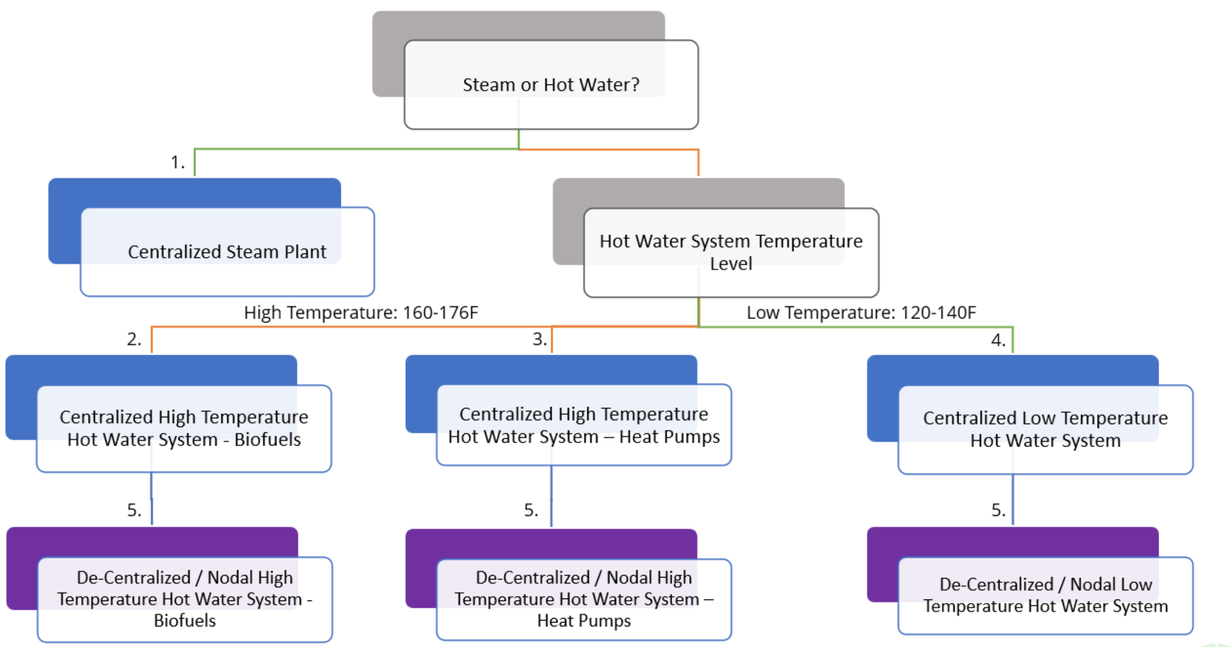


Figure 16 - WWU Decision Criteria / Selection Tree

For each of the main branches of the selection tree, the consultant team identified available technologies and system configurations, and evaluated their respective benefits, limitations and risks used in the options screening process. The following sections provide an overview of the options considered and the recommendation on whether they should be shortlisted for further analysis in the "Refine" phase. Options shown with a green background in the following figures are recommended for further analysis, whereas options with a red background are recommended to be eliminated.

Centralized Steam Plant

If the decision is to retain the existing steam infrastructure but seek to decarbonize to maximum extent practical, the following options are available:

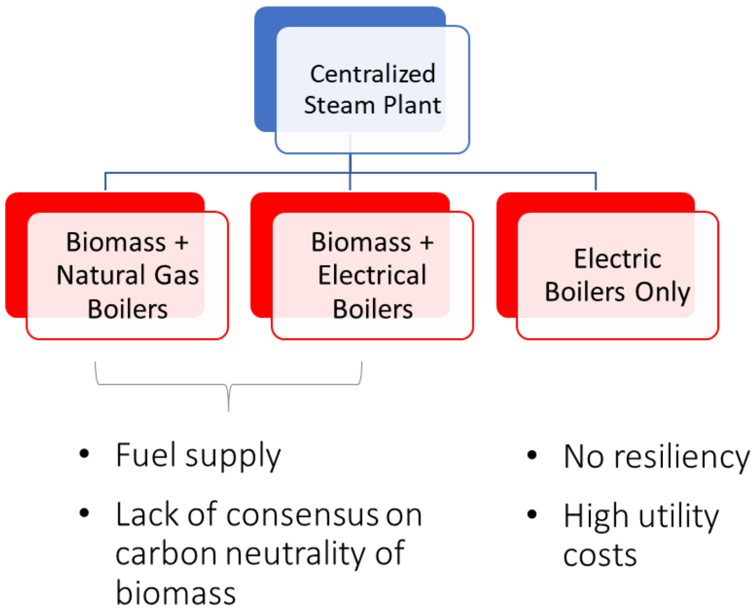


Figure 17 – Centralized Steam Plant Options

Limitations / Risks:

- Intrinsic inefficiencies of steam systems (baseline energy use for system pressurization)
- O&M can be significant, depending on the quality of the biomass product
- Long term availability of low-cost biomass is uncertain, given general biofuel scarcity in a carbon-constrained future
- Electric boilers offer no resiliency and high operating costs due to 100% reliance on electricity grid and low efficiency relative to heat pump options

Recommendation:

- None of these options are recommended. Steam does not align with Western's long-term vision

High Temperature Hot Water - Biofuels

If the decision is to transition to high temperature hot water system infrastructure with biofuel combustion, the following options are available:

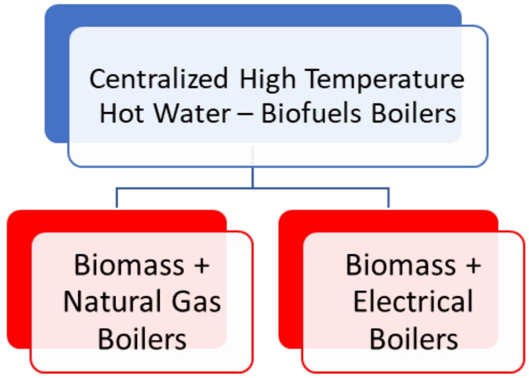


Figure 18 – Centralized High Temperature Hot Water – Biofuels Options

Limitations / Risks:

- Requires complex and expensive energy conversion technology with limited track record along with biomass storage and handling facilities
- Risk of potential extended downtimes of biomass system for maintenance.
- Future consideration of biomass as a carbon-neutral source is subject to change due to major uncertainty in GHG reduction benefits
- Long term availability of sufficient low-cost biomass is uncertain given general biofuel scarcity in carbon-constrained future

Recommendation:

- <u>Not recommended</u> due to uncertainty of biomass supply and lack of consensus on carbon neutrality of biomass

High Temperature Hot Water – Heat Pumps

If the decision is to transition to high temperature hot water system infrastructure without biofuel combustion technologies, the following options are available:

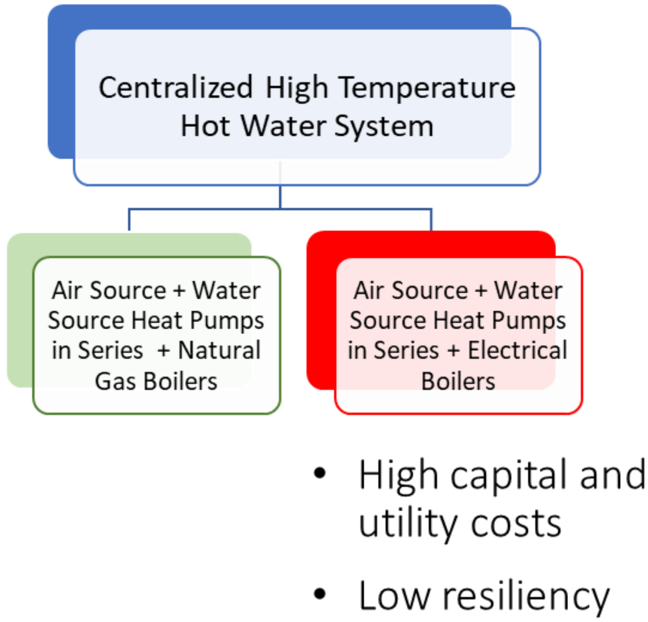


Figure 19 – Centralized High Temperature Hot Water – Heat Pump Options

Benefits:

- Potential for high efficiency and GHG reductions Resiliency is maintained thanks to mix of electricity and NG use
- High temperature could allow for an easier transition to hot water systems at building level

Limitations / Risks:

- Based on current commercially available heat pumps, it would require two-stage lift, sometimes referred to as a "cascade heat pump" solution. The cascade heat pump solution is where the discharge of an air source heat pump (ASHP) is directed into the intake of a water source heat pump (WSHP) to achieve high temperature heating water. This cascading heat pump configuration increases system complexity as well as diminished performance and reliability. Operating heat pumps at these high temperatures reduces their efficiencies and shortens their service lives.
- Lower GHG reductions compared to low temperature system

Recommendation:

- Evaluating this system in next stage of study is recommended, with preference on Natural Gas Peaking Boilers for fuel resiliency, recognizing also the likely much higher costs associated with operating electric boilers during grid winter peak demand periods.
- Explore system reset strategies that could allow for a single stage Heat Pump system use during most of the year (low temperature) and increase to high temperature regimes (and high temperature differentials between supply and return) at peak conditions. This configuration would eliminate the complexity of a two-stage lift configuration

Centralized Low Temperature Hot Water

If the decision is to transition to low temperature hot water system infrastructure, the following options are available:

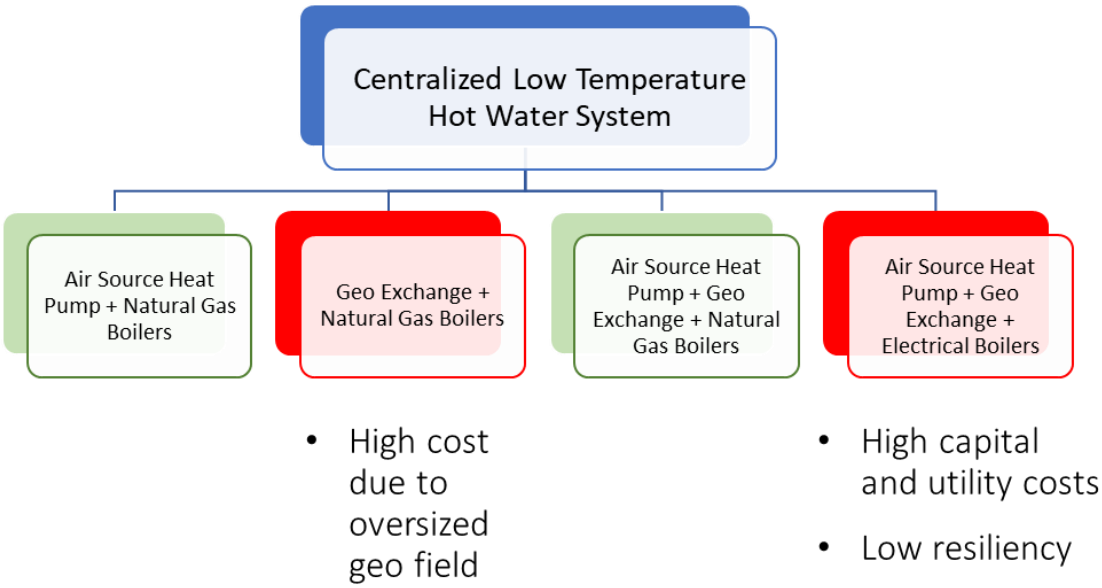


Figure 20 – Centralized Low Temperature Hot Water Options

Benefits:

- Potential for high efficiency and GHG reductions, which aligns with project objectives
- Resiliency is maintained thanks to electricity and natural gas use for peaking loads
- New pre-insulated HDPE (PERT) piping distribution network has lower capital cost than high temperature system

Limitations / Risks:

- Low temperature may be more difficult and capital intensive to integrate with building level heating systems
- High cost of geo-exchange when considered as the single heat source / sink

Recommendation:

- Low temperature system configurations that eliminate or optimize the use of geo-exchange are recommended for next stage of study

De-Centralized / Nodal Hot Water

If the decision is to transition to de-centralized hot water system infrastructure, the following options are available:

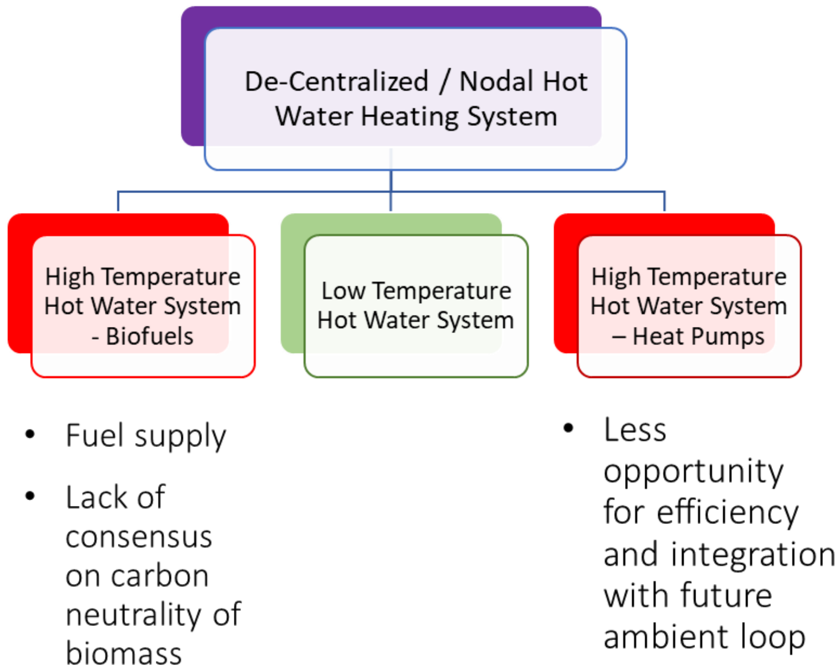


Figure 21 – De-Centralized Hot Water Options

Benefits:

- Allows for a phased transition and avoids whole campus disruption.

Limitations / Risks:

- Higher cost due to the higher overall capacity of the aggregate systems and backup systems
- Potential increased costs relative to centralized options due to increased electrical service upgrades and operations and maintenance costs
- Requires more space for mechanical equipment

Recommendation:

- Evaluating low temperature decentralized nodal plant configuration is recommended for next stage of study because it aligns with Western's long-term vision and phased construction

Summary of Recommended Options

The figure below shows the options that were selected for further analysis in the "Refine" phase of the project.

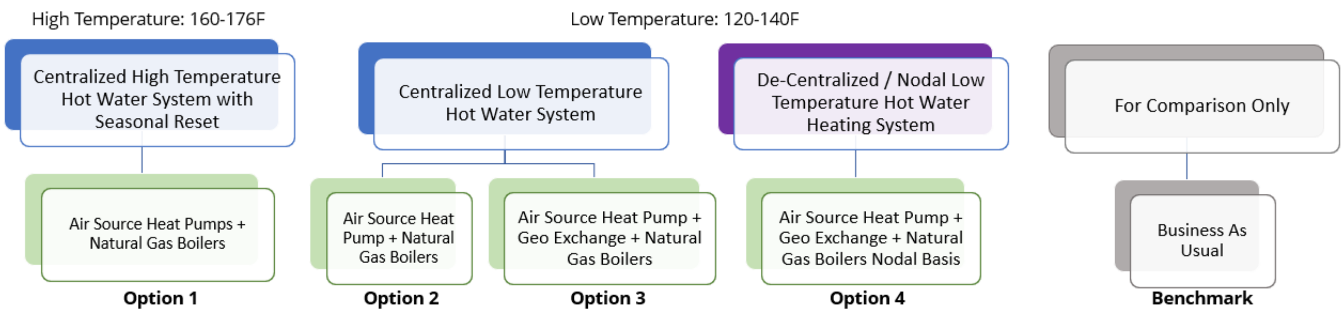


Figure 22 – Shortlisted Low Carbon Options

Low Carbon Options

As presented above, there were four Low Carbon configurations that were chosen to be evaluated in depth. Each option would be developed to meet the heating and cooling loads of connected buildings on the WWU campus through new heating and chilled water distribution piping systems.

Options 1 – 3 are all centralized options, meaning a single central plant would be provided to deliver heating and cooling water to the majority of WWU buildings[1]. This is similar to Western's current steam heating system, which uses a single central steam plant. Option 4 is a fully de-centralized or "nodal" option wherein 4 separate heating and cooling plants would be provided, each located to serve a different portion of the campus.

Common to all four options is the use of air-source heat pumps powered by electricity. During the heating season the air-source heat pumps efficiently extract heat from ambient outdoor air and generate heating water. During warmer periods of the year when cooling is needed in buildings these units can be configured to produce chilled water. Because there are periods of the year when both heating and cooling will be needed on the same day or simultaneously, each system is designed for instantaneous heat recovery from return chilled water and uses a pumped "4-pipe" water distribution infrastructure to serve buildings, meaning separate supply and return piping for both heating and chilled water would be provided.

[1] Energy, GHG and financial results revealed that including the South node (Fairhaven) in a centralized system heavily penalized the feasibility of centralized configurations. Hence, centralized options 1-3 were optimized to include all the campus buildings except for Fairhaven (South node), which was assumed to have its own nodal plant.

What differentiates the Options from each other are the following:

- Option 1 is sized and designed for higher temperature supply heating water (160 – 176F) at peak conditions (cold winter days) and would require natural gas boilers to operate to augment the air source heat pumps to achieve the higher design temperatures required on cold days. The distribution piping is sized for a "high" supply/return temperature differential (20F), which allows for smaller pipe diameters and lower cost for the distribution system relative to the low temperature options (2-4).
- Option 2 is sized and designed for distribution of "low" heating water supply temperatures (120 – 140F) at peak conditions. The distribution piping is sized for a supply/return temperature differential of 10F. On the coldest days some minimal operation of natural gas boilers is required due to a drop in efficiency and capacity of air source heat pumps on those days.
- Option 3 is, like Option 2, sized for low heating water supply temperatures at peak conditions, but includes deployment of a geo-exchange field, enabling the system to extract or reject heat from the earth by coupling the geo-exchange field to water-to-water (ground source) heat pumps. This strategy is a form of long-term thermal storage, enabling heat recovery between non-simultaneous loads, and offsets natural gas boiler operation with heat pump electricity and low-grade heat from the ground.
- Option 4 is a nodal version of Option 3, with a total of four nodal plants operating independently of one another. Northern and Southern nodes plants provide both heating and chilled water. Ridgeway and Fairhaven plants provide heating only because they are residential buildings which have not been provided with mechanical cooling in this analysis.

More detailed descriptions for each option follow below.

Option 1 – High Temperature Centralized

i. Description

The High Temperature Centralized option consists of Air Source Heat Pumps (ASHPs), and Natural Gas (NG) Boilers to produce high temperature heating water and chilled water. This configuration presents a pathway for the least building upgrades when compared to the other options. As many buildings on campus currently operate with a high temperature hydronic heating system, the high temperature heating water supplied by the option would more easily integrate with the existing systems. It must be noted that this is the only low carbon option that has the distribution piping sized for a 20°F temperature difference between supply and return heating water. This allows for a smaller and less costly distribution system. However, it also means that a high temperature differential will always be required to meet heating loads during winter, regardless of whether building terminal heating units are upgraded or not.

This option consists of constructing two new, central heating and cooling plants to provide high temperature heating water and chilled water to all connected campus buildings. One plant would be constructed to serve the North, South and Ridgeway nodes, and the other would be constructed to serve just the Fairhaven node. This is due to the geographic location and heating only nature of the Fairhaven node.

The plant schematic in the figure below illustrates the proposed configuration of the mechanical equipment in the North, South & Ridgeway central plant; a description of each key mechanical equipment and how it is utilized in the system is provided below:

- ASHP (4-Pipe): Provide heating and cooling, via heat recovery, during the summer and low heating load situations.
- ASHP (2-Pipe): Provide either heating or cooling during the summer and low load situations.
- NG Boilers: Provide heating during the winter and shoulder seasons and/or medium and high demand situations.
- Buffer Tanks: Creates thermoclines to control the ASHPs, and to provide hydraulic separation between primary and secondary pumping.
- Distribution Piping: Heating Water Distribution sized for 20°F temperature difference.

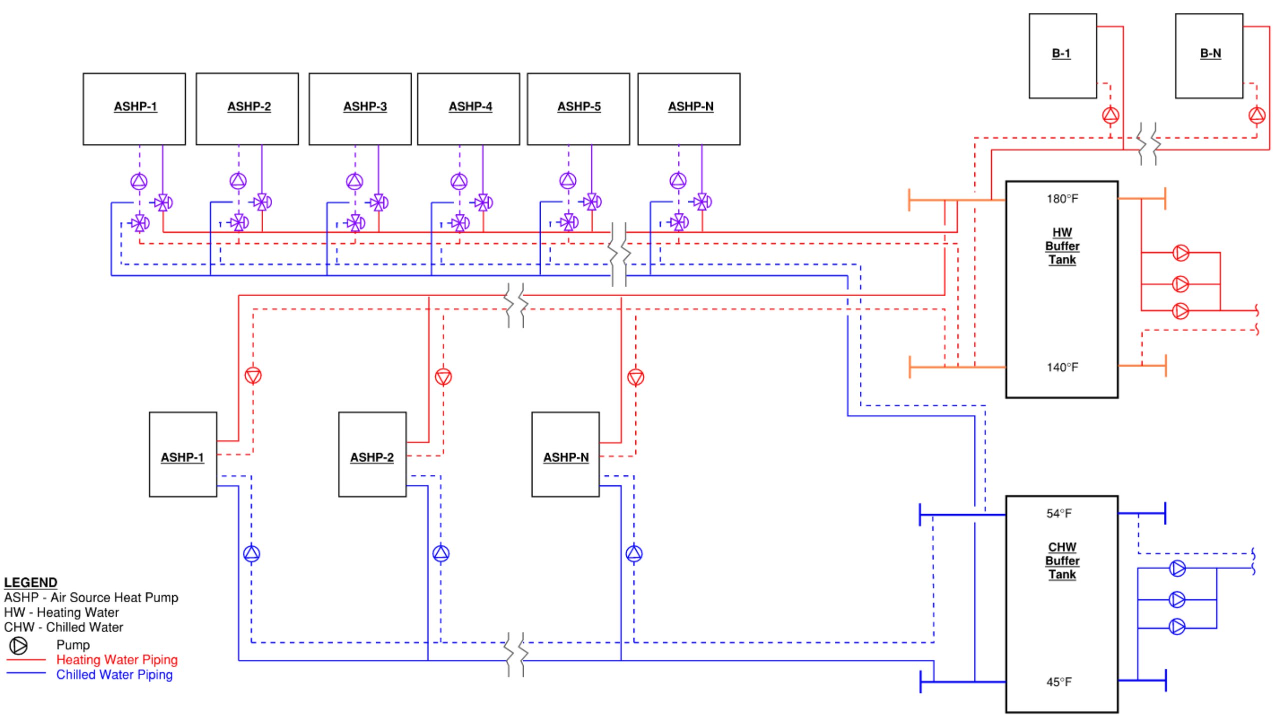


Figure 23 – High Temperature Centralized Option Schematic

The smaller Fairhaven plant would not contain any of the chilled water equipment and would only have 2-Pipe ASHPs for heating.

ii. Operation

The High Temperature Centralized option operates with a heating water temperature reset schedule. During the winter and shoulder seasons, the heating water supply temperature will be set at 176°F - 180°F, with a supply/return temperature differential of 20°F. In this high temperature, high supply/return temperature differential mode, the NG Boilers will meet all the heating demand of the campus (the ASHPs cannot meet these high temperature conditions) while the two-pipe ASHPs would provide cooling only. When the campus heating load is 50% or less of the peak heating load (design load for distribution piping system), a temperature regime of lower temperature and lower supply/return temperature differential (10°F) is sufficient to meet the loads. During these low-load conditions, the heating water supply temperature would be reset down to 143°F with a supply/return differential of 10°F. The four-pipe ASHPs would provide the required heating and any cooling via heat recovery, and the two-pipe ASHPs would provide either additional heating or cooling as required. An analysis of the correlation between campus heating load and outdoor air temperature suggests that the 50% load condition occurs at approximately 41°F – hence this temperature is used for the reset strategy. The figure below illustrates the reset strategy.

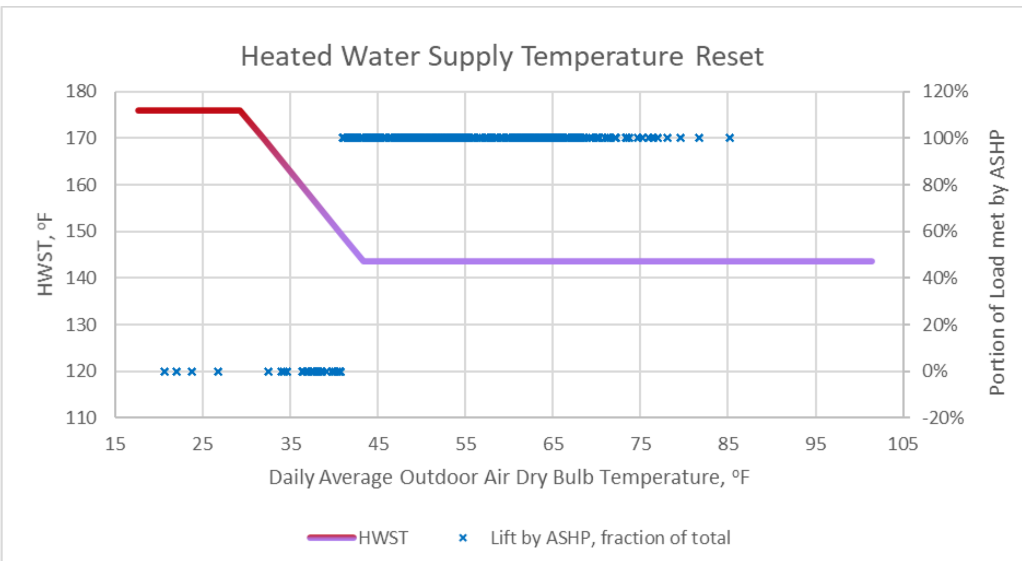


Figure 24 – Temperature reset strategy for Option 1

iii. Equipment

The following table presents the quantity and capacity of equipment that would be installed for the High Temperature Centralized option. Further discussion around the equipment and capacities can be found in the Options Evaluation section.

Table 6 – High Temperature Centralized Option Equipment

Equipment	Quantity	Individual Capacity	Total Capacity
ASHP (4-Pipe)	5	1,500 MBH	7,500 MBH
ASHP (2-Pipe)	20	1,500 MBH	30,000 MBH
NG Boilers	-	-	45,200 MBH
HW Buffer Tank	-	-	4,050 gal
CHW Buffer Tank	-	-	4,050 gal

Option 2 – Low Temperature Centralized Air Source Heat Pump without Geo-Exchange

i. Description

The Low Temperature Centralized ASHP without Geo-Exchange (GHX) option is similar to the High Temperature Centralized option and consists of ASHPs and NG Boilers to produce low temperature heating water and chilled water. Unlike the High Temperature Centralized option however, the low temperature heating water and lower supply/return temperature differential allows this configuration to rely more on the ASHPs (as opposed to the natural gas boilers) for heating. Natural gas boilers still need to be engaged when outdoor air is too cold for Air Source Heat Pump operation. Taking full advantage of the energy and carbon benefits of this option requires building upgrades to allow for the low temperature heating water and lower temperature differentials between supply and return (10°F). A system temperature reset strategy is proposed to allow for a functioning system during the conversion to low temperature terminal units in the buildings.

This option consists of constructing two new, central heating and cooling plants to provide low temperature heating water and chilled water to all connected buildings. One plant would be constructed to serve the North, South and Ridgeway nodes, and the other would be constructed to serve the Fairhaven node. This separate smaller Fairhaven node is due to it being geographic remote from the rest of campus and because it only requires heating.

The plant schematic in the figure below illustrates the proposed configuration of the mechanical equipment in the larger central plant. Key mechanical equipment and how they are used include:

- ASHP (4-Pipe): Provide simultaneous heating and cooling during normal operating conditions.
- ASHP (2-Pipe): Provide either heating or cooling during normal operating conditions.
- NG Boilers: Provide backup and peak heating during low outside air temperature (OAT) conditions (<32°F).
- Buffer Tanks: Create thermoclines to control the ASHPs, and to provide hydraulic separation between primary and secondary pumping.
- Distribution Piping: Heating Water Distribution sized for 10°F temperature difference.

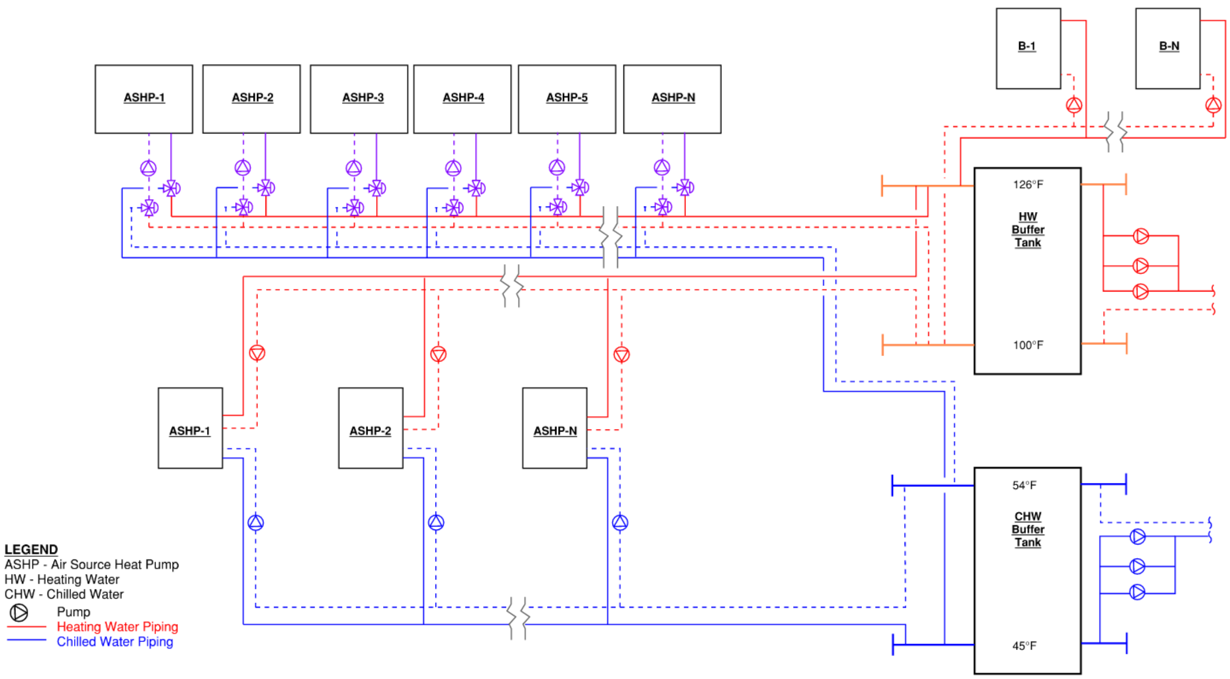


Figure 25 – Low Temperature Centralized ASHP w/o GHX Option Schematic

The Fairhaven plant differs from the configuration above in that it would not contain any of the chilled water equipment and would have only 2-Pipe ASHPs for heating.

ii. Operation

The Low Temperature Centralized ASHP without GHX option maximizes energy and GHG performance when it operates at a low temperature regime (122°F) throughout the year, as this allows to maximize use of heat pumps and minimize use of Natural Gas boilers. However, while campus buildings are retrofitted to accommodate low temperature regimes and lower temperature differentials, the following reset strategy would be applied. During low load conditions, the heating water supply temperature would be set at 122°F. Under low load conditions the four-pipe ASHPs would provide the required heating and any cooling via heat recovery, and the two-pipe ASHPs would provide either additional heating or cooling as required. In contrast, under low OAT / high heating load conditions the non-retrofitted buildings would require hot water temperatures higher than 122°F, hence the heating water supply temperature (HWST) would reset linearly up to 176°F-180°F. ASHPs cannot operate under high HWST and low OAT conditions, therefore, their contribution to hot water lift sharply decreases when OAT is lower than 42°F. The ASHPs would provide a fraction of the lift during the initial portion of the reset, while NG boilers use would ramp up and become the only heating source at OAT lower than 35°F. The reset strategy is illustrated in the figure below. Any cooling demand in these situations would be covered by the two-pipe ASHPs. Unlike Option 1, the reset strategy is driven by the requirements of the non-retrofitted buildings. Once the buildings on campus have low temperature terminal units the reset strategy would not be required, and the hot water supply temperature (HWST) would remain constant throughout the year.

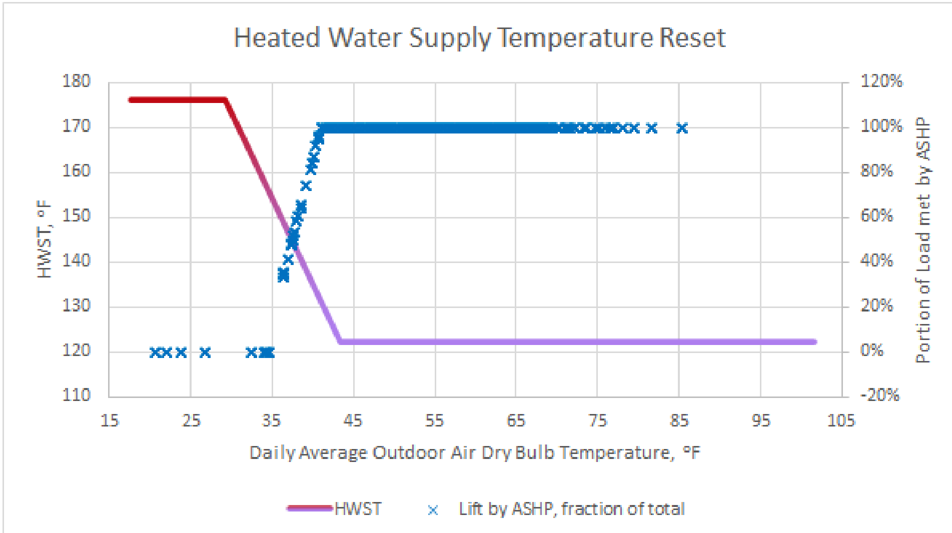


Figure 26 – Temperature reset strategy during transition

iii. Equipment

The following table presents the quantity and capacity of each equipment installed for Low Temperature Centralized ASHP without GHX option, based on the system operation and demands. Further discussion around the equipment and capacities can be found in the Options Evaluation section.

Table 7 – Low Temperature Centralized ASHP w/o GHX Option Equipment

Equipment	Quantity	Individual Capacity	Total Capacity
ASHP (4-Pipe)	5	1,500 MBH	7,500 MBH
ASHP (2-Pipe)	21	1,500 MBH	31,500 MBH
NG Boilers	-	-	45,200 MBH
HW Buffer Tank	-	-	4,050 gal
CHW Buffer Tank	-	-	4,050 gal

Option 3 – Low Temperature Centralized Air Source Heat Pump with Geo-Exchange

i. Description

The Low Temperature Centralized ASHP with Geo-Exchange (GHX) options consists of ASHPs, a closed-loop GHX coupled with Heat Recovery Chillers (HRCHs), and NG Boilers to produce the low temperature heating water and chilled water. This option provides greater seasonal efficiency by incorporating the benefits of GHX. The GHX well field acts as a thermal battery which allows heat to be rejected to and extracted from it. By coupling the well field with a HRCH, it provides an opportunity for simultaneous heating and cooling and seasonal thermal storage. Additionally, the HRCH does not have the limitations of outdoor air temperature (OAT) that comes with the ASHPs, therefore, the GHX and HRCH system can operate effectively throughout the year with no need to engage the natural gas boilers due to low OAT.

Taking full advantage of the energy and carbon benefits of this option requires building upgrades to allow for the low temperature heating water and lower temperature differentials between supply and return (10°F). A system temperature reset strategy is proposed to allow for a functioning system during the conversion to low temperature terminal units in the buildings.

Similar to the other centralized options, Option 3 consists of constructing two new, central heating and cooling plants and GHX well fields to provide low temperature heating water and chilled water to all connected buildings. One plant would be constructed to serve the North, South and Ridgeway nodes, and the other would be constructed to serve the Fairhaven node. This is due to the geographic location and heating only nature of the Fairhaven node.

The plant schematic in the figure below illustrates the proposed configuration of the mechanical equipment in the central plant; a description of each key mechanical equipment and how it is utilized in the system is provided below:

- HRCH: Provides both heating water and chilled water for the system.
- ASHP (4-Pipe) Provide simultaneous heating and cooling during normal operating conditions.
- ASHP (2-Pipe): Provide either heating or cooling during normal operating conditions.
- NG Boilers: Provide backup and peak heating.
- Buffer Tanks: Create thermoclines to control the ASHPs and HRCHs, and to provide hydraulic separation between primary and secondary pumping.
- Distribution Piping: Heating Water Distribution sized for 10°F temperature difference.
- GHX Headers: Provides hydraulic separation between geo-exchange pumps and thermal generation.
- GHX Well Field: Ground heat exchanger to reject heat to and extract heat from.

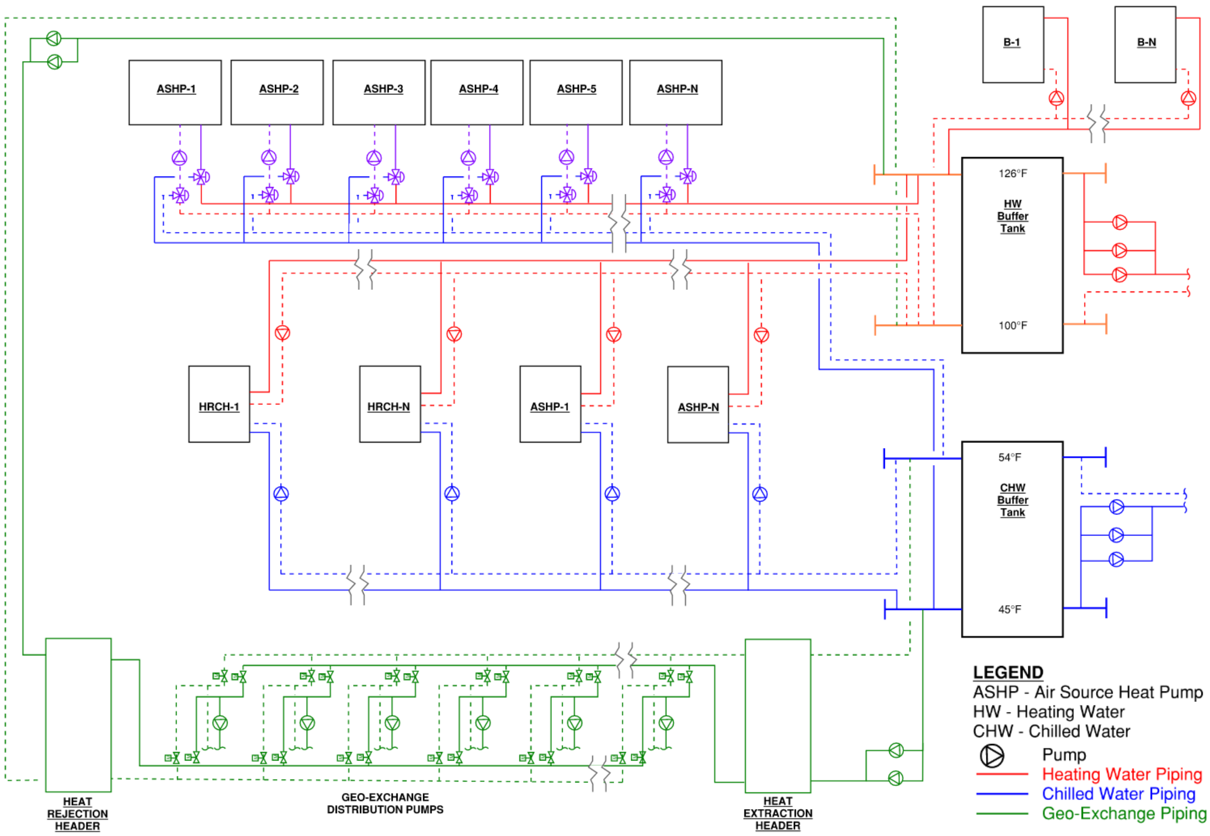


Figure 27 – Low Temperature Centralized ASHP w/ GHX Option Schematic

ii. Operation

The Low Temperature Centralized ASHP with GHX option operates differently to the previous options with the HRCH as the prime heating and cooling component. During normal conditions, the HRCH operates in either heating or cooling mode depending on the demand of the system. During heating mode, the HRCH aims to meet the required heating demand system by producing the necessary low temperature heating water while producing chilled water simultaneously. The chilled water is used for cooling as needed and any excess chilled water is sent to the GHX well field to reject heat to the field. The46uildinge occurs during cooling mode. In this configuration, the ASHPs are used to provide any additional heating or cooling that the HRCHs cannot. The NG Boilers are used during peak heating conditions or backup conditions.

This configuration would need to follow the same reset strategy as Option 2 while the buildings on campus are not prepared to operate at low temperatures at peak heating conditions. However, the reset strategy does not penalize performance of Option 3 as much, since the geo-exchange system allows the HRCH to operate at full capacity independently from outdoor air temperature, and its performance is only limited by the heating water supply temperature.

iii. Equipment

The following table presents the quantity and capacity of each equipment installed for Low Temperature Centralized ASHP with GHX option, based on the system operation and peak demands. Further discussion around the equipment and capacities can be found in the Options Evaluation section.

Table 8 – Low Temperature Centralized ASHP w/ GHX Option Equipment

Equipment	Quantity	Individual Capacity	Total Capacity
HRCH	12	1,640 MBH	19,680 MBH
ASHP (4-Pipe)	5	1,500 MBH	7,500 MBH
ASHP (2-Pipe)	17	1,500 MBH	25,500 MBH
NG Boilers	-	-	28,600 MBH
HW Buffer Tank	-	-	4,050 gal
CHW Buffer Tank	-	-	4,050 gal
GHX Boreholes	432	500 ft deep, 18ft spacing	-

Option 4 – Low Temperature Nodal Air Source Heat Pump with Geo-Exchange

i. Description

The Low Temperature Nodal ASHP with GHX option is a nodal version of Option 3. This option consists of four new, independent nodal plants each served by a dedicated GHX well field. For the purpose of this analysis the nodes were named North, South, Ridgeway and Fairhaven.

Plants serving the buildings at the North and South nodes would consist of 2- and 4- pipe ASHPs with a closed-loop GHX coupled with Heat Recovery Chillers (HRCHs) to produce the low temperature heating water and chilled water. NG Boilers would also be used to supplement water heating.

Plants serving the residential nodes, Ridgeway and Fairhaven, would consist of 2-pipe ASHPs, a closed-loop GHX coupled with single mode water to water heat pumps, and NG Boilers would also be used to supplement water heating.

As with the previous low temperature options, taking full advantage of the energy and carbon benefits of this option requires building upgrades to allow for the low temperature heating water and lower temperature differentials between supply and return (10°F). A system temperature reset strategy (same as low temperature Options 2 and 3) is proposed to allow for a functioning system during the conversion to low temperature terminal units in the buildings.

The main benefit of this option is to provide flexibility in the phasing and construction of the system. As each node contains its own system, this allows for the University to focus on the transition to low temperature heating water one node at a time, as funding becomes available. Furthermore, a nodal approach reduces the amount of distribution piping required, which in turn reduces capital costs.

The plant schematic in the figure below illustrates the proposed configuration of the mechanical equipment in the North and South nodal plants; a description of each key mechanical equipment and how it is utilized in the system is provided below:

- HRCH: Provides both heating water and chilled water for the system.
- ASHP (4-Pipe) Provide simultaneous heating and cooling during normal operating conditions.
- ASHP (2-Pipe): Provide either heating or cooling during normal operating conditions.
- NG Boilers: Provide backup and peak heating.
- Buffer Tanks: Create thermoclines to control the ASHPs and HRCHs, and to provide hydraulic separation between primary and secondary pumping.
- Distribution Piping: Heating Water Distribution sized for 10°F temperature difference.
- GHX Headers: Provides hydraulic separation between geo-exchange pumps and thermal generation.
- GHX Well Field: Ground heat exchanger to reject heat to and extract heat from.

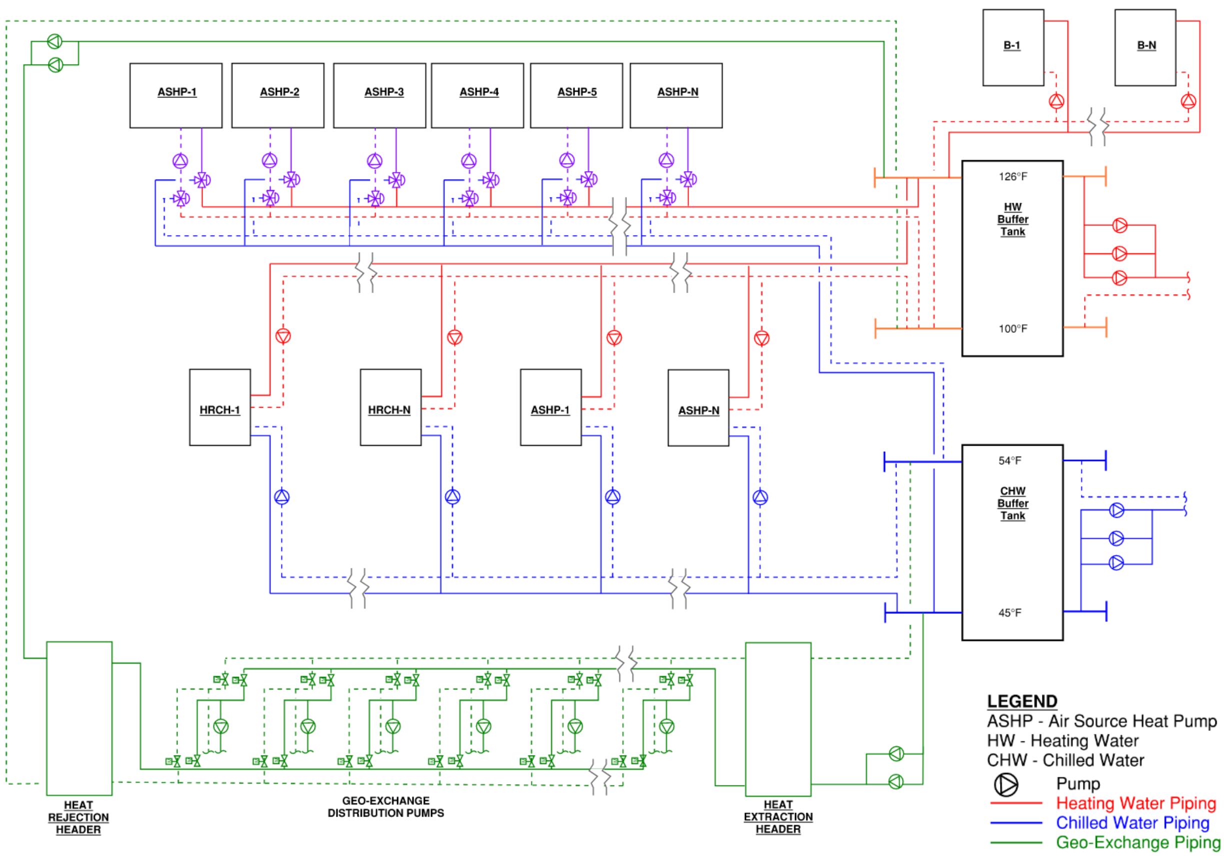


Figure 28 – Low Temperature Nodal ASHP w/ GHX Option – North and South Plants Schematic

As Ridgeway and Fairhaven do not require cooling, a heating only plant would be constructed at these nodes. In this configuration, there would be no CHW Buffer Tank, the two-pipe ASHPs would provide heating only, and the heat extraction from the GHX well field can be achieved using a more conventional water source heat pump (WSHP). The plant schematic in the figure below illustrates the proposed configuration of the mechanical equipment in the Ridgeway and Fairhaven nodal plants.

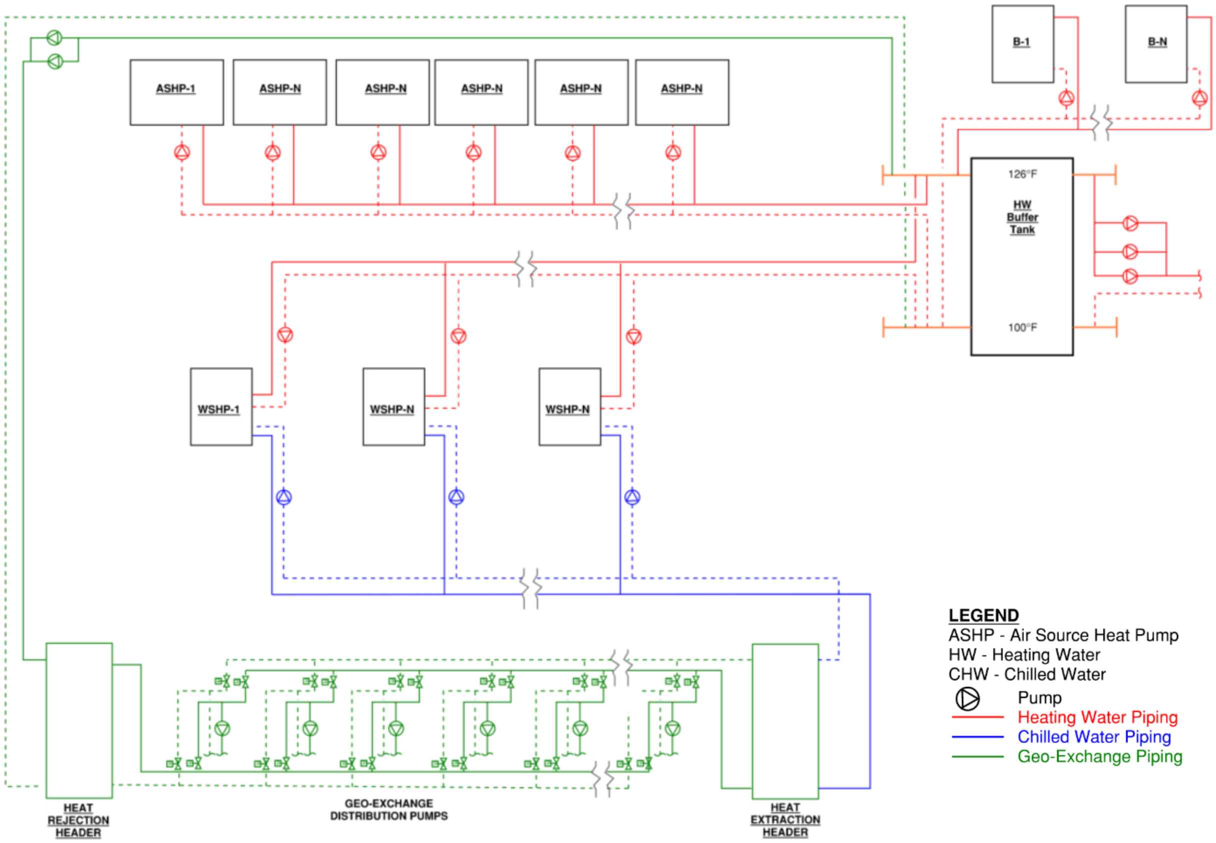


Figure 29 – Low Temperature Nodal ASHP w/ GHX Option – Ridgeway and Fairhaven Plants Schematic

ii. Operation

The Low Temperature Nodal ASHP with GHX option, for the North and South nodes, operates the same as the centralized option (Option 3). During normal conditions, the HRCH operates in either heating or cooling mode depending on the demand of the system. During heating mode, the HRCH aims to meet the required heating demand system by producing the necessary low temperature heating water while producing chilled water simultaneously. The chilled water is used for cooling as needed and any excess chilled water is sent to the GHX well field to reject heat to the field. The opposite occurs during cooling mode. In this configuration, the ASHPs are used to provide any additional heating or cooling that the HRCHs cannot. The NG Boilers are used during peak heating conditions or backup conditions. For the Ridgeway and Fairhaven nodes, the water source heat pump would operate in heating mode only and the system would always be extracting heat from the GHX. These systems would rely on the natural dissipation of heat within the earth to replenish thermal energy surrounding the well field.

iii. Equipment

The following table presents the quantity and capacity of each equipment installed for each node in the Low Temperature Nodal ASHP with GHX option, based on the system operation and demands. Further discussion around the equipment and capacities can be found in the Options Evaluation section.

Table 9 – Low Temperature Nodal ASHP w/ GHX Option Equipment

Equipment	Quantity	Individual Capacity	Total Capacity
North			
HRCH	3	1,640 MBH	4,920 MBH
ASHP (4-Pipe)	4	1,500 MBH	6,000 MBH
ASHP (2-Pipe)	5	1,500 MBH	7,500 MBH
NG Boilers	-	-	7,065 MBH
HW Buffer Tank	1	1060 gal	1060 gal
CHW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	160	500 ft deep, 18ft spacing, 40,633 SF	
South			
HRCH	6	1,640 MBH	9,840 MBH
ASHP (4-Pipe)	6	1,500 MBH	9,000 MBH
ASHP (2-Pipe)	4	1,500 MBH	6,000 MBH
NG Boilers	-	-	13,000 MBH
HW Buffer Tank	1	1060 gal	1060 gal
CHW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	300	500 ft deep, 18ft spacing, 76,782 SF	
Ridgeway			
WSHP	1	1,640 MBH	1,640 MBH
ASHP (2-Pipe)	3	1,500 MBH	4,500 MBH
NG Boilers	-	-	1,730 MBH
HW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	50	500 ft deep, 18ft spacing, 12,993 SF	
Fairhaven			
WSHP	2	1,640 MBH	3,280 MBH
ASHP (2-Pipe)	3	1,500 MBH	4,500 MBH
NG Boilers	-	-	3,900 MBH
HW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	50	500 ft deep, 18ft spacing, 28,109 SF	

Required Building Upgrades

Common to all 4 options are “Energy Transfer Stations” (ETS) that would be deployed in each building served to exchange heat or cooling between the central system infrastructure to the building hydronic heating and (if deployed) cooling loops.

The distribution loop will supply most of the energy for the building’s space and domestic water heating. New feeder lines are to be installed to carry water from the main loop to a new or revised mechanical room within the building that will house the buildings energy transfer station. Two lead-lag configured hydronic circulation pumps pull the heating water from the distribution loop thru the feeder lines and supply two separate hydronic systems within the energy transfer mechanical room, one for space heating and one for domestic water heating.

Space heating is provided by a counterflow plate frame heat exchanger sized for the full load of the building at a deltaT of approximately 30F. This should allow the building's hydronic heating water (HHW) to achieve temperatures within 5 degrees of nodal supply temperature. To distribute the heat from the mechanical room additional hydronic heating water distribution pumps will need to be added in buildings that currently use steam for air handlers.

Domestic water heating is provided by a double walled tube heat exchanger sized for the full load of the domestic water at a deltaT of approximately 30F. This should get the domestic water to approximately 90F – 100F. The target temperature for domestic water storage is 140F due to Legionella concerns. To achieve this domestic water target temperature without the use of natural gas or auxiliary steam heat the use of water-to-water heat pumps is employed. Current design technology limits the heat recovery rate of these units such that multiple units would be used in series and an additional hot water storage pressure tank added. The size of this storage tank is a function of the use of the building and the number of hot water fixtures. Buildings at Western that lack master mixing valves (MMV) would require these to be added to reduce the temperature of domestic hot water distributed from the storage tanks to fixtures.

The assumption is Western's campus chilled water distribution loop will provide chilled water at 45-50F to each building requiring cooling. New feeder lines are to be installed to carry the Nodal water from the main loop to a new or revised mechanical room within the building that will house the master energy transfer station. Two lead-lag configured hydronic circulation pumps pull the 45F water from the distribution loop thru the feeder lines and supply a hydronic system within the energy transfer mechanical room. An intermediate heat exchanger, similar to the heating system, may or may not be a part of the final design. For building that already have cooling the interconnection to central chilled water provides redundancy given existing installed chillers remain. For buildings that currently do not have cooling CHW distribution risers and piping will have to be added as well as hydronic cooling coils and modifications to terminal units in some instances. Ductwork modifications will be necessary and fan motors may need to be upgraded. A typical Energy Transfer Station that includes heating, cooling and DHW is shown in Figure 29.

An additional common-to-all component for the options evaluated are the upgrades required within the buildings served. These include upgrades to existing heating systems. For Options 2 – 4, the building heating systems need to be modified to be compatible with design supply heating water temperatures that are lower than what is currently generated using steam converters. The design lower heating water temperatures for these options (120F – 140F) are what can be efficiently generated using single stage heat pump technologies, whereas heating water supply temperatures generated by steam today are typically around 180F in 51uildinggs served by the Campus central steam system.

The building level heating upgrades generally entail replacing heating coils in air handling units and terminal units with equipment that can achieve the needed heating capacities using lower temperature heating water. Given the life cycle cost study runs 50 years, the assumption is that all these systems would require renewal within that time span. However, to meet Western's carbon reduction timeline objectives, future implementation or heating system upgrades would ideally be accelerated, and that was the assumption used for this study's financial analysis. Otherwise, the operation of the low temperature heating water options would rely in the long term on using peaking boilers to achieve the higher design heating water temperatures needed by buildings.

Given the 50-year life cycle period, building upgrade costs were also folded into the BAU case and Option 1 which assumes higher supply heating water temperatures are generated by the new central heating plant. Those are both assumed to be like-for-like replacement of all existing heating equipment. The basis for this assumption in the life cycle cost analyses is that existing heating equipment will require replacement due to reaching end of useful life within the 50-year period.

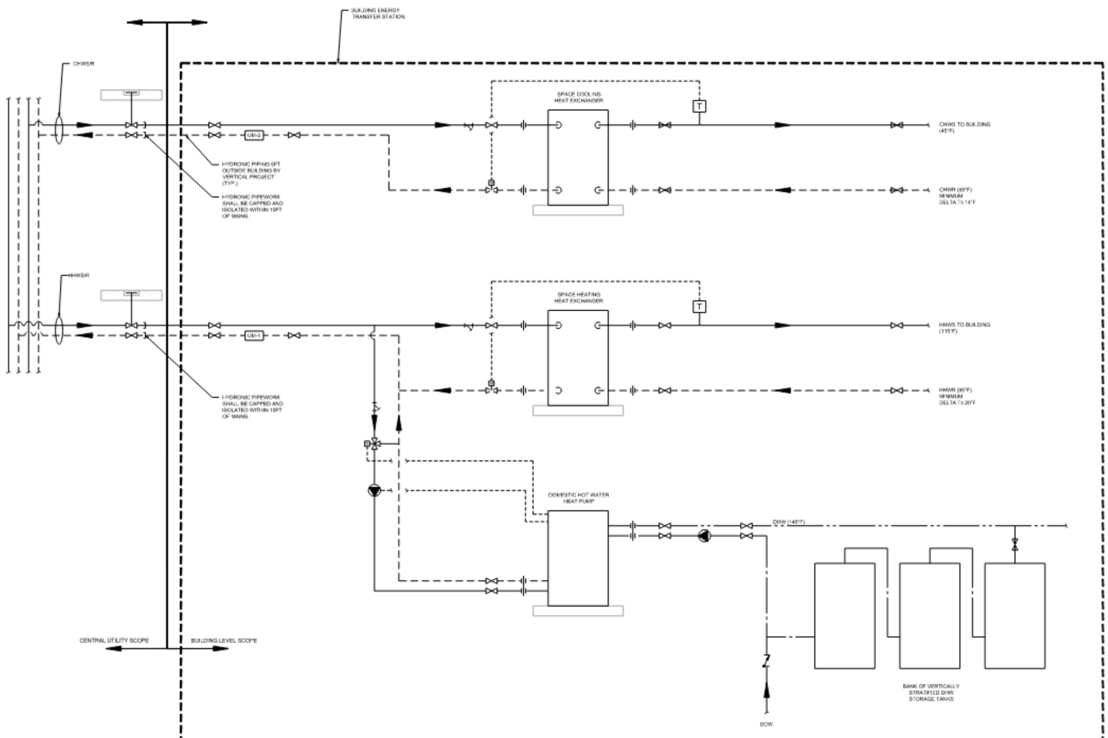


Figure 30 – Building Energy Transfer Stations

For the BAU, incorporation of new chiller plants in all buildings requiring cooling that don't currently have cooling was assumed to provide an equal basis for comparing the BAU case to the low-carbon options in the financial analysis. Chilled water production and subsequent use throughout each building is assumed to be obtained by the use of an air-to-water heat pump chiller sized at approximately 75% of the full cooling load and a water-to-water heat recovery heat pump sized at 25% of the full cooling load (note these relative percentages would be optimized during design). The water-to-water heat recovery heat pump would be tied into the heating loop. Just prior to the heating water entering the heat recovery chiller the heating water shall pass thru a false coil which shall drop the heating water temperature to an acceptable level of approximately 90F. The false coil can be installed within any rooftop or building exhaust discharge with enough CFM. In the process of generating chilled water, heat rejection from the water-to-water heat pump would boost the heating water temperatures back up, making the use of the false coil an energy neutral strategy that enables highly efficient cooling. New primary and secondary chilled water distribution pumps and piping risers and laterals are needed. Other building upgrades as described above for the low carbon options to install cooling coils and modify air systems and terminal units are also part of the BAU building upgrades.

Options Evaluation

Energy Performance

On an energy consumption basis, each of the options is dramatically better than the BAU case. This is not surprising given the relative efficiency of a heat-pump based solution relative to central steam systems. The figure below compares the annual electricity and natural gas use of the low carbon options against the Business as Usual (BAU) scenario. The energy values for the low temperature hot water options (Options 2-4) correspond to the end state of the system, when temperature reset is no longer required to meet peak heating loads.

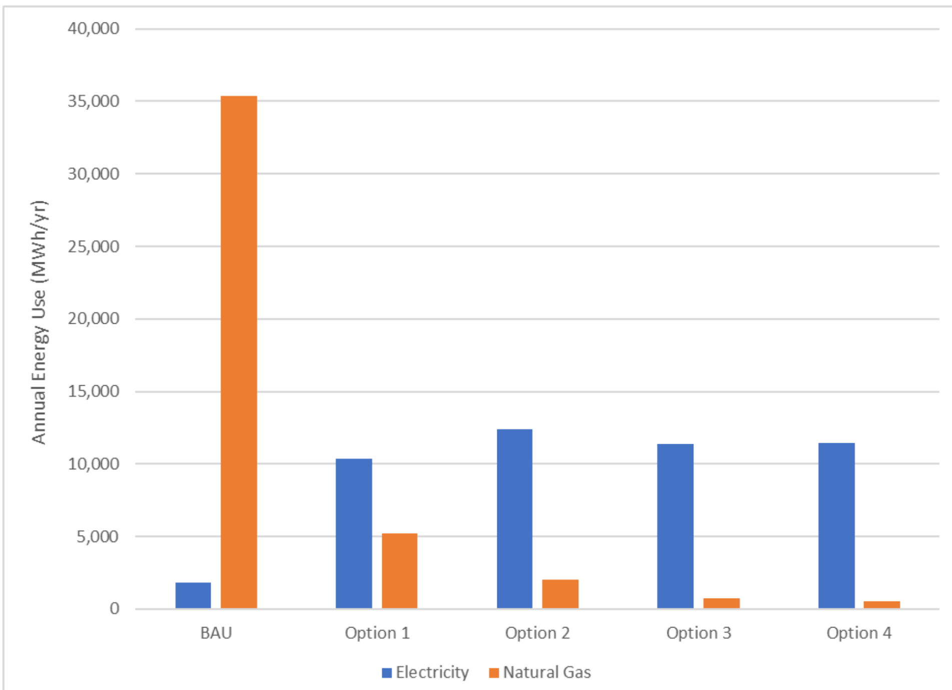


Figure 31 – Energy Use Results

Natural Gas consumption significantly drops in all the explored low carbon options. As expected, the drop in Natural Gas use is particularly high in the low temperature heating water options (Options 2-4), which allow for increased reliance on heat pumps as the primary heating system. The options that include geo-exchange (Options 3-4) result in the lowest use of natural gas, as geo-exchange fields enable even further operation of heat pumps during the coldest periods of the year.

In contrast, electricity use for thermal energy generation (heating and cooling) increases significantly. Electricity is only used for cooling in the BAU scenario, whereas it is used for both heating and cooling in the options that use heat pump technologies. Options 1, 2, 3, 4, show increasing levels of fuel switching from natural gas to electricity.

Overall, energy use of the low carbon options is remarkably low compared to the BAU due to the overall higher efficiency of the thermal energy generation and distribution system.

GHG Emissions

The increased efficiency in energy use combined with the switch in energy carriers (from predominantly natural gas to predominantly electricity) translate into the overall GHG reductions shown in Figure 31. These results assume the electricity use at Western carries no GHG emissions, since the university already purchases 100% green power through a Power Purchase Agreement (PPA) and in future Washington state utilities are committed to providing 100% renewable energy.

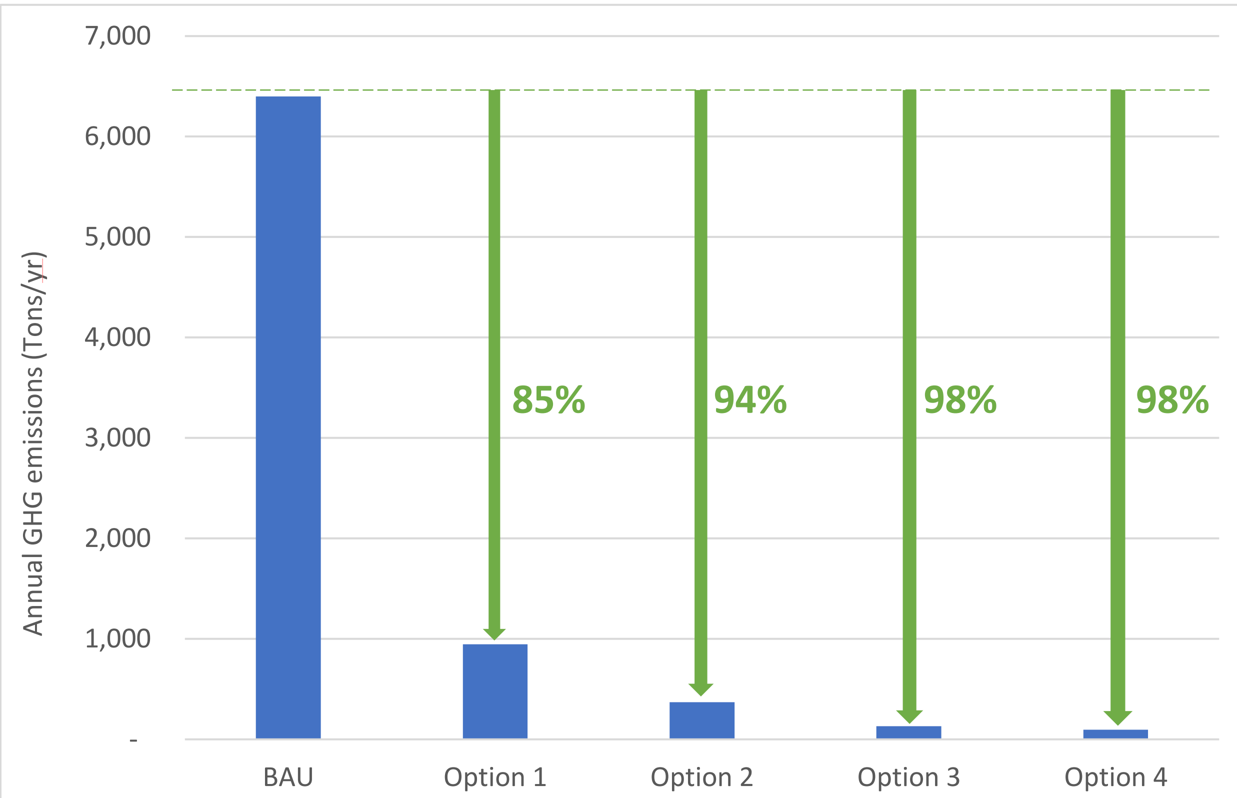


Figure 32 – GHG Emissions Results

Results show how increasing degrees of fuel-switching in the low carbon options translate into increasing savings in GHG emissions relative to the BAU scenario. The four low carbon options result in very large GHG savings. However, the figure exposes the inherent limitations of the high temperature heating water supply system Option 1 relative to the low temperature configurations (Options 2-4). This finding suggests a robust strategy that seeks carbon neutrality for the campus should favor lower temperature solutions, even if these can only be achieved on a long-term basis after additional building upgrades are completed.

Financial Performance

The total capital expenditures for new campus heating/cooling infrastructure and building upgrades are presented in Table 10, which assumes a phased implementation period of 15 years. As indicated, the total capital expenditures for the campus heating/cooling infrastructure ranges from a low of $126M for Option 1 to $189M for Option 3. The differences in capital costs of the systems across the four low carbon options are explained by the following factors:

- Geo-exchange systems significantly increase capital costs of options 3 and 4
- The reduced distribution network in the nodal Option 4 significantly reduces its cost relative to the centralized options (1-3)
- The reduced distribution piping size in Option 1 moderately reduces capital costs of this option relative to the lower temperature options (2-4)

The capital costs for the new campus heating/cooling infrastructure for each option are considerably lower than the estimated construction costs to complete upgrades required within buildings that enable them to heat using low temperature (140F) heating water.

The business as usual (BAU) estimated capital costs in Table 10 are those identified by Western that would be required to maintain existing systems for the next 15 years. No additional investments are shown to replace/upgrade aging heating systems within existing buildings served by campus steam or for the addition of cooling for buildings designated by Western as requiring it in future. This information was generated to illustrate what the minimum capital investment is should Western elect to not decarbonize their central heating system and postpone adding needed cooling to existing buildings.

Table 10 – 15-Year Capital Expenditures Summary

15 Year Capital Expenditures (Millions of dollars)	BAU	Option 1	Option 2	Option 3	Option 4
Capital Costs - Central Heating/Cooling Infrastructure (Generation and distribution)	$13	$126	$130	$189	$149
Capital Costs - Building Upgrades	N/A	$314	$314	$314	$314
Total Capital Costs over 15 Years	$13	$440	$444	$503	$463

Table 11 summarizes the results of the 50-year life cycle cost analysis. In contrast to the 15-year capital expenditures presented above, the BAU case <u>includes</u> the cost to incorporate standalone cooling systems in existing buildings as identified by Western, along with other costs to complete condition-based replacement of aging heating systems in existing buildings. These costs together provide a more equivalent BAU baseline case from which to compare the Options when considering costs for the next 50 years.

Table 11 – Life Cycle Cost Financial Results Summary

50 Year Life Cycle Costs (Millions of dollars)	BAU	Option 1	Option 2	Option 3	Option 4
Total Nominal O&M Costs	$119	$81	$81	$81	$81
Total Nominal Energy Costs	$100	$105	$116	$104	$104
Total Nominal Carbon Costs	$54	$8	$3	$1	$1
Total Nominal Energy & Carbon Costs	$154	$113	$119	$105	$105
Total Cost of Ownership	$745	$720	$731	$784	$747
Net Present Value (NPV)	$566	$561	$568	$620	$585
GHG Emissions, CO_2 (thousands of tons)					
Total GHG emissions over 50 Years	326	48	19	7	5

As indicated, over the 50-year analysis period the total energy expenditures of the BAU would be similar to the energy costs of the best performing low carbon options, in spite of the much lower energy use in the low carbon options. This is due to the much lower current price of natural gas relative to electricity. However, when carbon pricing is considered -- as directed by State of Washington when completing LCCA studies -- the combined cost of energy and carbon is significantly higher in the BAU relative to the low carbon options.

When capital, energy, carbon, and O&M costs are combined into the total cost of ownership over 50 years, options 1 and 2 are comparable to the BAU. Option 4 is slightly higher, but still within a similar range. Option 3 is markedly higher.

Detailed results of the financial analysis are reported in tabular form in Appendix C.

Figure 33 presents the financial and GHG performance of the options relative to the BAU in a bubble chart. The horizontal axis shows GHG emissions reductions relative to the BAU, where a high number is desirable. The vertical axis shows GHG abatement cost in $/Ton CO_2 abated. Abatement cost is calculated as the differential in NPV over the differential in total GHG emissions between an option and the BAU. A low abatement cost is desirable, as it indicates that an option is cost effective at reducing GHG emissions. The bubble size represents the difference in NPV between the option and the BAU, where a small bubble size is desirable.

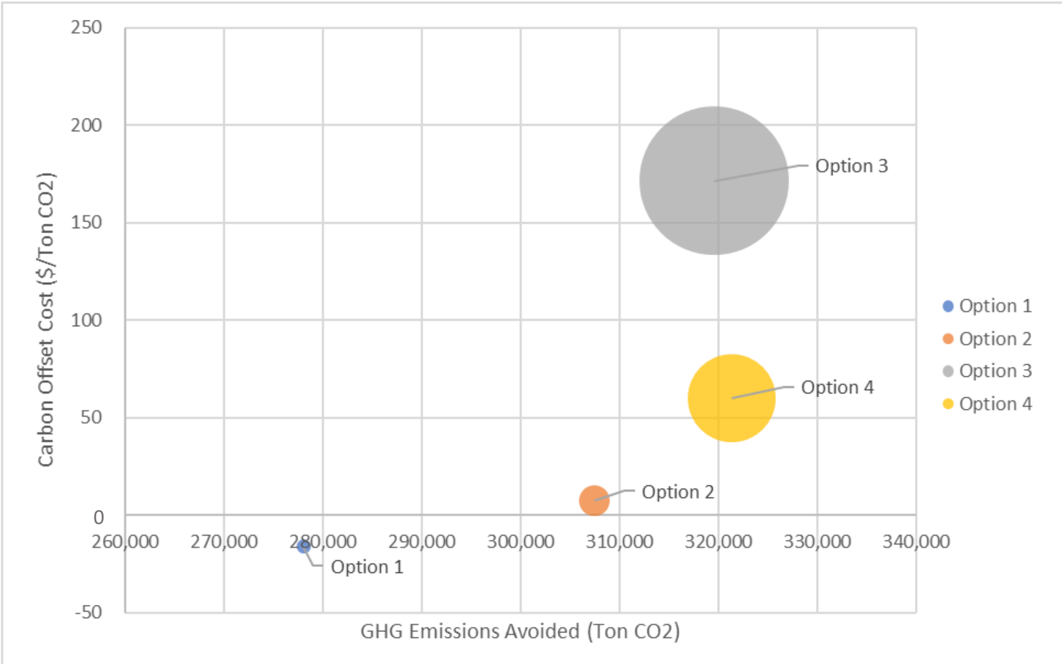


Figure 33 – Financial and GHG performance. Bubble size indicates difference in NPV between option and the BAU (small bubble size is desirable)

As indicated in the figure Option 1 is the best performer financially with a negative abatement cost, which indicates a positive return on investment. But Option 1 is the worst in terms of total carbon abated. Option 2 provides significantly better GHG savings at a very low abatement cost (practically cost neutral at $8/Ton CO_2). Option 4 is the best performer in terms of GHG emissions, but comes with a higher abatement cost. Option 3 is by far the least cost effective of the options at $172/Ton CO_2 and has the highest NPV relative to the BAU. The NPV of each option relative to the BAU is indicated by bubble size, which shows that in terms of overall project cost the order of performance (best to worse) is Option 1, Option 2, Option 4, Option 3. NPV of Option 1 is lower than the NPV of the BAU, which would correspond to a negative bubble size in the figure (shown as a “small” dot instead). As described in the methodology section, NPV calculations include capital cost (initial and replacement costs), energy costs, carbon costs, and O&M costs.

As discussed in the methodology section, financial analyses strongly depend on a wide range of uncertain financial assumptions. A sensitivity analysis was conducted to test how changes in some of the assumptions impacted GHG and financial results. Given relative utility costs are a strong driver in the results, a sensitivity iteration was completed using a natural gas cost of $10/MMBTU instead of the $5.6/MMBTU assumed in the base case results. The impacts on the bubble chart are shown in Figure 34.

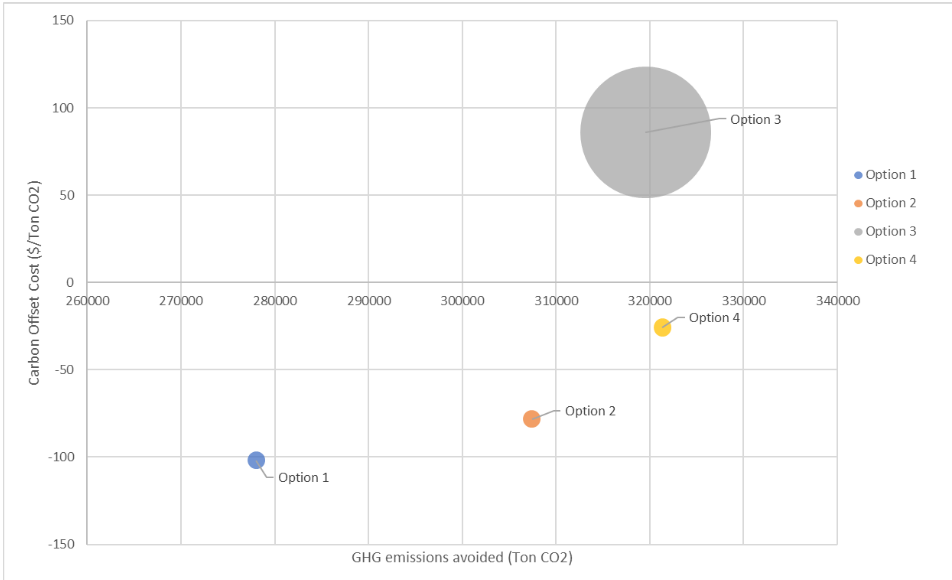


Figure 34 – Financial and GHG performance – Sensitivity to Natural Gas price

As indicated, the low carbon options are much more cost effective with a high natural gas price. This is because the BAU scenario is, by far, the option that uses the largest amount of natural gas – hence the most impacted by natural gas prices. Under this price scenario, Options 1, 2 and 4 all are positive investments relative to the BAU scenario – as shown by the negative carbon offset cost (vertical axis) as well as the bubble sizes. The negative incremental NPV of Options 1, 2, 4 relative to BAU would translate into "negative" bubble sizes, however, they are shown as small dots instead. Option 3 remains a relatively costly system compared to the BAU even under high natural gas prices.

The consultant team conducted a series of sensitivity runs to test the robustness of the conclusions. Given the GHG intensity of natural gas and electricity may be assumed constants (electricity is assumed to be carbon neutral thanks to the purchase of green power), the sensitivity runs did not result in changes in the GHG emissions, meaning the bubbles for options do not move left or right. Changes in financial assumptions did, however, impact cost effectiveness of options significantly (I.e., the bubbles did move up and down).

Given that low temperature options (2-4) have relatively similar use on electricity and natural gas, changes in utility cost and/or escalation of utility rates impacted them in a similar manner, leading to the same relative performance outcomes. That is, Option 3 is always more expensive than 4, which in turn is more expensive than 2.

Overall, the sensitivity analyses suggest that while the actual financial performance in absolute terms of the different low carbon options is highly sensitive to inputs, the relative performance among them is robust to changes in input assumptions.

Evaluation Criteria

Folding the results of the above financial analysis qualitatively into an overall evaluation matrix that considers other factors' relative advantages and weaknesses by each option yields an additional view as to how each option compares. Note that the Evaluation Criteria are set up to assess and compare options that provide relatively similar Carbon performance (which is the primary goal of the conversion study). The Evaluation Criteria are designed to ask how Western should decarbonize rather than if Western should decarbonize. The BAU is not assessed with the Evaluation Criteria as it does not provide comparable performance and would strongly skew the comparative results.

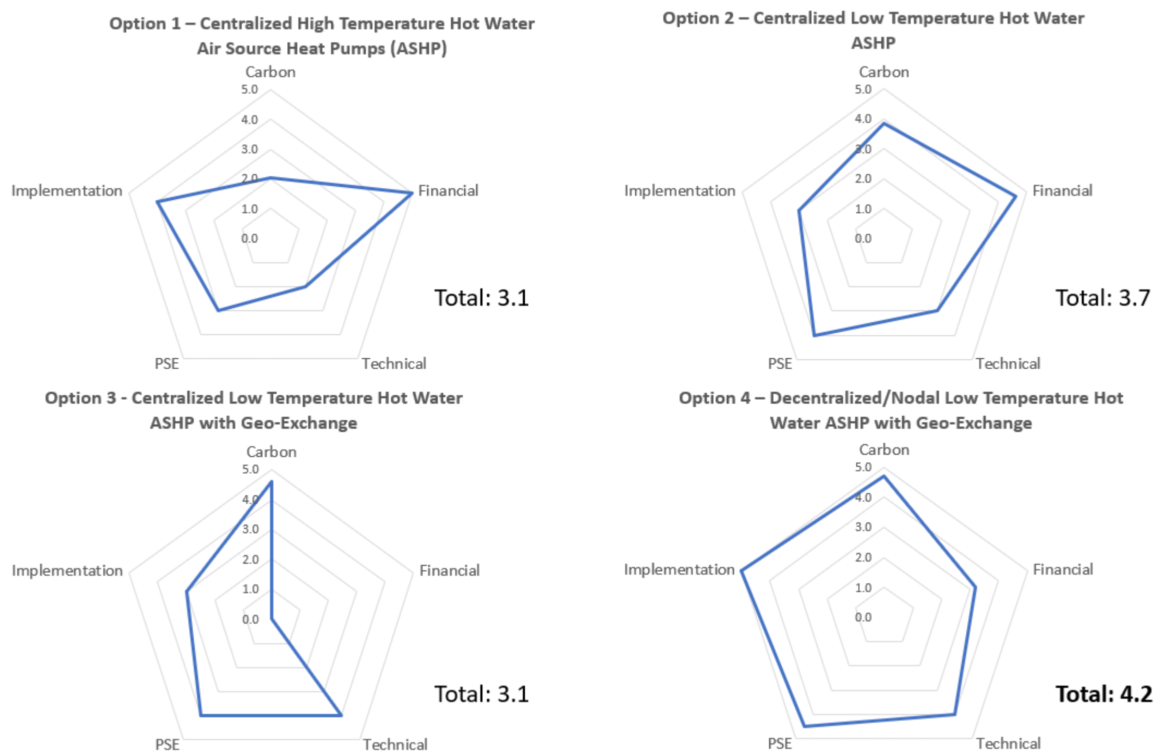


Figure 35 – Evaluation Criteria – Options 1 – 4 "Spider" Diagrams

As indicated in Figure 34, Option 1 excels in Financial performance, however it performs poorly in Carbon ("modest" GHG savings), Technical (lower overall efficiency) and PSE (reputational risk due to continued use of fossil fuel combustion).

Option 2 performs well in Financial and Carbon, but less so Technically (still relies 100% on natural gas boilers on cold days) and implementation (centralized systems requires full campus implementation to achieve GHG benefits).

Option 3 performs well in Carbon, Technical (higher efficiency), and PSE (lower noise pollution and higher reputation benefits due to geo-exchange). However, it has the same implementation challenges as Option 2, and shows a very poor financial performance due to the high cost of geo-exchange in addition to the extensive distribution network required by a centralized system.

Option 4 is the most "well rounded" of the options. It excels in Carbon, Technical and PSE thanks to the high performance of the system and the use of geo-exchange. It also excels in Implementation thanks to the flexibility that a nodal approach provides. Financial performance is penalized by the high cost of geo-exchange. However, the lower cost of the distribution piping system for the nodal approach makes it a much more attractive option compared to Option 3.

A summary of the detailed evaluation provided for the low carbon options according to evaluation criteria agreed upon and priority weighted by the WWU Working Group is provided in Appendix D.

Preferred Alternative Recommendation

While it did not have the lowest estimated first cost or life cycle cost (net present value) within the sensitivity of the analysis, Option 4 was identified as Western's Preferred Alternative because it had the lowest GHG emissions and provided the highest implementation flexibility.

Option 4 has both "common-to-all" advantages and distinct advantages relative to the other Options. Each option studied provides an enormous advantage in terms of GHG reductions relative to the BAU case of retaining the existing steam system. However, through leveraging the geo-exchange field to maximize use of heat pump technologies on colder days, Option 4 largely eliminates any need for natural gas boilers for peaking use, resulting in the lowest overall Greenhouse gas emissions (GHG) of any option studied. The estimated combined annual energy + carbon costs are also the lowest of all options and the BAU case. Employing a geo-exchange also provides a visual story for the community for how renewable thermal energy sources are being deployed.

As with the other options, by retiring and decommissioning the steam system the operational risks associated with continuing to maintain aging resources that are well past normal service life are mitigated. There is also a significant savings in O&M costs as full time, 24/7 steam plant operators are not required with a water-based centralized system that would be largely automated through state-of-the-industry controls. Deploying monitoring technologies would also enable optimization of operation.

The transition to "low-exergy" thermal infrastructure strategy using the nodal option with Geo-Exchange will also contribute to the resiliency of campus heating systems. By pairing electrification of the heat source with peaking/backup combustion boilers, the system not only optimizes geo-exchange field sizing, but also provides a second heating source should it be needed. Currently, the campus can only derive heating energy from combustion fed by natural gas or backup diesel. Having backup/peaking boilers will allow the campus to maintain heating to critical services should there be a major power outage, while during normal operation the heat pumps can pull a large free supply of heat from the earth.

What is recognized as the biggest advantage of the Option 4 nodal approach is it inherently provides more implementation flexibility. Each node can be implemented independent of the others, providing more manageable projects that may match up better to available funding. Based on other planned capital improvements Western can also choose strategically the order by which nodes are constructed.

Overall campus disruption during construction is also limited at any one time to the area of campus served by the node and distribution piping being installed.

Finally, given the high density of buildings and utilities infrastructure – including the existing steam system found in the central/south campus -- locating a single large central plant from where it can most efficiently distribute heating and chilled water appears problematic. Alternately, locating a single central plant on the perimeter of campus means much longer runs to the more remote buildings. Smaller nodes as proposed with Option 4 should enable those new resources to each be more strategically located to serve different parts of the campus, with smaller individual footprints, and a better chance of having one or more nodes proximate to areas where a geo-exchange field is installed, another advantage.

Analysis of Preferred Alternative

Conceptual Design

Conceptual schematic diagrams are provided in Appendix E and in the body of the report above. These depict the primary pieces of equipment required in each nodal plant, as well as their general configuration. Preliminary equipment sizes were established and optimized using the heating and cooling demand profiles and the modeling software that was used to estimate performance. These equipment sizes and quantities were subsequently also used as the basis for developing the cost estimate.

While nodal plant locations were selected in this study to inform development of the conceptual information needed for cost and performance analyses, these are *not* meant to represent specific proposed or recommended sites for the Preferred Alternative. For further discussion on design considerations for location of nodal plants, see the "Site Analysis" section below.

Electrical design considerations for the Conceptual design of the Preferred Alternative are discussed in Appendix F.

Space Needs and Configuration

Figures 36 and 37 below are simplified diagrams illustrating the preliminary space requirement for each of the 4 nodal plants. The general strategy of each plant is to locate natural gas-fired boilers, water source heat pumps and ancillary hydronic equipment including pumps within the plant structure while locating the air source heat pump (ASHP) equipment on the roof of the structure. It is currently envisioned that remaining air source heat pump equipment needed for the two larger plants that cannot be accommodated on the roof adjacent to the plant structure would be placed within a screened adjacent mechanical yard at grade level.

Based on the assumed areas served by each node under the study, the plant spatial needs are similar for the larger north and south campus nodal plants and include a yard for additional needed ASHPs. The Fairhaven and Ridgeview nodal plants are smaller based on the smaller heating demand that are proposed to be served by these.

Floor areas allocated for the nodal plants in figures below do not include the assumed minimal mechanical space required for HVAC needed to condition spaces in the plant itself or any ancillary program spaces Western may want to add for Operations staff (e.g., washrooms, janitorial closets, operator desk, storage & etc.).

This information is preliminary and was used to provide a basis for understanding the general space needs for the infrastructure contained in nodal plants. There will be an opportunity during a future Schematic Design phase to review and adjust plant structures based on Western's specific programmatic needs and the heating and cooling equipment selected and optimized based on actual thermal demand – i.e., the quantity and square footage of buildings served -- a particular nodal plant ends up serving, with an allowance for future capacity growth if determined appropriate. As well, the massing for plant's structures might adjust to fit the available space at selected location(s). For now, the cost estimates provided as part of this study do include a small grossing factor above the area needs identified within each plant for heating and cooling equipment sufficient to meet capacity needs given Western's 10-year growth plan.

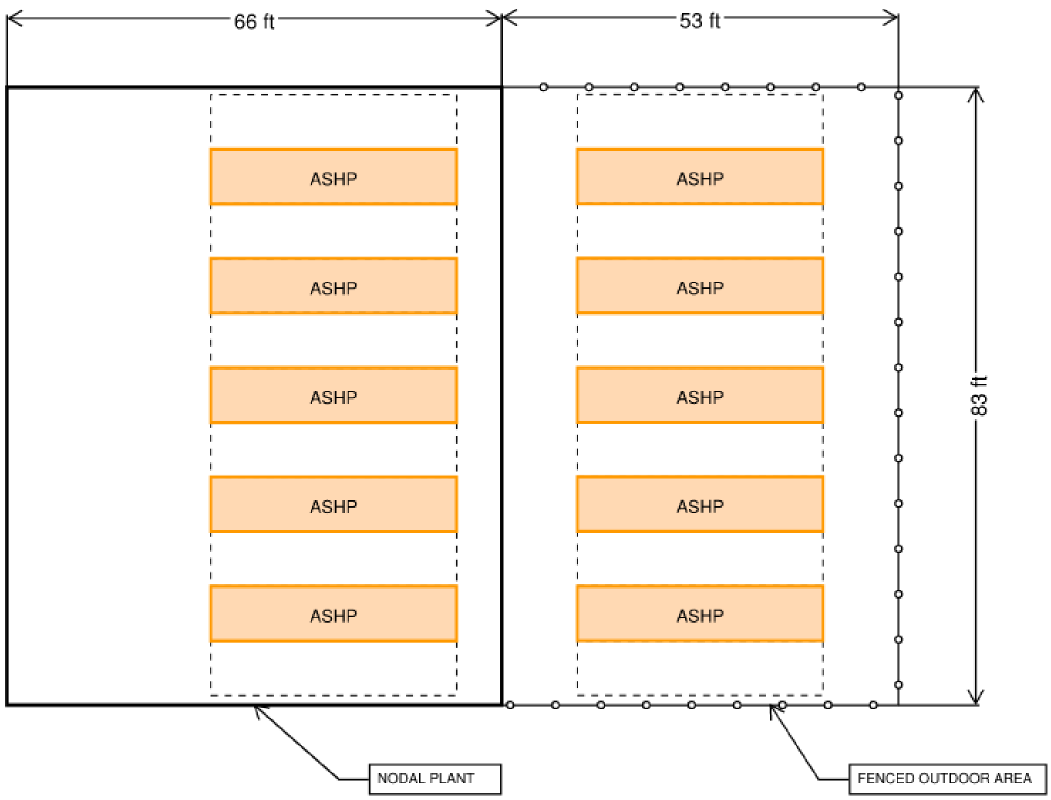


Figure 36 – Area Footprint for North and South Nodal Plants

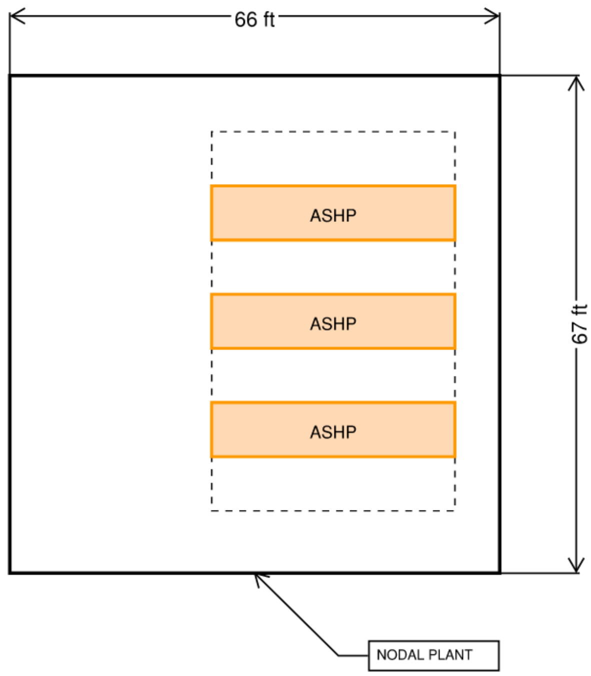


Figure 37 – Area Footprint for Fairhaven and Ridgeway Nodal Plant

Each nodal plant is assumed to have a dedicated geo-exchange field that was sized for their nodes as part of the performance modeling completed for the options evaluation.   Locations are indicated in Figure 38 below.

Site Analysis

Early during the Define phase of the project site walks and meetings led the consultant team to identify potential heating and cooling plant locations on the campus for both centralized and nodal options, as well as areas for GHX well/borehole fields. As a working assumption, these were needed for putting together cost estimates in our financial analysis and technical performance models. However, in discussion with the WWU Working Group it became apparent there are many complicating factors that would all need to be weighed carefully in collaboration with different stakeholder groups at Western, at times with very different priorities. As such, completing a meaningful evaluation process to resolve/optimize final locations for heating and cooling infrastructure was not undertaken as part of this study. This instead is recognized to be a priority during the future Schematic Design scope that Western is requesting funding for as part of the 2023-2025 biennium.

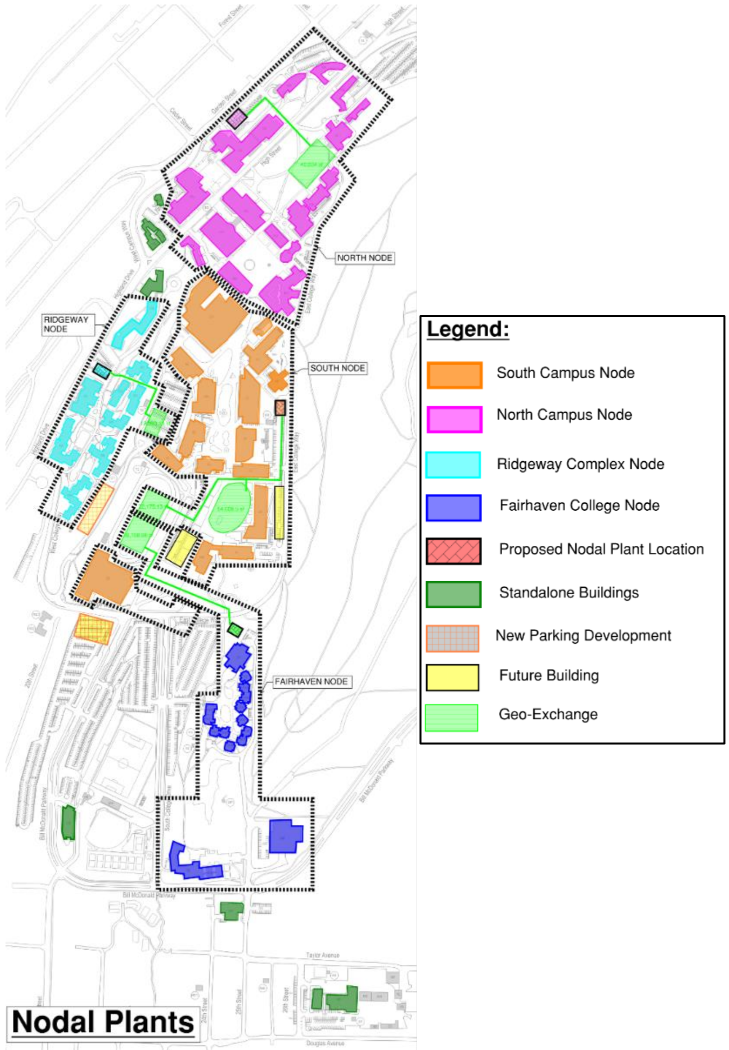


Figure 38 – Nodal Plants

Nonetheless, the consultant team, working with Western, did find it helpful to identify key factors that would need to be balanced as part of evaluating future heating and cooling plant location(s) on the campus. These include:

- Proximity of plant to loads (buildings) served. The capital cost for infrastructure is a direct function of the amount of distribution piping needed
- Piping distribution challenges. Congested areas of the campus tend to have more buried site utilities that would need to be navigated around/coordinated with. Possible water, storm, sewer utility piping relocations, hazardous buried materials mitigations and other enabling projects may get triggered based on constraints associated with practically running new long continuous lengths of buried HDPE distribution heating and chilled water piping in and out of a new plant, and/or the buildings served. Utility underground facilities would need to be avoided. Otherwise, their relocation would be more difficult given it may trigger altering existing drainage patterns. The design of buried piping would also need to account for areas where significant soil settlement. A WWU campus soil properties report completed by the

USDA Natural Resources Conservation Service (NRCS) in March 2022 indicates bedrock on the campus typically will be found at 48" – 52" but local conditions may include shallower areas that could impact use of buried piping. Geotech reports for recent specific building projects will also be leveraged when evaluating piping strategies.

In some areas it would be beneficial if portions of the existing steam tunnels can be reused for routing new hydronic piping. However, while the site assessment work indicates it is technically viable, this brings its own set of challenges. Phasing/scheduling when the work can be implemented is more difficult. Steam piping in tunnels ideally should not be demolished until the new system is completed and services can be cut-over. But, there is not generally sufficient space in the tunnels to run new large hydronic piping (up to 4 pipes) while retaining steam and condensate piping. Windows of time during the non-heating season might provide some opportunity, but steam is also a resource used for domestic heating water and as such the steam system operates year-round. Finally, using long continuous lengths of large HDPE piping is very cost effective when buried but when routed in a tunnel has constructability challenges that might force use of shorter length with more joints or the use of traditional steel piping.

- Visual impact. New heating and cooling plants are large and include both a new building (or integration in a new, larger building) and fenced yard to house equipment. As such, their visual impact on the campus needs to be carefully considered.
- Acoustical impact. New heating and cooling equipment, particularly air-source heat pumps that are located in either a fenced yard or on the roof of a new plant, produce noise, with sound power levels at 100% full load in the range of 100 dBA. Design mitigations such as screening walls may not be adequate to address this noise at some locations on the campus, and will always be a consideration, regardless of location.
- Proximity of Plant to GHX Field. The capital cost for integration with a GHX field is a direct function of the amount/length of piping needed to interconnect the two.
- Proximity to Power and Natural Gas. The capital cost for a new plant will include costs to bring a large electrical feeder, and provision for natural gas needed to supplement the heat pumps.
- Displacement of Parking. Areas on the campus identified during this study that would potentially provide good proximity between new heating and cooling plants and buildings served could displace some existing parking, something Western would like to avoid, if possible.
- Conflicts with Identified Locations for other Future Western Projects. The existing Western master plan identifies potential future building projects, and early in this study it was seen that some locations earmarked for those projects may conflict with potential new heating and cooling plant locations. As a potential synergy, it was noted that there could be benefits to integration of a new plant within new buildings supporting Western's Academic or Residential needs. This is something to be resolved as part of future planning.
- Accessibility for trucks and service equipment to maintain the system. New heating and cooling plants will need access for servicing equipment, and for future renewal/replacement at end of life.
- Primary Pedestrian and Traffic Flow Impacts. Studying potential impacts to pedestrian and traffic of potential heating and cooling plant locations will need to be completed and results factored into a site evaluation. Assuming impacts are minimal/acceptable but still adverse given Western's operations, mitigations would need to be developed.
- Existing Steam Plant as Opportunity. WWU's Working Group stated a preference to ideally leverage the existing steam plant building in the future. Yet, it was recognized that this also

perhaps the most challenging location to deploy new water-based heating and cooling equipment. This is because of the need for continuity of steam service until all buildings can be migrated over and the amount of underground infrastructure/congestion that emanates from it that is needed to fulfill that mission. Nonetheless, given the value of the building and its centralized location on campus, further evaluation during SD phase is recommended.

- Impact on Cultural Resources. As part of assessing possible plant locations and distribution pathways for buried piping the Department of Archaeology and Historic Preservation (DAHP) would need to be consulted with about potential about impact on cultural resources.

Alignment with Western's Long-Term Goals

This study was specifically commissioned to help Western develop a strategy to help address several long-term goals regarding their district heating system. These include reducing overall environmental impact, providing comfort cooling in select buildings in response to a warming climate, improving operational energy efficiency and helping mitigate future risks associated with continued operation of an aging central steam system.

By nearly eliminating fossil fuel burning for campus heating and hot water and dramatically reducing annual CO_2 emissions in the process the Preferred Alternative aligns with the Presidents Climate Commitment for which Western is a signatory. It also aligns with WWU Sustainability Action Plan that seeks to make Western a regional leader in the drive for a stable climate by exceeding state requirements and reaching carbon neutrality by 2035.

The GHG reductions would also enable Western to be a recognized regional leader among peer institutions and provide a hedge against future energy and carbon price risk.

The relative inefficiency and GHG emissions of the existing steam plant as well as the lack of centralized cooling as an available resource is currently driving new building projects at Western today to choose to deploy standalone heating and cooling systems that are not connected to the district. This represents the only available option currently for Western to meet high performance targets, including reduced GHG emissions. Extrapolated into the future, as more new facilities come online this decoupled, decentralized strategy results in overall higher O&M costs for the campus given a much greater amount of heating and cooling equipment is deployed. Conversion to a Preferred Alternative that leverages centralized nodal plants and adds centralized chilled water as a resource for buildings obviates the need for more future standalone solutions.

Alignment with State Laws and Regulations

Through conversion from a steam plant driven by natural gas-fired boilers to one that leverages highly efficient electric heat pumps Western will dramatically lower GHG emissions. This aligns with multiple existing Washington state laws and regulations. Perhaps most important among these is RCW 70A.45.020, which calls for state agencies to limit GHG emissions by 2050 to no greater than 95% relative to 1990 levels. Relying on electricity is the primary enabler of these GHG reductions, thanks to the May 7, 2019 passage of the Clean Energy Transformation Act (CETA) (SB 5116). The bill requires all electric utilities in Washington to transition to carbon-neutral electricity by 2030 and to 100 percent carbon-free electricity by 2045.

While this project is not a zero net energy project per se, future building modernizations and new building projects at Western will be able to leverage the highly efficient heating and cooling delivered by the new nodal plants, enabling them to more easily meet the requirements of Washington State Executive Order 18-01. This Executive Order requires building capital projects to design for reduction in GHG emissions and to strive to achieve zero net energy.

Finally, for existing and future new buildings at Western's campus, the higher efficiency heating and cooling systems provided by the Preferred Alternative will almost assure buildings on campus comply with the requirements of the Clean Buildings Act (HB 1257). The Clean Buildings Act requires buildings over 20,000 SF to achieve an operational energy performance level based on prescribed targets set by Department of Commerce. Over time, these targets are expected to become more stringent. Interconnection to the nodal plants, and upgrades required in buildings as part of the interconnection, will dramatically drive down the energy use associated with Western's buildings.

Elements Requiring Further Study

Moving forward into a future Schematic Design phase for the Preferred Alternative, perhaps the first priority is to complete the site analyses described above such that locations for future nodal plants and piping distribution pathways can be determined. Concurrent to that, several other problems were identified that require further study as part of design and development. Among the most important of these are:

- Scoping and Planning Required for Building Upgrades. As described elsewhere in this report, mechanical and plumbing upgrades are required in each building that is to be served by the nodal heating and cooling plant. As part of future work, the scope of these building-by-building projects needs to be fully established, but how and when they get implemented has other considerations besides just the interconnection. Questions to be answered include:
    - Should an individual building initially just be upgraded to provide just a new energy transfer station (ETS) for the interconnection to an existing building hydronic heating system, or should that project be combined with a capital renewal of that building's entire heating and cooling system?
    - Should the needed building upgrades be included as part of a functional and/or condition-based larger building modernization?
    - Similar to the residential complexes identified for future replacement, do soon-to-be-needed building modernizations based on age and condition potentially trigger a push to replace the entire building rather than update it?
    - What is the right timing for building upgrades relative to the installation of individual nodal plants?
    - How much do planned building upgrades improve (reduce) heating thermal demand, thereby impacting the sizing and cost of new central heating and cooling infrastructure?

- Implementation Schedule Relative to Other Western Capital Projects. Though discussed further elsewhere in this report, it needs to be reemphasized here that consideration of how and when the many projects associated with implementation of the Preferred Alternative should consider potential impacts – good and bad – to other Western capital projects that are concurrent. Interweaving and balancing operational, technical and financial factors is necessary, and these together speak to the high level of planning that is still needed.

- Optimization of Geo-Exchange. From the analysis of options described above it was found that the relative performance between Option 4 (the Preferred Alternative) and Option 2 -- both in the performance matrix as well as the financial results -- provides context for a potential optimization exercise for the Preferred Alternative. It could well be that a refined version of the Preferred Alternative that reduces the size of geo-exchange to improve financial performance would result in a GHG performance that, while not as good as proposed now, is still better than Option 2. In turn, the financial performance with less geo-exchange could even be better than Option 2, since the nodal configuration has intrinsic cost efficiencies.

- System Configuration Optimization. While a Preferred Alternative is suggested, the actual configuration of the new heating and cooling system will be explored during Schematic Design. Relevant questions worth investigating are:

    - Is four in fact the optimum number of separate nodal plants, or might more or less nodes offer advantages that are compelling?
    - Does interconnection of one or more or all of the nodal plants together via a large ambient temperature hydronic loop offer efficiency or resilience/redundancy advantages in a cost-effective way?
    - Does local or centralized diurnal thermal storage provide benefits considering operational efficiency, specific building or area of campus daily load profiles, anticipated future utility rate structures, etc.
    - Should provisions in the initial design be made to facilitate the future implementation of a nodal plant interconnection or thermal storage should changing conditions favor these?

- Verification of Existing Building Lowest Supply Heating Water Temperatures. The existing buildings connected to campus steam typically convert to hot water for distribution to heating coils in AHUs and to terminal units. Design supply temperature setpoints typically are 180F, meaning on the coldest day this temperature is needed to adequately heat a building. However, frequently in practice there may be some ability to reduce the design supply water temperatures due to some conservatism in the design. For this reason, it is recommended that Western perform some trials during the next heating season adjusting heating supply water temperatures to verify whether the peak temperatures can be reduced. This would have significant impact on the design and future operation of a new low carbon heating system, potentially reduce the overall cost of future upgrades.

- Port of Bellingham Waterfront District Energy Interconnection. The Port of Bellingham has brought on a district energy provider to supply heating and chilled water as a utility service for future development of the waterfront. While the physical distance between Western's campus and the waterfront area is not insignificant, and the planned system still relies partially on natural gas, there could be financial or resiliency/redundancy reasons why interconnection, or a provision for future interconnection, could make sense for Western.

- Provisions for Future Campus Growth. As mentioned earlier, for purposes of developing the future campus heating and cooling demand profiles used in the analysis Western provided the consultant team information on anticipated new building projects, covering approximately the next 10 years. In designing the nodal plants, allowances ideally should also be made to allow for some as yet unplanned longer-term growth. Areas of the campus may more naturally support more or less of this future expansion. For those areas on campus likely to have future expansion additional space could inexpensively be provided in nodal plants to accommodate installation of additional heating and cooling equipment in the future to boost peak capacity. It may also be determined prudent as part of design to increase the size of distribution piping for one or more of the nodes.

Alignment with Western's Future Capital Projects

The WWU Working Group identified for the study planned future capital projects such as new academic buildings and housing replacement projects. One of the new future buildings, the Interdisciplinary Science Building (ISB), actually came on-line during the study. The other three – the Student Success Center, Coast Salish Longhouse, and Kaiser Borsari Hall are not yet constructed. The housing projects include the replacement of Fairhaven and Ridgeway Towers. It is anticipated that these future buildings and housing replacement projects will be completed within the next 10 years. All these future developments provide opportunities for alignment with the Preferred Alternative. New heating/cooling plants could in part or whole be located within the new/replacement build projects, or developed concurrently if adjacent to each other. This has could reduce the visual impact to the campus of a new stand-along heating and cooling plant and potentially reduce some of the first cost.

The mechanical system in future buildings or building replacement projects would be designed from Day 1 to use low temperature hot water for heating, and so be a natural customer for heat provided by the Preferred Alternative. Cooling, if considered necessary for a new or replacement buildings, would also be designed based on using chilled water generated by the preferred alternative central plant. Moreover, in alignment with Western's goals, new buildings will be designed to go beyond the energy code minimum requirements, resulting in ultra-low energy demand buildings. For example, it is understood that the housing replacement projects may be designed using the Passive House standards such that they have a net low heating and cooling demand. This not only will help in reducing the size and cost of new heating and cooling infrastructure, but also help in lowering utility costs and GHG emissions.

Analysis of Alternative Project Delivery Models

The proposed conversion and upgrades to Western's heating system infrastructure represents a massive and complex undertaking, one that ultimately impacts the vast majority of buildings on the campus. The estimated construction costs dwarf the typical capital funding allocations provided to Western through the conventional biennial state budgeting process. For these reasons, Western's baseline assumption is the Preferred Alternative should be viewed of and planned as a program consisting of many smaller projects, with the program completed over an extended time, possibly up 10 years or more.

With this understanding, the analysis and ultimate determination of an appropriate delivery model for the program are not as straightforward as those for more typical capital projects for new buildings or renovation work. Traditional delivery mechanisms used by state schools under the Revised Code of Washington (RCW) include Design/Bid/Build, Design/Build, and GC/CM may or may not be good choices in this case.

Under traditional funding mechanisms -- and assuming Western would like to retain (after conversion) a similar operations model whereby they manage and maintain the central heating and cooling as a utility that serves buildings as "customers" – a design/build delivery model probably would have the most advantages for Western when implementing new central plants. While introducing more cost risk due to inherent design challenges, distribution (piping) infrastructure on the campus, and possibly the energy transfer stations in each building might also work well if delivered as design/build, though GC/CM sometimes is favored when the level of complexity is greater and discovery around on-site conditions and uncertainty around design approach and cost.

Depending on how individual building upgrades – i.e., those needed to convert them to use low temperature heating water and provide AC through central chilled water – are packaged with other modernizations, these might still go as individual design/build projects. But GC/CM has been found by some public clients to be more advantageous when working on complex projects within existing facilities.

The above considerations though, can only be carried to a conclusion assuming traditional funding via state capital improvement budget allocations is secured. If alternative funding through private mechanisms needs to be used for some or all of the work, other delivery models may deserve consideration, including design/build/operate/maintain (DBOM), as might be something a private district energy firm might propose who would also procure funding. This procurement strategy would obviously come with significant ramifications for Western's facility operations, beyond what is inherent with moving away from centralized steam heat.

Given the uncertainties, Western is planning to allocate funds in FY 2023 to help further investigate and research viable alternate opportunities for program delivery. This work, together with refinement of the technical scope and estimated costs as established during Schematic Design, will hopefully provide the needed clarify around the most advantageous and feasible path for program implementation as allowed by a public institution like Western.

Implementation Path and Schedule Considerations

The determination of actual nodal plant locations and specific strategies/routing for piping distribution on the campus are being deferred until SD phase, as is the schedule for funding procurement and release. Together, these considerations make development of specific implementation and phasing scenarios problematic at this stage. There are simply too many if-then scenarios.

However, key considerations have been identified, and these should help inform future planning and design. These include:

- Node-by-Node Implementation. The Preferred Alternative's multiple, smaller modal central heating and cooling plants are designed to serve different quadrants of Western's campus inherently supports a phased approach to implementation. A best-case funding scenario might see one node constructed every biennium starting in 2025. This would include all distribution piping and building interconnections for that node. This sequencing would potentially enable the entire build-out of new infrastructure prior to 2035, supporting Western's goal of achieving carbon neutrality in accordance with the Sustainability Action Plan.
- Flexibility in Node Implementation Sequence. The order by which nodes are developed is also inherently flexible and of course may ultimately hinge on the level of funding procured, and when. However, there are advantages to timing the implementation of a phase with other planned projects at Western's campus. For example, if the Fairhaven residence hall complex is replaced in the near future as planned, that would be a logical time to complete work on all or some of the node that serves it.
- Timing of Other Capital Building Projects. Similar to Fairhaven node implementation timing, the timing for work needed as part of the Preferred Alternative implementation at or around other new buildings should ideally align with when those buildings are constructed. This will avoid site disturbance and campus disruption at a new building happening twice. Also, Western's needing to authorize design of those new buildings with standalone heating and cooling or connecting them to the existing steam system due to new nodal plants not being available on the same timeline is problematic to Western achieving all their goals for this conversion program. As an interim strategy in such a case, Western may find it attractive to deploy portable temporary heating and cooling plants during any interim periods between completion of a building project and upgrade and being able to interconnect to a nodal central heating and cooling system

  Overall, alignment in how future major building projects are completed relative to nodal system implementation is critically important. As a recommendation going forward, Western should consider updating their campus master plan including the new heating and cooling system infrastructure as an integral part that informs the plan.
- Flexibility of Implementation of Existing Building Upgrades. The proposed scope includes significant upgrades in existing buildings to enable them to provide sufficient heat from a lower temperature heating water source. In addition, for select buildings modifications to systems are needed to enable them to be cooled using chilled water provided by the new central system. Timing for implementation of this work is

inherently flexible, and as noted earlier could be packaged with larger building modernizations where it makes sense. Ideally, though, this work would also be completed prior to 2035. This likely represents an acceleration over typical capital renewal planning for aging systems.

- Spend the "Big Money" Upfront if Practical. As a general rule, implementing the "big ticket" portions of the program is recommended when considering infrastructure projects like this one. So, nodal plant construction upfront, if possible, would be desirable as a strategy. The primary reason is the significant increased future costs for construction (see Table 12). However, this strategy admittedly needs to be balanced against the financing and operational challenges of potentially ending up with a large amount of relatively underutilized capital assets in the equipment that makes up each nodal plant.
- Timing for Decommissioning Central Steam Plant. As new nodal central plants come on-line and begin to serve new building "customers" on Western's campus the existing central steam plant's utilization will gradually drop. The cost burden of maintaining and operating a system that becomes more and more oversized as time goes on may eventually become prohibitive. To complete decommissioning of the steam system early, Western may choose at some point down the road as steam system utilization drops to deploy on an interim basis temporary heating and cooling for buildings that still otherwise would rely on central steam as they wait for the future interconnection to a new, nodal central plant.

Table 12 – Construction Cost Escalation Factors

YEAR	ESCALATION FACTOR	COMPOUNDED
2022	3.8%	3.80%
2023	3.2%	7.12%
2024	3.0%	10.34%
2025	3.5%	14.20%
2026	3.3%	17.91%
2027	3.3%	21.74%
2028	3.5%	26.00%
2029	3.5%	30.41%
2030	3.5%	34.98%
2031	3.5%	39.70%
2032	4.0%	45.29%
2033	3.5%	50.37%
2034	3.5%	55.64%
2035	3.5%	61.08%

Alignment with Community Stakeholders and Local Jurisdictions

Looking ahead, engagement within Western's community and other local stakeholders is a necessary component to future design and planning. At Western, there is high interest by diverse stakeholder groups in what recommendations come out of this study. Areas of interest or concern include: (1) eliminating use of fossil fuels at Western and driving down overall GHG emissions to meet carbon reduction goals, (2) visual and acoustical impact of new heating and cooling plants, (3) impact on operations during construction and (4) capital and future O&M costs. It is recommended that immediately after issuing this report, as part of any public comment period meeting(s) be scheduled and invitations sent to identified groups and individuals who have or likely would be interested in participating. These meetings would transparently review findings and discuss the study recommendations, including proposed next steps. These meetings should accommodate both answering questions but also fielding ideas or suggestions for additional study, given they could improve the project or at least increase alignment to greatest extent if alternate suggestions are thoughtfully examined.

Looking ahead to a future SD phase, this is understood to be the opportunity to develop technical concepts and implementation scenarios more deeply as well as for different financing and delivery options to be evaluated. Here too, given the breadth and impact of this project to Western, a transparent engagement and inclusion of stakeholder groups is recommended.

Given the very significant impact to Western's current usage of gas and power, additional stakeholders and hopefully potential partners are the impacted local utility providers. Early planning meetings with those companies are recommended in SD.

Project Budget Analysis

Presentation of Cost Estimate

The construction cost estimate used to inform the financial analysis and results presented above (see Table 12) for the different options including the BAU case may be found in Appendix G.

As noted earlier, the Preferred Alternative is envisioned as something that would be implemented as a multi-year program. Further development is needed during SD phase to establish nodal plant locations and site-specific distribution strategies, along with detailing of building-by-building work scopes. At that time, phased implementation scenarios can be developed that align with Western's larger campus development plans and potential funding mechanisms. This information together will inform future refinements to the cost estimate.

State of Washington C-100

To communicate the project cost estimates to budget officers in the standard format required for capital project budget requests to the Washington State Office of Financial Management (OFM), a C-100 was completed for the Preferred Alternative. This may be found in Appendix H.

Operation and Maintenance Costs

Operation and Maintenance costs for the BAU as well as the Preferred Alternative were estimated based on the detailed cost breakdowns provided in Western's 2022 budget spreadsheet.

The O&M personnel costs in the recommended option are estimated to be 25% lower than the BAU due to the reduced need for system supervision. The current steam plant requires 24/7 supervision, which is not necessary in a low temperature hot water system. The personnel cost estimated for the preferred option for the first year is $660,000/yr, down from $880,000/yr in the 2022 budget for the BAU.

The cost of small O&M projects was also estimated based on Western's records. The annual average expenses in O&M projects in the BAU is $323,000/yr. 50% of these costs correspond to projects directly associated with steam distribution systems. Therefore, the general budget for small O&M projects for the recommended option is estimated at $161,000/yr. These costs only include small general maintenance costs independent of the main pieces of equipment (which vary across options).

Costs of replacement of major equipment (e.g., ASHPs) is accounted for in the capital costs section of the LCCA, and vary across options. Replacement cycles and life expectancies are consistent with ASHRAE charts, and account for the shorter life expectancy of Heat Pump technologies compared to natural gas boilers.

Appendices

Appendix A
Thermal Losses in the Steam Distribution System

Date	Year	Month	Total Steam Produced (lbs)	Steam Used (Lbs)	Total Loss (lbs)	Loss Factor
Jan-18	2018	1	20,553,521	16,048,913	4,504,608	22%
Feb-18	2018	2	21,601,105	16,308,570	5,292,535	25%
Mar-18	2018	3	18,537,496	14,026,047	4,511,449	24%
Apr-18	2018	4	14,658,282	10,949,414	3,708,868	25%
May-18	2018	5	9,198,061	6,620,938	2,577,123	28%
Jun-18	2018	6	7,503,996	5,549,037	1,954,959	26%
Jul-18	2018	7	5,054,237	3,720,593	1,333,644	26%
Aug-18	2018	8	3,905,024	3,807,304	97,720	3%
Sep-18	2018	9	6,928,952	4,774,652	2,154,300	31%
Oct-18	2018	10	13,353,335	9,618,275	3,735,060	28%
Nov-18	2018	11	16,072,320	10,664,355	5,407,965	34%
Dec-18	2018	12	19,568,631	15,760,268	3,808,363	19%
Jan-19	2019	1	19,568,499	16,511,935	3,056,564	16%
Feb-19	2019	2	24,621,450	22,515,235	2,106,215	9%
Mar-19	2019	3	17,846,053	12,183,367	5,662,686	32%
Apr-19	2019	4	13,815,069	9,445,251	4,369,818	32%
May-19	2019	5	9,537,640	5,938,576	3,599,064	38%
Jun-19	2019	6	6,963,222	4,099,037	2,864,185	41%
Jul-19	2019	7	5,253,652	3,091,290	2,162,362	41%
Aug-19	2019	8	3,824,699	2,469,146	1,355,553	35%
Sep-19	2019	9	6,863,440	3,649,732	3,213,708	47%
Oct-19	2019	10	15,348,925	9,872,998	5,475,927	36%
Nov-19	2019	11	17,162,332	11,141,432	6,020,900	35%
Dec-19	2019	12	18,671,912	12,525,260	6,146,652	33%
					Average Loss Factor	**29%**

Appendix B
Climate Change Scenarios

Global climate is warming as the concentration of GHGs in the atmosphere increases. The relationship between global GHG concentration and climate parameters, such as temperature and precipitation, is a "physics problem" that Global Climate Models (GCMs) compute with increasing accuracy. A key input into the climate models is the projection of GHG concentration in the atmosphere over time, which in turn depends on the trajectory of GHG emissions globally.

Given the uncertainty of global emissions trajectories, the climate models are run for a range of "standard" GHG emissions scenarios called Representative Concentration Pathways (or RCPs). The Intergovernmental Panel on Climate Change (IPCC) defines the RCPs as follows:

- RCP 2.6 is a low emissions scenario, which assumes that strict controls are placed on GHG emissions so that they peak in the 2020s. Global warming mean and likely range (1.0°C, 0.3 to 1.7°C).
- RCP 4.5 and RCP 6.0 scenarios are stabilization without overshoot scenarios, where a range of strategies for GHG emissions are implemented and total radiative forcing stabilizes before 2100. GHG emissions peak in the 2040s for the RCP4.5 scenario and in the 2080s for the RCP6.0 scenario. Global warming mean and likely ranges (1.8°C, 1.1 to 2.6°C) and (2.2°C, 1.4 to 3.1°C).
- RCP 8.5 is a high emissions scenario with few, or no controls placed on GHG emissions. Total radiative forcing increases over the entire 21st century. Global warming mean and likely range (3.7°C, 2.6 to 4.8°C).

The figure below shows how temperature projections strongly depend on the emissions scenario or RCP.

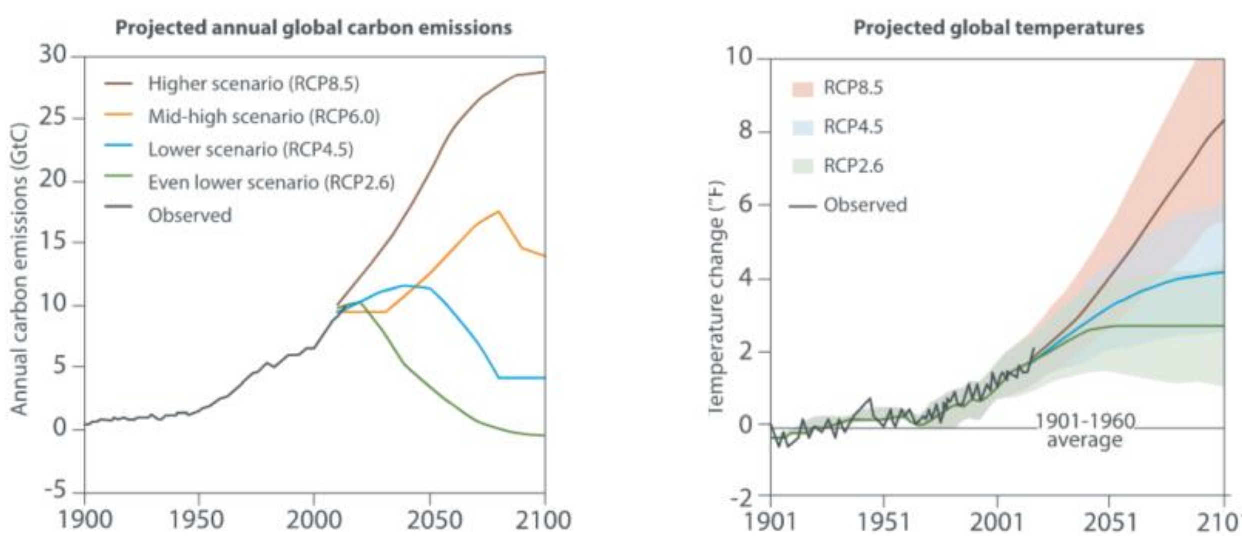


Figure 1: Projected emissions and global temperature under different RCPs.

The direct impact of increasing temperatures on Western's future district heating and cooling plant(s) is the expected decrease in heating demands and the expected increase in cooling demands. For the purpose of this analysis, heating and cooling demand profiles were generated based on a morphed hourly weather file that corresponds to an RCP 4.5 scenario and a 2050s-time horizon specific to

Bellingham, WA. The future shifted weather file captures the anticipated changes in temperature patterns throughout the year (I.e., not only a general increase in temperature, but also a change in temperature distribution on a daily and seasonal basis. The weather file used to develop the load profile was obtained from Weathershift (https://www.weathershift.com/). Detailed information on climate projections for US locations is available at Climate Tool (https://climatetoolbox.org/tool/climate-mapper).

Appendix C
Detailed Financial Results

		BAU	Option 1	Option 2	Option 3	Option 4
Summary	Capital Cost (w/ residual value deducted)	$472.3 Million	$526.3 Million	$531.1 Million	$597.6 Million	$561.7 Million
	Total Nominal O&M Costs	$118.6 Million	$81 Million	$ 81 Million	$81 Million	$81 Million
	Total Nominal Energy Costs	$99.6 Million	$105.1 Million	$115,7 Million	$103.9 Million	$104 Million
	Total Nominal Carbon Costs	$54.1 Million	$8.0 Million	$3.1 Million	$1.1 Million	$819,447
	Total Nominal Energy & Carbon Costs	$153.7 Million	$113.1 Million	$118.8 Million	$105 Million	$104.8 Million
	Total Cost of Ownership	$744.6 Million	$720.4 Million	$730.9 Million	$784.0 Million	$747.5 Million
	Net Present Value (NPV)	$565.7 Million	$561.1 Million	$568.0 Million	$620.5 Million	$584.9 Million
	Total GHG emissions over period (Ton CO2)	326,280	48,247	18,858	6,748	4,943
Cumulative	Total energy use (kWh)	1,894,298,961	793,941,990	734,763,120	618,224,142	611,455,320
	Total GHG emissions (kg CO2)	326,279,599	48,246,680	18,858,305	6,747,612	4,942,527
	Total energy cost ($)	$99.6 Million	$105.1 Million	$115.7 Million	$103.9 Million	$104 Million
	Carbon tax costs ($)	$34.9 Million	$5.2 Million	$2 Million	$722,418	$529,160
	Carbon offsets cost ($)	$19.2 Million	$2.8 Million	$1.1 Million	$396,304	$290,287
	Total carbon cost ($)	$54.1 Million	$8 Million	$3.1 Million	$1.1 Million	$819,447
	Total operating cost ($)	$153.7 Million	$113.1 Million	$118.8 Million	$105 Million	$104.8 Million
Year 0	Total energy use (kWh/yr)	37,143,117	15,567,490	14,407,120	12,122,042	11,989,320
	Total GHG emissions (kg CO2/yr)	6,397,639	946,013	369,771	132,306	96,912
	Total energy cost ($/yr)	$841,064	$1.1 Million	$1.2 Million	$1.1 Million	$1.1 Million
	Carbon tax costs ($/yr)	$485,581	$71,802	$28,066	$10,042	$7,356

	Carbon offsets cost ($/yr)	$159,941	$23,650	$9,244	$3,308	$2,423
	Total carbon cost ($/yr)	$645,522	$95,453	$37,310	$13,350	$9,778
	Total operating cost ($/yr)	$1.5 Million	$1.1 Million	$1.2 Million	$1.1 Million	$1.1 Million
Year 50	Total energy use (kWh/yr)	37,143,117	15,567,490	14,407,120	12,122,042	11,989,320
	Total GHG emissions (kg CO2/yr)	6,397,639	946,013	369,771	132,306	96,912
	Total energy cost ($/yr)	$4 Million	$3.5 Million	$3.8 Million	$3.4 Million	$3.4 Million
	Carbon tax costs ($/yr)	$875,517	$129,462	$50,603	$18,106	$13,262
	Carbon offsets cost ($/yr)	$528,687	$78,176	$30,557	$10,933	$8,009
	Total carbon cost ($/yr)	$1.4 Million	$207,638	$81,160	$29,040	$21,271
	Total operating cost ($/yr)	$6.4 Million	$4.3 Million	$4.4 Million	$4 Million	$4 Million
Relative Performance	Total GHG emissions abated (Ton C02)	N/A	278,033	307,421	319,532	321,337
	Delta Net Present Value ($)	N/A	-4,530,911	2,310,043	54,837,751	19,242,496
	Abatement cost ($/ton CO2)	N/A	-16	8	172	60
	Delta Capital Cost	N/A	$54 Million	$58.8 Million	$125.3 Million	$89.4 Million
	Delta Total Nominal Energy Costs	N/A	$5.4 Million	$16.1 Million	$4.2 Million	$4.4 Million
	Delta Total Nominal Carbon Costs	N/A	-$46.1 Million	-$50.1 Million	-$53 Million	-$53 Million
	Delta Total Nominal Energy & Carbon Costs	N/A	-$40.6 Million	-$34.8 Million	-$48.7 Million	-$48.0 Million
	Delta Total Cost of Ownership	N/A	-$24.3 Million	-$13.8 Million	$39 Million	$2.8 Million

Appendix D
Evaluation Criteria

Option 1. Centralized High Temperature Hot Water

Distribution piping sized for high temperature, high dT (20F)
AS Heat Pumps (4 pipe) - Instantaneous heat recovery (heating/cooling) during low load periods
Air Source Heat Pumps (2 pipe) - Reminder of heating during low load periods, cooling
Boilers (NG / electric) - Heating at medium and high load periods

Weight	Key System Components	Pros	Cons	Score (1-5)
34%	Carbon	Annual GHG emissions (tCO2/yr)		946
		- Major GHG improvement relative to BAU	- Higher NG use compared to low temp options. - "locked in" to boiler technologies (high exergy). No further GHG reductions achievable.	2.0
25%	Financial	Total Capital cost (M$)		526
		NPV (M$)		565
		Abatement cost ($/tonCO2)		-102
		- Lower capital cost (relative to Options 2-4) due to smaller piping	- Potential higher life cycle cost relative to BAU	5.0
20%	Technical	- Hybrid system allows greater redundancy/resiliency .	- Higher thermal losses relative to low exergy systems - Require peaking/redundant heat source for when ASHP are outside their operating range (cold days). - Limited capacity of distribution, can only reset temperature down a limited amount.	2
8%	PSE	- Reputational benefits moving forward to campus carbon reductions relative to BAU steam system	- Risk of noise pollution. - Campus disruption during construction - Electricity as the primary fuel source are more susceptible to electrical GHGI changes. - Reputational risk: Continued higher reliance on NG boilers a visible reminder that WWU still burns fossil fuels on campus.	3
13%	Implementation	- Minimizes requirements of in-building system upgrades	- Requires full campus implementation to achieve the carbon benefits - Campus disruption	4
100%	Total Score (Weighted Average)			3.1

Option 2. Centralized Low Temperature Hot Water (Without Geo Exchange)

Distribution piping sized for low temperature, low dT (10F)
AS Heat Pumps (4 pipe) - Instantaneous heat recovery (heating/cooling)
Air Source Heat Pumps (2 pipe) - Reminder of heating/cooling
Boilers (NG / electric) - Heating at peak load periods (high temp reset)

Weight	Key System Components	Pros	Cons	Score (1-5)
34%	Carbon	Annual GHG emissions (tCO2/yr)		370
		- Allows for graduated GHG reductions that track with when in-building systems are upgraded to support low temperature heating water	- GHG reduction limited by operating range of ASHP and the need to engage boilers on colder days	3.8
25%	Financial	Total Capital cost (M$)		531
		NPV (M$)		570
		Abatement cost ($/tonCO2)		-78
		- Lower capital cost relative to options with geo-exchange (3, 4)	- High capital costs compared to BAU and Option 1	4.4
20%	Technical	- Higher system efficiency compared to High Temp Option 1. - Lower distribution losses compared to high temperature systems. - Hybrid system allows greater redundancy/resiliency	- Requires peaking/redundant heat source for when ASHP are outside operating range (cold days).	3
8%	PSE	- Reputational benefits moving forward to campus carbon neutrality - Electricity as the primary fuel source are more susceptible to electrical grid GHGI changes.	- Risk of noise pollution. - Campus disruption during construction	4
13%	Implementation	- No apparent implementation benefits.	- Extensive in-building system upgrades required - Requires full campus implementation to achieve the carbon benefits - Campus disruption	3
100%	Total Score (Weighted Average)			3.7

Option 3. Centralized Low Temperature Hot Water (with Geo Exchange)

Distribution piping sized for low temperature, low dT (10F)
Heat Pumps (4 pipe) - Heat recovery (heating/cooling)
Geo-exchange fields - coupled with 4-pipe HPs, maximize seasonal heat recovery.
Air Source Heat Pumps (2 pipe) - Reminder of heating/cooling
Boilers (NG / electric) - Heating at peak load periods (high temp reset)

Weight	Key System Components	Pros	Cons	Score (1-5)
34%	Carbon	Annual GHG emissions (tCO2/yr)		132
		- Achieves the highest degree of GHG reductions, with no need ultimately to engage boilers after building upgrades are completed	None, provided low GHGI electrical grid is achieve in future	4.6
25%	Financial	Total Capital cost (M$)		598
		NPV (M$)		621
		Abatement cost ($/tonCO2)		86
		- Potential for lowest operating cost	- Highest capital cost option due to geo largest upfront cost	0.0
20%	Technical	- Greatest overall system efficiency - Lower distribution losses compared to high temperature systems. - Can meet all heating demand without boiler support.	- Slightly more complex system (controls) compared to options without geoexchange (Option 2)	4
8%	PSE	- Reputational benefits moving forward to campus carbon neutrality - Electricity as the primary fuel source are more susceptible to electrical GHGI changes. - Lower risk of noise pollution (fewer ASHPs) - Geo Exchange provides more compelling story for community and politically	- Larger campus disruption during construction, due to Geo-exchange	4
13%	Implementation	- No apparent implementation benefits.	- Extensive in-building system upgrades required - Requires full campus implementation to achieve the carbon benefits - Campus disruption - Large campus areas required for geo exchange field(s)	3
100%	Total Score (Weighted Average)			3.1

Option 4. Nodal Low Temperature Hot Water (with Geo Exchange)

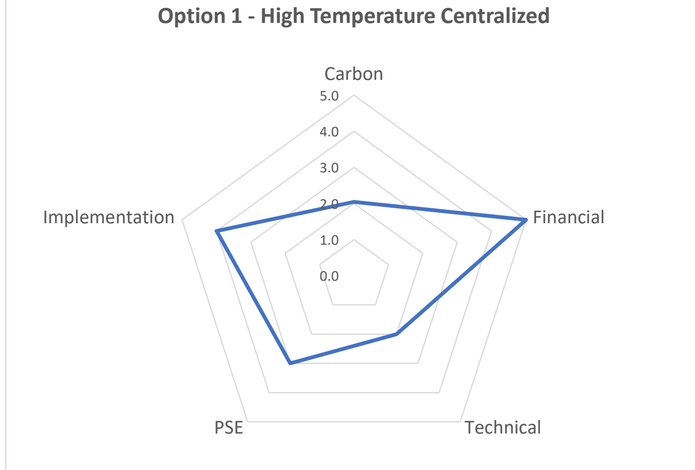
Distribution piping sized for low temperature, low dT (10F)
Heat Pumps (4 pipe) - Heat recovery (heating/cooling)
Geo-exchange fields - coupled with 4-pipe HPs, maximize seasonal heat recovery.
Air Source Heat Pumps (2 pipe) - Reminder of heating/cooling
Boilers (NG / electric) - Heating at peak load periods (high temp reset)

Weight	Key System Components	Pros	Cons	Score (1-5)
34%	Carbon	Annual GHG emissions (tCO2/yr)		97
		- Achieve the highest degree of GHG reductions, not needing to engage boilers	None, provided low GHGI electrical grid is achieve in future	4.7
25%	Financial	Total Capital cost (M$)		562
		NPV (M$)		585
		Abatement cost ($/tonCO2)		-26
		- Potential for lowest operating cost - Greater schedule flexibility compared to centralized.	- Highest capital cost option due to geo largest upfront cost	3.2
20%	Technical	- Greatest overall system efficiency - Lower distribution losses compared to high temperature systems. - Can meet all heating demand without boiler support. - Higher degree of flexibility in locating geo-exchange fields compared to centralized Option 3	- Slightly more complex system (controls) compared to options without geoexchange (Option 2); also more total equipment to operate and maintain given nodal plants -Steam system needs to remain operational until final nodal plant is completed	4
8%	PSE	- Reputational benefits moving forward to campus carbon neutrality - Electricity as the primary fuel source are more susceptible to electrical GHGI changes. - Lower risk of noise pollution (fewer ASHPs) - Campus disruption can be better managed compared to centralized options - Geo Exchange provides more compelling story for community and politically	- Risk of having to use BAU steam system for a longer period of time, until the last node is implemented. - Larger campus disruption during construction, due to Geo-exchange	4.5
13%	Implementation	- Implementation can be phased in smaller / more manageable projects (e.g., based on availability of external funding)	- Extensive in-building system upgrades required - Requires full campus implementation to achieve the carbon benefits - Large campus areas required for geo exchange field(s) -Steam system needs to remain operational until final nodal plant is completed	5
100%	Total Score (Weighted Average)			4.2

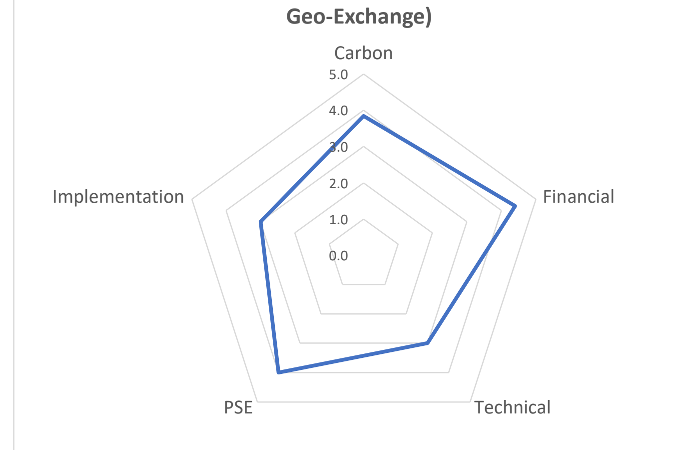
BAU: Central Steam System (with NG + Carbon Offsets)

Central steam boilers with steam distribution network

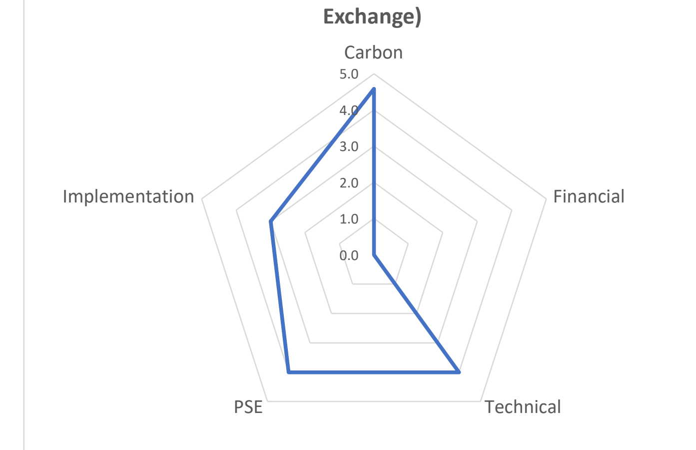
Weight	Key System Components	Pros	Cons	Score (1-5)
34%	Carbon	Annual GHG emissions (tCO2/yr)		6398
		-Carbon reductions based on purchase of RNG.	- High natural gas consumption -High carbon emissions. -Availability of RNG.	0.0
25%	Financial	Total Capital cost (M$)		472
		NPV (M$)		594
		Abatement cost ($/tonCO2)		N/A
		- Lowest capital cost option	- Costs still associated with BAU option - Steam boilers are nearing end of life. - Costly carbon offsets and/or RNG.	4.6
20%	Technical	- No apparent benefits	- Least efficient option due to high distribution losses and steam production efficiency.	0
8%	PSE	- No additional noise pollution -Minimal campus disruption (maintenance related)	- With purchases of RNG, campus is not moving forward to carbon neutrality (carbon emissions) - No reputational benefits. - Does not align with Western's and the State of Washington's long term carbon reduction goals. - Does not take advantage of future electrical grid GHGI changes.	0
13%	Implementation	- Minimal campus disruption (maintenance related) - No building upgrades required.	- Ongoing upgrades and maintenance.	5
100%	Total Score (Weighted Average)			1.8



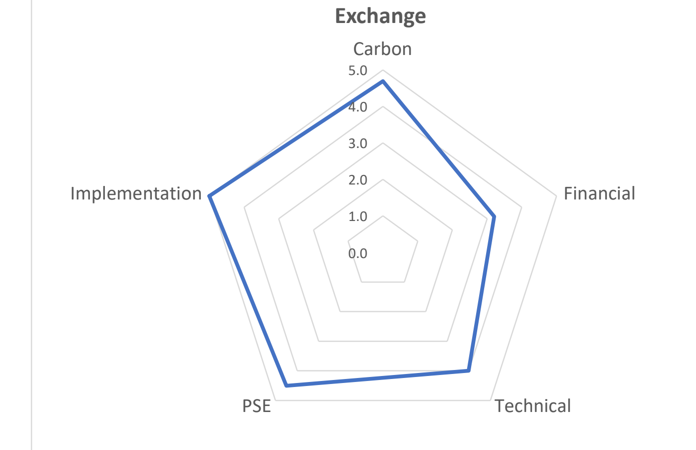
Option 1 - High Temperature Centralized



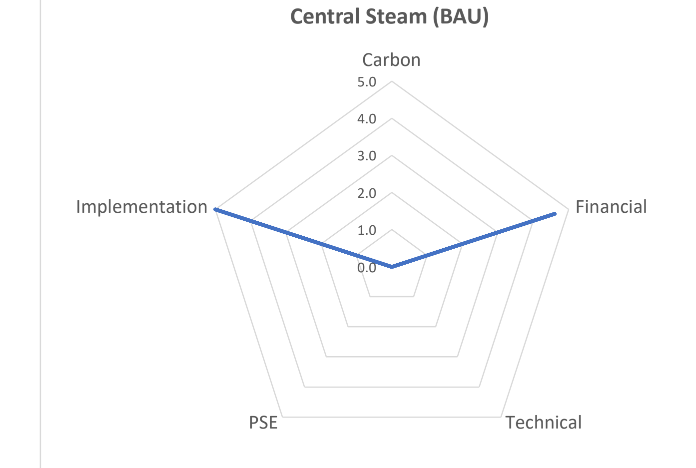
Option 2 - Low Temperature Centralized ASHP without Geo-Exchange)



Option 3 - Low Temperature Centralized ASHP with Geo-Exchange)



Option 4 - Low Temperature Nodal ASHP with Geo-Exchange

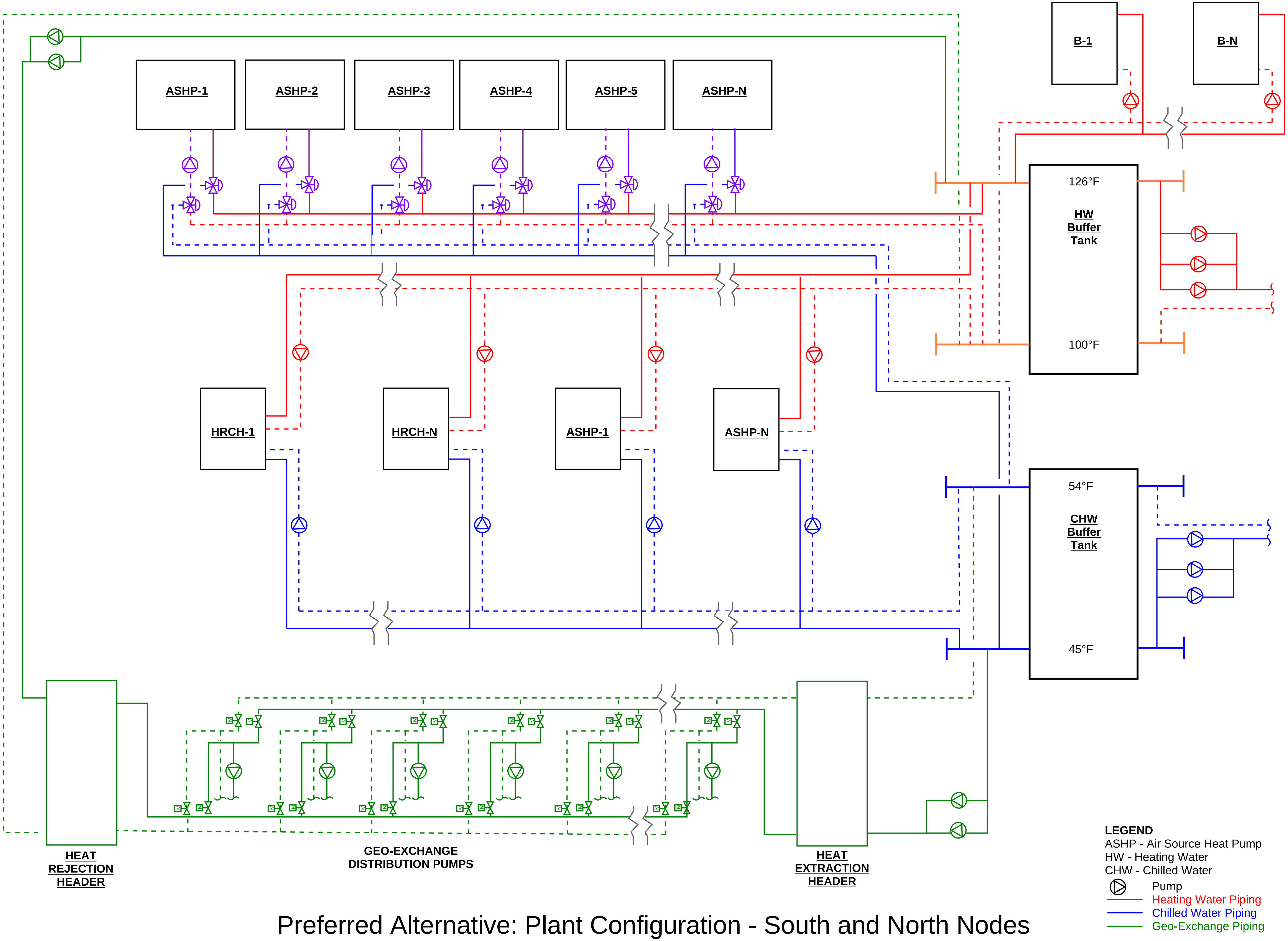


Central Steam (BAU)

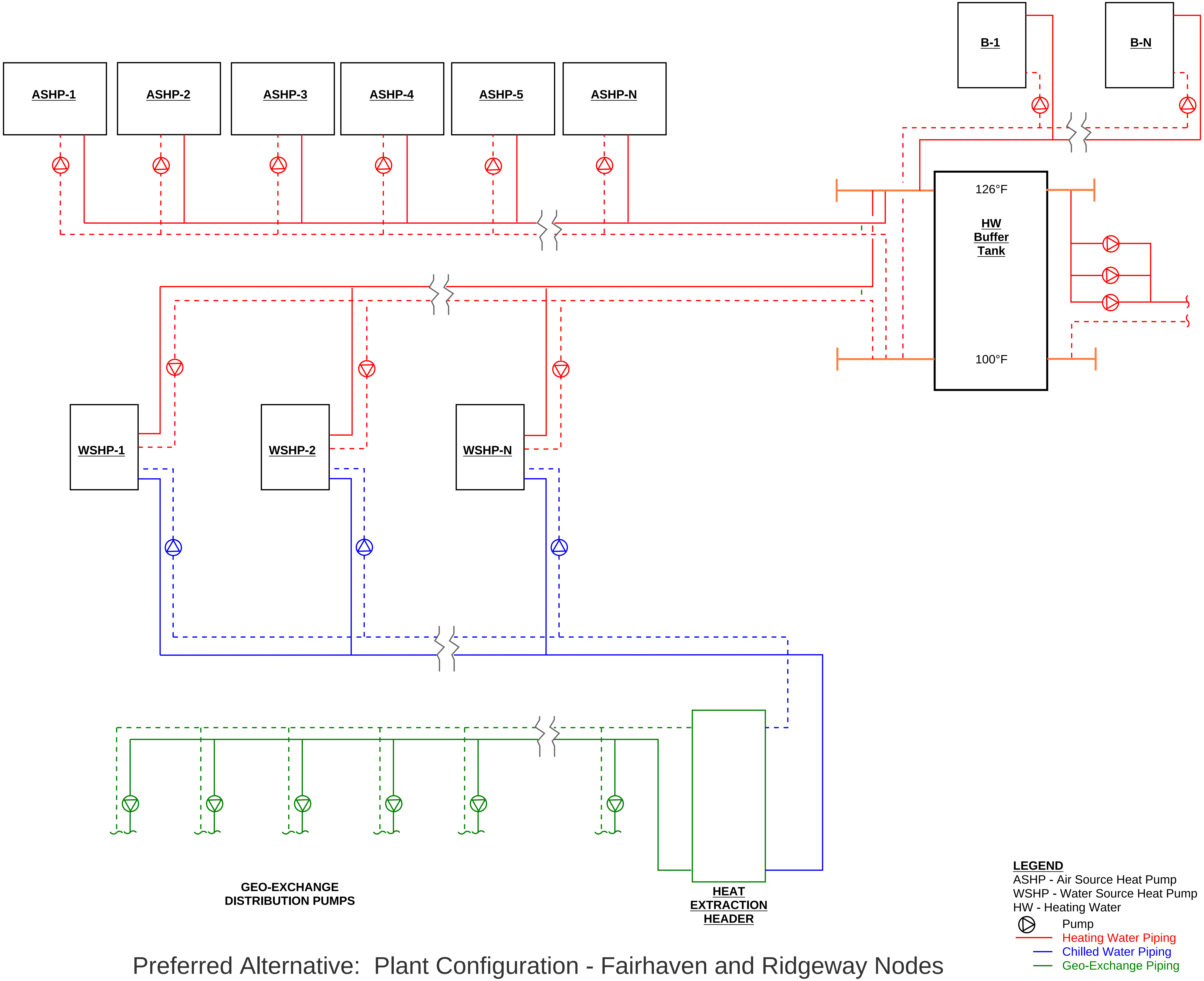
Appendix E
Concept Design

Equipment	Quantity	Individual Capacity	Total Capacity
North			
HRCH	3	1,640 MBH	4,920 MBH
ASHP (4-Pipe)	4	1,500 MBH	6,000 MBH
ASHP (2-Pipe)	5	1,500 MBH	7,500 MBH
NG Boilers	-	-	7,065 MBH
HW Buffer Tank	1	1060 gal	1060 gal
CHW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	160	500 ft deep, 18ft spacing, 40,633 SF	
South			
HRCH	6	1,640 MBH	9,840 MBH
ASHP (4-Pipe)	6	1,500 MBH	9,000 MBH
ASHP (2-Pipe)	4	1,500 MBH	6,000 MBH
NG Boilers	-	-	13,000 MBH
HW Buffer Tank	1	1060 gal	1060 gal
CHW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	300	500 ft deep, 18ft spacing, 76,782 SF	
Ridgeway			
WSHP	1	1,640 MBH	1,640 MBH
ASHP (2-Pipe)	3	1,500 MBH	4,500 MBH
NG Boilers	-	-	1,730 MBH
HW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	50	500 ft deep, 18ft spacing, 12,993 SF	
Fairhaven			
WSHP	2	1,640 MBH	3,280 MBH
ASHP (2-Pipe)	3	1,500 MBH	4,500 MBH
NG Boilers	-	-	3,900 MBH
HW Buffer Tank	1	1060 gal	1060 gal
GHX Boreholes	50	500 ft deep, 18ft spacing, 28,109 SF	

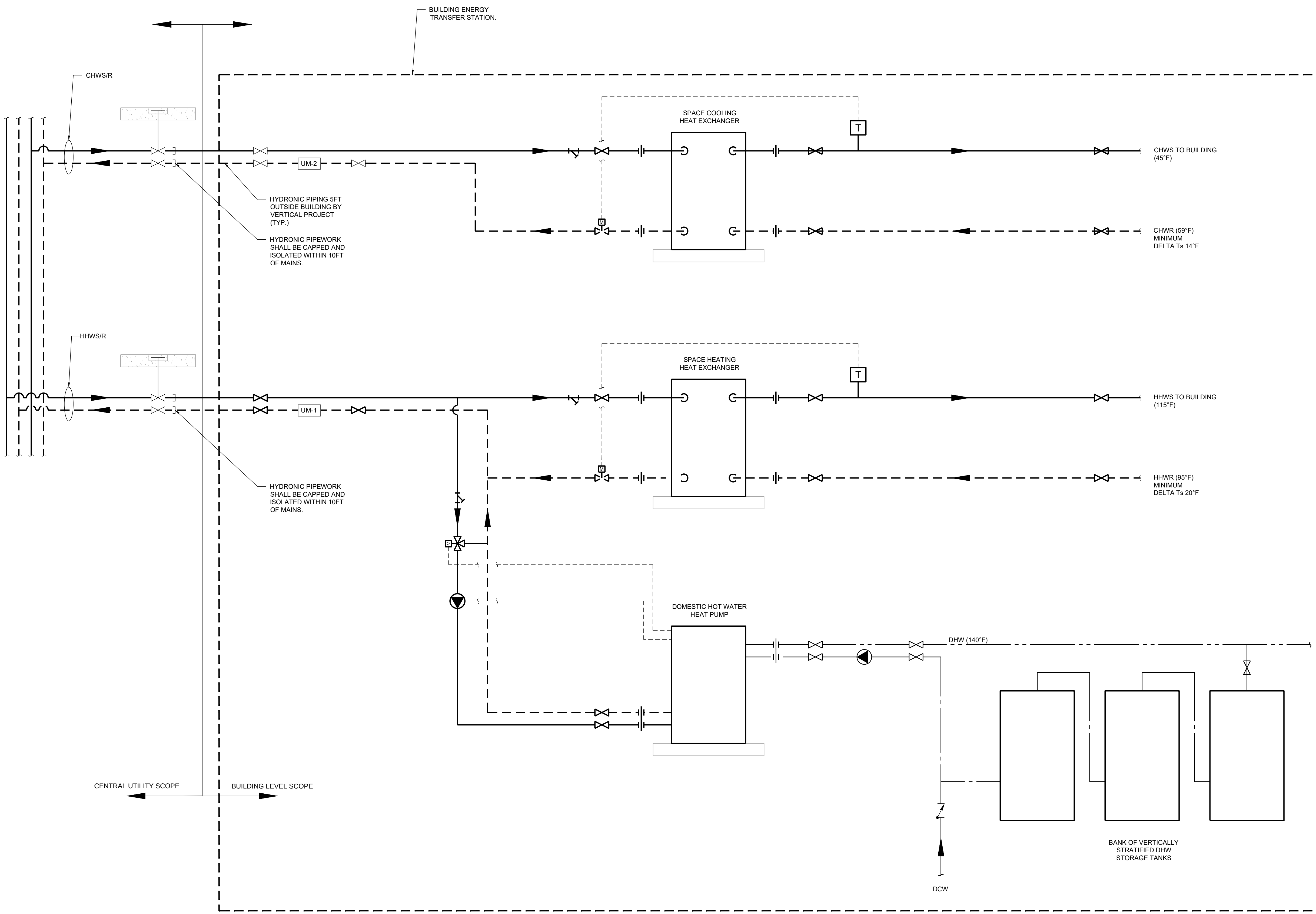
*The total capacity of natural gas (NG) boilers is the combined total capacity of boilers. The total capacity can be divided into multiple boilers to offer different levels of redundancy.



Preferred Alternative: Plant Configuration - South and North Nodes



Preferred Alternative: Plant Configuration - Fairhaven and Ridgeway Nodes



Typical Building Energy Transfer Station Configuration

ID	Property ID	Building Name
AA	1037	ART ANNEX
AB	1108	ARCHIVES BUILDING
AC	1126	ADMINISTRATIVE SERVICES CENTER
AH	1074	ARNTZEN HALL
AI	1145	ACADEMIC INSTRUCTIONAL CENTER - EAST
AL	1100	ALUMNI HOUSE
AN	1120	ANTENNA BUILDING
AW	1146	ACADEMIC INSTRUCTIONAL CENTER - WEST
BC	1043	BIRNAM WOOD COMMUNITY
BG	1119	BIOLOGY GREENHOUSE
BH	1036	BOND HALL
BI	1110	BIOLOGY BUILDING
BL	1044	BIRNAM WOOD LAUNDRY
BQ	1159	BUCHANAN TOWERS (EAST)
BS	1135	BUS SHELTER
BT	1069	BUCHANAN TOWERS (CLASSIC)
BW01	1045	BIRNAM WOOD BUILDING 1 (BA)
BW02	1046	BIRNAM WOOD BUILDING 2 (BD)
BW03	1047	BIRNAM WOOD BUILDING 3 (BE)
BW04	1048	BIRNAM WOOD BUILDING 4 (BJ)
BW05	1049	BIRNAM WOOD BUILDING 5 (BU)
BW06	1050	BIRNAM WOOD BUILDING 6 (BV)
BW07	1051	BIRNAM WOOD BUILDING 7 (BY)
CA	1010	CANADA HOUSE
CB	1109	CHEMISTRY BUILDING
CF	1136	COMMUNICATION FACILITY
CG	1172	ALMA CLARK GLASS HALL
CH	1007	COLLEGE HALL
CM	1038	COMMISSARY
CS	1131	CAMPUS SERVICES BUILDING
CV	1004	CARVER
EH	1002	EDENS HALL
EN	1012	EDENS NORTH
EQ	1083	EQUIPMENT SHED
ES	1072	ENVIRONMENTAL STUDIES
ET	1091	ROSS ENGINEERING TECHNOLOGY
EU	1092	ENGINEERING STORAGE
FA	1052	FAIRHAVEN COLLEGE
FI	1009	FINE ARTS BUILDING
FR	1023	FRASER HALL
FS	1017	FAIRHAVEN CABIN - SOUTH
FU	1066	FAIRHAVEN BRIDGE
FV	1065	FAIRHAVEN PLAYGROUND BUILDING
FX01	1053	FAIRHAVEN TOWER 1 (FB)
FX02	1054	FAIRHAVEN TOWER 2 (FP)
FX03	1055	FAIRHAVEN TOWER 3 (FD)
FX04	1056	FAIRHAVEN TOWER 4 (FE)
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FX11	1063	FAIRHAVEN TOWER 11 (FL)
FX12	1064	FAIRHAVEN TOWER 12 (FM)
HG	1020	HIGGINSON HALL
HH	1018	HAGGARD HALL
HS	1067	HIGH STREET HALL
HU	1022	HUMANITIES BUILDING
IS	1171	INTERDISCIPLINARY SCIENCE BUILDING
MA	1034	MATHES HALL
MF	1040	MAINTENANCE FUEL STATION
MG	1093	MAINTENANCE GARAGE
MH	1006	MILLER HALL
MS	1116	MARSHALLING STORAGE
MU	1163	HARRINGTON FIELD
MW	1154	MAINTENANCE WAREHOUSE
MY	1099	MARSHALLING YARD
NA	1035	NASH HALL
OM	1001	OLD MAIN
OP	1155	OUTBACK PAVILION
PA	1011	PERFORMING ARTS CENTER
PH	1090	PARKS HALL
PP	1039	PHYSICAL PLANT
RA	1024	RIDGEWAY ALPHA
RB	1031	RIDGEWAY BETA
RC	1025	RIDGEWAY COMMONS
RD	1026	RIDGEWAY DELTA
RE	1112	RECYCLE CENTER
RG	1032	RIDGEWAY GAMMA
RK	1030	RIDGEWAY KAPPA
RO	1027	RIDGEWAY OMEGA
RS	1028	RIDGEWAY SIGMA
SB	1084	BASEBALL FIELD STORAGE
SE	1041	SERVICE STORAGE SHED
SL	1117	SMATE (SCIENCE FACILITY III)
SP	1008	STEAM PLANT
SV	1138	WADE KING RECREATION CENTER
TB	1082	TRACK BUNKER
TD	1142	TENNIS STORAGE
TE	1118	TRACK EQUIPMENT BUILDING
VC	1021	VIKING COMMONS
VU	1014	VIKING UNION
WL	1003	WILSON LIBRARY
WT	1076	AEROBIC CENTER

Legend:

- Central Steam Plant
- Buildings on District Energy System (Steam)
- Independent buildings
- Buildings with on site Chillers
- DHW - STEAM
- DHW - ELECTRIC
- Distribution Routing

Steam System Network

ID	Property ID	Building Name
AA	1037	ART ANNEX
AB	1108	ARCHIVES BUILDING
AC	1126	ADMINISTRATIVE SERVICES CENTER
AH	1074	ARNTZEN HALL
AI	1145	ACADEMIC INSTRUCTIONAL CENTER - EAST
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BC	1043	BIRNAM WOOD COMMUNITY
BG	1119	BIOLOGY GREENHOUSE
BH	1036	BOND HALL
BI	1110	BIOLOGY BUILDING
BL	1044	BIRNAM WOOD LAUNDRY
BQ	1159	BUCHANAN TOWERS (EAST)
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BW03	1047	BIRNAM WOOD BUILDING 3 (BE)
BW04	1048	BIRNAM WOOD BUILDING 4 (BJ)
BW05	1049	BIRNAM WOOD BUILDING 5 (BU)
BW06	1050	BIRNAM WOOD BUILDING 6 (BV)
BW07	1051	BIRNAM WOOD BUILDING 7 (BY)
CA	1010	CANADA HOUSE
CB	1109	CHEMISTRY BUILDING
CF	1136	COMMUNICATION FACILITY
CG	1172	ALMA CLARK GLASS HALL
CH	1007	COLLEGE HALL
CM	1038	COMMISSARY
CS	1131	CAMPUS SERVICES BUILDING
CV	1004	CARVER
EH	1002	EDENS HALL
EN	1012	EDENS NORTH
EQ	1083	EQUIPMENT SHED
ES	1072	ENVIRONMENTAL STUDIES
ET	1091	ROSS ENGINEERING TECHNOLOGY
EU	1092	ENGINEERING STORAGE
FA	1052	FAIRHAVEN COLLEGE
FI	1009	FINE ARTS BUILDING
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FS	1017	FAIRHAVEN CABIN - SOUTH
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HS	1067	HIGH STREET HALL
HU	1022	HUMANITIES BUILDING
IS	1171	INTERDISCIPLINARY SCIENCE BUILDING
MA	1034	MATHES HALL
MF	1040	MAINTENANCE FUEL STATION
MG	1093	MAINTENANCE GARAGE
MH	1006	MILLER HALL
MS	1116	MARSHALLING STORAGE
MU	1163	HARRINGTON FIELD
MW	1154	MAINTENANCE WAREHOUSE
MY	1099	MARSHALLING YARD
NA	1035	NASH HALL
OM	1001	OLD MAIN
OP	1155	OUTBACK PAVILION
PA	1011	PERFORMING ARTS CENTER
PH	1090	PARKS HALL
PP	1039	PHYSICAL PLANT
RA	1024	RIDGEWAY ALPHA
RB	1031	RIDGEWAY BETA
RC	1025	RIDGEWAY COMMONS
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RK	1030	RIDGEWAY KAPPA
RO	1027	RIDGEWAY OMEGA
RS	1028	RIDGEWAY SIGMA
SB	1084	BASEBALL FIELD STORAGE
SE	1041	SERVICE STORAGE SHED
SL	1117	SMATE (SCIENCE FACILITY III)
SP	1008	STEAM PLANT
SV	1138	WADE KING RECREATION CENTER
TB	1082	TRACK BUNKER
TD	1142	TENNIS STORAGE
TE	1118	TRACK EQUIPMENT BUILDING
VC	1021	VIKING COMMONS
VU	1014	VIKING UNION
WL	1003	WILSON LIBRARY
WT	1076	AEROBIC CENTER

Campus Cooling

Central Plant

ID	Property ID	Building Name
AA	1037	ART ANNEX
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AH	1074	ARNTZEN HALL
AI	1145	ACADEMIC INSTRUCTIONAL CENTER - EAST
AL	1100	ALUMNI HOUSE
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BC	1043	BIRNAM WOOD COMMUNITY
BG	1119	BIOLOGY GREENHOUSE
BH	1036	BOND HALL
BI	1110	BIOLOGY BUILDING
BL	1044	BIRNAM WOOD LAUNDRY
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BW06	1050	BIRNAM WOOD BUILDING 6 (BV)
BW07	1051	BIRNAM WOOD BUILDING 7 (BY)
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CB	1109	CHEMISTRY BUILDING
CF	1136	COMMUNICATION FACILITY
CG	1172	ALMA CLARK GLASS HALL
CH	1007	COLLEGE HALL
CM	1038	COMMISSARY
CS	1131	CAMPUS SERVICES BUILDING
CV	1004	CARVER
EH	1002	EDENS HALL
EN	1012	EDENS NORTH
EQ	1083	EQUIPMENT SHED
ES	1072	ENVIRONMENTAL STUDIES
ET	1091	ROSS ENGINEERING TECHNOLOGY
EU	1092	ENGINEERING STORAGE
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FI	1009	FINE ARTS BUILDING
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FS	1017	FAIRHAVEN CABIN - SOUTH
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SL	1117	SMATE (SCIENCE FACILITY III)
SP	1008	STEAM PLANT
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TE	1118	TRACK EQUIPMENT BUILDING
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VU	1014	VIKING UNION
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WT	1076	AEROBIC CENTER

Nodal Plants

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CH	1007	COLLEGE HALL
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CV	1004	CARVER
EH	1002	EDENS HALL
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EU	1092	ENGINEERING STORAGE
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FX01	1053	FAIRHAVEN TOWER 1 (FB)
FX02	1054	FAIRHAVEN TOWER 2 (FP)
FX03	1055	FAIRHAVEN TOWER 3 (FD)
FX04	1056	FAIRHAVEN TOWER 4 (FE)
FX05	1057	FAIRHAVEN TOWER 5 (FF)
FX06	1058	FAIRHAVEN TOWER 6 (FQ)
FX07	1059	FAIRHAVEN TOWER 7 (FH)
FX08	1060	FAIRHAVEN TOWER 8 (FO)
FX09	1061	FAIRHAVEN TOWER 9 (FJ)
FX10	1062	FAIRHAVEN TOWER 10 (FK)
FX11	1063	FAIRHAVEN TOWER 11 (FL)
FX12	1064	FAIRHAVEN TOWER 12 (FM)
HG	1020	HIGGINSON HALL
HH	1018	HAGGARD HALL
HS	1067	HIGH STREET HALL
HU	1022	HUMANITIES BUILDING
IS	1171	INTERDISCIPLINARY SCIENCE BUILDING
MA	1034	MATHES HALL
MF	1040	MAINTENANCE FUEL STATION
MG	1093	MAINTENANCE GARAGE
MH	1006	MILLER HALL
MS	1116	MARSHALLING STORAGE
MU	1163	HARRINGTON FIELD
MW	1154	MAINTENANCE WAREHOUSE
MY	1099	MARSHALLING YARD
NA	1035	NASH HALL
OM	1001	OLD MAIN
OP	1155	OUTBACK PAVILION
PA	1011	PERFORMING ARTS CENTER
PH	1090	PARKS HALL
PP	1039	PHYSICAL PLANT
RA	1024	RIDGEWAY ALPHA
RB	1031	RIDGEWAY BETA
RC	1025	RIDGEWAY COMMONS
RD	1026	RIDGEWAY DELTA
RE	1112	RECYCLE CENTER
RG	1032	RIDGEWAY GAMMA
RK	1030	RIDGEWAY KAPPA
RO	1027	RIDGEWAY OMEGA
RS	1028	RIDGEWAY SIGMA
SB	1084	BASEBALL FIELD STORAGE
SE	1041	SERVICE STORAGE SHED
SL	1117	SMATE (SCIENCE FACILITY III)
SP	1008	STEAM PLANT
SV	1138	WADE KING RECREATION CENTER
TB	1082	TRACK BUNKER
TD	1142	TENNIS STORAGE
TE	1118	TRACK EQUIPMENT BUILDING
VC	1021	VIKING COMMONS
VU	1014	VIKING UNION
WL	1003	WILSON LIBRARY
WT	1076	AEROBIC CENTER

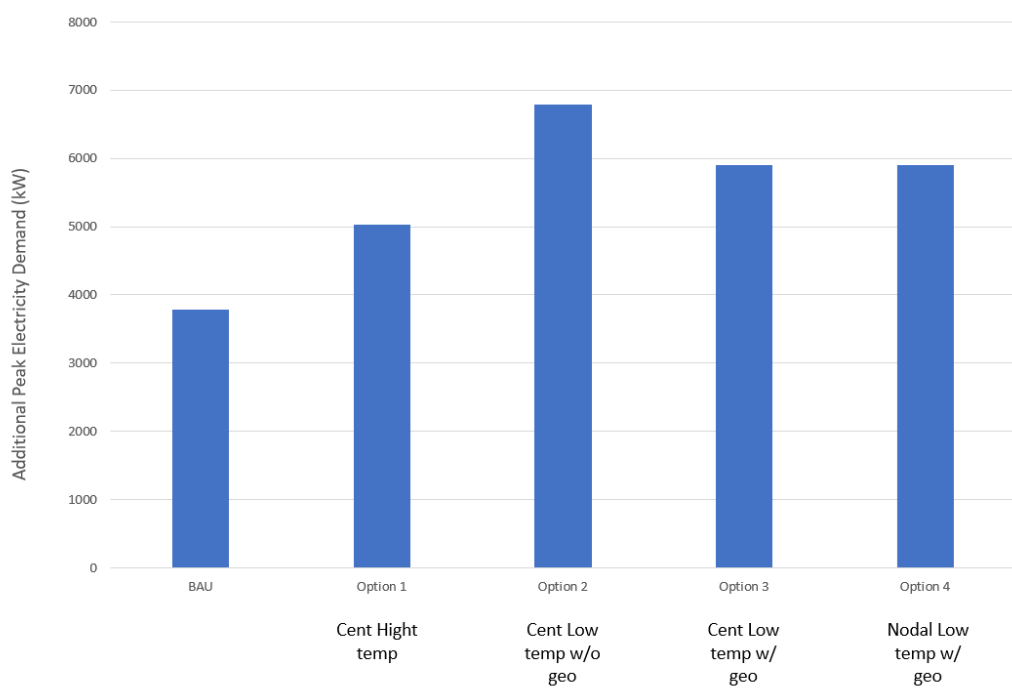
GEO-EXCHANGE FIELD LOCATION OPTIONS

Appendix F

Electrical Analysis

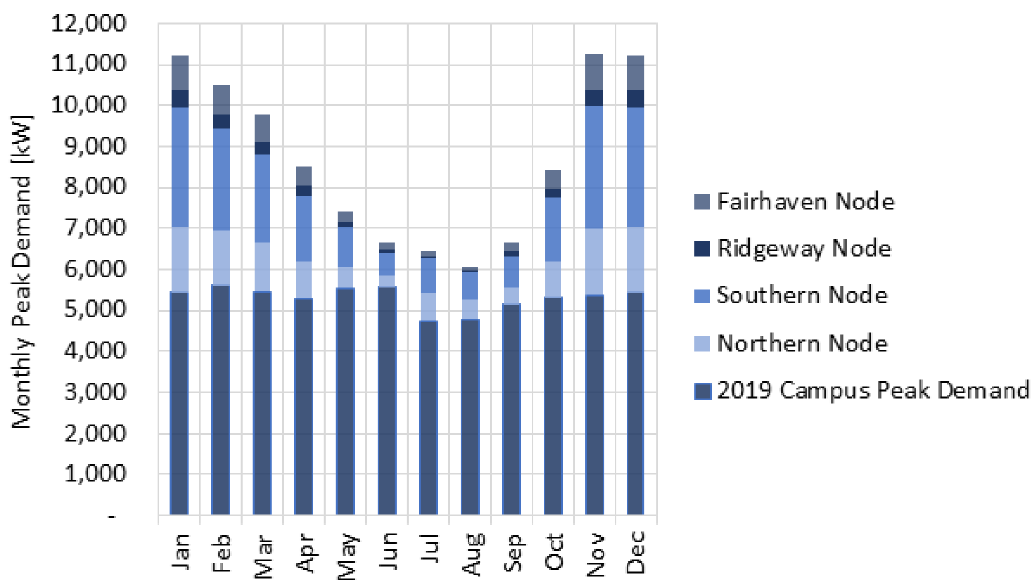
As described in the main body of this report, the consultant team investigated whether the existing service is adequate for the proposed energy conversion by analyzing the potential increase in feeder currents, the resultant temperature rise in the underground ductbanks, the thermal-dissipation capabilities of the ductbanks, and the overall effect the increased temperature will have on the feeder conductor current carrying limits. Soil measurements per ASTM D-2216 and ASTM D-5334 adjacent to the duct banks are recommended at strategic locations as part of Schematic Design, such as near the utility substation, to allow the current limits to be more thoroughly evaluated.

Mechanical team members on the consultant team generated information through their analysis as to the anticipated additional peak loads (see bar chart below) along with a preliminary estimate of the increase in MW anticipated with a fully built out new district energy system.

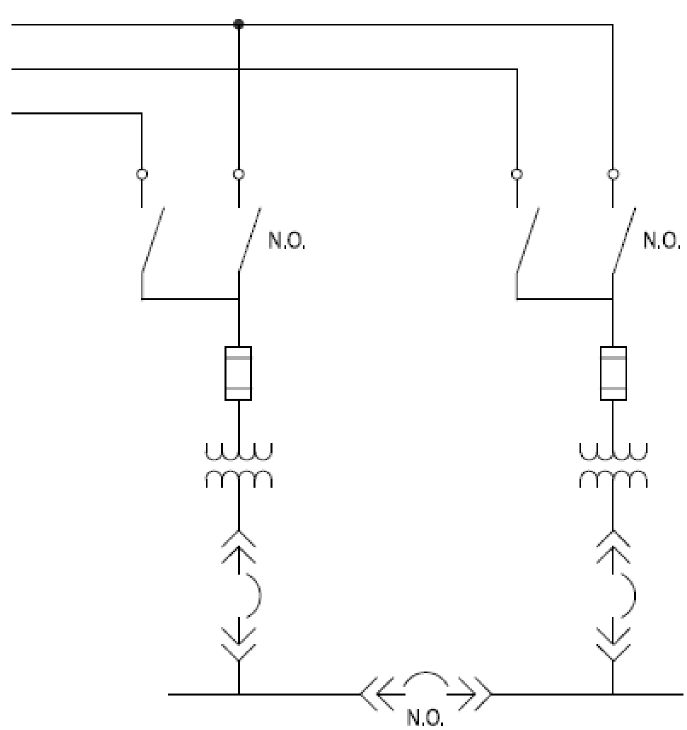


The existing campus load consists of a base load at 2,113kW with variable loads contributing to a peak of 5,577kW. As documented in the Utilities Master Plan, the campus is presently served via three primary feeders. Each feeder has the individual capacity to carry the entire peak load, enabling any feeder to be isolated for testing and maintenance while the campus remains fully operational on redundant feeders.

Following the thermal energy plant conversion, the peak load will double to approximately 11,500kW. Two feeders will then be required to supply the campus demand. Shutting down any feeder would require selectively shifting its loads to the remaining feeders without overloading either one. While any one feeder is off, the other feeders will have no redundancy.



It is recommended the distribution system be configured to provide two feeders to each nodal plant with the third feeder available as an alternate for feeder testing/maintenance. Within each nodal plant, a double-ended substation would provide alternate paths for redundant mechanical equipment and load balancing for non-redundant equipment. An example of three feeders supplying a double-ended substation at a nodal plant is shown in the figure above. The cost premium for redundancy is approximately 35% for a double-ended substation over a single-ended substation, and less than 15% for



the third feeder in a new duct bank. Installing a third feeder in spare ducts of existing duct banks is estimated to be approximately $60/ft.

Longer term, consideration of a potential revision to Western's utility master plan is recommended in the event overall campus loads begin to approach the threshold of 14MW, beyond which Western would require that all three primary feeders be engaged to supply the peak demand load. This would signal the need for adding a fourth primary feeder for testing/maintenance flexibility.

Appendix G

Cost Estimate

Western Washington University
Heating Conversion Feasibility Study

Western Washington University
Heating Conversion Feasibility Study

Prepared for:

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Western Washington University

Heating Conversion Feasibility Study

Contents

Western Washington University
Heating Conversion Feasibility Study

Overall Summary

	SF	$/SF	TOTAL
Buildings for Business as Usual			254,246,452
Business as Usual Infrastructure			15,299,978
Business as Usual			**269,546,431**
Buildings for Options 1 through 4			363,935,484
Option 1. Centralized High Temperature Hot Water			35,242,871
Option 2. Centralized Low Temperature Hot Water			129,792,573
Option 3. Centralized Low Temperature Hot Water with Geo Exchange			188,397,865
Option 4. Nodal Low Temperature Hot Water with Geo Exchange			119,076,396
Option 1. Centralized High Temperature Hot Water			35,242,871
Buildings			363,935,484
TOTAL Option 1			399,178,355
Option 2. Centralized Low Temperature Hot Water			129,792,573
Buildings			363,935,484
TOTAL Option 2			493,728,057
Option 3. Centralized Low Temperature Hot Water with Geo Exchange			188,397,865
Buildings			363,935,484
TOTAL Option 3			552,333,349
Option 4. Nodal Low Temperature Hot Water with Geo Exchange			119,076,396
Buildings			363,935,484
TOTAL Option 4			483,011,880

Western Washington University

Heating Conversion Feasibility Study

Building Cost Summary

	Quantity	Unit
Areas	2,155,840	Total GSF
Combined	2,155,840	SF
Buildings for Business as Usual	2,155,840	SF

Cost below relate to the Building Upgrades workbook including required heating, cooling upgrades and architectural/structural work necessary to complete the work.

Scope includes

General Conditions, Permits and BIM - Sub

Mechanical upgrades -per workbook including circ pumps

Piping and connections

Crane and rigging

Seismic engineering, vibration isolation and restraints

Architectural and structural building back

Contractor Mark ups

	QTY	SF	Rate	Sum
Academic Instruction/West	130,649	SF	130.60	17,062,245
Administration Building				N/A
Alumni House				N/A
Archives Building				N/A
Arntzen Hall	98,337	SF	126.01	12,391,582
Biology Building	81,120	SF	126.75	10,282,029
Birnam Wood				N/A
Bond Hall	91,168	SF	117.70	10,730,702
Bookstore				N/A
Buchanan Towers				N/A
Campus Services				N/A
Carver Gymnasium	167,346	SF	113.16	18,936,565
Chemistry Building	77,226	SF	115.73	8,937,065
Clark Glass Hall	117,340	SF	109.49	12,848,079
College Hall				N/A
Commissary				N/A
Communications	131,365	SF	135.13	17,750,953
Edens Hall				N/A
Edens Hall North				N/A
Engineering Technology (Ross)	77,592	SF	124.53	9,662,723
Environmental Studies Center	111,145	SF	125.61	13,960,706
Fairhaven				N/A
Fraser Hall	13,562	SF	124.95	1,694,562
Fine Arts	59,300	SF	137.72	8,166,505
Haggard Hall	107,971	SF	115.53	12,474,016

Western Washington University

Heating Conversion Feasibility Study

Building Cost Summary

	Quantity	Unit		
Higginson Hall				*N/A*
High Street Hall				*N/A*
Highland 1 and 2				*N/A*
Humanities	33,342	SF	114.45	3,815,954
Mathes		SF		*N/A*
Miller Hall	135,369	SF	124.47	16,848,735
Nash Hall				*N/A*
Old Main	145,474	SF	107.63	15,656,730
Parks Hall	56,109	SF	116.01	6,509,119
Performing Arts Center	128,649	SF	104.90	13,495,673
Physical Plant				*N/A*
SMATE (Sci/Ed/Tech)				*N/A*
Student Recreation Center	98,300	SF	114.35	11,240,411
Viking Commons	30,739	SF	108.94	3,348,599
Viking Union	122,494	SF	111.01	13,597,690
Wilson Library	141,243	SF	105.04	14,835,812
	2,155,840	SF	117.93	254,246,452

Western Washington University
Heating Conversion Feasibility Study

Cost Options

				Total
Business as Usual Infrastructure				15,299,978

Steam boilers and supporting equipment are replaced and/or rebuilt

Plant Equipment				
NG steam boiler rebuild in existing steam plant	65,000	MBH	40.00	2,600,000
Boiler controls systems (Pneumatic & Direct digital)	5	EA	1,100.00	5,500
Buried fuel oil tanks	126,000	GAL	8.00	1,008,000
Boiler draft fans	5	EA	8,780.00	43,900
Existing 2 x De-aerator tanks -150,000 LB/HR- Service only	150,000	LB/HF	0.50	75,000
Condensate receiver tank	3,500	GAL	8.00	28,000
Boiler Feed pumps (200 gpm)	5	EA	10,000.00	50,000
Circulation pumps	4	EA	28,000.00	112,000
Valves and connections	45	EA	4,650.00	209,250
Skids and ancillaries	1	LS	50,000.00	50,000
Instrumentation & appurtenances for new equipment	1	LS	75,000.00	75,000
Electrical Connections	1	LS	100,000.00	100,000
Distribution				
Extension of trench/tunnel to new buildings	1,950	LF	355.00	692,250
Extension of steam/condensate piping to new buildings	3,900	LF	250.00	975,000
Replacement of Steam/Condensate piping	7,500	LF	260.00	1,950,000
Valves and connections	10	EA	5,000.00	50,000
District Plant Building and infrastructure				
Building upgrade				*Not required*
Cost Before Markups				8,023,900
Z10 General Requirements	7.50%			601,793
Z11 Design Contingency	20.00%			1,725,139
Z12 Construction Contingency	3.00%			310,525
Z13 General Conditions	7.00%			746,295
Z22 Liability Insurance	1.00%			114,077
Z23 Payment & Performance Bond	1.50%			172,826
Z24 Overhead & Profit Fee	5.00%			584,728
Z25 Sales Tax (WA)	10.25%			1,258,626
Z30 Escalation to Midpoint (May 2025)	13.02%			1,762,071
Recommended Budget - Central Plant- Option 1				15,299,978

Western Washington University

Heating Conversion Feasibility Study

Building Cost Summary

	Quantity	Unit		
Areas	2,717,230	Total GSF		
Combined	2,717,230	SF		
Buildings for Options 1 through 4	2,717,230	SF		

Cost below relate to the Building Upgrades workbook including required heating, cooling upgrades and archtectural/structural work necessary to complete the work.

Scope includes

General Conditions, Permits and BIM - Sub

Demolition of mechanical systems - all buildings

Mechanical upgrades -per workbook

Piping and connections

Crane and rigging

Seismic engineering, vibration isolation and restraints

HVAC ductwork, exhaust fans, duct wrap and grilles

HVAC DDC controls

Mechanical piping insulation

HVAC balancing

Commissioning

Architectural and structural building back

Contractor Mark ups

Academic Instruction/West	130,649	SF	149.59	19,543,510
Arntzen Hall	98,337	SF	144.34	14,193,618
Biology Building	81,120	SF	145.18	11,777,286
Bond Hall	91,168	SF	134.82	12,291,206
Bookstore	17,986	SF	125.16	2,251,191
Buchanan Towers	140,439	SF	146.17	20,527,842
Carver Gymnasium	167,346	SF	129.61	21,690,401
Chemistry Building	77,226	SF	132.56	10,236,731
Clark Glass Hall	117,340	SF	125.42	14,716,501
College Hall	32,917	SF	96.90	3,189,552
Commissary	37,121	SF	110.96	4,118,835
Communications	131,365	SF	154.78	20,332,373
Edens Hall	63,662	SF	107.15	6,821,097
Edens Hall North	26,432	SF	107.15	2,832,070
Engineering Technology (Ross)	77,592	SF	142.64	11,067,917
Environmental Studies Center	111,145	SF	143.87	15,990,931
Fairhaven				*N/A*
Fraser Hall	13,562	SF	143.12	1,940,992
Fine Arts	59,300	SF	157.74	9,354,112

Western Washington University

Heating Conversion Feasibility Study

Building Cost Summary

	Quantity	Unit		
Haggard Hall	107,971	SF	132.33	14,288,040
Higginson Hall	50,417	SF	143.82	7,251,003
Highland 1 and 2				*N/A*
Humanities	33,342	SF	131.09	4,370,886
Mathes	75,381	SF	133.33	10,050,210
Miller Hall	135,369	SF	142.57	19,298,949
Nash Hall	76,891	SF	133.86	10,292,975
Old Main	145,474	SF	123.28	17,933,598
Parks Hall	56,109	SF	132.88	7,455,702
Performing Arts Center	128,649	SF	120.16	15,458,271
Ridgeway				*N/A*
SMATE (Sci/Ed/Tech)	40,144	SF	134.03	5,380,657
Student Recreation Center	98,300	SF	130.98	12,875,039
Viking Commons	30,739	SF	124.78	3,835,566
Viking Union	122,494	SF	127.15	15,575,124
Wilson Library	141,243	SF	120.31	16,993,298
	2,717,230	SF	133.94	363,935,484

Western Washington University
Heating Conversion Feasibility Study

Cost Options

				Total
Option 1. Centralized High Temperature Hot Water				**35,242,871**

Distribution piping sized for high temperature, high dT (20F)
AS Heat Pumps (4 pipe) - Instantaneous heat recovery (heating/cooling) during low load periods
Air Source Heat Pumps (2 pipe) - Reminder of heating during low load periods, cooling
Boilers (NG) - Heating at medium and high load periods

Central Plant				
Energy transfer station (each building- 32)				
DHW Heat pump	128	EA	68,500.00	8,768,000
Pump module skid	32	EA	58,000.00	1,856,000
Heat exchangers (Plate frame- 6300 MBH)	32	EA	36,000.00	1,152,000
Heat exchangers (Dbl wall tube steel 1200 MBH)				*Existing*
Economizer				*Existing*
Circulation pumps				*Existing*
HW Storage	32	EA	26,000.00	832,000
Valves and piping	17,920	LF	200.00	3,584,000
Electrical connections	256	EA	1,200.00	307,200
Coring and grouting	512	EA	750.00	384,000
Chilled water storage - 21 buildings -21 tanks varying sizes	17,950	GAL	6.80	122,060
Chilled water loop and valves	8,190	LF	196.33	1,607,943
Circulation pumps	63	EA	28,000.00	1,764,000
Central Plant				
NG boiler capacity	45,200	MBH	40.00	1,808,000
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	10	EA	570,000.00	5,700,000
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	15	EA	490,300.00	7,354,500
Cooling buffer tank volume	4,050	GAL	38.00	153,900
Cooling Low Loss Header diameter	60	inch	376.00	22,560
Cooling Low Loss Header length	15	FT		*INCL*
Heating buffer tank volume	4,050	GAL	41.00	166,050
Heating Low Loss Header diameter	60	inch	380.00	22,800
Heating Low Loss Header length	15	FT		*INCL*
Ancillary equipment	1	EA	500,000.00	500,000
Distribution				
Trench (52"D x 60"W), temp cover and backfill	18,203	LF	202.00	3,676,905
Routing complexities	18,203	LF	37.50	682,594
Heating Distribution Pipe - 14" diameter	1,640	LF	298.51	489,553
Heating Distribution Pipe - 12" diameter	3,100	LF	255.86	793,178
Heating Distribution Pipe - 10" diameter	3,100	LF	213.22	660,982
Heating Distribution Pipe - 8" diameter	3,550	LF	208.31	739,501

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Heating Distribution Pipe - 6" diameter	4,240	LF	200.14	848,594
Heating Distribution Pipe - 4" diameter	7,225	LF	188.20	1,359,745
Cooling Distribution Pipe - 14" diameter	650	LF	298.51	194,030
Cooling Distribution Pipe - 12" diameter	-			*N/A*
Cooling Distribution Pipe - 10" diameter	4,750	LF	213.22	1,012,795
Cooling Distribution Pipe - 8" diameter	2,200	LF	208.31	458,282
Cooling Distribution Pipe - 6" diameter	1,800	LF	200.14	360,252
Cooling Distribution Pipe - 4" diameter	4,150	LF	188.20	781,030
Heating Distribution Pumps - power (each)	150	HP		
Heating Distribution Pumps - quantity	3	EA	85,500.00	256,500
Cooling Distribution Pumps - power (each)	150	HP		
Cooling Distribution Pumps - quantity	3	EA	85,500.00	256,500
Valves and connections	468	EA	4,650.00	2,176,200
District Plant Building and infrastructure				
Equipment controls	1	LS	262,000.00	262,000
Electrical feeders and connections wiring and conduit	1,000	LF	532.00	532,000
Electrical panels	6	EA	10,500.00	63,000
Infrastructure				
Building structure -two structures	25,850	SF	533.00	13,778,050
Fencing and gates	1,000	LF	90.00	90,000
Pads	6,000	SF	30.00	180,000
Equipment seismic restraint	1	LS	88,000.00	88,000
Grate walks and safety rails	400	LF	176.00	70,400
Cost Before Markups				20,377,203
Z10 General Requirements	7.50%			1,528,290
Z11 Design Contingency	20.00%			4,381,099
Z12 Construction Contingency	3.00%			788,598
Z13 General Conditions	7.00%			1,895,263
Z22 Liability Insurance	1.00%			289,705
Z23 Payment & Performance Bond	1.50%			438,902
Z24 Overhead & Profit Fee	5.00%			1,484,953
Z25 Sales Tax (WA)	10.25%			
Z30 Escalation to Midpoint (May 2025)	13.02%			4,058,858
Recommended Budget - Central Plant- Option 1				35,242,871

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Option 2. Centralized Low Temperature Hot Water				129,792,573

Distribution piping sized for high temperature, high dT (10F)
AS Heat Pumps (4 pipe) - Instantaneous heat recovery (heating/cooling)
Air Source Heat Pumps (2 pipe) - Reminder of heating /cooling
Boilers (NG) - Heating at peak load periods (high temp set)

Central Plant				
Energy transfer station (each building- 32)				
DHW Heat pump	128	EA	68,500.00	8,768,000
Pump module skid	32	EA	58,000.00	1,856,000
Heat exchangers (Plate frame- 6300 MBH)	32	EA	36,000.00	1,152,000
Heat exchangers (Dbl wall tube steel 1200 MBH)				*Existing*
Economizer				*Existing*
Circulation pumps				*Existing*
HW Storage	32	EA	26,000.00	832,000
Valves and piping	17,920	LF	200.00	3,584,000
Electrical connections	256	EA	1,200.00	307,200
Coring and grouting	512	EA	750.00	384,000
Chilled water storage - 21 buildings -21 tanks varying sizes	17,950	GAL	6.80	122,060
Chilled water loop and valves	8,190	LF	196.33	1,607,943
Circulation pumps	63	EA	28,000.00	1,764,000
Central Plant				
NG boiler capacity	45,200	MBH	40.00	1,808,000
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	10	EA	570,000.00	5,700,000
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	15	EA	490,300.00	7,354,500
Cooling buffer tank volume	4,050	GAL	38.00	153,900
Cooling Low Loss Header diameter	60	inch	376.00	22,560
Cooling Low Loss Header length	15	FT		*INCL*
Heating buffer tank volume	4,050	GAL	41.00	166,050
Heating Low Loss Header diameter	60	inch	380.00	22,800
Heating Low Loss Header length	15	FT		*INCL*
Ancillary equipment	1	EA	500,000.00	500,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	18,203	LF	216.00	3,931,848
Routing complexities	18,203	LF	37.50	682,613
Heating Distribution Pipe - 18" diameter	1,640	LF	383.80	629,432
Heating Distribution Pipe - 16" diameter	3,100	LF	341.15	1,057,565
Heating Distribution Pipe - 14" diameter	3,100	LF	298.51	925,375
Heating Distribution Pipe - 12" diameter	3,550	LF	255.86	908,317

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Heating Distribution Pipe - 10" diameter	4,240	LF	213.22	904,053
Heating Distribution Pipe - 8" diameter				*N/A*
Heating Distribution Pipe - 6" diameter	7,225	LF	200.14	1,446,012
Cooling Distribution Pipe - 18" diameter	650	LF	383.80	249,470
Cooling Distribution Pipe - 16" diameter				
Cooling Distribution Pipe - 14" diameter	4,750	LF	298.51	1,417,913
Cooling Distribution Pipe - 12" diameter				*N/A*
Cooling Distribution Pipe - 10" diameter	2,200	LF	213.22	469,084
Cooling Distribution Pipe - 8" diameter	1,800	LF	208.31	374,958
Cooling Distribution Pipe - 6" diameter	4,150	LF	200.14	830,581
Heating Distribution Pumps - power (each)	250	HP		
Heating Distribution Pumps - quantity	3	EA	147,060.00	441,180
Cooling Distribution Pumps - power (each)	250	HP		
Cooling Distribution Pumps - quantity	3	EA	147,060.00	441,180
Valves and connections	468	EA	4,650.00	2,176,200
District Plant Building and infrastructure				
Equipment controls	1	LS	276,000.00	276,000
Electrical feeders and connections wiring and conduit	1,000	LF	532.00	532,000
Electrical panels	6	EA	10,500.00	63,000
Infrastructure				
Building structure - two structures	25,850	SF	533.00	13,778,050
Fencing and gates	1,000	LF	90.00	90,000
Pads	6,000	SF	30.00	180,000
Equipment seismic restraint	1	LS	88,000.00	88,000
Grate walks and safety rails	400	LF	176.00	70,400
Cost Before Markups				68,068,243
Z10 General Requirements	7.50%			5,105,118
Z11 Design Contingency	20.00%			14,634,672
Z12 Construction Contingency	3.00%			2,634,241
Z13 General Conditions	7.00%			6,330,959
Z22 Liability Insurance	1.00%			967,732
Z23 Payment & Performance Bond	1.50%			1,466,114
Z24 Overhead & Profit Fee	5.00%			4,960,354
Z25 Sales Tax (WA)	10.25%			10,677,162
Z30 Escalation to Midpoint (May 2025)	13.02%			14,947,977
Recommended Budget - Central Plant- Option 2				129,792,573

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Option 3. Centralized Low Temperature Hot Water with Geo Exchange				188,397,865

Distribution piping sized for high temperature, high dT (10F)
 Heat Pumps (4 pipe) - Heat recovery (heating/cooling)
Geo-exchange fields- coupled with 4-pipe HPs, maximize seasonal heat recovery
Air Source Heat Pumps (2 pipe) - Reminder of heating /cooling
Boilers (NG) - Heating at peak load periods (high temp set)

Central Plant with Geo-exchange				
Energy transfer station (each building- 32)				
DHW Heat pump	128	EA	68,500.00	8,768,000
Pump module skid	32	EA	58,000.00	1,856,000
Heat exchangers (Plate frame- 6300 MBH)	32	EA	36,000.00	1,152,000
Heat exchangers (Dbl wall tube steel 1200 MBH)				*Existing*
Economizer				*Existing*
Circulation pumps				*Existing*
HW Storage	32	EA	26,000.00	832,000
Valves and piping	17,920	LF	200.00	3,584,000
Electrical connections	256	EA	1,200.00	307,200
Coring and grouting	512	EA	750.00	384,000
Chilled water storage - 21 buildings -21 tanks varying sizes	17,950	GAL	6.80	122,060
Chilled water loop and valves	8,190	LF	196.33	1,607,943
Circulation pumps	63	EA	28,000.00	1,764,000
Central Plant				
NG boiler capacity	25,600	MBH	40.00	1,024,000
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	10	EA	570,000.00	5,700,000
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	15	EA	490,300.00	7,354,500
Cooling buffer tank volume	4,050	GAL	38.00	153,900
Cooling Low Loss Header diameter	60	inch	376.00	22,560
Cooling Low Loss Header length	15	FT		*INCL*
Heating buffer tank volume	4,050	GAL	41.00	166,050
Heating Low Loss Header diameter	60	inch	380.00	22,800
Heating Low Loss Header length	15	FT		*INCL*
Ancillary equipment	1	EA	500,000.00	500,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	19,353	LF	216.00	4,180,248
Routing complexities	19,353	LF	37.50	725,738
Heating Distribution Pipe - 18" diameter	1,640	LF	383.80	629,432
Heating Distribution Pipe - 16" diameter	3,100	LF	341.15	1,057,565
Heating Distribution Pipe - 14" diameter	3,100	LF	298.51	925,375

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Heating Distribution Pipe - 12" diameter	3,550	LF	255.86	908,317
Heating Distribution Pipe - 10" diameter	4,240	LF	213.22	904,053
Heating Distribution Pipe - 8" diameter				*N/A*
Heating Distribution Pipe - 6" diameter	7,225	LF	200.14	1,446,012
Cooling Distribution Pipe - 18" diameter	650	LF	383.80	249,470
Cooling Distribution Pipe - 16" diameter				
Cooling Distribution Pipe - 14" diameter	4,750	LF	298.51	1,417,913
Cooling Distribution Pipe - 12" diameter				*N/A*
Cooling Distribution Pipe - 10" diameter	2,200	LF	213.22	469,084
Cooling Distribution Pipe - 8" diameter	1,800	LF	208.31	374,958
Cooling Distribution Pipe - 6" diameter	4,150	LF	200.14	830,581
Heating Distribution Pumps - power (each)	250	HP		
Heating Distribution Pumps - quantity	3	EA	147,060.00	441,180
Cooling Distribution Pumps - power (each)	250	HP		
Cooling Distribution Pumps - quantity	3	EA	147,060.00	441,180
Valves and connections	468	EA	4,650.00	2,176,200
District Plant Building and infrastructure				
Equipment controls	1	LS	276,000.00	276,000
Electrical feeders and connections wiring and conduit	1,000	LF	532.00	532,000
Electrical panels	6	EA	10,500.00	63,000
Infrastructure				
Building structure - two structures	25,850	SF	533.00	13,778,050
Fencing and gates	1,000	LF	90.00	90,000
Pads	6,000	SF	30.00	180,000
Equipment seismic restraint	1	LS	88,000.00	88,000
Grate walks and safety rails	400	LF	176.00	70,400
Geo-Exchange field				
Geofield - 1040 bores at 500 SF	520,000	LF	41.40	21,528,000
Distribution piping	2,300	LF	384.00	883,200
Loop Pumps- GSHP	12	EA	12,500.00	150,000
Heating panels and trench convectors	1,000	SF	5.00	5,000
Heat exchangers (19,800 MBH) heating	1	EA	345,000.00	345,000
Heat exchangers (8,300 MBH) cooling	1	EA	156,000.00	156,000
Branch pumps	1,040	EA	2,650.00	2,756,000
Air separators, expansion tank and ancillaries	48	EA	85,000.00	4,080,000
Electrical connections	1	LS	75,000.00	75,000
Import/Export	23,111	CY	50.00	1,155,556
Grouting	1,040	EA	90.00	93,600

Western Washington University

Heating Conversion Feasibility Study

Cost Options

		Total
Cost Before Markups		98,803,123
Z10 General Requirements	7.50%	7,410,234
Z11 Design Contingency	20.00%	21,242,671
Z12 Construction Contingency	3.00%	3,823,681
Z13 General Conditions	7.00%	9,189,580
Z22 Liability Insurance	1.00%	1,404,693
Z23 Payment & Performance Bond	1.50%	2,128,110
Z24 Overhead & Profit Fee	5.00%	7,200,105
Z25 Sales Tax (WA)	10.25%	15,498,225
Z30 Escalation to Midpoint (May 2025)	13.02%	21,697,444
Recommended Budget - Central Plant- Option 3		188,397,865

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Option 4. Nodal Low Temperature Hot Water with Geo Exchange				119,076,396

Distribution piping sized for high temperature, high dT (10F)
Heat Pumps (4 pipe) - Heat recovery (heating/cooling)
Geo-exchange fields- coupled with 4-pipe HPs, maximize seasonal heat recovery
Air Source Heat Pumps (2 pipe) - Reminder of heating /cooling
Boilers (NG) - Heating at peak load periods (high temp set)

Nodal Plants with Geo-exchange				
Energy transfer station (each building- 32)				
DHW Heat pump	128	EA	68,500.00	8,768,000
Pump module skid	32	EA	58,000.00	1,856,000
Heat exchangers (Plate frame- 6300 MBH)	32	EA	36,000.00	1,152,000
Heat exchangers (Dbl wall tube steel 1200 MBH)				*Existing*
Economizer				*Existing*
Circulation pumps				*Existing*
HW Storage	32	EA	26,000.00	832,000
Valves and piping	17,920	LF	200.00	3,584,000
Electrical connections	256	EA	1,200.00	307,200
Coring and grouting	512	EA	750.00	384,000
Chilled water storage - 21 buildings -21 tanks varying sizes	17,950	GAL	6.80	122,060
Chilled water loop and valves	8,190	LF	196.33	1,607,943
Circulation pumps	63	EA	28,000.00	1,764,000
Nodal Plant 1- North				
NG boiler capacity	7,065	MBH	40.00	282,600
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	4	EA	570,000.00	2,280,000
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	5	EA	490,300.00	2,451,500
Cooling buffer tank volume	1,060	GAL	38.00	40,280
Cooling Low Loss Header diameter	12	inch	376.00	4,512
Cooling Low Loss Header length	40	FT		*INCL*
Heating buffer tank volume	1,060	GAL	41.00	43,460
Heating Low Loss Header diameter	12	inch	450.00	5,400
Heating Low Loss Header length	40	FT		*INCL*
Ancillary equipment	1	EA	125,000.00	125,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	7,446	LF	216.00	1,608,336
Routing complexities	7,446	LF	37.50	279,225
Heating Distribution Pipe - 12" diameter				*N/A*
Heating Distribution Pipe - 10" diameter	2,600	LF	213.22	554,372
Heating Distribution Pipe - 8" diameter	3,950	LF	208.31	822,825

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Heating Distribution Pipe - 6" diameter	1,670	LF	200.14	334,234
Cooling Distribution Pipe - 14" diameter	1,150	LF	298.51	343,287
Cooling Distribution Pipe - 12" diameter	1,550	LF	255.86	396,583
Cooling Distribution Pipe - 10" diameter	300	LF	213.22	63,966
Cooling Distribution Pipe - 8" diameter	1,600	LF	208.31	333,296
Cooling Distribution Pipe - 6" diameter	950	LF	200.14	190,133
Heating Distribution Pumps - power (each)	50	HP		*Included*
Heating Distribution Pumps - quantity	3	EA	56,430.00	169,290
Cooling Distribution Pumps - power (each)	75	HP		*Included*
Cooling Distribution Pumps - quantity	3	EA	56,430.00	169,290
Valves and connections	104	EA	4,650.00	483,600
Plant Building and infrastructure				
Equipment controls	1	LS	69,000.00	69,000
Electrical feeders and connections wiring and conduit	250	LF	532.00	133,000
Electrical panels	2	EA	10,500.00	21,000
Infrastructure				
Building structure	5,850	SF	533.00	3,118,050
Fencing and gates	250	LF	90.00	22,500
Pads	1,200	SF	30.00	36,000
Equipment seismic restraint	1	LS	22,000.00	22,000
Grate walks and safety rails	100	LF	176.00	17,600
SUM- Node 1				*14,420,338*
Nodal Plant 2- South				
NG boiler capacity	13,000	MBH	40.00	520,000
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	6	EA	570,000.00	3,420,000
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	4	EA	490,300.00	1,961,200
Cooling buffer tank volume	1,060	GAL	38.00	40,280
Cooling Low Loss Header diameter	12	inch	376.00	4,512
Cooling Low Loss Header length	40	FT		*Included*
Heating buffer tank volume	1,060	GAL	41.00	43,460
Heating Low Loss Header diameter	12	inch	450.00	5,400
Heating Low Loss Header length	40	FT		*Included*
Ancillary equipment	1	EA	125,000.00	125,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	8,248	LF	216.00	1,781,568
Routing complexities	8,248	LF	37.50	309,300
Heating Distribution Pipe - 14" diameter	1,655	LF	298.51	494,031
Heating Distribution Pipe - 10" diameter	1,100	LF	213.22	234,542
Heating Distribution Pipe - 8" diameter	2,250	LF	208.31	468,698

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Heating Distribution Pipe - 6" diameter	3,225	LF	200.14	645,452
Cooling Distribution Pipe - 14" diameter	1,100	LF	298.51	328,359
Cooling Distribution Pipe - 12" diameter	1,300	LF	255.86	332,618
Cooling Distribution Pipe - 10" diameter	1,350	LF	213.22	345,411
Cooling Distribution Pipe - 8" diameter	1,010	LF	208.31	210,393
Cooling Distribution Pipe - 6" diameter	870	LF	200.14	174,122
Heating Distribution Pumps - power (each)	60	HP		*Included*
Heating Distribution Pumps - quantity	3	EA	62,073.00	186,219
Cooling Distribution Pumps - power (each)	75	HP		*Included*
Cooling Distribution Pumps - quantity	3	EA	74,487.60	223,463
Valves and connections	104	EA	4,650.00	483,600
District Plant Building and infrastructure				
Equipment controls	1	LS	69,000.00	69,000
Electrical feeders and connections wiring and conduit	250	LF	533.00	133,250
Electrical panels	2	EA	10,500.00	21,000
Infrastructure				
Building structure	5,850	SF	532.00	3,112,200
Fencing and gates	250	LF	90.00	22,500
Pads	1,200	SF	30.00	36,000
Equipment seismic restraint	1	LS	22,000.00	22,000
Grate walks and safety rails	100	LF	176.00	17,600
SUM- Node 2				*15,771,176*
Nodal Plant 3- Ridgeway				
NG boiler capacity	1,730	MBH	55.00	95,150
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)				*N/A*
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	3	EA	490,300.00	1,470,900
Cooling buffer tank volume				*N/A*
Cooling Low Loss Header diameter				*N/A*
Cooling Low Loss Header length				*N/A*
Heating buffer tank volume	1,060	GAL	41.00	43,460
Heating Low Loss Header diameter	12	inch	450.00	5,400
Heating Low Loss Header length	40	FT		*INCL*
Ancillary equipment	1	EA	105,000.00	105,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	2,110	LF	216.00	455,760
Routing complexities	2,110	LF	37.50	79,125
Heating Distribution Pipe - 10" diameter	560	LF	213.22	119,403
Heating Distribution Pipe - 8" diameter	1,225	LF	208.31	255,180
Heating Distribution Pipe - 6" diameter	1,424	LF	200.14	284,999

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
Cooling Distribution Pipe				*N/A*
Heating Distribution Pumps - power (each)	30	HP		*Included*
Heating Distribution Pumps - quantity	3	EA	35,000.00	105,000
Cooling Distribution Pumps - power (each)				*N/A*
Cooling Distribution Pumps - quantity				*N/A*
Valves and connections	60	EA	4,650.00	279,000
District Plant Building and infrastructure				
Equipment controls	1	LS	38,640.00	38,640
Electrical feeders and connections wiring and conduit	200	LF	532.00	106,400
Electrical panels	1	EA	10,500.00	10,500
Infrastructure				
Building structure	4,000	SF	560.00	2,240,000
Fencing and gates	200	LF	90.00	18,000
Pads	1,000	SF	30.00	30,000
Equipment seismic restraint	1	LS	16,000.00	16,000
Grate walks and safety rails	50	LF	176.00	8,800
SUM- Node 3				*5,766,717*
Nodal Plant 4- Fairhaven				
NG boiler capacity	3,900	MBH	55.00	214,500
4-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)				*N/A*
2-Pipe ASHP Cooling capacity (@ 1,500 MBH Heating)	3	EA	490,300.00	1,470,900
Cooling buffer tank volume				*N/A*
Cooling Low Loss Header diameter				*N/A*
Cooling Low Loss Header length				*N/A*
Heating buffer tank volume	1,060	GAL	41.00	43,460
Heating Low Loss Header diameter	12	inch	450.00	5,400
Heating Low Loss Header length	40	FT		*Included*
Ancillary equipment	1	EA	105,000.00	105,000
Distribution				
Trench (56"D x 60"W), temp cover and backfill	3,353	LF	216.00	724,248
Routing complexities	3,353	LF	37.50	125,738
Heating Distribution Pipe - 10" diameter	500	LF	213.22	106,610
Heating Distribution Pipe - 8" diameter	1,340	LF	208.31	279,135
Heating Distribution Pipe - 6" diameter	3,100	LF	200.14	620,434
Cooling Distribution Pipe				*N/A*
Heating Distribution Pumps - power (each)	40	HP		*Included*
Heating Distribution Pumps - quantity	3	EA	39,000.00	117,000
Valves and connections	100	EA	4,650.00	465,000

Western Washington University

Heating Conversion Feasibility Study

Cost Options

				Total
District Plant Building and infrastructure				
Equipment controls	1	LS	38,640.00	38,640
Electrical feeders and connections wiring and conduit	200	LF	532.00	106,400
Electrical panels	1	EA	10,500.00	10,500
Infrastructure				
Building structure	4,000	SF	560.00	2,240,000
Fencing and gates	200	LF	90.00	18,000
Pads	1,000	SF	30.00	30,000
Equipment seismic restraint	1	LS	88,000.00	88,000
Grate walks and safety rails	50	LF	176.00	8,800
SUM- Node 4				*6,817,765*
Geo-Exchange field				
Geofield - 1040 bores at 500 SF	80,000	LF	41.40	3,312,000
Distribution piping	6,531	LF	384.00	2,507,904
Loop Pumps- GSHP	12	EA	12,500.00	150,000
Heating panels and trench convectors	250	SF	5.00	1,250
Heat exchangers (19,800 MBH) heating	1	EA	345,000.00	345,000
Heat exchangers (8,300 MBH) cooling	1	EA	156,000.00	156,000
Branch pumps	1,040	EA	2,650.00	2,756,000
Air separators, expansion tank and ancillaries	48	EA	85,000.00	4,080,000
Electrical connections	1	LS	100,000.00	100,000
Import/Export	23,111	CY	50.00	1,155,556
Grouting	1,040	EA	90.00	93,600
Cost Before Markups				77,810,509
Z10 General Requirements	7.50%			5,835,788
Z11 Design Contingency	20.00%			16,729,259
Z12 Construction Contingency	3.00%			3,011,267
Z13 General Conditions	7.00%			7,237,078
Z22 Liability Insurance	1.00%			1,106,239
Z23 Payment & Performance Bond	1.50%			1,675,952
Z24 Overhead & Profit Fee	5.00%			5,670,305
Z25 Sales Tax (WA)	10.25%			
Z30 Escalation to Midpoint (May 2025)	13.02%			
Recommended Budget - Nodal Plant- Option 4				119,076,396
				53,614,653
				65,461,743

Appendix H

C-100

State of Washington
AGENCY / INSTITUTION PROJECT COST SUMMARY
Updated June 2022

Agency	Western Washington University	
Project Name	Heating Conversion Project - Plants and Distribution System	
OFM Project Number		

Contact Information	
Name	Brian Ross
Phone Number	360.650.6539
Email	brian.ross@wwu.edu

Statistics			
Gross Square Feet		MACC per Gross Square Foot	
Usable Square Feet		Escalated MACC per Gross Square Foot	
Alt Gross Unit of Measure			
Space Efficiency		A/E Fee Class	A
Construction Type	Heating and power plant	A/E Fee Percentage	9.54%
Remodel	Yes	Projected Life of Asset (Years)	50
Additional Project Details			
Procurement Approach	DB-Progressive	Art Requirement Applies	No
Inflation Rate	4.90%	Higher Ed Institution	No
Sales Tax Rate %	8.80%	Location Used for Tax Rate	Bellingham
Contingency Rate	10%		
Base Month (Estimate Date)	July-22	OFM UFI# (from FPMT, if available)	
Project Administered By	Agency		

Schedule			
Predesign Start	October-21	Predesign End	July-22
Design Start	July-23	Design End	June-26
Construction Start	July-26	Construction End	June-33
Construction Duration	83 Months		

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Project Cost Estimate

Total Project	**$113,874,236**	Total Project Escalated	**$148,999,806**
		Rounded Escalated Total	**$149,000,000**

Cost Estimate Summary

Acquisition			
Acquisition Subtotal	$0	**Acquisition Subtotal Escalated**	$0

Consultant Services			
Predesign Services	$428,980		
Design Phase Services	$5,394,441		
Extra Services	$4,360,000		
Other Services	$2,423,589		
Design Services Contingency	$1,260,701		
Consultant Services Subtotal	**$13,867,710**	**Consultant Services Subtotal Escalated**	**$16,687,991**

Construction			
Maximum Allowable Construction Cost (MACC)	$74,500,000	Maximum Allowable Construction Cost (MACC) Escalated	$97,198,700
DB-Progressive Risk Contingencies	$1,490,000		$2,129,359
DB-Progressive Management	$2,980,000		$4,258,718
Owner Construction Contingency	$7,450,000		$10,646,795
Non-Taxable Items	$0		$0
Sales Tax	$7,604,960	Sales Tax Escalated	$10,052,554
Construction Subtotal	**$94,024,960**	**Construction Subtotal Escalated**	**$124,286,126**

Equipment			
Equipment	$100,000		
Sales Tax	$8,800		
Non-Taxable Items	$0		
Equipment Subtotal	**$108,800**	**Equipment Subtotal Escalated**	**$155,487**

Artwork			
Artwork Subtotal	**$0**	**Artwork Subtotal Escalated**	**$0**

Agency Project Administration			
Agency Project Administration Subtotal	$3,476,765		
DES Additional Services Subtotal	$0		
Other Project Admin Costs	$0		
Project Administration Subtotal	**$3,476,765**	**Project Administration Subtotal Escalated**	**$4,968,646**

Other Costs			
Other Costs Subtotal	**$2,396,000**	**Other Costs Subtotal Escalated**	**$2,901,556**

Project Cost Estimate

Total Project	**$113,874,236**	Total Project Escalated	**$148,999,806**
		Rounded Escalated Total	**$149,000,000**

Funding Summary

	Project Cost (Escalated)	Funded in Prior Biennia	New Approp Request 2023-2025	2025-2027	Out Years
Acquisition					
Acquisition Subtotal	$0				**$0**
Consultant Services					
Consultant Services Subtotal	$16,687,991		$8,113,000	$2,213,000	**$6,361,991**
Construction					
Construction Subtotal	$124,286,126			$30,000,000	**$94,286,126**
Equipment					
Equipment Subtotal	$155,487				**$155,487**
Artwork					
Artwork Subtotal	$0				**$0**
Agency Project Administration					
Project Administration Subtotal	$4,968,646		$1,037,190	$1,037,190	**$2,894,266**
Other Costs					
Other Costs Subtotal	$2,901,556		$850,000	$750,000	**$1,301,556**

Project Cost Estimate

	Project Cost (Escalated)	Funded in Prior Biennia	New Approp Request 2023-2025	2025-2027	Out Years
Total Project	**$148,999,806**	**$0**	**$10,000,190**	**$34,000,190**	**$104,999,426**
	$149,000,000	**$0**	**$10,000,000**	**$34,000,000**	**$104,999,000**
Percentage requested as a new appropriation			**7%**		

What is planned for the requested new appropriation? (*Ex. Acquisition and design, phase 1 construction, etc.*)

Partial Design including studies, surveys, and testing

Insert Row Here

What has been completed or is underway with a previous appropriation?

Feasbility Study

Insert Row Here

What is planned with a future appropriation?

Remainder of design and construction (over 4 subsequent biennia)

Insert Row Here

Cost Estimate Details

Acquisition Costs					
Item	**Base Amount**		**Escalation Factor**	**Escalated Cost**	**Notes**
Purchase/Lease					
Appraisal and Closing					
Right of Way					
Demolition					
Pre-Site Development					
Other					
Insert Row Here					
ACQUISITION TOTAL	**$0**		**NA**	**$0**	

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Cost Estimate Details

Consultant Services					
Item	Base Amount		Escalation Factor	Escalated Cost	Notes
1) Pre-Schematic Design Services					
Programming/Site Analysis					
Environmental Analysis	$416,111				
Predesign Study					
DOC Fees	$12,869				
Insert Row Here					
Sub TOTAL	**$428,980**		**1.0490**	**$450,000**	Escalated to Design Start
2) Construction Documents					
A/E Basic Design Services	$5,394,441				69% of A/E Basic Services
Other					
Insert Row Here					
Sub TOTAL	**$5,394,441**		**1.1249**	**$6,068,207**	Escalated to Mid-Design
3) Extra Services					
Civil Design (Above Basic Svcs)	$1,500,000				
Geotechnical Investigation	$285,000				
Commissioning	$150,000				
Site Survey	$500,000				
Testing	$500,000				
LEED Services	$100,000				
Voice/Data Consultant					
Value Engineering					
Constructability Review	$350,000				
Environmental Mitigation (EIS)	$200,000				
Landscape Consultant	$250,000				
Travel & per diem	$50,000				
Renderings & models	$100,000				
Cost consultant	$100,000				
Energy modeling	$100,000				
Security consultant	$25,000				
Phasing and Building evaluation	$150,000				
Sub TOTAL	**$4,360,000**		**1.1249**	**$4,904,564**	Escalated to Mid-Design
4) Other Services					

Bid/Construction/Closeout	$2,423,589			31% of A/E Basic Services
HVAC Balancing				
Staffing				
Other				
Insert Row Here				
Sub TOTAL	**$2,423,589**	**1.4291**	**$3,463,552**	Escalated to Mid-Const.
5) Design Services Contingency				
Design Services Contingency	$1,260,701			
Insert Row Here				
Sub TOTAL	**$1,260,701**	**1.4291**	**$1,801,668**	Escalated to Mid-Const.
CONSULTANT SERVICES TOTAL	**$13,867,710**		**$16,687,991**	

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Cost Estimate Details

Construction Contracts					
Item	Base Amount		Escalation Factor	Escalated Cost	Notes
1) Site Work					
G10 - Site Preparation					
G20 - Site Improvements					
G30 - Site Mechanical Utilities					
G40 - Site Electrical Utilities					
G60 - Other Site Construction					
Energy Transfer Stations	$13,500,000				
Distribution System	$15,500,000				
Geo-Exchange Field	$13,500,000				
Sub TOTAL	**$42,500,000**		**1.2110**	**$51,467,500**	
2) Related Project Costs					
Offsite Improvements					
City Utilities Relocation					
Parking Mitigation					
Stormwater Retention/Detention					
Other					
Insert Row Here					
Sub TOTAL	**$0**		**1.2110**	**$0**	
3) Facility Construction					
A10 - Foundations					
A20 - Basement Construction					
B10 - Superstructure					
B20 - Exterior Closure					
B30 - Roofing					
C10 - Interior Construction					
C20 - Stairs					
C30 - Interior Finishes					
D10 - Conveying					
D20 - Plumbing Systems					
D30 - HVAC Systems					
D40 - Fire Protection Systems					
D50 - Electrical Systems					
F10 - Special Construction					
F20 - Selective Demolition					
General Conditions					
Nodal Plants	$32,000,000				
Insert Row Here					
Sub TOTAL	**$32,000,000**		**1.4291**	**$45,731,200**	
4) Maximum Allowable Construction Cost					

MACC Sub TOTAL	**$74,500,000**		**$97,198,700**	
	NA			*NA per 0*
5) GCCM Risk Contingency				
GCCM Risk Contingency	$1,490,000			
Other				
Insert Row Here				
Sub TOTAL	**$1,490,000**	**1.4291**	**$2,129,359**	
6) GCCM or Design Build Costs				
GCCM Fee	$2,980,000			
Bid General Conditions				
GCCM Preconstruction Services				
Other				
Insert Row Here				
Sub TOTAL	**$2,980,000**	**1.4291**	**$4,258,718**	
7) Owner Construction Contingency				
Allowance for Change Orders	$7,450,000			
Other				
Insert Row Here				
Sub TOTAL	**$7,450,000**	**1.4291**	**$10,646,795**	
8) Non-Taxable Items				
Other				
Insert Row Here				
Sub TOTAL	**$0**	**1.4291**	**$0**	
9) Sales Tax				
Sub TOTAL	**$7,604,960**		**$10,052,554**	
CONSTRUCTION CONTRACTS TOTAL	**$94,024,960**		**$124,286,126**	

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Cost Estimate Details

Equipment					
Item	Base Amount		Escalation Factor	Escalated Cost	Notes
1) Equipment					
E10 - Equipment	$50,000				
E20 - Furnishings	$50,000				
F10 - Special Construction					
Other					
Insert Row Here					
Sub TOTAL	**$100,000**		**1.4291**	**$142,910**	
2) Non Taxable Items					
Other					
Insert Row Here					
Sub TOTAL	**$0**		**1.4291**	**$0**	
3) Sales Tax					
Sub TOTAL	**$8,800**			**$12,577**	
EQUIPMENT TOTAL	**$108,800**			**$155,487**	

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Cost Estimate Details

Artwork					
Item	Base Amount		Escalation Factor	Escalated Cost	Notes
1) Artwork					
Project Artwork	$0				0.5% of total project cost for new construction
Higher Ed Artwork	$0				0.5% of total project cost for new and renewal construction
Other					
Insert Row Here					
ARTWORK TOTAL	**$0**		**NA**	**$0**	

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Cost Estimate Details

Project Management					
Item	**Base Amount**		**Escalation Factor**	**Escalated Cost**	**Notes**
1) Agency Project Management					
Agency Project Management	$3,476,765				
Additional Services					
Other					
Insert Row Here					
Subtotal of Other	*$0*				
PROJECT MANAGEMENT TOTAL	**$3,476,765**		**1.4291**	**$4,968,646**	

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Cost Estimate Details

Other Costs					
Item	**Base Amount**		**Escalation Factor**	**Escalated Cost**	**Notes**
Mitigation Costs					
Hazardous Material Remediation/Removal	$451,000				
Historic and Archeological Mitigation					
Document reproduction	$15,000				
PW Assist	$500,000				
Advertising	$15,000				
On-Site Representatives	$1,415,000				
OTHER COSTS TOTAL	**$2,396,000**		**1.2110**	**$2,901,556**	

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C-100(2022)
Additional Notes

Tab A. Acquisition
Insert Row Here

Tab B. Consultant Services
Insert Row Here

Tab C. Construction Contracts
Insert Row Here

Tab D. Equipment
Insert Row Here

Tab E. Artwork
Insert Row Here

Tab F. Project Management
Insert Row Here

Tab G. Other Costs
Insert Row Here

Appendix I

Project Consultant Team

Consultant	Discipline	Business Address	Primary Contact
Säzän Group	Mechanical and Electrical Engineering	600 Stewart Steet Suite 1400 Seattle, WA 98109	Tom Marseille, P.E. tmarseille@sazan.com 206.755.7392
Integral Group	Mechanical Engineering	200 Granville St #180, Vancouver, BC V6C 1S4, Canada	Vladimir Mikler, P.Eng. vmikler@integralgroup.com +1 604.374.3595
DCW Cost	Cost Estimating	815 1st Ave #176 Seattle, WA 98104	Trish Drew, CPE trish@dcwcost.com 206.259.2991
Mithun	Architecture	1201 Alaskan Way # 200, Seattle, WA 98101	Michael Fowler, AIA mikef@mithun.com 206.971.5531
Herrera	Civil Engineering	1329 N State St Suite 200, Bellingham, WA 98225	Colleen Mitchell, P.E. cmitchell@herrerainc.com 360.684.1741