University of Washington

Energy Renewal Plan

PHASE 2 - PROJECT IDENTIFICATION

December 20, 2024

Affiliated Engineers

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1.0 Executive Summary

The University of Washington (UW) Energy Renewal Plan (ERP) represents an important step in the long-term goal of decarbonizing the UW Campus. The ERP addresses the phased decarbonization of University of Washington's campus utility and energy infrastructure, with the goal of significantly reducing Greenhouse Gas Emissions (GHG).

Fossil fuel-based combustion boilers will be transitioned to an electrified system that uses heat pump technology to recover energy from sources within and adjacent to the campus. The technology will then deliver the energy to the campus buildings through a medium temperature hot water system.

This Phase II report represents a major milestone in the ERP process, building on the work presented in the Phase I Baseline Assessment Report issued on February 16, 2024[1]. The Phase II report documents key decisions for the ERP's direction and provides an initial review of cost and schedule implications.

Goals of the Phase II Project Identification and Prioritization study included:

- Developing a list of projects and alternatives.
- Confirming and evaluating projects, providing narratives, one-line diagrams, and conceptual drawings.
- Developing a milestone schedule and cost for individual project elements.
- Identifying potential outside funding opportunities.
- Establishing the framework of the life cycle cost analysis.
- Identifying construction logistics phasing opportunities.
- Identifying impacts on campus operations.

The Phase II effort focused on developing projects to enable UW's transition to heat pump technology. High-level descriptions of projects targeted for Phase III implementation and estimated costs are summarized in Tables 1.0-1 and 1.0-2 and Figure 1.0-1 below.

[1] See the Phase I report for an analysis of the existing and future campus load characteristics and a discussion of concepts explored in the Phase II Project Identification and Prioritization Report.

Table 1.0-1: Projects Targeted for Phase III

Category	Description	Projects targeted for Phase III implementation
Energy Sources	Develop systems that allow capture of alternate heat sources to replace fossil fuel boilers, including campus waste heat, lake water, sewer water, outdoor air and geothermal.	• Recover heat from campus waste heat and connection to King County sewer and Lake Washington.
Plant and Electrical System Upgrades	Enhance existing Campus Utility Plants (CUPs) and Campus Electrical Infrastructure to improve reliability and support new energy sources.	• Improvements to the Power Plant and West CUP to harness recovered heat through thermal energy storage, heat recovery chillers, and electric boilers. • Improvements to the campus electrical system to address required capacity and reliability.
Mechanical Distribution	Connect energy sources, plants, and campus buildings with new hot water distribution system.	• Install a new hot water distribution system reusing the campus's existing underground tunnel system and supplementing with buried utilities. • Expansion of the existing cooling water distribution system.
Electrical Distribution	Enhance the existing campus electrical system to provide reliable and resilient capacity required to support ERP improvements and future growth on the campus.	• New substation located in west campus between existing Seattle City Light substation and University of Washington electrical receiving station. • Provide new connections to support new electrified heating systems within the campus utility plants and new infrastructure buildings.
Building Conversions	Renovate existing building heating systems to accept new hot water system and chilled water systems to allow removal of building chillers to consolidate capacity to campus utility plants.	• Convert building heating systems to accept new hot water distributions system. Heat exchangers, pumps, and replacement of air-handling systems. • Remove chillers distributed across campus buildings and connect to campus cooling water system. • Provide local steam plants to allow elimination of campus steam distribution system.

Table 1.0-1: Projects Targeted for Phase III

Category	Description	Projects targeted for Phase III implementation
Building Energy Efficiency Measures	Implement efficiency and load reduction measures at building level to decrease capacity requirements.	• Replacement of high-energy systems through Buildings Renewal Program efforts.
Building Controls and System Analytics	Implement modernization of campus monitoring and analytic systems to allow better operation and control of the campus and building thermal and electrical systems.	• Upgrades of legacy building control systems to modern digital systems. • Implement comprehensive metering and data analytics platforms.

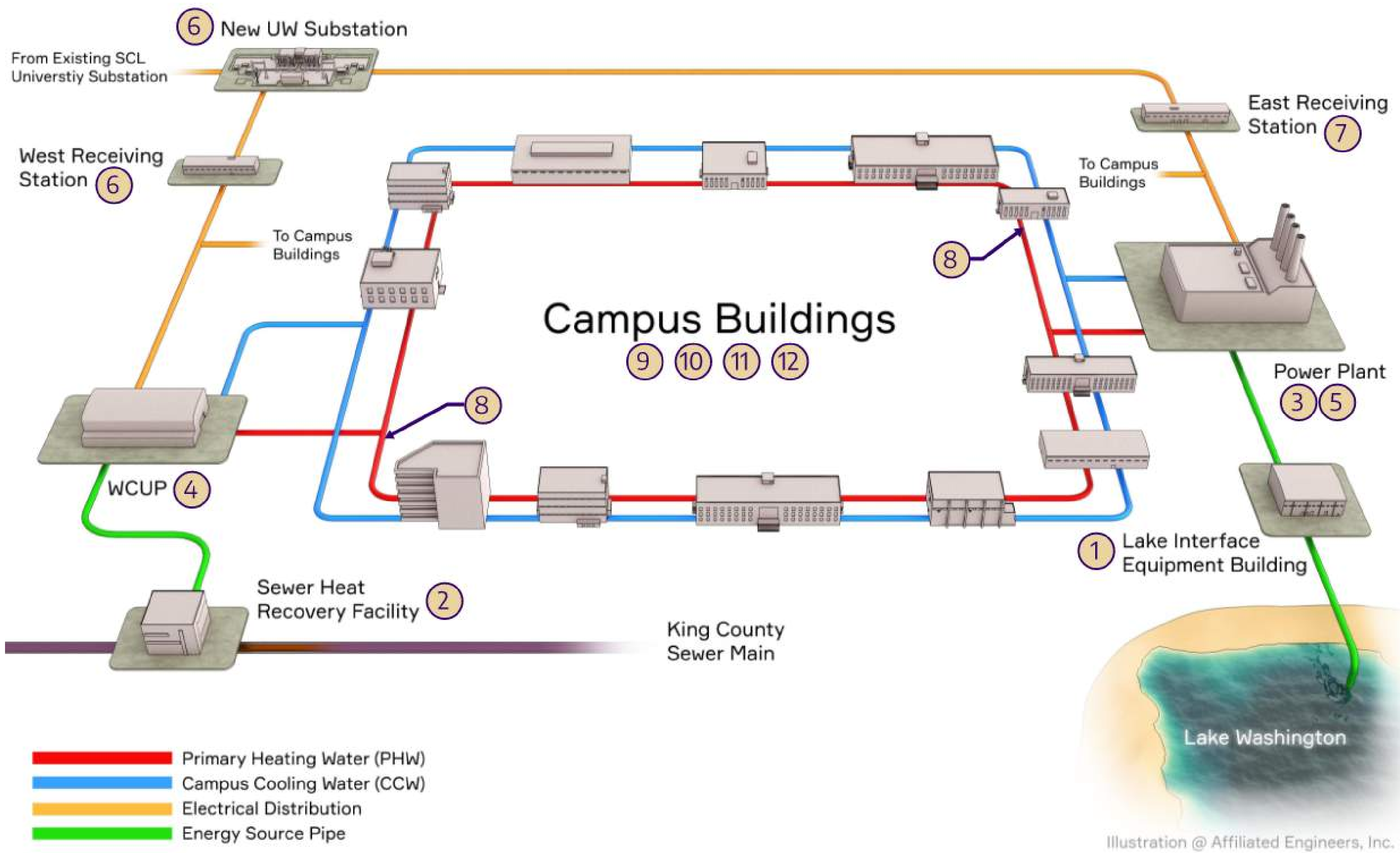


Figure 1.0-1: *Diagram of projects across the campus energy and utility systems*

Table 1.0-2: Cost summaries for projects within each project category.

KEY #	Description	ROM Cost ($ 2024)
	Energy Sources	
1	Lake Water Interface System	$137,177,539
2	Sewer Heat Recovery System	$54,545,627
	Subtotal:	$191,723,166
	Plant & Electrical System Upgrades	
3	Power Plant Improvements	$210,075,592
4	WCUP Improvements	$99,026,805
5	Thermal Energy Storage System	$73,055,180
6	UW Substation and West Receiving Station Upgrades	$30,531,457
7	East Receiving Station Upgrades	$12,918,972
	Subtotal:	$425,608,006
	Site Distribution	
8	Mechanical Site Distribution	$486,784,041
	Subtotal:	$486,784,041
	Building Upgrades and Conversions	
9	Building Heating System Conversions	$260,097,167
10	Building Chiller Replacements	$20,573,390
11	Local Steam Plants	$60,469,792
12	Building Controls, Metering, and System Analytics	$8,799,745
	Subtotal:	$349,940,094
	UW ERP Project Cost Total:	$1,454,055,307

Table 1.0-2 Notes:

1. Refer to Phase III report for final cost estimate details. Table 1.0-2 represents the final cost estimates incorporating updates from Phase III.
2. Costs in this table are represented in 2024 dollars. Refer to Phase III Report for funding required in the given year of the different timelines of project execution presented.

Based on assessments of IRA tax credit eligibility for the projects developed for the ERP Phase II, the total rough order of magnitude potential tax credit for the entire project is in the range of $20M to $120M, depending on the project factors described in this report. More detailed analysis on the tax credits is being performed based on the latest cost estimates and is expected to be provided as part of the Phase III analysis.

The Energy Renewal Program is anticipated to begin construction in late 2025, and based on early scheduling efforts, will be completed in 2035. See Figure 1.0-2 for a high-level timeline of the project's major phases provided in UW's Energy Strategy. The Phase III Implementation Plan will outline the recommended sequencing, scheduling, and funding approaches for the implementation of the projects identified in this report.

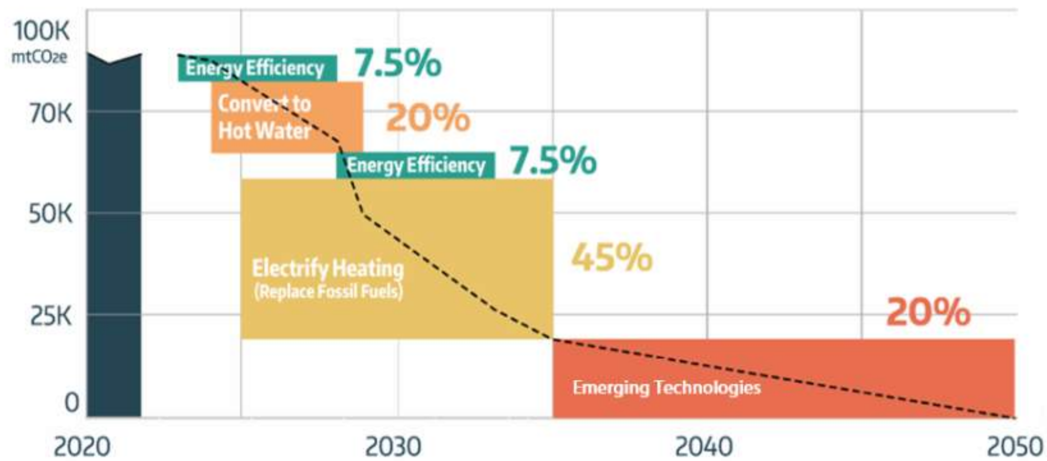


Figure 1.0-2: *High-level schedule of major project phases from the UW Energy Strategy*

2.0 Introduction

2.1 Project Definition and Goals

The goal of the University of Washington (UW) Energy Renewal Plan (ERP) is to advance concepts developed from studies dating back to 2009 into a set of actionable plans addressing items like budgeting, funding, and logistics that will meet the long-term goal of decarbonizing the UW campus.

This report documents the work completed during Phase II of the ERP process. It identifies specific project elements that will achieve the University's goals and defines budgets and anticipated construction durations for each project element.

The primary drivers for this report include:

- Delivery of reliable and resilient thermal and electrical utilities to the campus. The University of Washington's Seattle campus also provides critical functions as a Tier 1 research university and a regional hospital in the University of Washington Medical Center (UWMC).
- Continued commitment from UW students, faculty, and administration to be leaders in the reduction of greenhouse gas emissions on college campuses.
- Compliance with Washington State House Bill 1390, which requires the development of a plan to decarbonize district heating systems by 2050.
- The Phase I report, issued on February 16, 2024, which provided the baseline assessment of existing conditions.

Phase III will evaluate various scenarios for phasing the work based on issues such as logical workflow, impacts on campus life, and funding opportunities. The Phase III final report will document a detailed implementation plan with schedules, cost estimates, and funding plans.

The UW Campus includes buildings that are both owned and leased beyond the footprint of what is traditionally thought of as the UW campus. The ERP excludes leased buildings, undeveloped sections of the East Campus, Husky Stadium, and other properties that are outside of an agreed-upon proximity to existing district energy utilities. See Appendix 9.2 for a site plan of buildings excluded from the study and buildings identified as provisioned for future connection (e.g., housing/athletics and facilities with stand-alone systems).

2.2 Integration with the Building Renewal Plan (BRP)

The University engaged a separate team, led by Miller Hull, to generate a Building Renewal Plan (BRP) to develop a prioritization of removal, renovation, or replacement of existing buildings. This study was primarily focused on optimizing the utilization of campus building stock and reducing deferred maintenance of existing facilities to an acceptable level. The ERP and BRP teams coordinated through a series of workshops that informed the two efforts on prioritization needs from the two perspectives of deferred maintenance and the campus energy system transition.

While it is understood that the ERP-related work is the near-term funding priority for the campus, there may be remodel, renovation, and replacement projects that occur during ongoing ERP work. Together, the ERP and BRP teams developed concepts for the mechanical systems renovations to occur in the early building work, which allow those systems to integrate into the ERP systems with minimal disruption once the ERP systems are available to the building.

2.3 Background

In addition to the work documented in the Phase 1 Baseline Assessment report, the following studies, assessments, and reports inform the history of campus infrastructure and building master plans for the ERP study:

- 2011 University of Washington South of Pacific Avenue Master Infrastructure Review
- 2014 University of Washington Hot Water Conversion Study
- 2016 South Campus Study
- 2017 University of Washington Hot Water Conversion Study: Phase II
- 2019 University of Washington Seattle Campus Master Plan
- 2021-22 ISES Facilities Condition Assessment
- 2022 Utilities Infrastructure Assessment
- UW Cultural Resources Report

2.4 Process and Collaboration with University of Washington Staff

The University of Washington is supporting the planning effort with a highly developed oversight and governance structure, dedicated staff to provide day-to-day direction and oversight, and Project Working Teams.

Project Working Teams (PWTs) support the transfer of knowledge, data gathering, review of proposed concepts, prioritization of tasks, and forming outreach strategies for external entities. Both the ERP consulting team and the University of Washington internal team of experts were integrated into the PWTs. These teams met regularly from the baseline assessment through the project identification phase with a focus on:

- Funding and Financing
- Central Plant, Thermal Energy Storage, and Distribution
- Thermal Transfer (Lake Interface and Sewer Heat Recovery)
- Buildings
- Electrification

The University's internal team of experts included staff with experience in operations, engineering, sustainability, energy conservation, data management, and transitioning university campuses from steam to hot water. The ERP consulting team consisted of firms with specialty knowledge and experience, including:

- Affiliated Engineers, Inc. (AEI) – Prime consultant and mechanical and electrical master planning and engineering
- KPFF – Civil engineering and site utilities planning
- Whiting-Turner (W-T) – Cost estimating, phasing, and logistics analysis
- Shannon & Wilson (S&W) – Lake water technical and permitting specialists
- Ernst & Young (EY) – Financial analysis and funding plans
- Makai Ocean Engineering – Subject matter experts in pipeline design for lakes and oceans
- Rolluda Architects – Architectural and site development concepts and campus planning

2.5 Commonly-Used Terms

Campus Cooling Water (CCW)	Term used to refer to the existing district cooling system on the UW campus.
Coefficient of Performance (COP)	Measure of system efficiency. For chillers and heat recovery chillers, it is the ratio of useful heating provided to work (energy) required.
East Receiving Station (ERS)	Electrical distribution point located at the Power Plant.
Heat Recovery Chiller (HRC)	A device that can produce useful heating and cooling in the form of heated or cooled water at a campus scale.
Inflation Reduction Act (IRA)	A Federal law established in 2022 aiming to invest in domestic energy production and promote clean energy.
MBH	1,000 British Thermal Units (BTUs), an imperial unit measurement of heat energy. MBH is commonly used in heating applications to quantify thermal energy and evaluate energy consumption and efficiency.
Magnusson Health Science Center (MHSC)	A science complex made up of many buildings, located on adjacent to the Medical Center.
Megawatt (MW)	An International System (SI) measurement of power, typically used for electrical systems (1 MW = 1,000 Kilowatts = 1,000,000 Watts).
Megawatts thermal (MWth)	Measurement of thermal power. The “th” is used as a clarifier to denote heat rather than electrical.
Primary Heating Water (PHW)	Term used to refer to the new district heating system on the UW campus.
Power Plant (PP)	The original central utility plant, located on the east side of campus.
University of Washington Medical Center (UWMC)	The University of Washington’s healthcare facility.
West Campus Utility Plant (WCUP)	The most recent campus utility plant, located on the west side of campus serving facilities with critical cooling loads.
West Receiving Station (WRS)	Main point of entry for power from Seattle City Light.

3.0 Load Analysis

3.1 Overview

Analysis of campus heating, cooling, and electrical demands was provided in the Baseline Assessment Report. Table 3.1-1 summarizes the present day and future campus loads (demand) and proposed capacities (plant equipment), revised based on the work done in Phase II.

Table 3.1-1: Present Day and Future Campus Load and Capacity Summary

Utility Category	Present Day Load [MW]	Present Day Capacity [MW]	Future Load [MW]	Future Capacity [MW]	Comments
Heating Plants	100	216	81	88	Present day load based on 2022 data.
Cooling Plants	65	58	123	130	Present day load is based on 2022 data without distributed chillers.
Electrical System	52	46.2	114	135	Capacity information is provided in N+1 mode.
Process Steam	7.3	216	No longer served by central steam. Distributed systems used.		

3.2 Campus Heating and Cooling Load Projections

3.2.1 Campus Cooling Water (CCW) Load Projections

Using the hourly 2022 CCW load profiles as a starting point, cooling load projections were estimated for the anticipated future connection of cooling loads to the CCW system.

The following load growth factors have been accounted for in these projections:

- Loads from distributed chillers consolidated into CCW system.
- UW Medical Center cooling – noted as a future load.
- Cooling added to buildings without cooling.
- Impact of future climate changes (see Section 3.2.4).

The projections do not account for the impact of individual building cooling loads decreasing over time through renovations, energy efficiency improvements, or demolition/removal. Even with a campus plan not adding additional building area to the campus it is anticipated that new spaces will be more load intense than existing due to higher utilization or a shift from office/general academic uses to higher intense loads associated with laboratories and research and development.

A distributed cooling load profile was estimated from the UW Facilities distributed chiller and cooling tower equipment inventory with consideration for buildings and cooling loads likely to be connected to campus CCW systems as part of the Energy Renewal Plan, shown in Figure 3.2.1-1. Process cooling loads were separated from general HVAC space conditioning loads. Equipment or buildings not likely to be in the scope of the ERP were excluded. A process cooling load of 1,000 tons and a general HVAC cooling load of 11,700 tons (diversified down to 9,000 tons) is estimated for this analysis. An inventory of the distributed heating and cooling system across campus was provided in the Baseline Assessment Report.

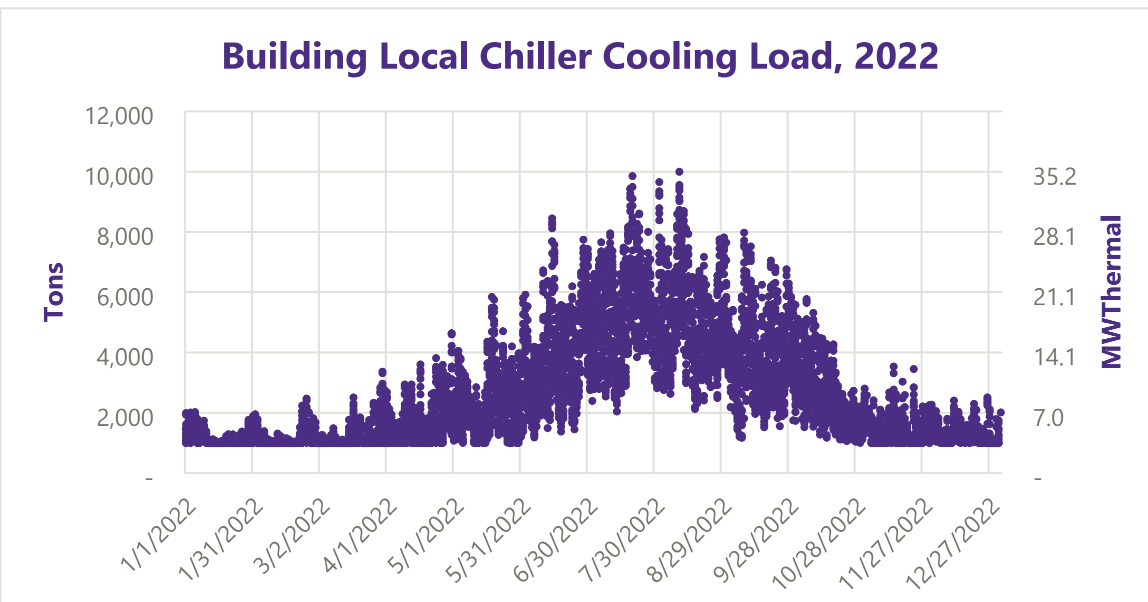


Figure 3.2.1-1: *Estimated hourly CCW production profiles for existing distributed cooling system (local chillers) to be consolidated as part of the Energy Renewal Plan*

The total Campus CCW load profile shown in Figure 3.2.1-2 is a combination of the hourly Power Plant CCW, WCUP CCW, and distributed cooling CCW with an estimated peak of 28,000 tons as compared to the 2022 historical weather data.

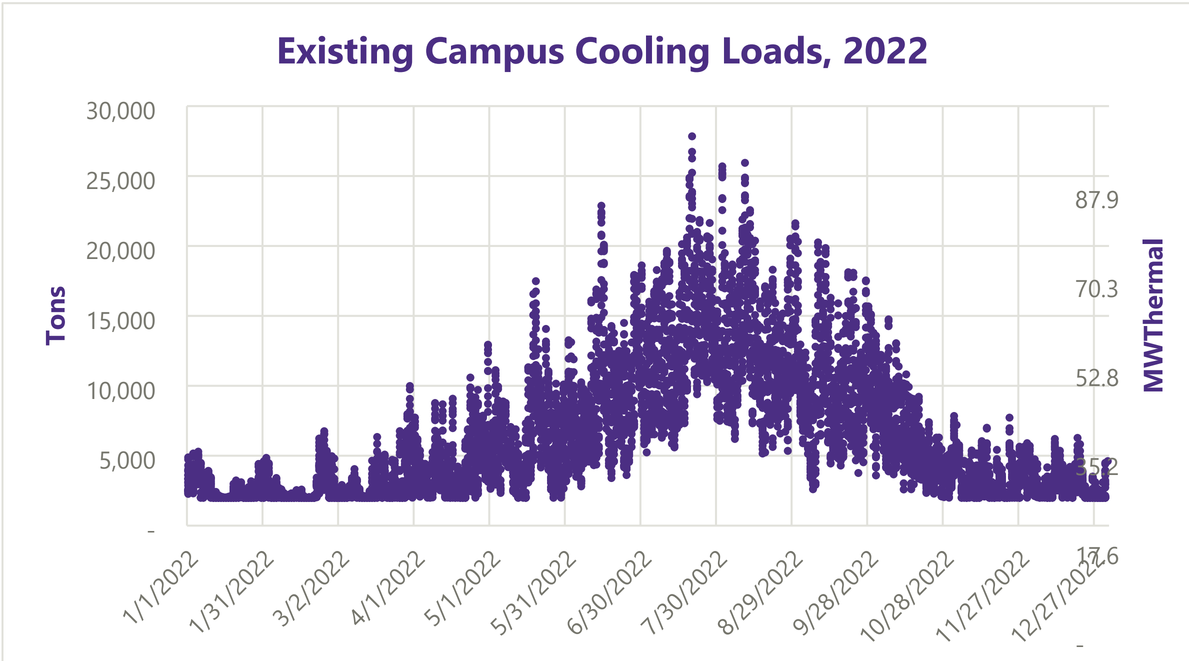


Figure 3.2.1-2: *Existing cooling loads on campus for the year 2022 including Power Plant, WCUP, and local building chillers*

3.2.2 Hot Water (PHW) Load Projections

The campus hot water demand profile was formulated by combining the available building steam condensate data with high-level energy model results; these energy models consisted of prototype buildings roughly representative of the broad building types seen across a university campus, including laboratory, administration/office, athletics, student union, and dormitory buildings. These model results run for Seattle 2022 historical weather were applied to buildings missing steam meter data based on the characterization of the buildings in the data sources provided. The campus profile was then calibrated to the monthly steam production data provided by UW for 2022 as well as the total annual production.

Anecdotal peak production was also included in the calibration process. A typical winter peak of 320,000 lbs./hr and a max historical observed of 350,000 lbs./hr was accounted for, with the campus model peak after this calibration process being 340,000 lbs./hr. Distribution and makeup water losses were accounted for through an estimate of pipe distribution length and heat loss factors. The process steam baseload was broken out separately based on prior knowledge of the campus and facility staff knowledge. All these considerations ultimately yielded the hot water profile shown below.

The steam process equipment load is estimated to be a constant 25,000 lbs./hr based on information provided to AEI in previous study efforts with the University of Washington. The estimated process steam load has been deducted from the data set in order to calculate the campus hot water demand.

The hourly campus steam heating demand was converted to a future heating hot water demand shown in Figure 3.2.2-1. The steam distribution loss was modeled at 15% based on a takeoff of the campus piping system length, assuming insulation effectiveness and average pipe diameters. The makeup water loss was modeled based on the monthly data provided by UW. The average annual make water loss was calculated to be 8%.

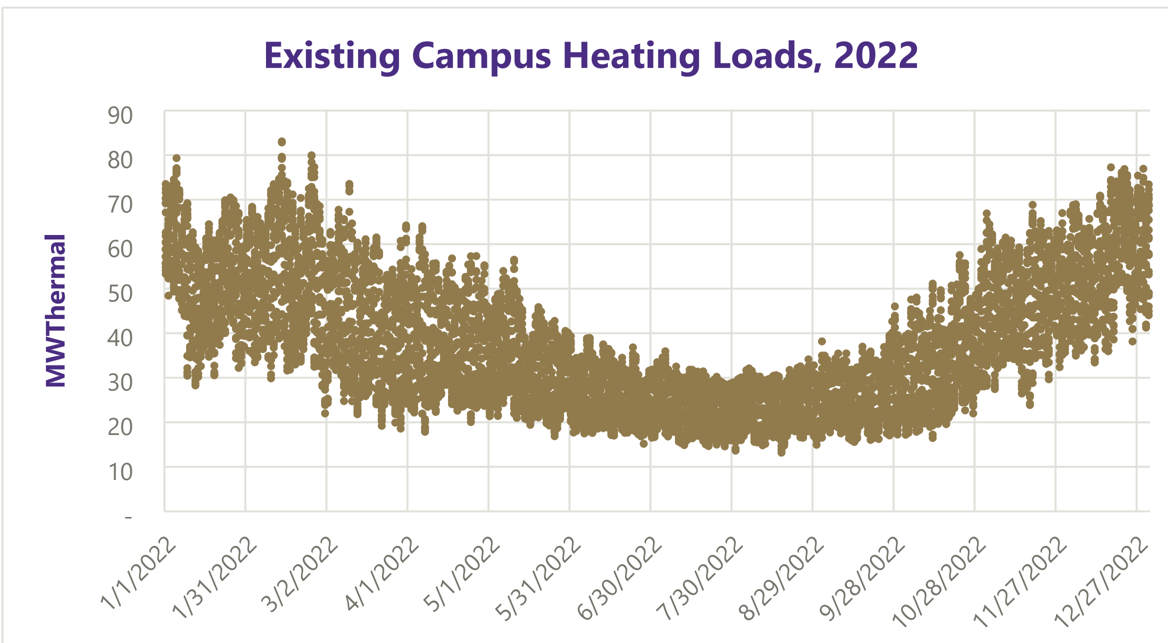


Figure 3.2.2-1: *Estimated total campus hot water demand for 2022 weather data*

3.2.3 Campus Heating and Cooling Load Projections

The combined hourly load profiles for CCW and steam converted to a campus hot water system are given in Figure 3.2.3-1 with simultaneous load shown to illustrate the potential heat recovery. The heating peaks corresponds to 275,000 kBtu/hr and the cooling peak to 28,000 Tons. Approximately 48% of the heating load and 54% of the cooling load are overlapping simultaneous load suitable for energy recovery.

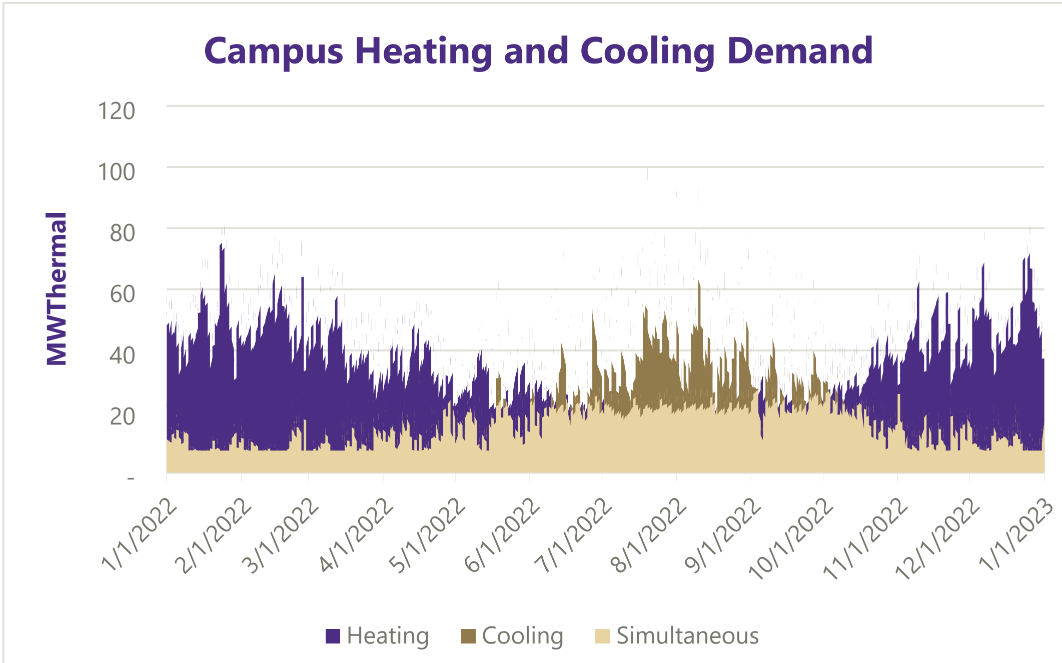


Figure 3.2.3-1: *Hourly total campus CCW and Campus Hot Water load profiles*

3.2.4 Impact of Future Climate

IPCC AR5 (Fifth Assessment Report) emissions scenarios were evaluated and the impact to campus loads was discussed with the UW Project Working Teams. These scenarios are called representative concentration pathways (RCPs) and are modeled scenarios from the climate science community that look at different emission scenarios and how they are anticipated to impact weather.

Two RCPs were investigated for their impacts on the campus loads, RCP4.5 and RCP8.5. The numbers denote the additional flux of solar radiation (W/m2) equivalent from the greenhouse gas effect for that scenario; RCP4.5 yields 4.5W/m2 additional heat flux where RCP8.5 yields 8.5W/m2 additional heat flux. RCP4.5 is considered a moderate emission scenario, assuming that carbon emissions plateau begins to decrease in 2040. RCP8.5 assumes greater emissions without any curtailment and therefore yields more warming and more extreme temperatures. It was decided that RCP8.5 was too extreme and would yield exorbitant cooling loads not likely to be seen by the campus, therefore RCP4.5 was selected for this study.

Extrapolations for the cooling load (current CCW and local building chillers) and the newly electrified hot water load are shown in Figure 3.2.4-1 for RCP4.5. Note that data points for 2070 and 2080 are absent but will be included in the final LCCA for Phase III. This cooling load is anticipated to increase by 17% between 2020 and 2060. The heating load is anticipated to decrease by 5.5% between 2020 and 2060.

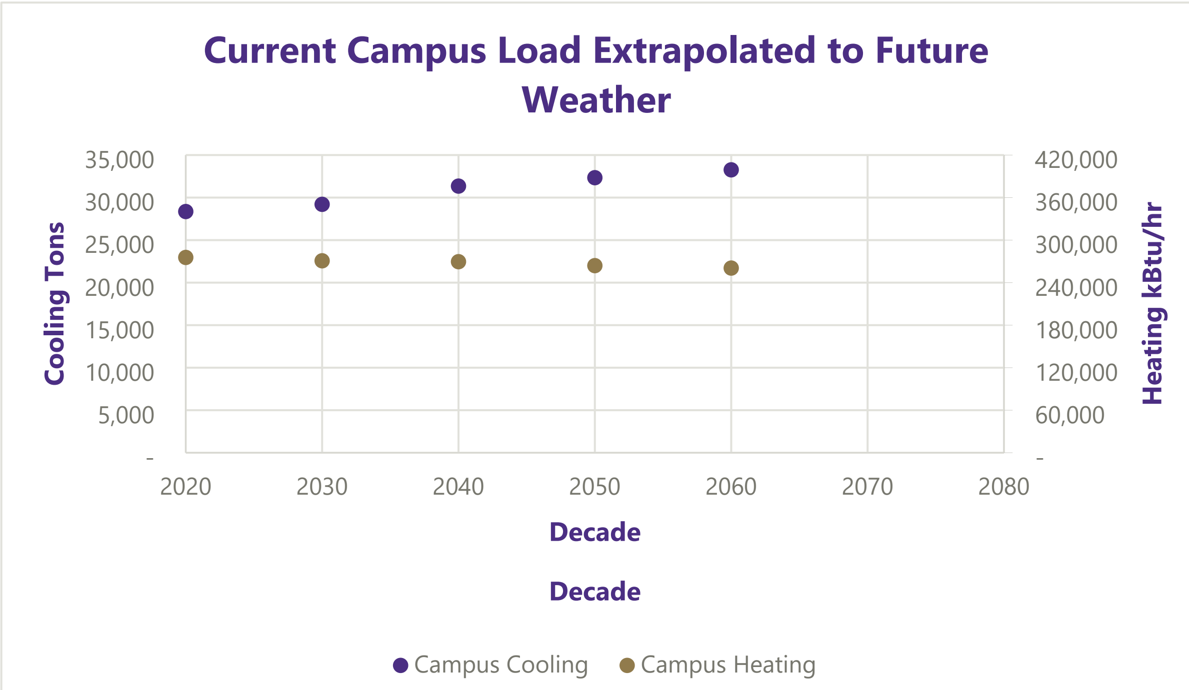


Figure 3.2.4-1: *Hourly total campus CCW and Campus Heating peak loads in a given year based on the RCP4.5 future weather model*

An additional 2300 Tons of future cooling is anticipated for buildings not currently provided with cooling. The additional cooling across the campus associated with a warming climate is 4,400 Tons or 16% of the current campus load. The total anticipated campus load in 2060 is 35,000 Tons.

Retrofits to cooling systems within existing buildings, and new cooling systems within new buildings should account for predicted future weather conditions equivalent to a summer design condition of 95°F dry-bulb and 76°F wet-bulb (predicted conditions in year 2050).

4.0 Project Identification & Prioritization

The following section outlines the major projects identified as part of the Energy Renewal Plan. Projects are organized into the following categories:

- Energy Sources – studying the various sources of energy for the use of electrified heat pumps.
- Plant Upgrades – project options that will enable the energy transition from steam to electrified hot water.
- Utility Distribution – projects associated with distributing heating, cooling, and electricity to the campus.
- Building Systems – identifying the necessary building work to support the energy transition.
- System Analytics – projects to improve system analytics for optimization of energy efficiency and operations.

The scope of work associated with these projects was formed into documents for cost estimating. These documents are a companion to this section and provide a more specific level of detail for what the cost estimates are based on. Refer to Appendix 9.13 Scope of Work Documents for this level of detail.

4.1 Energy Sources

4.1.1 Introduction

University of Washington's Energy Renewal Plan (ERP) represents a major transition from fossil fuel combustion with boilers to electrically driven heat exchange with heat pumps. This technology transition enables the campus to use the carbon free electrical energy in the Seattle City Light electrical grid to recover and share energy between buildings on the campus and recover energy from various alternative heat sources as outlined below.

This section describes the alternative sources considered for energy recovery utilizing heat pump technology, those shown in **Bold** are recommended to be included the project.

- **Campus Waste Heat Recovery**
- **Sewer Water Heat Recovery**
- **Lake Interface Heating & Cooling**
- Air-Source Heat Pumps
- Geothermal Heating & Cooling

Each source varies in energy potential, efficiency, and operational considerations, including operating cost, reliability, resiliency, and redundancy. The infrastructure upgrades needed to utilize the source and the impacts on the existing campus environment also vary for each of these sources.

Each source is described in detail in the following sections. A summary of the recommended system characteristics is provided at the end of each section. Systems that are not part of the recommended ERP solution are noted as such and provided with details of their potential outputs and characteristics.

4.1.1.1 Emerging Technology Considerations

Several alternate heat sources / generation technologies were not investigated in detail as their development is not currently at a point where they could be considered viable and reliable for use on the campus. However, these technologies may play a role in UW's energy future should they become more widely available and develop a proven track record. Technologies that fit this category include:

- Micro-nuclear applications
- Cost-effective hydrogen boilers
- Renewable natural gas

4.1.2 Campus Waste Heat Recovery

System Overview

The first source targeted for recovery is heat generated by critical campus processes which, under current operating conditions, would be cooled by the campus cooling water and the heat ultimately rejected into the atmosphere via campus cooling towers. Heat recovery chillers are used to produce chilled water to absorb this heat from the processes and upgrade the temperature of that heat source to a level usable in heating other areas of the campus where it is needed. This process of recovering campus waste heat is very efficient since both sides of the process produce useful energy. Recovery of campus waste heat can result in a chiller COP > 5.5.

Sources of campus waste heat which will be captured include:

- Processes that require year-round cooling (e.g., data centers, laboratory, or healthcare equipment).
- Interior spaces within large buildings which require year-round cooling.
- Building exhaust air.

Many buildings on campus currently have stand-alone chilling capacity to provide chilled water for the processes identified above dure times of the year when the CCW system is deactivated. The plan provides for removal of these chillers and operation of the CCW system year-round allowing the new heat recovery chillers to capture the associated heat for use elsewhere on the campus.

Existing historical data from the campus BAS systems on chiller operation provides a good way to measure the current potential for campus waste heat.

Another approach considered to increase heat recovery is the use of cooling coils within the exhaust air of buildings with high rates of process exhaust or outdoor air ventilation. This process is referred to as “false cooling” and currently exists in some areas of the campus.

Recommendations

Heat recovery from current campus operations as outlined above provides a stable and viable source of heat for the campus. Heat recovery chillers provide a reliable means to capture and upgrade the temperature of the heat source making it usable for the campus. Implementation of waste heat recovery as described herein is recommended as a source for the campus.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of this project.

Key System Characteristics

- Installation of heat recovery chillers to recover campus waste heat. Capacity is anticipated to be approximately 4,000 nominal tons. This capacity will be located in both the Power Plant and WCUP.
- Installation of CCW and PHW thermal energy storage to support system operations and resiliency as described below.

- If campus waste heat recovery opportunity grows over time, through false cooling or the addition of significant data center / IT equipment loads, this would offset the need for other forms of heat pump heating (e.g., lake, sewer) and additional heat recovery chillers would not be required.

Campus waste heat recovery system capacity and characteristics:

- Estimated peak heat recovery potential based on expected winter cooling load / false cooling capacity:
  - 6,700 tons / 23.7 MWth cooling.
  - 117,000 MBH / 34.3 MWth heating.
- Maximum campus heat recovery capability with proposed equipment:
  - 12,500 tons / 44 MWth cooling.
  - 217,500 MBH / 63.8 MWth heating.
  - These values are unlikely to be achieved based on the expected winter cooling load / false cooling capacity noted above.
- HRCs deliver the following:
  - 167°F hot water supply.
    - Building equipment will be sized for 162°F temperature from the campus system to provide a buffer on HRC operation, TES storage temperature, and distribution losses.
  - 42°F campus cooling water supply.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

The campus cooling load profiles were analyzed to estimate the current winter cooling load, which currently is estimated at 1000 tons. Data collected on the quantity, capacity, and use of building level chillers allows for an estimate of the potential winter cooling load that would be added by consolidation of building level chillers representing an additional 1,000 tons.

Alternatives and Scenarios

Campus waste heat recovery is the most basic of the energy source options since recovery of wintertime cooling load is only limited by:

- The magnitude of the wintertime cooling load
- Relative magnitude of the cooling load to a simultaneous need for heating
- Installed capacity of heat recovery chillers
- Operational stability of the heat recovery chillers

The two primary factors that were studied with respect to the opportunity for campus waste heat recovery were:

- Building exhaust air heat recovery (also referred to as “false cooling”)
- Thermal energy storage

Building Exhaust Air Heat Recovery / False Cooling

Campus waste heat recovery can be augmented through a strategy commonly referred to as “false cooling,” where hydronic coils are installed in building exhaust air. These coils allow for heat to be captured from building exhaust before it is discharged to the atmosphere.

This method of heat recovery is not considered as efficient as a recovering campus waste through simultaneous heating and cooling. With false cooling only the heat output of the system is useful energy. The cooling effect on the exhaust air prior to being discharged to atmosphere does not provide any value and is thus not considered in the calculation of the system COP.

A number of UW buildings already use a false cooling strategy on a building level. These include the Hans Rosling Center for Population Health and the ARCF buildings as well as others. These buildings typically use an air-to-air energy recovery device, often referred to as a runaround loop. These systems are used to pre-heat or pre-cool the incoming outdoor air by exchanging heat with the building exhaust air. This process is most effective at the temperature extremes (i.e., during times of peak load) and less effective during milder conditions as the difference between outdoor air and exhaust air is decreased.

Figure 4.1.2-1 shows a simplified diagram of an option that combines both the peak load reduction of a runaround loop with the annual energy savings opportunity of a false cooling coil setup.

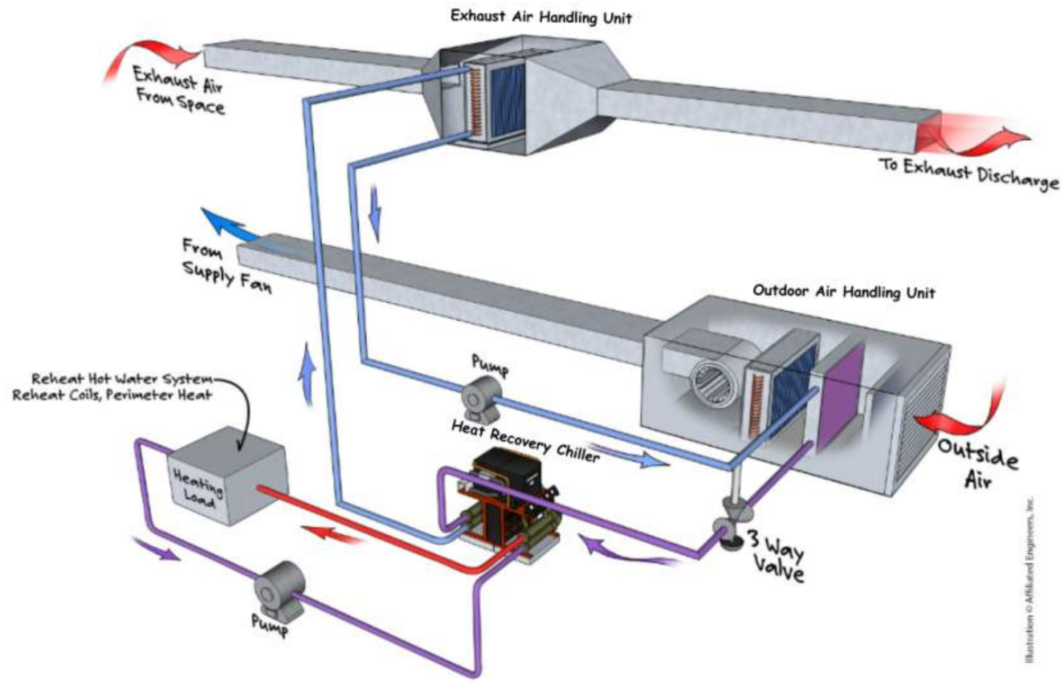


Figure 4.1.2-1: *Enhanced run-around loop energy recovery diagram*

Implementing false cooling on a larger scale would be justified when there is a need to offset or augment the capacity of the heating system relative to a decrease in capacity or utilization of another heating system. For example, winter storm events in King County can cause sewer water temperatures to decrease thereby reducing the available capacity of the sewer for a period of a few hours. False cooling could be used as an alternative source of energy during those periods rather than relying on other back up sources such as fossil fuel combustion boilers or electric boilers.

Replacing one of the other major heat sources recommended for the ERP with false cooling would require a massive amount of building exhaust air sources. For instance, to replace the Lake Interface system would require roughly 3,550,000 CFM of building exhaust air to be provided with heat recovery coils connected to the CCW system. The Hans Rosling and ARCF systems noted as already existing represent only 6% of this value.

For the above reasons, lower energy efficiency compared to other forms of heat pump heating, scale of heat capacity relative to exhaust airflow, and concerns with the ability to control the system at a campus scale (see Operational Considerations section for more detail), false cooling is not included as an element in the ERP concept.

Thermal Energy Storage

Thermal energy storage plays two important roles in campus waste heat recovery.

The primary role is to allow for campus-scale heat recovery chillers to operate at a high capacity, often greater than the instantaneous need for heating and cooling. Heat recovery chillers in this size range and operating at the high pressures required to generate campus heating water have limited ability to turn down or dial in their speed to match a given load. With that in mind, thermal energy storage tanks are used to absorb a shortfall or surplus in heat recovery capacity relative to the campus demands. If more heat or cooling is being generated than the campus requires, the thermal storage tanks will be charged. If less heat or cooling is being generated than the campus requires, the thermal storage tanks will discharge.

Thermal energy storage also allows recovery of energy with less dependency on the loads being needed at the same instant in time. The thermal energy storage tanks store campus return water until such time that a heat recovery chiller can operate and run for an extended period of time at its full-load and peak efficiency operating point.

Without the thermal energy storage tanks, heat recovery chillers would need to be right sized to the expected loads and their operation would be limited to times when heating and cooling energy are needed in the same time period.

That said, the size required to optimize campus waste heat recovery and allow for heat recovery chiller operation is 50% to 75% less than what is required to meet the campus goals for resilience during a utility outage. Thus, campus waste heat recovery is not the main factor in determination of the thermal energy storage tank size.

Refer to Section 4.2.2.1 Power Plant Upgrades – Mechanical for additional detail on the conceptual design of the thermal energy storage tanks.

Energy Potential

The heating thermal energy storage (HTES) will be sized for 1,300,000 gallons while the cooling thermal energy storage (CTES) will be sized for 4,200,000 gallons. The tanks charge when the heat recovery chiller capacity exceeds the campus demand and discharge during periods of high load to mitigate the electrical demand of the system.

The campus heating demand and the HTES adjusted heat generation is shown below in Figure 4.1.2-2 for a week in January. The HTES discharges in the early morning to mitigate the heating load peak. The tank recharges during mid-morning by utilizing simultaneous load, sewer heat, and finally lake heat. During this period, the heating plant load increases due to the additional load needed to recharge the tank.

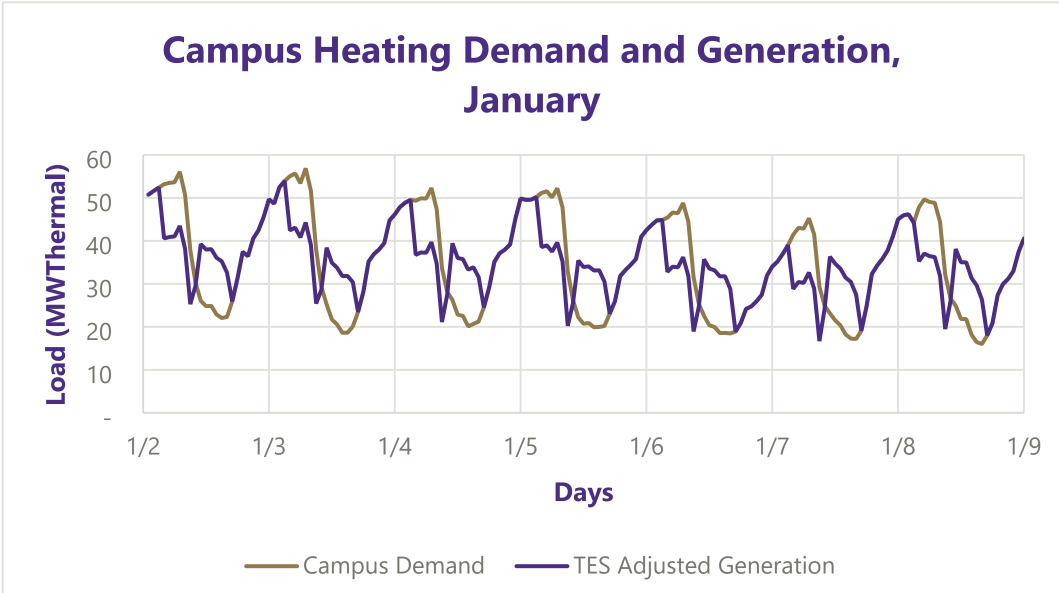


Figure 4.1.2-2: *Comparison of camps heating demand vs generation shifted by operation of HTES*

The campus cooling demand and the CTES adjusted CCW generation is shown below in Figure 4.1.2-3 for one week in July. The graph shows CTES discharges in the afternoon to mitigate the cooling load peak. The tank recharges during the night and early morning by utilizing simultaneous load, sewer, and finally the lake; during this period, the load seen by the cooling plant increases because of the additional load needed to recharge the tank.

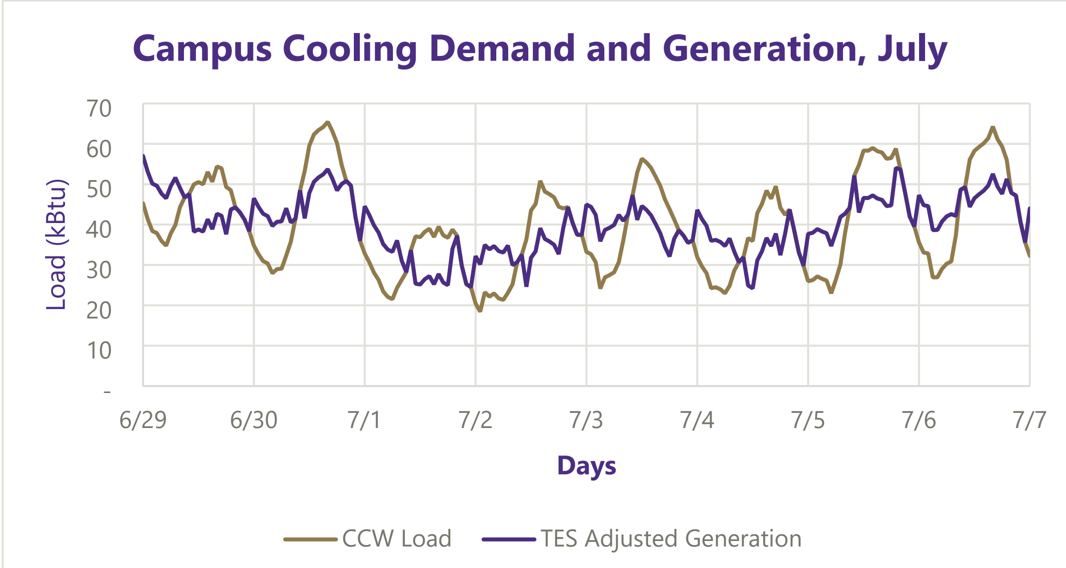


Figure 4.1.2-3: *Campus cooling demand and cooling generation shifted by operation of CTES*

The HTES reduces the amount of electric trim boiler operation in terms of load, energy consumption, run hours, and peak campus electrical demand are shown in Table 4.1.2-1.

Table 4.1.2-1: Summary of Impact of TES

		Excluding TES	Including TES	% Savings
Trim Boiler	% of Heating Load	9%	7%	
	% of Heating Energy	13%	11%	
	Run Hours	1484	1430	6%
	Campus Peak MW	86.8	81.9	6%

These results are based on all the campus comfort heating load moving from steam to electrified hot water and cooling needs served by local building chillers are moved to the CCW. This significantly increases the amount of available simultaneous heating and cooling, improving the performance of the system and decreasing the loads and energy impact of the TES. However, the TES still benefits the campus by reducing peak electrical demand, particularly when the sewer source becomes unavailable due to the diminished temperature during rainstorms.

The potential for campus waste heat recovery without the incorporation of local building chillers is 1,700 tons. Adding the building level chillers increases this to 2,500 tons. The region with the highest potential for campus waste heat recovery is the South of Pacific building chillers.

Energy Efficiency

The efficiency of a campus waste heat recovery varies based on how much false cooling is utilized. Heat recovery between a campus cooling load and heating load will be achieved at a chiller COP of 5.5 or higher based on the heat recovery chiller equipment selected for this study. False cooling loads utilizing building exhaust air as the heat source produce only heat and not useful cooling and thus will have a comparable efficiency to other heat sources (3.2 COP).

Campus waste heat recovery is amplified by several integral steps to centralizing the heating and cooling systems. These steps include removal of building level chillers, installation of the new campus heating water loop, and installation of thermal energy storage tanks at the Power Plant.

To achieve the maximum campus waste heat recovery potential, the building level chillers will need to be consolidated into the campus cooling water system. This will require extension of CCW to new regions of the campus (north, west).

Refer to Section 4.4.2 Plant Upgrades for more details on these parts of the project.

Impacts to the Existing Campus Environment

The thermal energy storage tanks are large structures and will have a visual impact on the campus. The need for the tanks can be partially attributed to the campus waste heat recovery source. Refer to Section 4.4.2 Plant Upgrades for discussion on the impact of the thermal energy storage tanks.

The tanks will be located at the east side of campus just north of the Power Plant. This location has been coordinated with UW campus Planning staff to validate that it represents an appropriate location.

Operational Considerations

Capturing the campus waste heat recovery will require combining the Power Plant and WCUP CCW systems into a single operating system. Historically these have been operated as independent systems except in short periods of supervised operation. In addition to a learning period, controls upgrades (largely at the Power Plant) will be required to achieve this new operational mode.

If false cooling were to be implemented on a campus wide scale, there are potential pitfalls in communicating a system level decision from the Campus Utility Plants to building level controllers to initiate false cooling logic. False cooling setups have the potential to waste a significant amount of energy if the logic is triggered at inappropriate times and building exhaust air is cooled when the campus cannot use that heat elsewhere. Therefore, to expand the current capacity of false cooling capacity on the campus significant controls upgrades and staff operational enhancements would be required which are not believed to be economically feasible at this time. However, existing false cooling systems will be integrated into the campus heat recovery system wherever deemed feasible on a building-by-building basis.

Risks

There are no significant risks associated with campus waste heat recovery.

Emerging Technology Considerations

A district energy system configured for campus waste heat recovery can accept many other forms of heat if they become viable in the future. These may include:

- Hydrogen
- Fuel cells
- Micro nuclear technology

4.1.3 Sewer Water Heat Recovery (SWHR)

System Overview

Hot water from residential and commercial buildings drains to the city sewer system. This results in a large amount of unutilized heat within the King County sewer conveyance pipes that route through and adjacent to campus. A growing technology application called Sewer Water Heat Recovery represented in Figure 4.1.3-1 allows this heat to be captured via a series of sewer water heat exchangers and pumping loops paired with heat pumps elevating the heat to a useful temperature for campus heating. This system has a high energy efficiency and consumes zero potable water which represents a significant cost and environmental savings opportunity.

The main components of the SWHR system include:

- An underground diversion structure installed at the tie-in location to the sewer system.

- An underground wet well to receive the incoming sewer water and locate sewer water pumps.
- An above-grade Sewer Water Heat Recovery Facility for solids filtration, heat exchangers, and clean-water pumps to send water to/from heat pumps located at the WCUP.

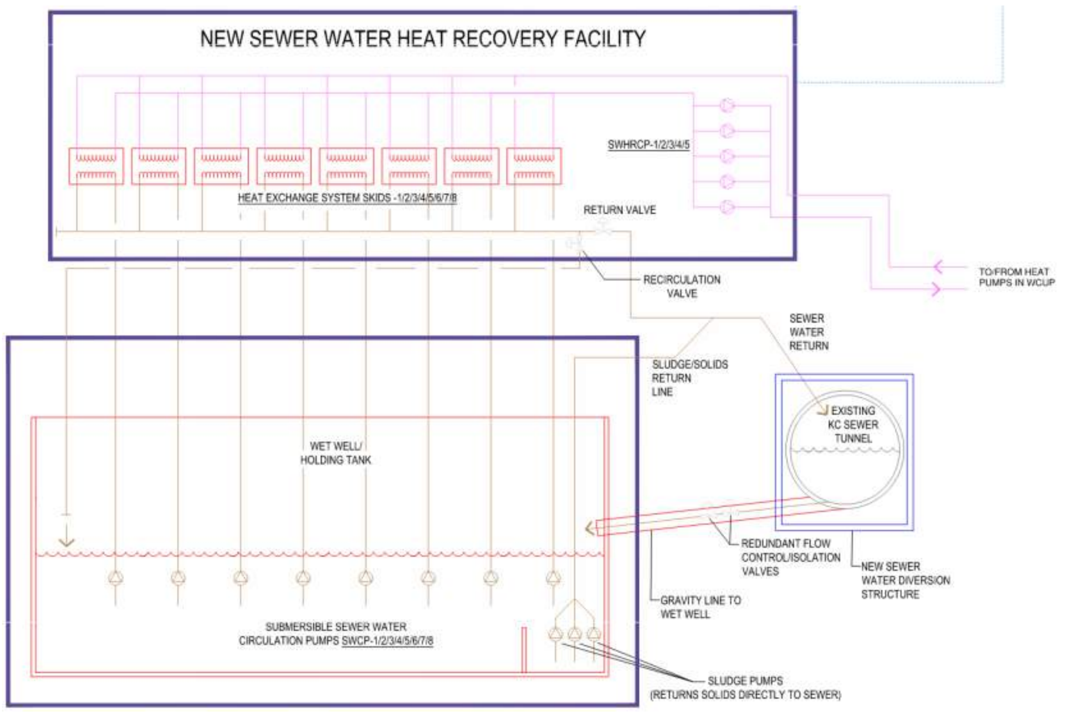


Figure 4.1.3-1: *Mechanical system diagram for the Sewer Water Heat Exchange System. Refer to Appendix 9.3 MSSD-1, Mechanical System Schematic Diagram for a larger format version of this diagram for readability.*

Recommendations

Sewer water heat recovery provides an excellent opportunity to tap into an existing unutilized heat source, especially given the proximity to the sewer line and King County's willingness to cooperate. The Sewer Water Heat Recovery system is planned as the second stage of heating capacity after campus waste heat recovery.

These systems have been developed as proprietary technology by two major manufacturers, Sharc Energy and Huber Technology. The Sharc system has been used as the basis of design for this study, however evaluating an alternate system layout based on Huber is recommended at the next phase of design/analysis.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of this project.

Key System Characteristics

The following characterizes the Sewer Heat Recovery System:

- 54,000 MBH / 15.8 MWth heat delivered to WCUP
- 79,500 MBH / 23.3 MWth heat delivered to campus (after HRCs)
- 6°F delta-T on sewer water side of HX.
- 3°F approach on sewer water/clean water HX.
- 7°F delta-T on clean water (heat pump) side of HX.
- Sewer water diversion structure located near NE corner of Benjamin Hall.
- Wet well located in Publications Services Building loading dock to serve as holding tank and location for submersible sewer water and sludge pumps.
- Sewer Water Heat Exchange Facility Building, located at 711 NE Northlake Place.
- Heat transfer requirements equate to approximately (10) SHARC 1212 heat exchange system skids.(N+1)
- Submersible sewer water pumps: 10 x 2,500 GPM / 125 HP each (one per SHARC skid) to supply approximately 19,800 GPM of sewer water to sewer water heat exchange system, ~10% of which is used during the filtration process.
- Sludge pumps: 3 x 50 HP each, to pump solids back into sewer system.
- SWHR (clean water) pumps: 5 x 5,250 GPM / 150 HP each, to supply approximately 21,000 GPM of clean water flow to heat pumps (N+1).

Assessment Data

The King County sewer system is a combined sewer/storm system, meaning that the flowrates within the sewer increase and the temperatures decrease during rain events.

Based on data provided by King County, sewer water temperatures range from 41.5°F to 68°F throughout the year, with the colder temperatures during rain events These rain events tend to drive the sewer water temperatures down below 50°F for a period of 4-12 hours during the winter months. Refer to Figure 4.1.3-2 which shows a year of sewer water temperature data and the duration of these depressed temperatures from December 2022 to December 2023. Temperatures below 50°F are more difficult to extract heat from with heat recovery chillers, with the absolute minimum temperature that can be recovered from being 46°F.

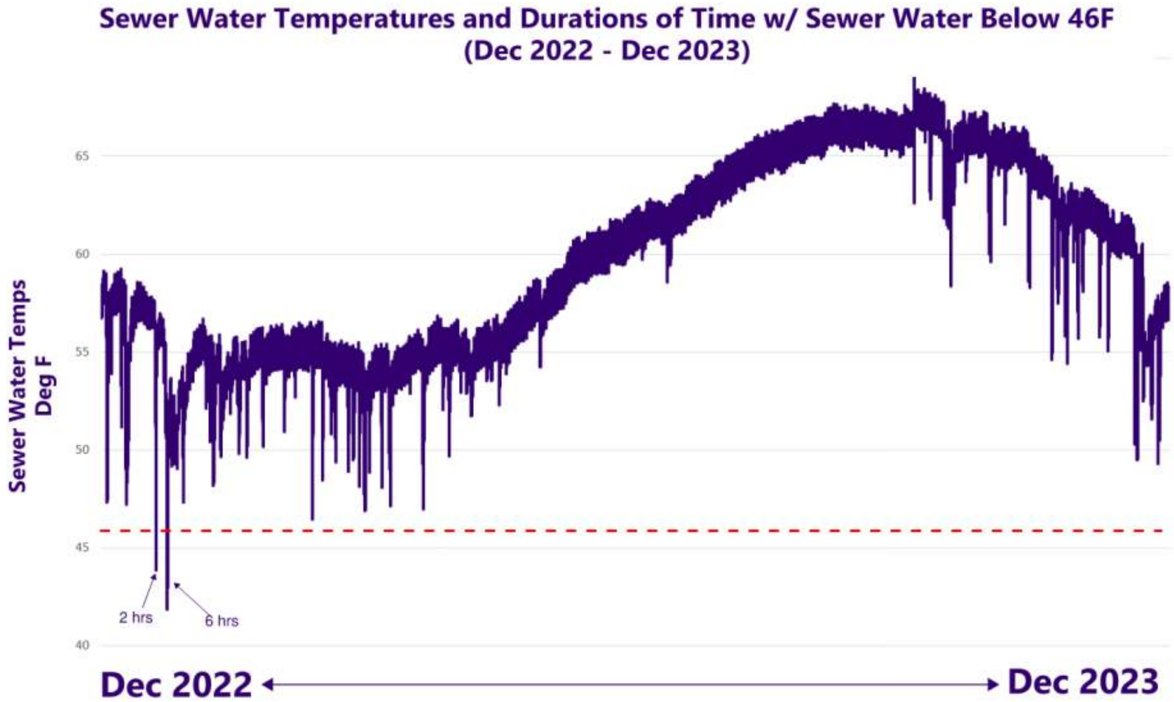


Figure 4.1.3-2: *Measured sewer water temperature provided by King County for the period of December 2022 to December 2023 with specific callouts where sewer water temperature falls below 46°F*

Alternatives and Scenarios

Sewer Heat Exchange System Options: SHARC, Huber, Uhrig

Two manufacturers, SHARC (British Colombia) and Huber (Germany), are at the forefront of the emerging sewer heat recovery industry and use slightly different approaches to filtration and heat exchange. These heat exchange systems pull sewer water from the system, filter it as required, send it through a heat exchanger, and return it to the sewer.

The SHARC process includes three levels of filtration/maceration before the sewer water enters the heat exchanger, and it utilizes flow-reversing valves to periodically perform system flush. A schematic diagram and images of the SHARC system are shown below in Figure 4.1.3-3 and Figure 4.1.3-4. SHARC has several large systems operating in Vancouver, B.C. and a new SHARC 880 system was just installed in Seattle in 2023 (not yet operational). They have 20+ systems commissioned since 2008. SHARC is an equipment supplier, as opposed to a design/build/operate/maintain (DBOM) business model that Huber and its North American partner Noventa tend to operate under. SHARC was used as the baseline manufacturer for this project. The Noventa/Huber system is similar enough that the cost and performance of the SHARC system is anticipated to be representative of both technologies.

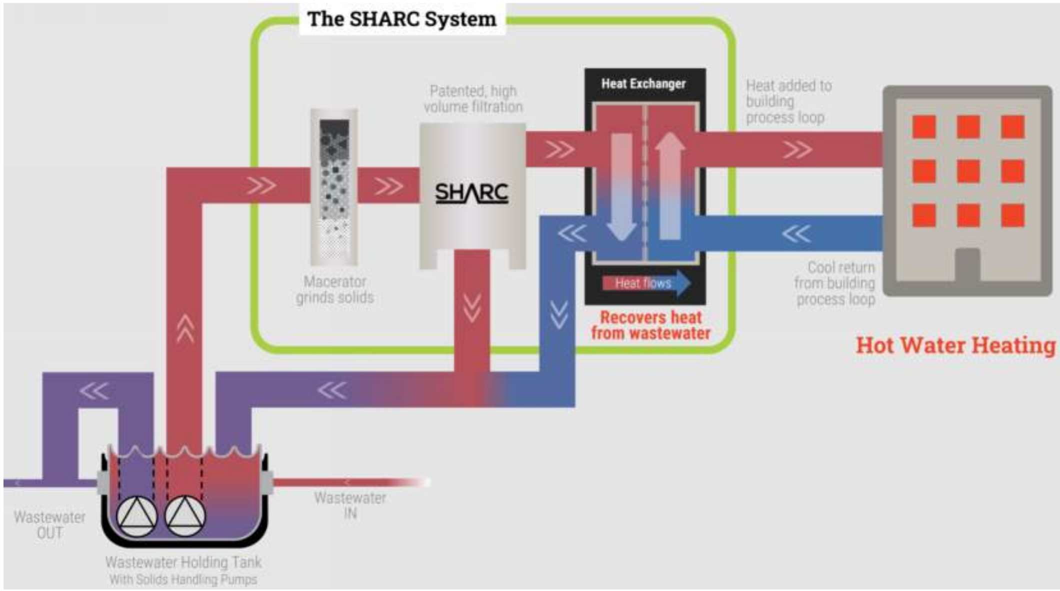


Figure 4.1.3-3: *SHARC system flow diagram in heating mode*

Figure 4.1.3-4: *Example photos of SHARC installations and equipment skids*

The Huber process is slightly different. They utilize a proprietary filtration/auger system in the wet well for the first stage of filtration, then pump directly to the heat exchanger. The heat exchanger is outfitted with a self-cleaning system to maintain heat transfer in the unit, refer to schematic diagram in Figure 4.1.3-5A and Figure 4.1.3-5B. Huber' filtration system allows a smaller holding tank than is required by the SHARC system. Most of the installations by Huber are in Europe however Huber (and their North American partner, (Noventa) are involved in a large project at Toronto Western Hospital, which is currently under construction and being commissioned summer/fall of 2024. Virtually all the Huber/Noventa projects tend to be of the design/build/operate/maintain (DBOM) project delivery model.

Figure 4.1.3-5A: *Example photo of Huber (represented by Noventa) sewer water heat exchange system*

Figure 4.1.3-5B: *Huber (represented by Noventa) sewer water heat exchange system diagram*

Another manufacturer, based out of Germany, Uhrig, takes a different approach. They construct modules of pipes that are installed directly in the sewer pipe. See Figure 4.1.3-6. Although this approach is attractive in that is does not take up additional real estate, it is a more intrusive installation than the SHARC or Huber options, especially that the lengths required for a system this size would be well over 3000' in the sewer line itself. Installation of the Uhrig system would mean several shutdowns and bypass configurations. In addition, maintenance of the heat exchange system would require complex shutdowns of the sewer system to ensure personnel safety. Initial feedback from King County is that this type of installation internal to the sewer system is not preferred and it is therefore not considered further.

Figure 4.1.3-6: *Photos / renderings of the Uhrig sewer water heat exchange system*

Diversion Structure, Tie-In Location, and Draw-Off Estimates

Running primarily from east to west, a large sewer line sourced from the Montlake trunk lines is routed along the south edge of campus under Pacific Avenue (the Montlake Combined section shown in Figure 4.1.3-7) and passes near the WCUP. More than double the heat capacity can be found in the same sewer tunnel further west, after a branch coming from U-District / Lake City Interceptor is added (the UW Combined section).

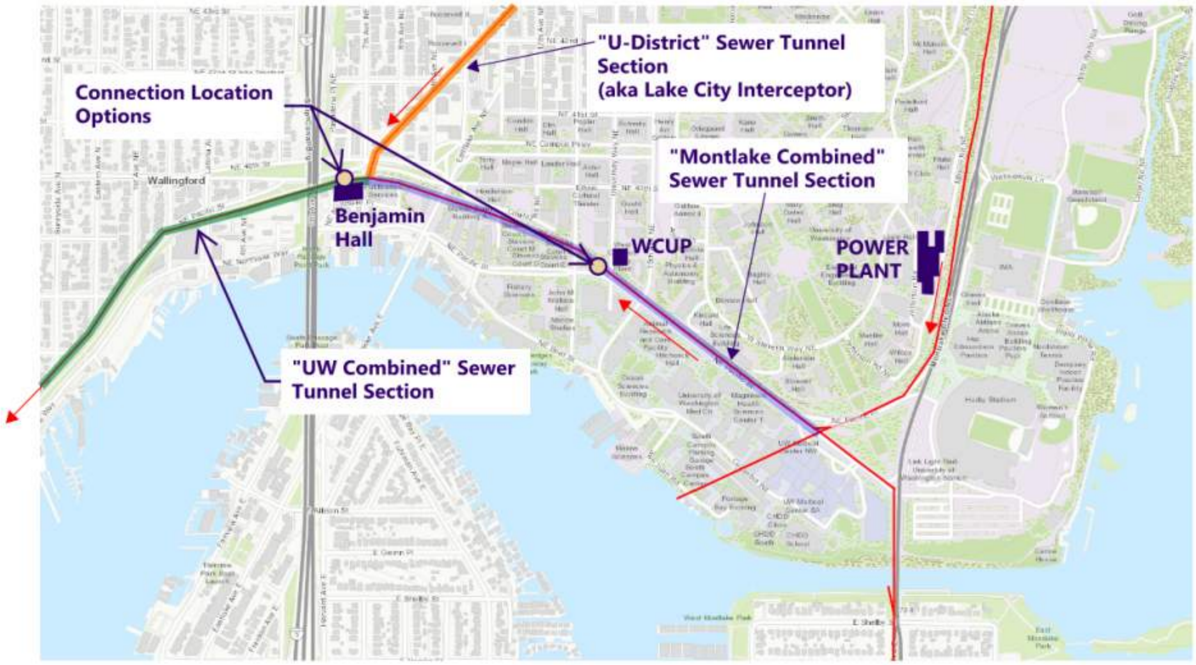


Figure 4.1.3-7: *King County sewer heat recovery opportunity map*

For the projects identified in this report, a sewer water heat recovery (SWHR) facility and tie-in point near Ben Hall were assumed with the tie-in located downstream of the sewer junction to take advantage of the high flows seen in the "UW Combined" sewer line. Although a more local tie-in point near the WCUP was attractive to reduce piping requirements, the lower capacity available in the Montlake Combined sewer and a lack of siting options for the SWHR heat exchanger facility near the WCUP made a location further west the more feasible.

The tie-in location requires the installation of an underground sewer diversion structure/vault to intercept the 108"Ø King County Metro Sewer Trunkline west of the existing 7th Ave vault location, near Pasadena Place. The diversion structure is estimated to be approximately 13'W x 20'L x 13'H precast vault with channelized bottom to guide flow from the sewer line to the wet well structure. Slide gates operated from above grade are provided to stop flow from entering the system during maintenance periods. The diversion structure will also house a return opening for the sewer water returning from the heat exchange facility. An example of a diversion structure is depicted in Figure 4.1.3-8 below. A custom designed diversion structure will result in a high draw-off percentage from the sewer line. This is especially important at lower flow rates seen during the summer. For purposes of the following analysis, a 95% draw-off rate is assumed for capacity availability.

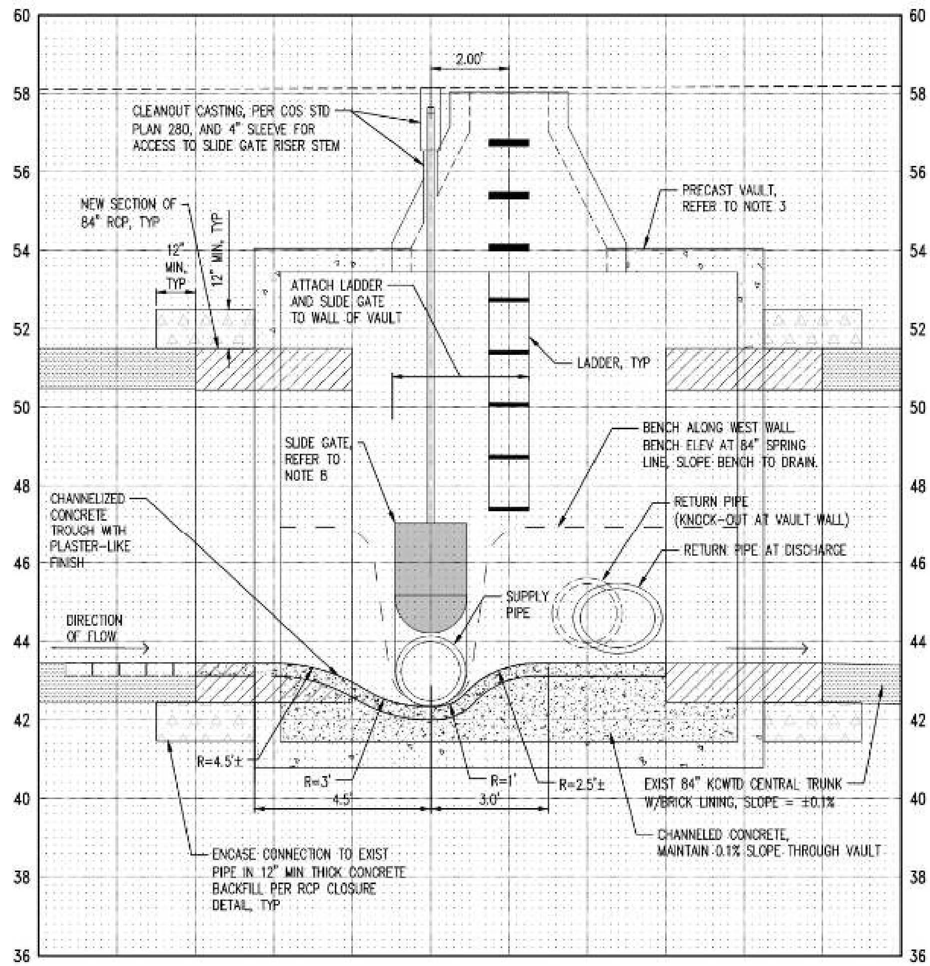


Figure 4.1.3-8: *Section of an example intercept vault (not specific to UW).*

Three diversion structure “tie-in” locations were investigated during this phase: the NE Corner of Ben Hall, Pasadena Place, and Lincoln Towing. Refer to Figure 4.1.3-9 for a vicinity plan.

Figure 4.1.3-9: *Vicinity plan showing sewer water heat recovery system component locations*

The pros/cons of each diversion structure/tie-in location are listed below in Table 4.1.3-1. Three locations were considered by the project team, and the location at Pasadena Place NE was chosen for the baseline tie-in/diversion structure location. Another location at the north end of Lincoln Towing was also considered, and was a good candidate from a siting perspective, but was determined to not be available because this property is owned by WSDOT and not possible to purchase. Reconsideration of the diversion structure locations could allow for a more compact system installation, if any new real estate options or opportunities present themselves.

Table 4.1.3-1: Diversion Structure/Tie-In Location Pros and Cons

NE Corner of Ben Hall		North End of Pasadena Place		North End of Lincoln Towing Parcel	
Baseline Tie-In Location		Alternate Tie-In Location		Reference Only – Property Not Available	
Pros	Pros	Pros	Cons	Pros	Cons
Better site/staging options than Ben Hall	Closer proximity to wet well at PSB than Pasadena Place location	Better site/staging options than Ben Hall	Further from wet well at PSB than Ben Hall	Tie-In, wet well and HXF could all be located in close proximity	Property is owned by WSDOT and is not available
Further from Ben Hall foundation = less shoring required	Construction staging partially located on UW Property	Further from Ben Hall foundation = less shoring required	Construction staging located in SDOT ROW	Minimal conflicts with existing utilities	
			Construction staging may affect Ben Hall parking garage entrance	Staging area at south end of parcel	
				Construction staging could likely be located entirely on the property	

Wet Well

A wet well serves as a buffer to smooth out fluctuations in sewer water intake flow, a home for submersible sewage pumps, and as a settling tank for filtering solids out of the sewer flow. A gravity line from the diversion structure leads to the wet well. From there submersible sewer pumps deliver sewer water flow to the heat recovery heat exchangers located in the SWHR Facility.

In addition, sludge pumps or another solid conveyance system are used to send solids back to the sewer system without going through the heat exchanger filtration system and heat exchanger itself. In this regard there are some differences in recommendations between SHARC and Huber. SHARC recommends larger wet wells (holding tanks) along with sludge pumps to handle solids, whereas Huber recommends a proprietary screen filter and auger system to returns solids to the sewer water system.

Wet well sizes and depth requirements vary between SHARC and Huber, but approximate size requirements for the tanks are 254,000 gallons for SHARC and 115,000 gallons for a Huber system. Both systems require a wet well depth to be minimum 10'-0" below the invert elevation of the main sewer line.

The wet well location considered to be the baseline for this study is below the drive aisle of the existing Publications Services Building (PSB), refer to Figure 4.1.3-10. Access hatches to enter the wet well for maintenance would be located in the drive aisle, and access/drivability would need to be maintained with the wet well constructions to allow for truck deliveries to the south side of the PSB.

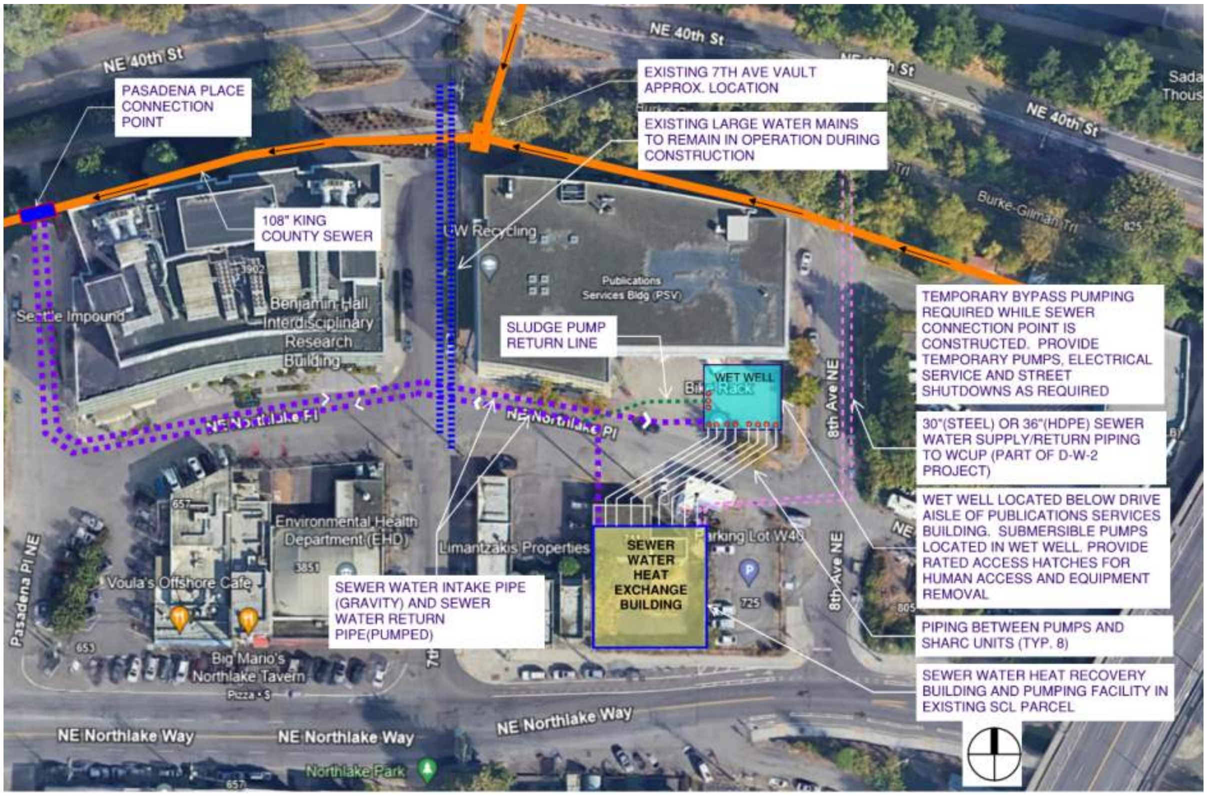


Figure 4.1.3-10: *Vicinity plan of SWHR system components*

Alternate locations were considered, refer to Vicinity Plan in Figure 4.1.3-10. Each of these locations were viable and could be considered during the design phase, however the Publication Services location was used for estimating purposes as UW owns this parcel. A simple pros/cons table is shown below in Table 4.1.3-2

Table 4.1.3-2: Wet Well Location Pros and Cons

Drive Aisle of Publication Services Bldg		Alternate Locations along Northlake Way	
Baseline Wet Well Location		**Wet Well Location Considered**	
Pros	**Cons**	**Pros**	**Cons**
UW owns this parcel	Not directly next to/under either SWHX Facility or diversion structure	Proximity to SWHXF	Contaminated soil concerns with large amounts of excavation
		Could be combined with SWHX Facility scope	Distance from sewer line/ diversion structure

Sewer Water Heat Recovery (SWHR) Facility

A building structure housing the heat exchange system is required in the vicinity of the sewer tie-in/wet well location. Sewer water is pumped from the wet well, through the heat exchanger facility, and finally returned to the sewer main. Hence, proximity is important.

Several locations were considered for this sewer water heat recovery facility, including the existing Publication Services Building and the Benjamin Hall parking garages. After reviewing drawings and performing site visits, neither of these existing buildings provided the spatial needs that the installation of the heat recovery equipment required for installation or maintenance.

The Lincoln Towing parcel would provide an acceptable home for the SWHR Facility, but the real estate barriers at that location preclude it from being a prime candidate. The lot is owned by WSDOT and leased to Lincoln Towing and coordination with WSDOT has determined that they plan to utilize this site for a future stormwater treatment facility from the adjacent I-5 bridge.

A parcel owned by Seattle City Light at 711 NE Northlake Pl best meets the project goals, with reasonable distances to/from the wet well and diversion structure locations. Refer to Figure 4.1.3-10 for vicinity plan of the area.

For the 711 NE Northlake Pl location, a two-story facility was required to provide space for the full buildout of the sewer water heat recovery system. Refer to Figure 4.1.3-11 for an architectural rendering of the facility. Refer to Appendix 9.7 Site Analysis & Zoning Study for additional details. The facility houses the heat exchange systems, the ambient loop/clean water circulation pumps, electrical rooms and space allocation for an office and restrooms. Refer to Figure 4.1.3-12 for basic mechanical/electrical layout.

Figure 4.1.3-11: *Architectural rendering of SWHR Facility on Northlake Avenue*

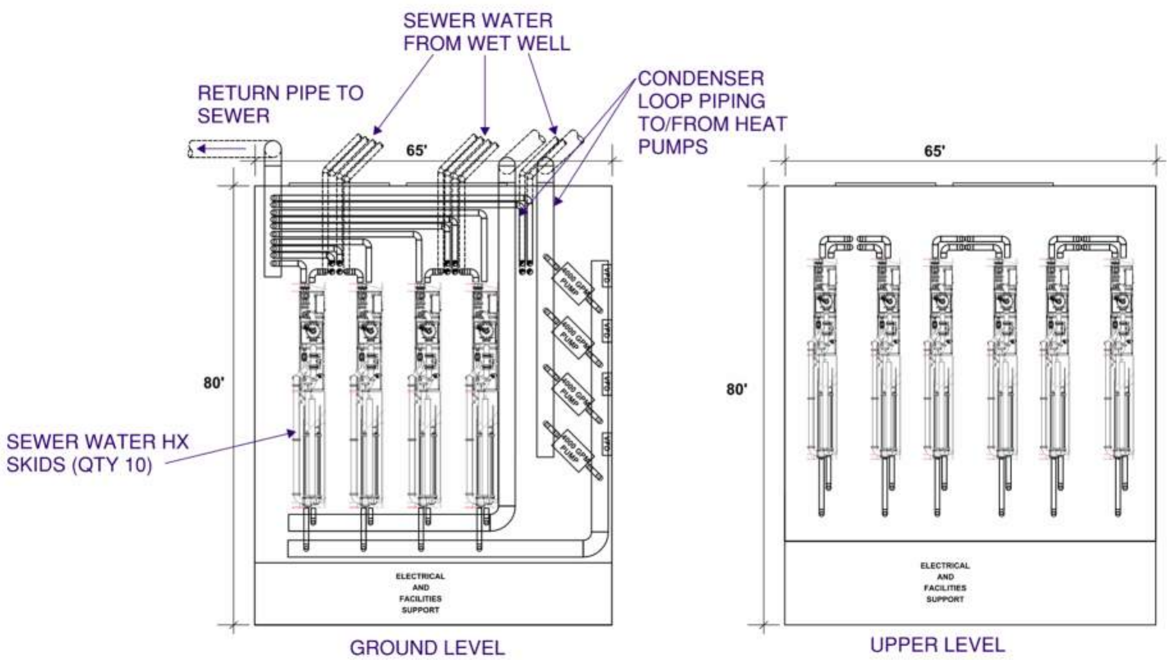


Figure 4.1.3-12: *Conceptual mechanical layout of a 2-level SWHR facility*

Piping to/from the wet well and the sewer diversion structure are envisioned to enter the building from below grade, with heat exchange equipment located on both levels. The large distribution pumps would be located on ground level. Removable exterior panels on the north side of the building provide necessary access for maintenance or phased installation of equipment.

This site is known to have contaminated soil, and it is assumed that matter will need to be resolved as part of the building construction. An option to consider is to locate the wet well below the SWHR Facility building or in the adjacent W40 parking lot. Since a higher level of excavation may be required to resolve the contaminated soil issue, it may benefit the project to locate the wet well below the new building in lieu of the PSB location.

Energy Potential

Full utilization of the sewer flow located near Benjamin Hall could provide up to 25% of campus heat source requirements for heating, and up to 27% heat sink requirements for cooling on an annualized basis.

Anticipated Sewer Heat Source/Sink Availability

The availability of heat is a function of the flow rates available and the temperatures of the sewer water. Temperatures in the Combined UW Sewer vary throughout the year from the low-40s to upper-60s. Given approach temperature assumptions and heat pump minimum allowable temperatures, 46°F has been used as the minimum usable sewer water temperature This condition occurs less than 1% of hours throughout the year. Flow rates vary widely depending on the season between 6000 GPM in the summer and over 100,000 GPM during storm events. See Figures 4.1.3-13 to 4.1.3-15 below. The wet well is situated in a vertical position relative to the sewer line such that the sewer flow and sewer water level in the wet well inherently remains in an acceptable range. During major storm events, when high backpressure can build up in the sewer system, it may be necessary to isolate the heat recovery system and wait for the sewer flow rates to decrease to acceptable levels. This can be achieved through a set of automatic float switches to automatically close off flow into the wet well. This system decoupling would occur automatically via redundant high-level and/or pressure switches in the wet well.

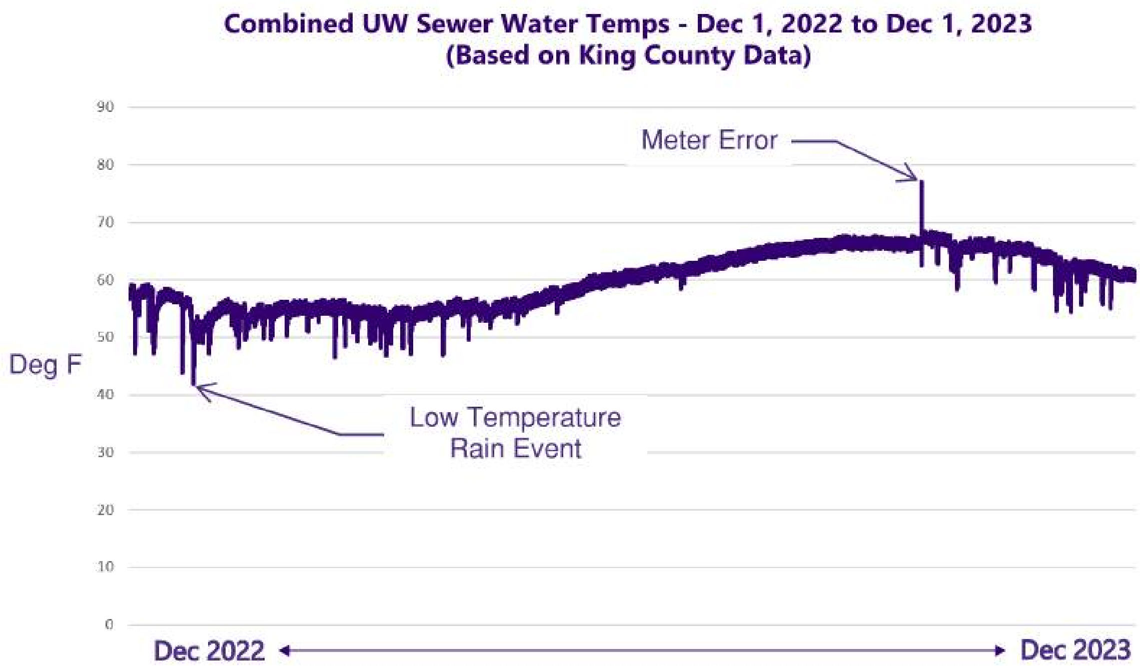


Figure 4.1.3-13: *Sewer water temperatures throughout the year*

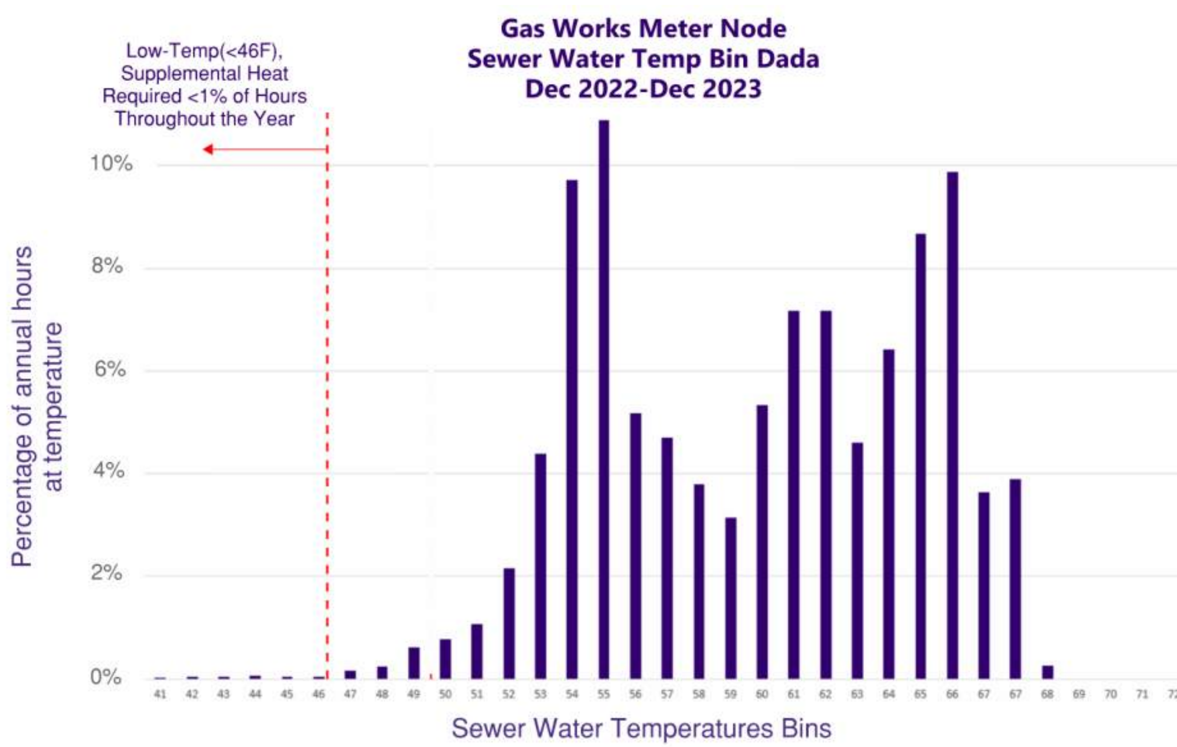


Figure 4.1.3-14: *Sewer water temperature bin data chart*

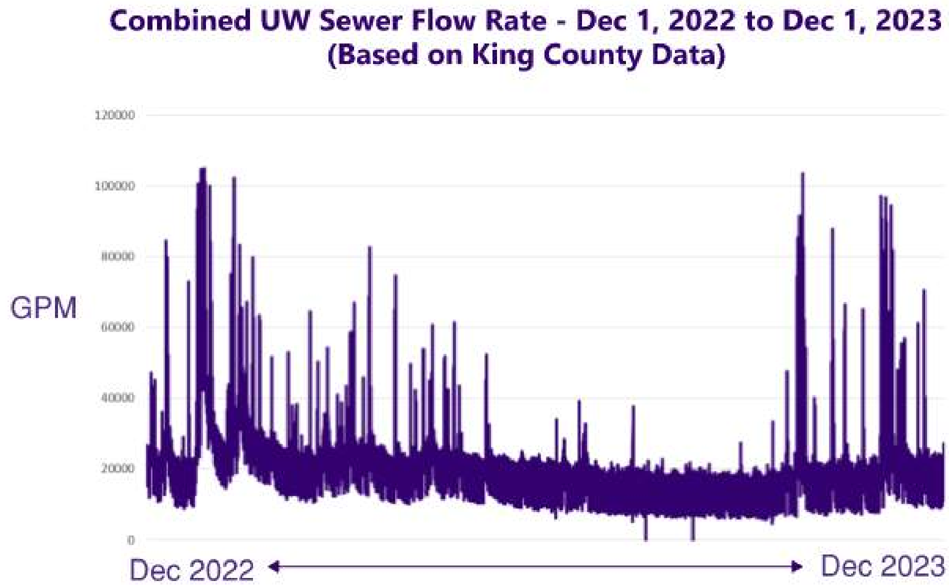


Figure 4.1.3-15: *Sewer water flow rates throughout the year*

As stated above in the diversion structure description, it was assumed that 95% of the total sewer water flow could be diverted to the heat recovery system, and a 6°F delta-T in the sewer water was used to calculate the heating capacity. Capacity of the heat recovery system was then calculated: Flow Rate (GPM) x Delta-T (°F) x 0.5 / 3413 x 1.45 (heat of compression) = Heat Output to Campus (MWth). While temporary spikes in the sewer water flow rate indicate a heat recovery availability of up to 70 MWth, a base load of approximately 5.25 MWth (roughly equal to one 1500-ton heat recovery chiller) is available 97-98% of the hours throughout the winter. See Figure 4.1.3-16A and 4.1.3-16B. Although the sewer system experiences periodic events with very high flow, the maximum anticipated flow rate from the sewer into the heat recovery system is estimated to be 20,000-22,000 GPM, accounting for heat transfer and additional flow required for filtration processes.

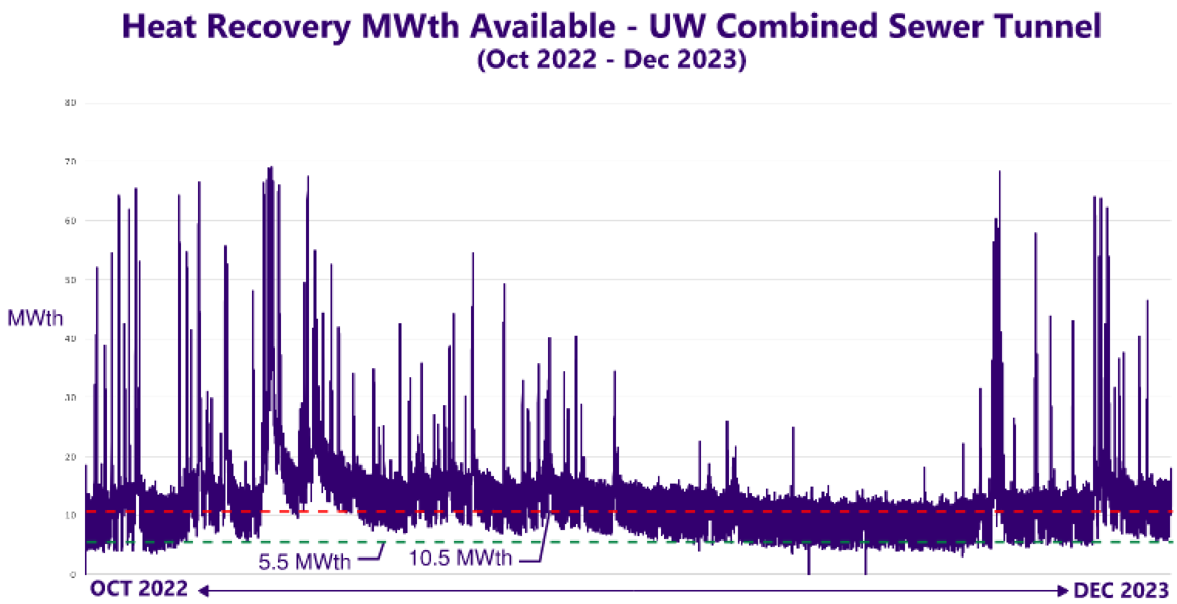


Figure 4.1.3-16A: Heat recovery availability, in MWth – UW Combined Sewer Tunnel

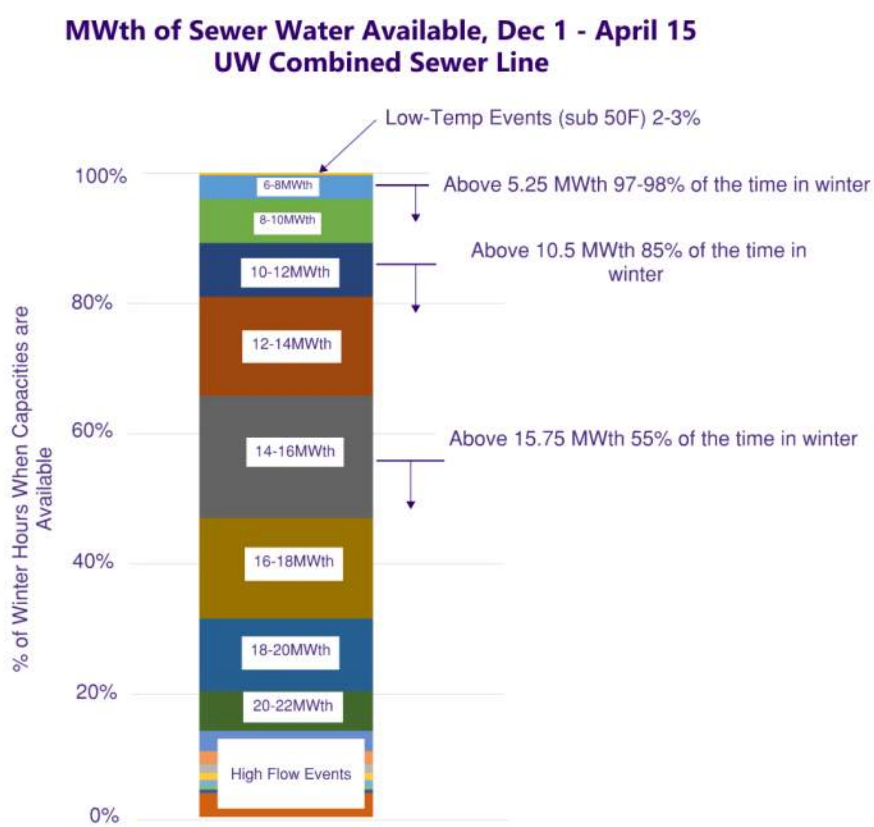


Figure 4.1.3-16B: Percent number of hours at different levels of heat source capacity (heating mode)

A comparison of the available sewer heat compared to the campus heating load is given in the Figure 4.1.3-16C below. The sewer heat and campus heating demand are roughly staggered, with the sewer heat at a minimum during the early morning hours and the campus heat demand peaking during this time. The sewer heat peaks during the day while the campus heating demand is at a minimum. This means that the Thermal Energy Storage tanks will play a crucial role in aligning the sewer heat capacity to the system demand.

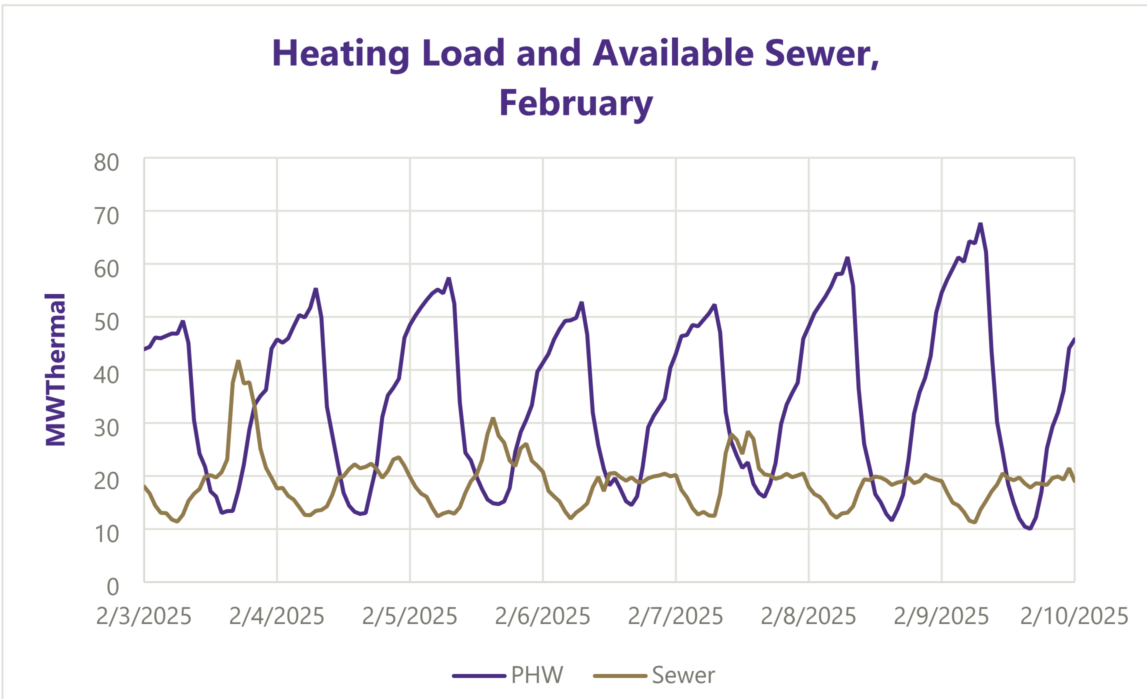


Figure 4.1.3-16C: *Campus heating load plotted against available sewer heat*

A comparison of the available sewer heat rejection capacity compared to the campus cooling load is given in Figure 4.1.3-16D. The sewer heat rejection capacity and cooling demand are roughly aligned, with both peaking during the day. This is favorable for utilizing the sewer as a heat sink for cooling.

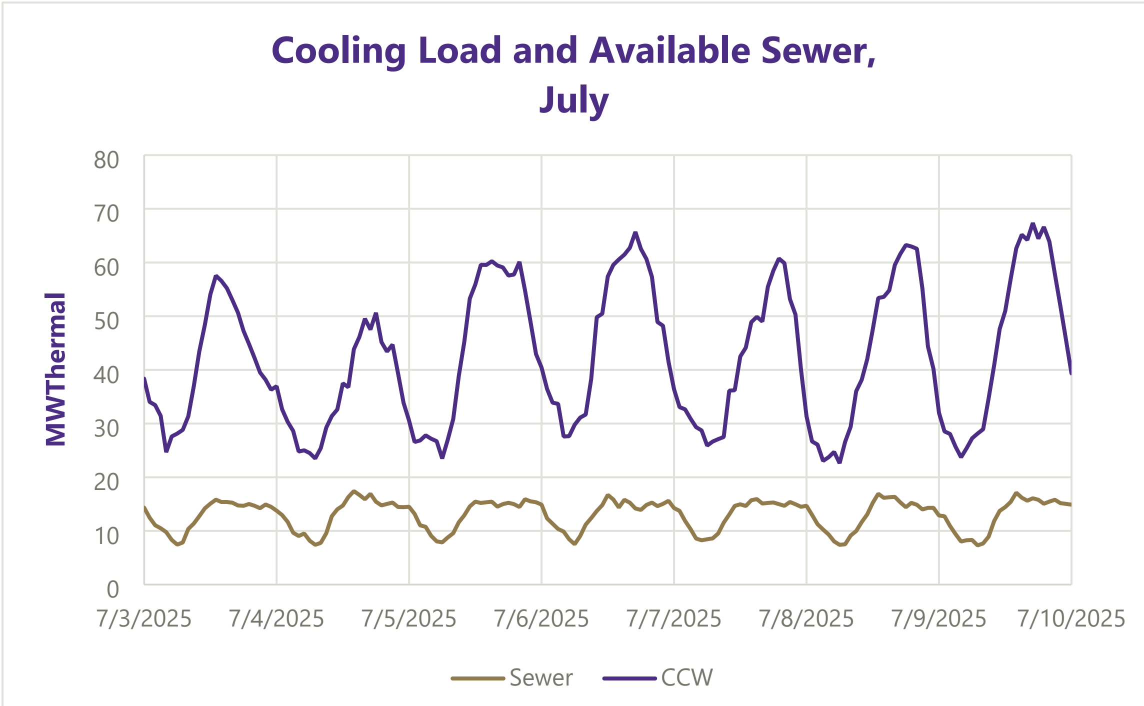


Figure 4.1.3-16D: *Campus cooling load plotted against available sewer heat rejection capacity.*

For cooling, an analysis of the available heat sink via the sewer shows that approximately 93% of the hours throughout the summer there is at least 7 MWth of heat sink available, and 45% of the hours there is at least 14 MWth of heat sink available. It is unlikely that a third heat recovery chiller would be able to run consistently in cooling mode, refer to Figure 4.1.3-16E, below. This amount of heat rejection roughly corresponds to two 1500-ton heat recovery chillers running. Refer to Figure 4.1.3-16C.

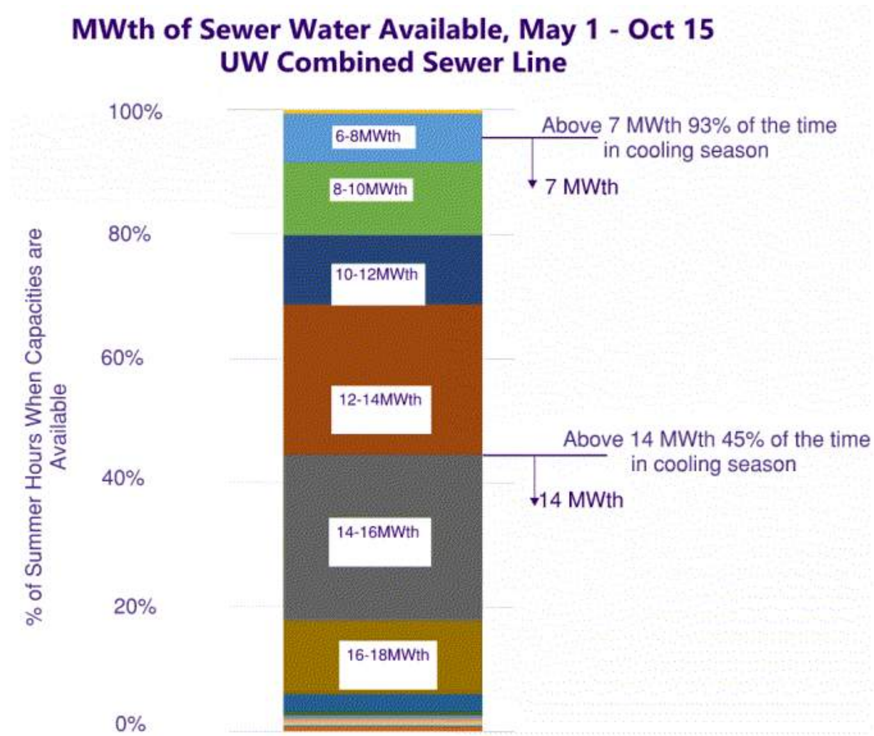


Figure 4.1.3-16E: *Percent number of hours at different levels of heat rejection capacity (cooling)*

Energy Efficiency

The efficiency of sewer water heat recovery ranges with the incoming temperature of the sewer water stream.

The heating efficiency is dependent on the temperature difference between the source (sewer water) and the sink (campus heating loop) resulting in an expected chiller COP of 3.2-3.4 with the variance attributed to the sewer water temperature. The cooling efficiency will also vary throughout the season based on the sewer temperature.

The cooling energy efficiency is anticipated to be comparable to the conventional cooling-only chillers at elevated sewer water temperatures, but for the majority of the year it should be more energy efficient. In addition to the energy efficiency gains, there will be a significant cost savings associated with zero water use for cooling.

Impacts to the Existing Campus Environment

During construction, a significant construction site is required to create the sewer water diversion structure. Since this sewer line is currently active, the sewer water will require to be bypassed around the diversion structure location until the project is completed. After the sewer line is cut off from flow by insertion of plugs into the large sewer pipe, temporary pumps, piping, and electrical generation will be required to achieve the bypass requirements. Figure 4.1.3-17 shows an example of such equipment from another similar project. The space required for this bypass requirement will be significant. Temporary increase in noise and spatial impacts will occur at the site of the diversion structure during this time, which is required to take place during periods of low flow, i.e., summer.

Figure 4.1.3-17: *Example of temporary Pumping Skids and Electrical Generation*

Both the wet well and the SWHX Facility will be significant building projects with required staging areas, and temporary street shutdowns/traffic revisions. The Publications Services Building drive aisle access will be greatly reduced or wholly unavailable during the construction of the wet well.

Once constructed and operational, the SWHR system is largely unnoticed from the perspective of the passersby. The facility would be large relative to the adjacent properties along NE Northlake Way; however, it will be architecturally aligned with other UW buildings in that area (Benjamin Hall, Publication Services Building).

Operational Considerations

Winter

While the sewer temperature and flow rate data allow a high-level view of the heat available in the sewer system, a review of the flow rates and temperatures on a daily and hourly level indicates characteristics and challenges in utilizing the full potential of the sewer water heat under all operational conditions. Figure 4.1.3-18 plots sewer water temperature, average air temperature, and heating capacity (in MWth).

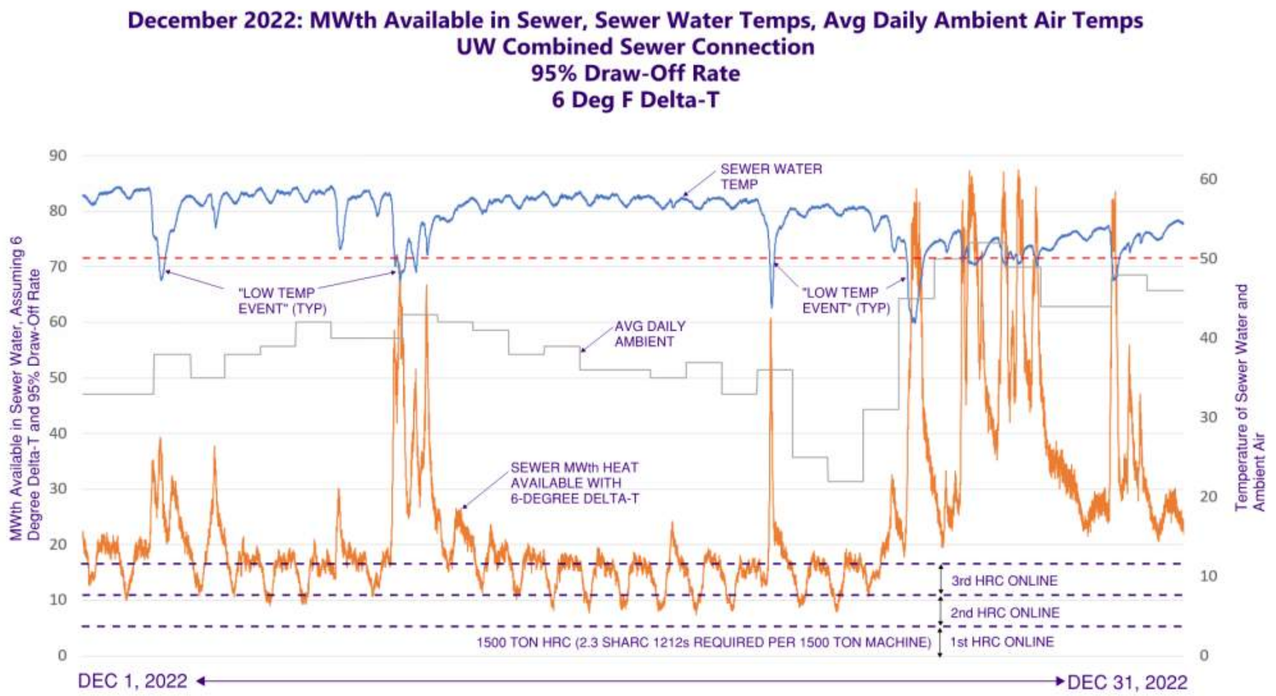


Figure 4.1.3-18: *Sewer Water Heat Source Availability, Sewer Water and Avg Ambient Temps. – Heating Mode – December*

Some key takeaways from this data are:

- Extreme drops in sewer water temperatures (below 50°F) often correspond with higher flow rates, and normally correspond to a storm event.
  - These typical storm events that happen in winter can be accompanied by sewer water temperatures that are unusable (<46°F) for several hours at a time.
  - These storm events can be anticipated through weather forecasts, and the plant can adjust its heating modes as required during these periods. This would typically be done by ensuring the Thermal Energy Storage system was fully charged ahead of these events through other heat sources.
  - For the purposes of this study, it was assumed that sewer water temperatures down to 46°F are available to provide usable heat.

- The sewer water temperatures and flow rates tend to follow a diurnal pattern, with sewer water flow rates and temperature increasing during the day and tapering off at night. This can be seen by inspecting Figure 4.1.3-19.
- Heat recovery chillers will be required to be staged and modulated to match the heat available in the sewer.
  - Using weather forecasting and upstream temperature meters from King County, this staging could be done in a proactive rather than a reactive manner.
- The capacity lines for three 1,500-ton heat recovery chillers planned for the WCUP expansion are shown at the bottom of the chart in Figure 4.1.3-19.
  - Based on the capacity profiles developed during the winter months, the first HRC will be fully loaded 100% of the time, if required. There will be heat available for the second HRC to run ~85% of the time, and about 55% of the time there will be enough heat available to fully load three 1,500-ton HRCs.
- A higher delta-T on the sewer water may be achieved (>6°F), allowing for more heat capacity to be realized which would result in more periods of the year where two or three HRCs could operate.

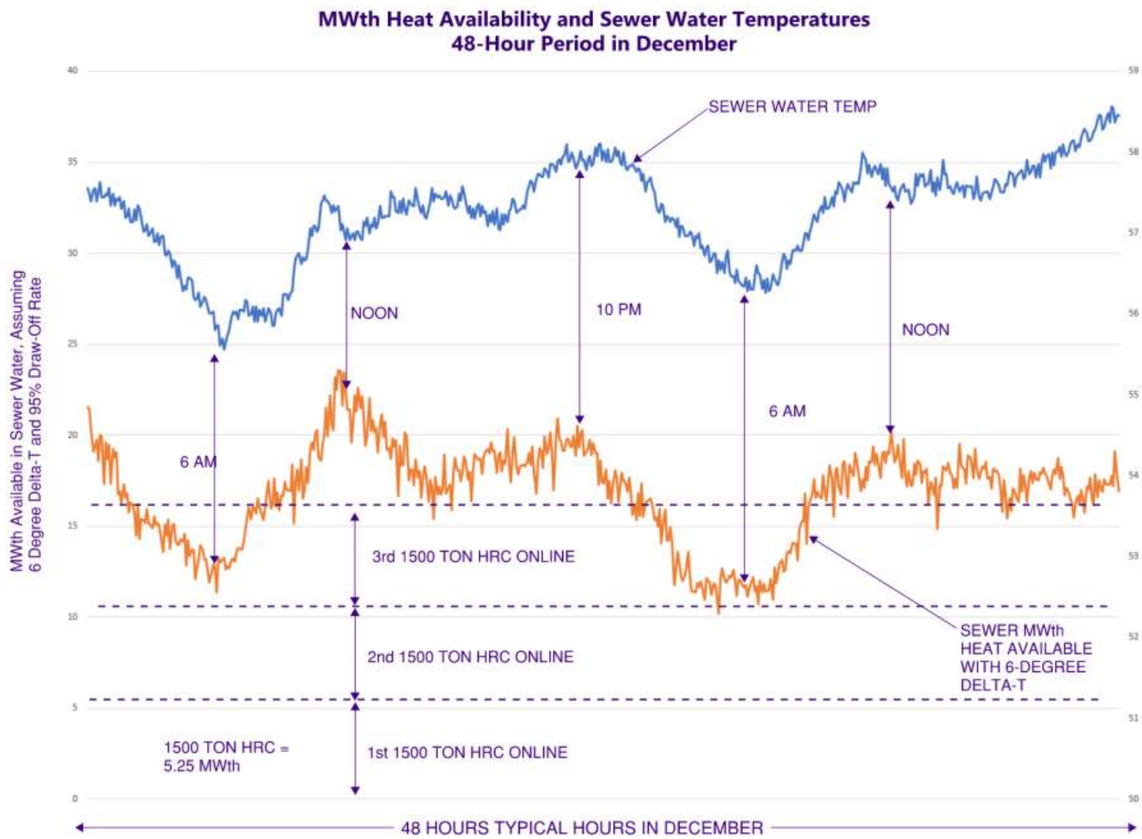


Figure 4.1.3-19: *Sewer Water Heat Source Availability and Temps over 48 hours – Heating Mode – December*

It should be noted that the HRCs located at the WCUP facility will be configured for both SWHR mode and campus waste heat recovery, so HRCs that are not used for SWHR heating or cooling mode may be operated in heat recovery mode as required.

Summer

Similarly, a review of the flow rates and temperatures on a daily and hourly level during the summer indicates characteristics and challenges in utilizing the full potential of the sewer water heat. Figure 4.1.3-20 plots sewer water temperature, average air temperature, and heating capacity (in MWth).

Some key takeaways from this data are:

- The diurnal trends are more consistent than during the winter operation (fewer rain events). This could allow for more steady operation day-to-day.
- The capacity lines for three 1,500-ton heat recovery chillers planned for the WCUP expansion are shown at the bottom of the chart in Figure 4.1.3-21. These

capacity lines are higher (~7 MW increments) than those in heating mode since this mode rejecting the heat of the compressor to the sewer.

- Based on the capacity profiles developed during the summer months, the first 1,500-ton HRC in the model will be able to operate ~93% of the time, if required. There will be sufficient sewer flow available for the second HRC to operate ~40-45% of the hours throughout the summer. The third HRC is not expected to operate in sewer water cooling mode during summer and will be available for either heat recovery mode or heat rejection to the cooling tower system.
- During the lower flows in summer months, it may be possible to recirculate a portion of the sewer water back to the wet well to maximize heat transfer opportunities.

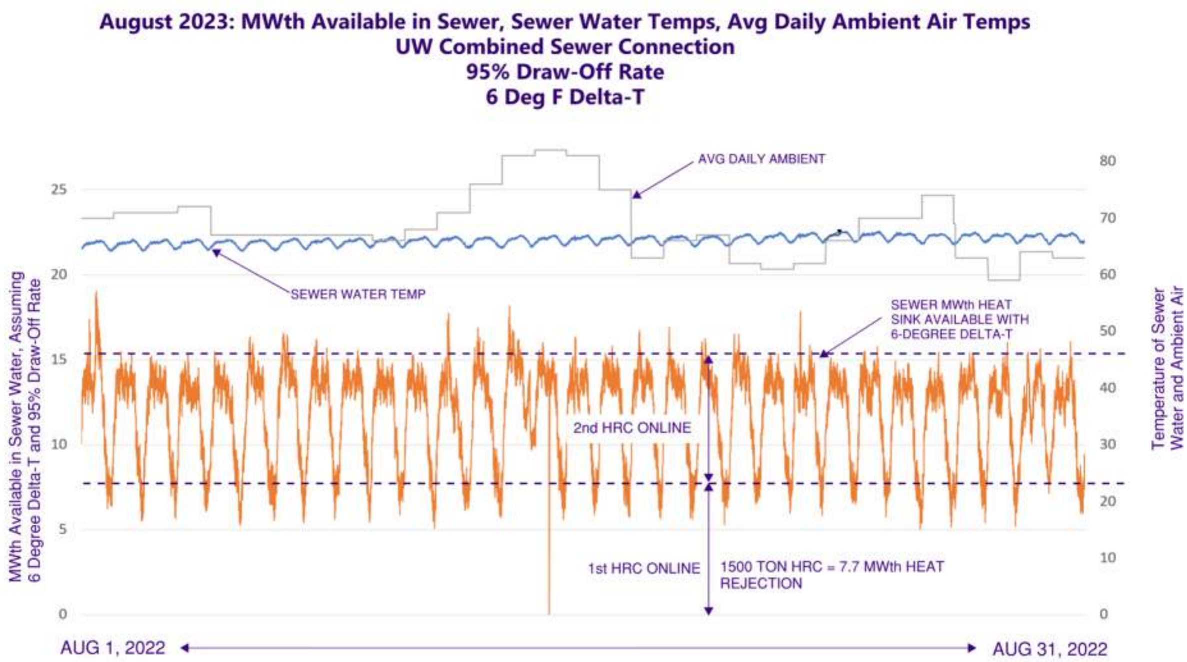


Figure 4.1.3-20: *Sewer Water Heat Sink Availability, Sewer Water and Avg Ambient Temps– Cooling Mode – August*

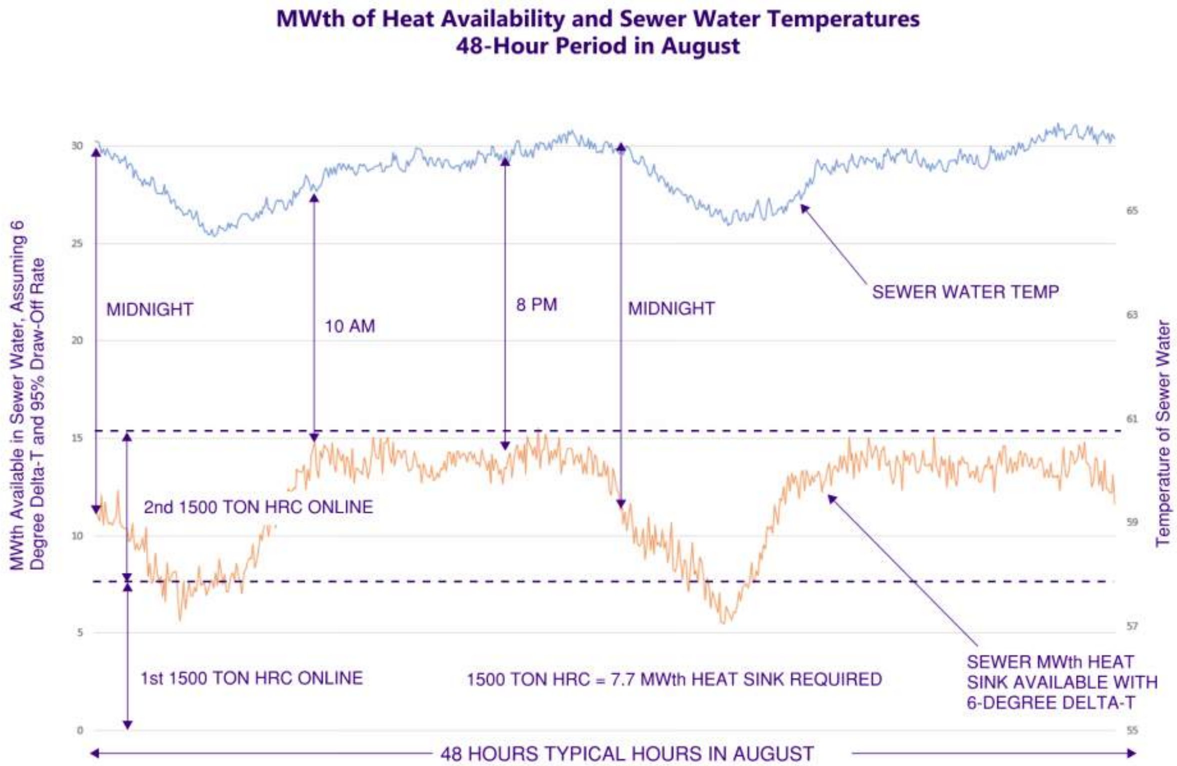


Figure 4.1.3-21: *Sewer Water Heat Sink Availability and Temps over 48 hours – Cooling Mode – August*

Shoulder Season Operation

Looking at similar plot in Figure 4.1.3-22 during for the month of May 2023 we again see a clear diurnal cycle with fairly consistent sewer water heat available to use as either a source or a sink.

Key takeaways from this data are:

- Sewer water temperature continue to rise as the month progresses closer to summer, but the temperatures are still usable for either a heat source or a heat sink.
- Operationally, the system can run fairly consistently on a day-to-day basis.
- It is possible to base load one 1500-ton HRC in either heating or cooling mode, and bring additional HRCs online when flow is available.

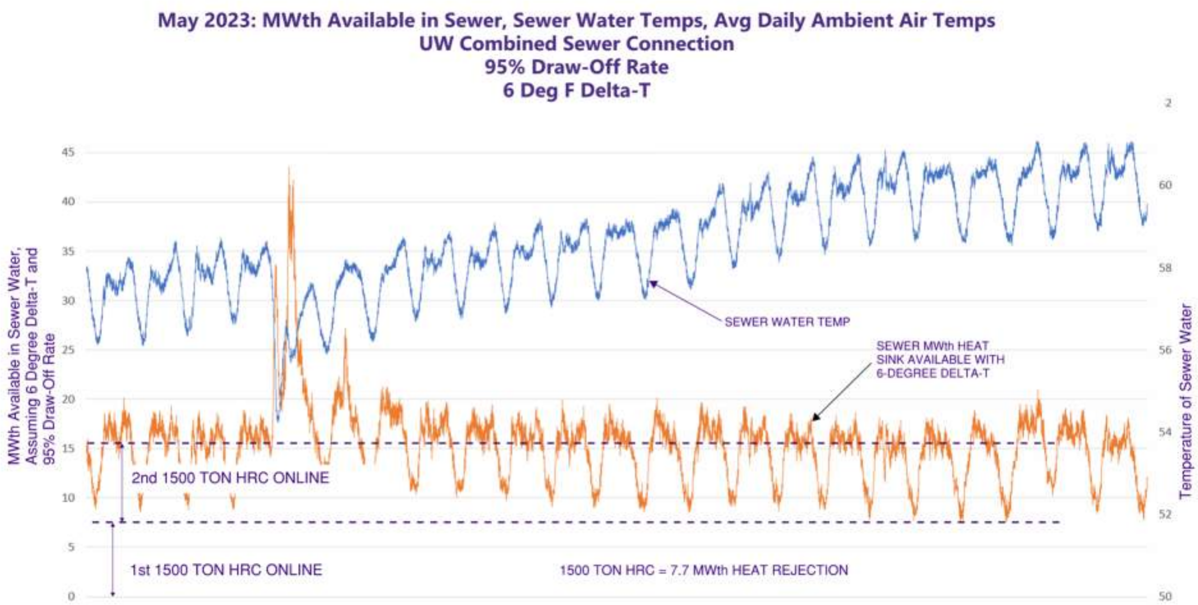


Figure 4.1.3-22: *Sewer Water Heat Sink Availability and Temps– Shoulder Season – May*

Risks

The sewer system is a consistent heat source/sink and an excellent opportunity for energy savings, and the location is favorable to implementation. Sewer water flow rates have been consistent over time, and the temperatures do not appear to be increasing significantly year-to-year. The filtration and heat exchange technology, while nascent, is relatively simple and straightforward operationally. Yet, some risks remain in order to incorporate this system.

- The size of the planned sewer water heat recovery system is large, potentially the largest in North America. The high sewer water diversion flow rates and high percentage of draw-off desired (95%) will be a challenging, but possible, endeavor.
- Construction of the diversion structure should occur during the short time period of low sewer flow rates in late summer. If abnormal weather patterns present themselves, it could increase bypass requirements or delay the project.
- The bypass pumping of the KC trunk sewer requires a large area for all the pumps and above ground piping. This area should be determined early in design.
- The size of the sewer diversion structure is a rough order of magnitude and could potentially increase in size when final siting questions have been settled.

Additional length or width may require additional shoring, especially in close proximities to existing buildings.

- Operational considerations with variable flows and temperatures could prove challenging regarding heat pump staging.
- Maintenance requirements for sewer water heat exchange is notoriously high, and unit downtime could be significant.
- Portions of the construction may be below the groundwater table and may require mitigation measures.
- The supply and return lines from the trunk sewer to the wet well in the PSB drive aisle are large and deep, crossing under a 42-inch and a 24-inch SPU water transmission line. These water lines are old and extremely important to the City's water supply. We recommend the exact horizontal and vertical location as well as condition of these pipes be determined during design in order to determine the costs to protecting these pipes during construction.
- Preliminary studies have determined that gravity flow is possible for the sewer supply line to the wet well 10-feet below the trunk sewer invert elevation. The wet well may need to be deeper depending on actual survey and utility pothole data supplied during design.
- The sewer diversion structure, supply and return lines, pump force mains from the wet well to the sewer heat exchangers and the SWHR pipes to the Burke-Gilman Trail (BGT) are all in SDOT ROW requiring Utility Major Permits as well as Long Term Permits. These permits could require 8-12 months or longer for approval, so the schedule should anticipate this.
- The sewer flows are influenced by outside entities. Given the area served by these sewer trunks, the flows should be relatively consistent however the available of heat is technically out of the University’s control. Any extended outages caused by King County would reduce the University’s ability to meet its heating demands.

Emerging Technology Considerations

Both the Huber and SHARC systems are still relatively new technologies, and anecdotal knowledge from recent and ongoing projects will prove useful to avoiding pitfalls.

4.1.4 Lake Interface (Heating & Cooling)

System Overview

The Lake Interface concept developed for the ERP brings water from the depths of Lake Washington to a new Lake Interface Equipment Building on the campus shoreline, cools or warms the lake water through a heat exchange process and returns the water to a nearby discharge location. Using heat recovery chillers, this heat transfer from the lake to the campus can be used to produce heating and cooling efficiently and without the use of on-site fossil fuel combustion.

The campus borders Union Bay, Portage Bay, and the Ship Canal / Montlake Cut bodies of water of which are part of a single Lake Washington system managed by the U.S. Army Corps of Engineers (Corps). Example systems from across the world that operate heat pumps to exchange heat with bodies of water draw water from a depth where temperatures are stable seasonally. Bodies of water immediately adjacent to the campus are not deep enough to see these constant temperatures. Waters deep enough to exhibit a consistent seasonal temperature range are found just over a mile from the shoreline.

To reach these stable depths, a pipe system would be installed across Union Bay with an intake location in Lake Washington within the vicinity of Webster Point. Once the lake water has passed through a heat exchanger, it will be returned to the body of water in a region where the exit water temperature is cooler than the surrounding water, creating a zone of cool water that may act as a refuge for migrating salmon.

Refer to Appendix 9.4 Preliminary Permitting & Environmental Considerations – Phase 2 for additional details on background of Lake Washington, permitting landscape and strategy, environmental and temperature considerations, and analysis of available data sets.

This section of the report summarizes and includes excerpts from the detailed report compiled by Makai Ocean Engineering in Appendix 9.6 Lake Water Engineering Report. Refer to Makai's report for additional detail and clarification.

Recommendations

The team has determined that a lake water heating and cooling system is technically feasible with low overall technical risk. Many hurdles remain, however. There are numerous agencies with jurisdiction impacting the ability to construct and operate this type of system. The ERP team has been opening dialogs with each of these agencies to understand and address their concerns.

The preferred alternative for the pipe installation is a trenched intake pipe solution due to its lower cost (half that of a tunneled solution) and risk. This method carries more permitting risks due to a higher potential for ecological impact during construction.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of this project.

Key System Characteristics

Lake Interface capacity and characteristics:

- 22,000 GPM
- 77,000 MBH / 22.5 MWth heat delivered to Power Plant
- 113,000 MBH / 33 MWth heat delivered to campus (after HRCs)
- 6,000 tons / 21 MWth cooling capacity available
- Intake location: Near Webster Point as indicated in Figure 4.1.4-1 installed at a depth of 20 meters / 66 ft.
- Discharge location: Portage Bay.
- System components:
- Three lake water pumps with VFDs - 11,000 GPM, 50 ft head, 200 motor HP each
- Three CCW pumps with VFDs - 11,000 GPM, 70 ft head, 250 motor HP each
- Heat exchangers between lake water loop and CCW system
- Lake Interface Equipment Building: 2,000 sq ft.

Lake interface mechanical performance criteria are shown in Tables 4.1.4-1 and 4.1.4-2 for heating mode and cooling mode, respectively. Additional detail can be found in Appendix 9.6 Lake Water Engineering Report.

Table 4.1.4-1: Lake Interface Mechanical Performance Criteria in Heating Mode

Parameter	Values	US Units	Values	SI Units
Lake Water Loop Flowrate	21,714	*GPM*	1,370	*kg/s*
Fluid	Lake Water	-	Lake Water	-
Lake Water Intake Temperature	45	*°F*	7.2	*°C*
Temperature Returned to Lake from Outfall Pipeline	38	*°F*	3.3	*°C*
Pressure Drop Through Lake Water Heat Exchanger	10	*psig*	68,950	*Pag*
Campus Chilled Water Loop Flowrate	21,714	*GPM*	1,370	*kg/s*
Fluid	Chilled Water	-	Chilled Water	-
Water Temperature to Campus Chillers	43	*°F*	6.1	*°C*
Water Temperature from Campus Chillers	36	*°F*	2.2	*°C*
Pressure Drop Through Campus Heat Exchanger	10	*psig*	68,950	*Pag*
Design Peak Load Experience by Lake	22.3	*MW*	22.3	*MW*

Table 4.1.4-2: Lake Interface Mechanical Performance Criteria in Cooling Mode

Parameter	Values	US Units	Values	SI Units
Lake Water Loop Flowrate	21,714	*GPM*	1,370	*kg/s*
Fluid	Lake Water	-	Lake Water	-
Lake Water Intake Temperature	50	*°F*	10	*°C*
Temperature Returned to Lake from Outfall Pipeline	57*	*°F*	13.9	*°C*
Pressure Drop Through Lake Water Heat Exchanger	10	*psig*	68,950	*Pag*
Campus Chilled Water Loop Flowrate	10,133	*GPM*	640	*kg/s*
Fluid	Chilled Water	-	Chilled Water	-
Water Temperature to Campus Chillers	60	*°F*	15.6	*°C*
Water Temperature from Campus Chillers	75	*°F*	23.9	*°C*
Pressure Drop Through Campus Heat Exchanger	10	*psig*	68,950	*Pag*
Design Peak Load Experience by Lake	22.3	*MW*	22.3	*MW*

*Temperature will be controlled/regulated to not exceed the temperature of the receiving water body temperature.

Assessment Data

Relevant data for this analysis included available measured and modeled lake water temperature data, Union Bay and Lake Washington bathymetric data, site plans, campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

Available bathymetry charts of Union Bay (see Figure 4.1.4-1) show the extent of the shallow depth of Union Bay, outside of the Union Bay Reach which is a naval passage corridor dredged and maintained by the U.S. Army Corps of Engineers (Corps).

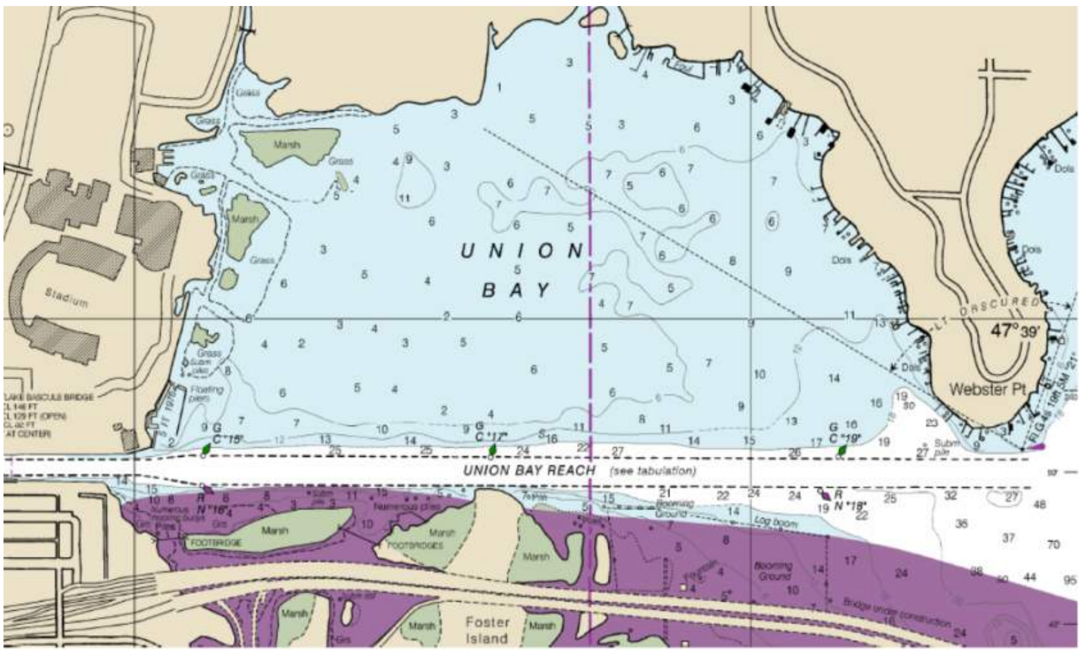


Figure 4.1.4-1: *Nautical Chart 18447 with Union Bay depth soundings and contours shown in feet. Datum is Low Lake Level (LLL)*

Measured data available on lake water temperature at depth is limited. Predictive modeled data provided for public use by DSI, a local modeling firm who have prepared a thermal model of this area of Lake Washington, is being used at this stage to gauge the potential temperatures at the proposed intake location. Refer to Appendix 9.4 Preliminary Permitting & Environmental Considerations – Phase 2 which includes a study of the lake water temperature data. The minimum and maximum anticipated temperatures at depths 20 meters or below in the vicinity of the proposed intake location are 43°F (min) and 49°F (max).

Subsurface geotechnical survey data is available within Union Bay through Washington Department of Natural Resources web portal. This data is from borings dating to 1961.

Future data collection recommended as part of next steps if this option is to be pursued further:

- Lake water temperature testing near the proposed intake for at least one year.
- High resolution bathymetric survey using aerial drone or a marine vessel with multibeam sonar.
- Geotechnical survey within the vicinity of the proposed intake location and at points along the determined route of the lake water intake pipe.
- Soil sampling and testing along the proposed route to gain an understanding of the soils near the lakebed for chemical, biological, or invasive species contamination.

Refer to Appendix 9.4 and 9.6 for Preliminary Permitting & Environmental Considerations – Phase 2 and Lake Water Engineering Report respectively, which provide additional details on next steps.

Alternatives and Scenarios

The Lake Interface system has been studied in detail through Phase I and II of the ERP effort. This section summarizes many of the alternatives and scenarios developed and reviewed by the team. The direction chosen for further development and analysis is described in the Key System Characteristics section. For additional detail on these scenarios refer to Appendix 9.4 and 9.6 for the Preliminary Permitting / Environmental Considerations Report and Lake Water Engineering Report.

Alternatives and scenarios are detailed later in this section. The proposed locations for the intake, discharge, and Lake Interface Equipment building are shown in Figure 4.1.4-2.

***Figure 4.1.4-2**: Proposed locations of intake, discharge, and Lake Interface Equipment building*

Intake and Discharge Location

The nearest point of Lake Washington with adequate depth to achieve consistent temperatures is southeast of Webster Point, at a depth of approximately 20 m / 66 ft. This was determined as discussed in the Assessment section. There are limited options for the location (not depth) of the intake. An alternate location is discussed in Appendix 9.6 Lake Water Engineering Report that moves the intake closer to Webster Point to avoid crossing the Union Bay Reach. The length of intake piping is approximately equal and thus the location is considered roughly equivalent from the perspective of this study. During system pre-design, it is anticipated that the location would be finalized.

Contrasted with the intake location, the discharge location had significant differences between the available options.

Example installations of similar systems either discharge the water back to the source lake at a depth anticipated to have roughly equivalent temperatures to the discharged water or consume the water (in the case of potable water supply systems like City of Toronto).

For the University of Washington, there is a unique opportunity to both satisfy the required heating/cooling needs of the university while also providing a benefit to a critical part of the Pacific Northwest's ecology, migrating salmon. Rather than discharge the water back to Lake Washington, the discharge can be delivered at the western end of the Montlake Cut and into Portage Bay, where it would provide a benefit of creating a zone of water that is cooler than the receiving body of water. The intent is to provide salmon with a beneficial zone of thermal refuge during migrations between Puget Sound and the main body of Lake Washington and its tributaries. A larger effort to study the potential engineering measures to alleviate overheating in the Ship Canal between Lake Washington and the Ballard Locks is being conducted through a combined effort by Long Live the Kings and the Water Resource Inventory Area 8 (WRIA8) Salmon Recovery Council. The UW and ERP team have had several coordination meetings with organizations involved to help identify synergetic opportunities between the two efforts.

The benefits of this approach are significant:

- Potential ecological benefit to salmon migration under normal operating conditions (overlap between UW and Ship Canal required cooling).
  - During peak summer weather, UW would add heat to the deep lake water before discharging to Portage Bay, while still benefiting the Ship Canal.
  - During non-peak summer weather (night or outdoor air temperatures <80°F) the UW would add less, or in some cases, no heat prior to discharging to the canal providing an increased benefit to the Ship Canal temperatures.
- Environmental benefits: Emissions from electrical utilities are reduced with the increased energy efficiency of a lake cooling system compared to traditional systems. Potable water use is also reduced.
- Electrical utility benefits: Reduced demand for electricity to meet UW campus cooling needs reduces stress on the electrical grid and frees up this capacity for other customers.
- Cost savings to the University: Discharge back to the lake would require an additional buried pipeline back to the deeper parts of the lake, roughly doubling the cost of an already expensive offshore piping system. Discharging to Portage Bay would increase the cost of the buried discharge piping system, though the onshore piping is typically less expensive than the offshore piping.

Lake Interface Equipment Building

A Lake Interface Equipment Building houses heat exchangers (separating the campus cooling water from the lake water loop), the wet well and associated pumps, and electrical room.

The location of the Lake Interface Equipment Building is important as it defines the starting point for the offshore / intake piping. Several options were reviewed, as seen in Figure 4.1.4-3.

Figure 4.1.4-3: *On-shore locations considered for the Lake Interface Equipment Building*

Of the options, the building location selected for this study is located in Parking Lot E-8 in the East Campus. Refer to Figure 4.1.4-4 for a vicinity map and Figure 4.1.4-5 and Figure 4.4.1-6 for concept plans and sections of the new building.

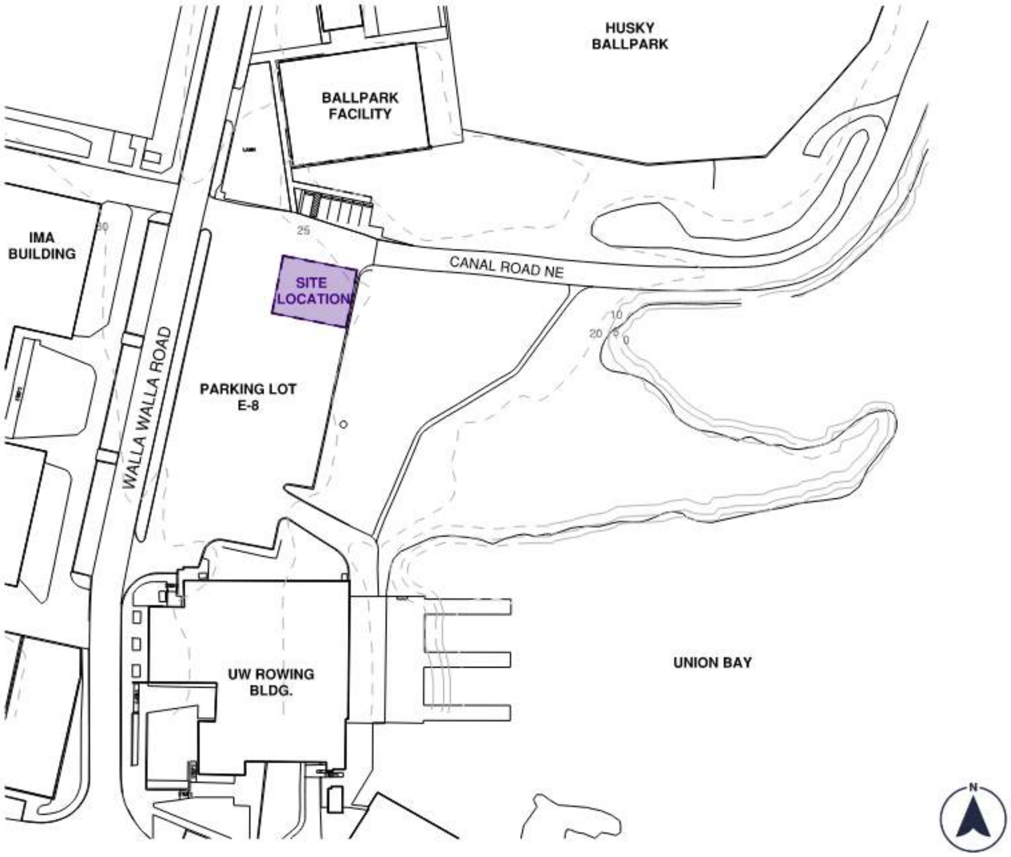


Figure 4.1.4-4: *Lake Interface Equipment Building vicinity map*

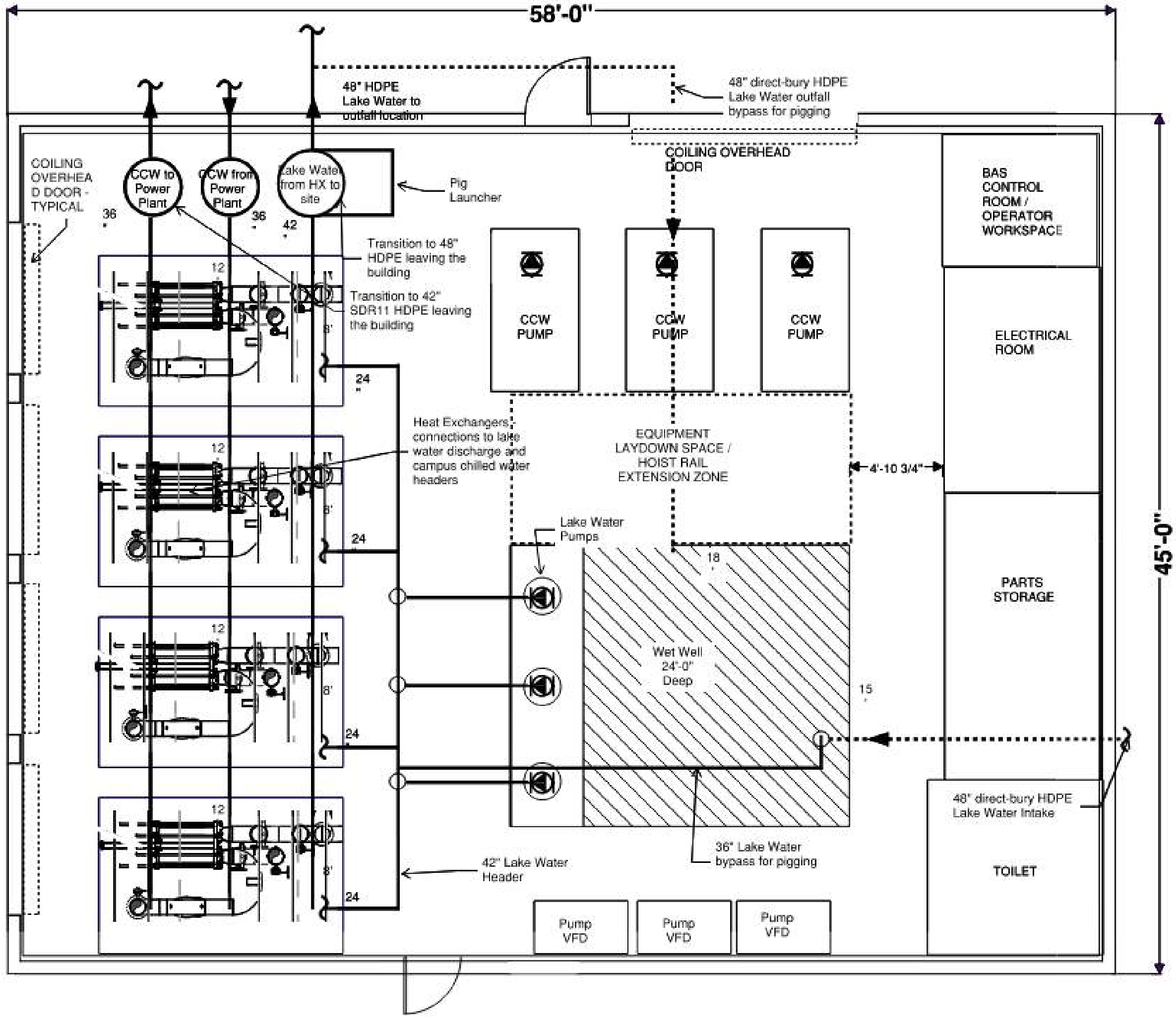


Figure 4.1.4-5: *Lake Interface Equipment Building concept plan*

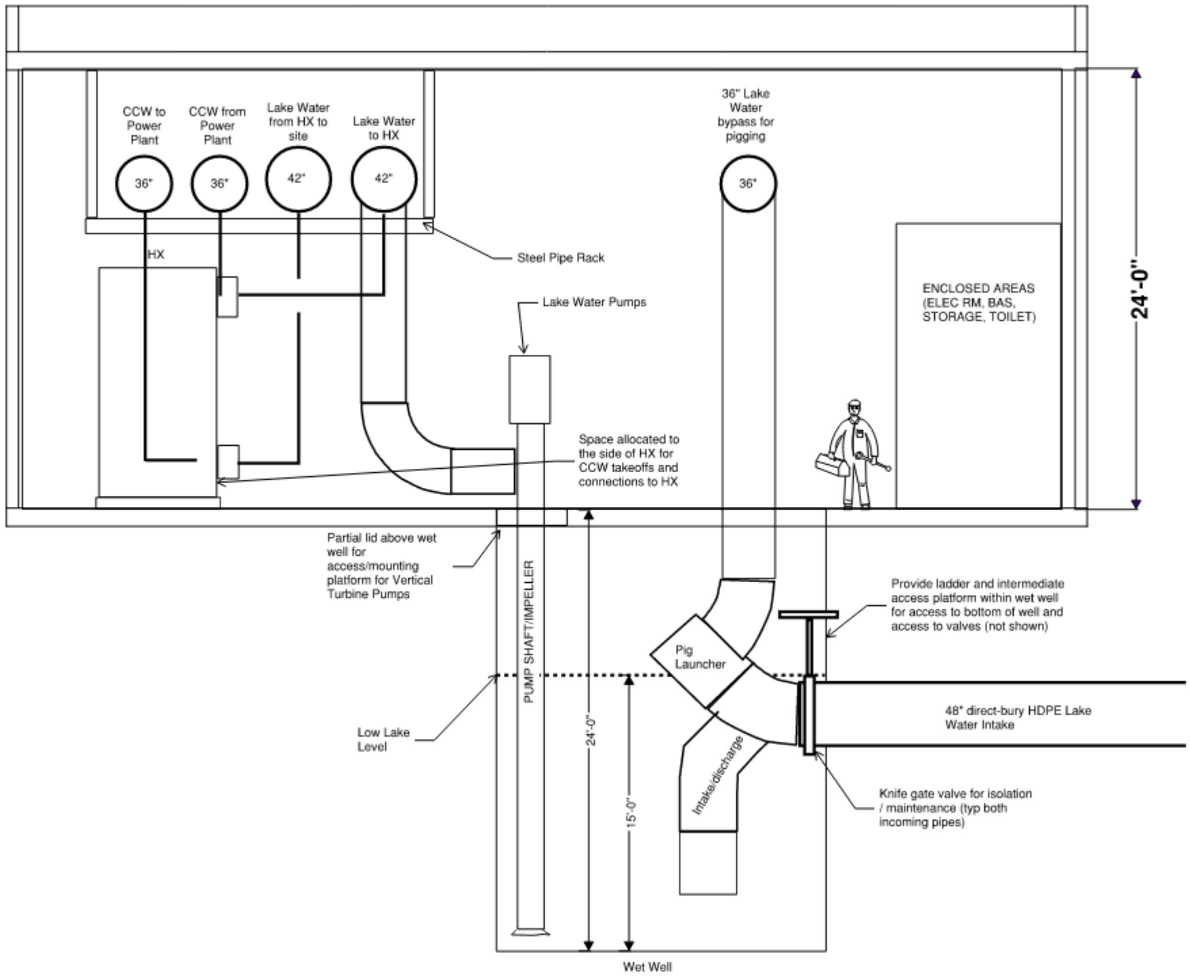


Figure 4.1.4-6: *Lake Interface Equipment Building concept section*

Offshore / Intake Piping

The west side of Union Bay is shallow with a depth ranging between 2-5 feet. This shallow depth prohibits the placement of the pipeline(s) directly on top of the lakebed, since the top of the required ~4' diameter pipe would be above the lake surface in certain locations, and slightly below in other locations, creating a hazard to navigation, and potentially interfering with recreational activities such as rowing. Since the crown of the pipeline(s) should not be placed at the lake surface, the pipeline should be tunneled or trenched.

Table 4.1.4-3: Tunnel vs. Trench Advantages

	Advantage	
Land Use and Permitting	**Tunnel**	**Trench**
Permit Complexity (local, state and federal)	✓	
Navigation	✓	
Environmental		
Water Quality	✓	
Fish and Wildlife	✓	
Contaminated Soil, Groundwater, and Sediments	✓	
Risk		
Technical – Design/Construction		
Geotechnical		✓
Constructability		✓
Construction		✓
Campus Impact (Construction)		
Above-ground Space Needs		✓
Traffic Impacts (parking, access, disruption)		✓
Non-traffic Impacts (noise, dust)		✓
Cost		✓
Capital Cost		✓
Life Cycle Cost		✓
Schedule		
Duration		✓

The advantages of tunneling vs. trenching are summarized in Table 4.1.4-3. Refer to Appendix 9.4 and 9.6 for the Preliminary Permitting & Environmental Considerations – Phase 2 and Lake Water Engineering Report for additional details.

Trenching is the preferred method and what is included in the ERP concept for this study. The following details highlight the advantages of the trenched method:

- Low technical risk due to unknown subsurface conditions
- Lower construction costs – assuming soft sediment and limited backfill
- Shorter construction schedule

- Less campus disturbance (tunneling requires onshore staging and drilling site)
- Tunneling may not be technically feasible depending on length of tunneled section and subsurface geology.
- Tunneling entire 6600' route is higher risk.
- Shorter tunneled sections of only 1000' or 2000' would be lower risk and could be considered for crossing the Union Bay Reach.

In studying the geology of Union Bay for the purposes of determining the trenched approach, there appears to be a layer of peat that is 40' – 55' thick. This allows for steep slope angles, generally good for dredging. Below that layer is a layer of glacial soils which can contain unknown boulders, logs, or obstacles for tunneling. A detailed geotechnical survey will be crucial in avoiding the technical risks associated with these unknowns. Figures 4.1.4-7 and 4.1.4-8 show example sections of a trench through typical sections of Union Bay and for crossing the Union Bay Reach.

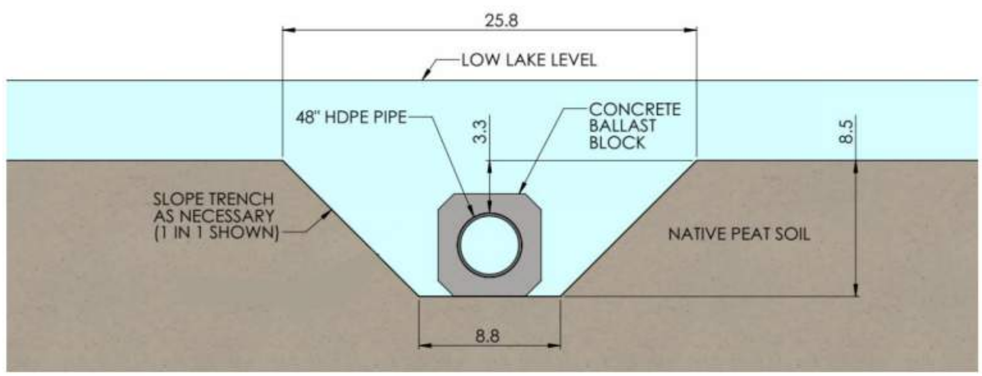


Figure 4.1.4-7: *Example section through Union Bay. Backfill material is not shown, but is expected to be required*

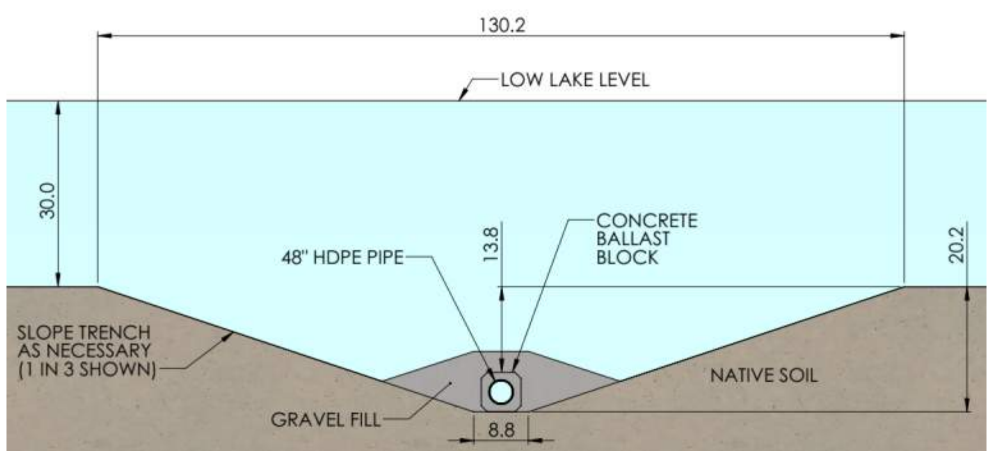


Figure 4.1.4-8: *Example section through Union Bay Reach*

The proposed routing from the lake shore at the University to the chosen intake location is shown in Figure 4.1.4-9 in plan view and a pipeline elevation profile, assuming a trenched installation, is shown in in Figure 4.1.4-10.

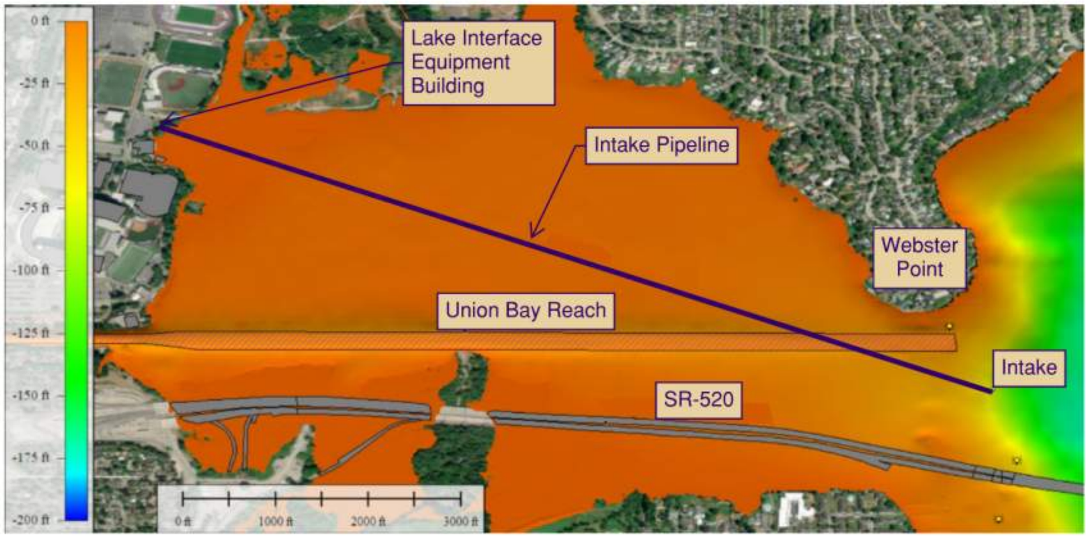


Figure 4.1.4-9: *Proposed route of lake intake piping*

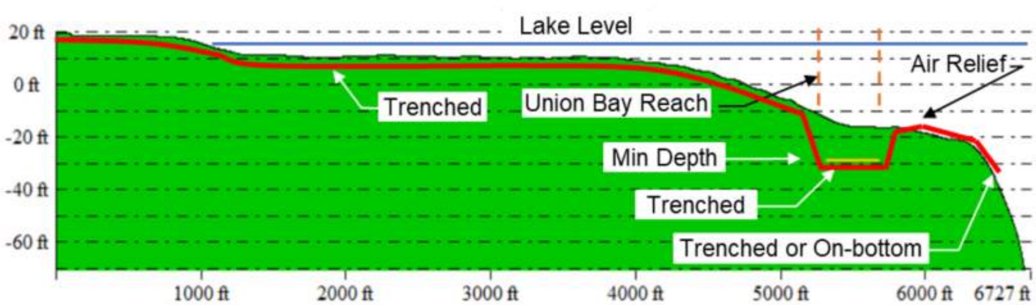


Figure 4.1.4-10: *Trenched pipeline elevation profile (NAVD88 datum) where Low Lake Level is +16.75 ft.*

Intake screens are required to reduce the impact on the nearby water velocity on aquatic life (0.4 ft/s max NOAA Fisheries WCR Anadromous Salmonid Design Manual - Screen Design Specifications) and to reduce the frequency of pipeline cleaning maintenance by limiting the amount of debris entrained into the pipe. The selected intake style is a cylindrical wedge wire screen with automatic rotating electric brush. An example of potential lake water intake structure is shown in Figure 4.1.4-11.

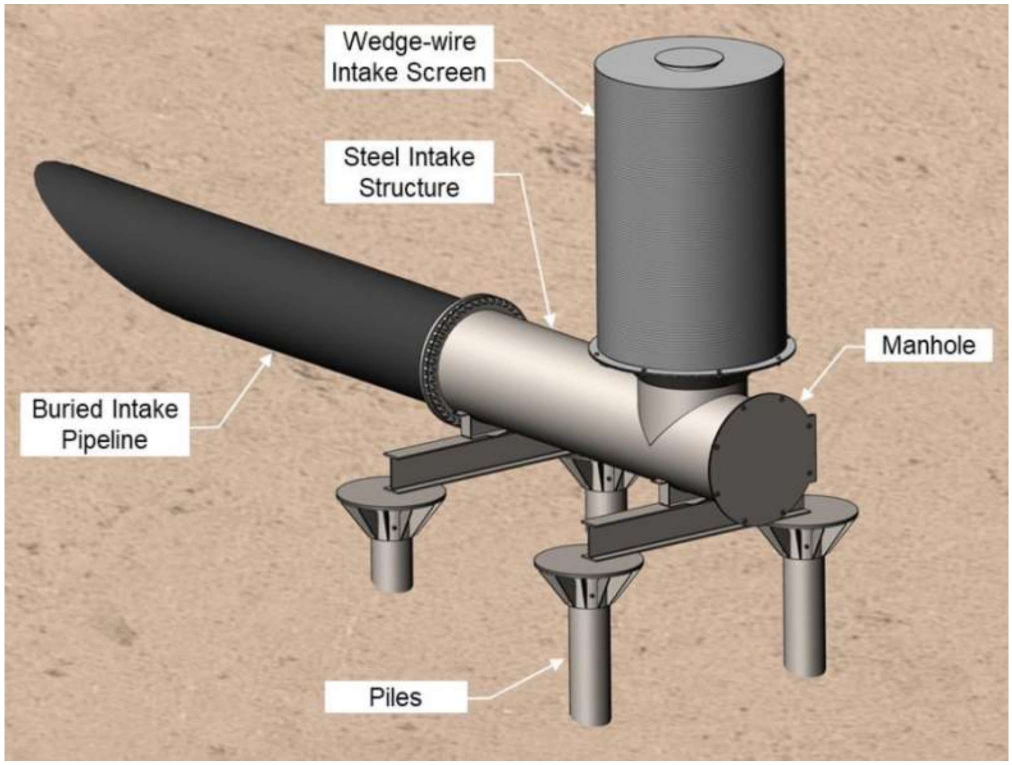


Figure 4.1.4-11: *Example intake structure*

Onshore / Discharge Piping

The proposed routing from the lake shore at the University to the discharge location in Portage Bay is shown in Figures 4.1.4-12 and 4.1.4-13.

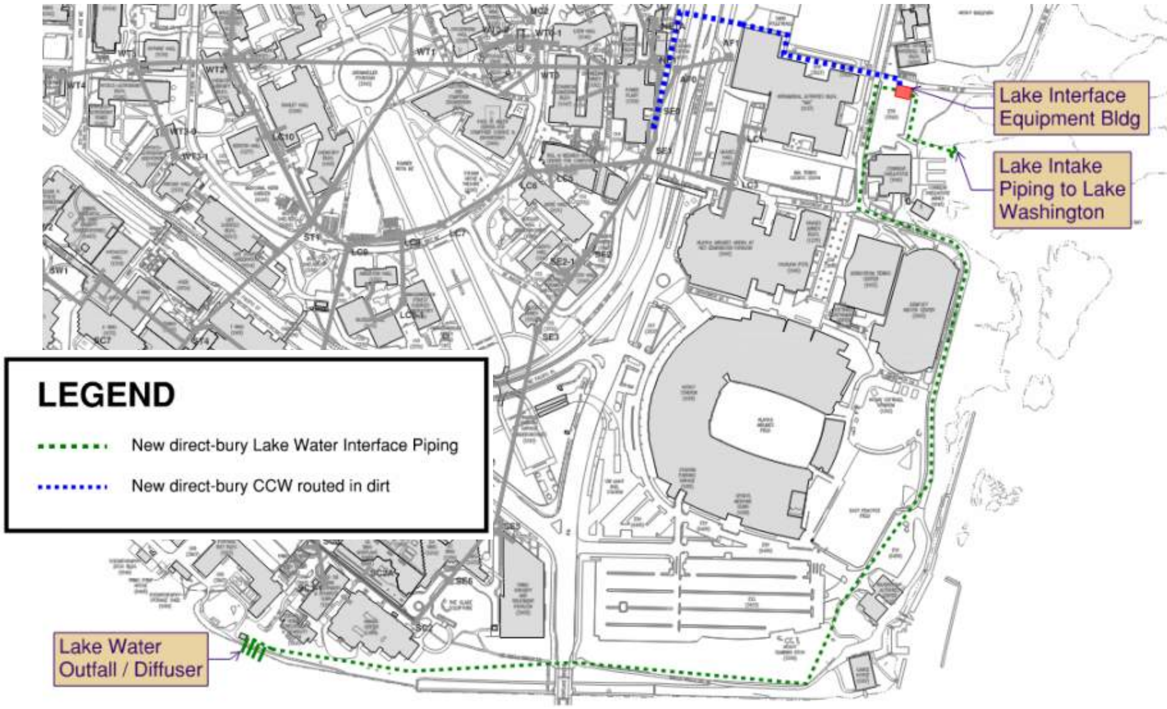


Figure 4.1.4-12: *Proposed route of lake discharge piping and outfall/diffuser location at Portage Bay*

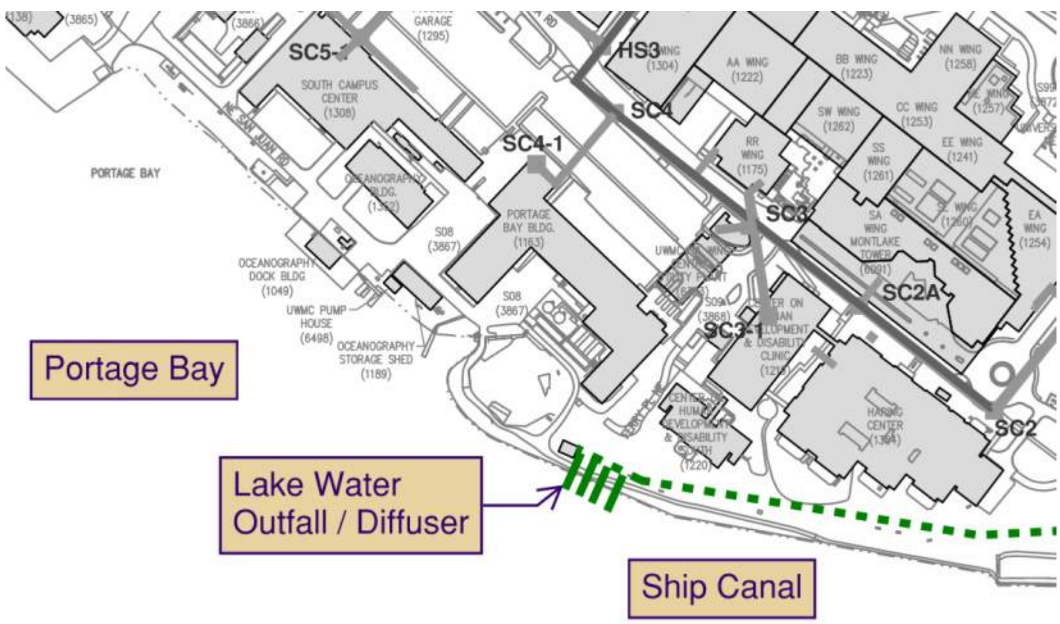


Figure 4.1.4-13: *Enlarged view of outfall/diffuser location at Portage Bay*

The design of the discharge outlet will depend on the requested performance by the governing agencies. One option shown in Figure 4.1.4-14 uses a series of diffusers that would aim to mix the discharge water with the receiving water and limit the change in temperature. Four 24” discharge branches would be provided, with a length of 25 ft each and 6 diffuser ports angled into the water. Alternative designs will be developed if it is determined that it is desirable to create a distinct zone of cool temperature below the water surface. These designs would utilize a more laminar style of flow distribution to limit mixing.

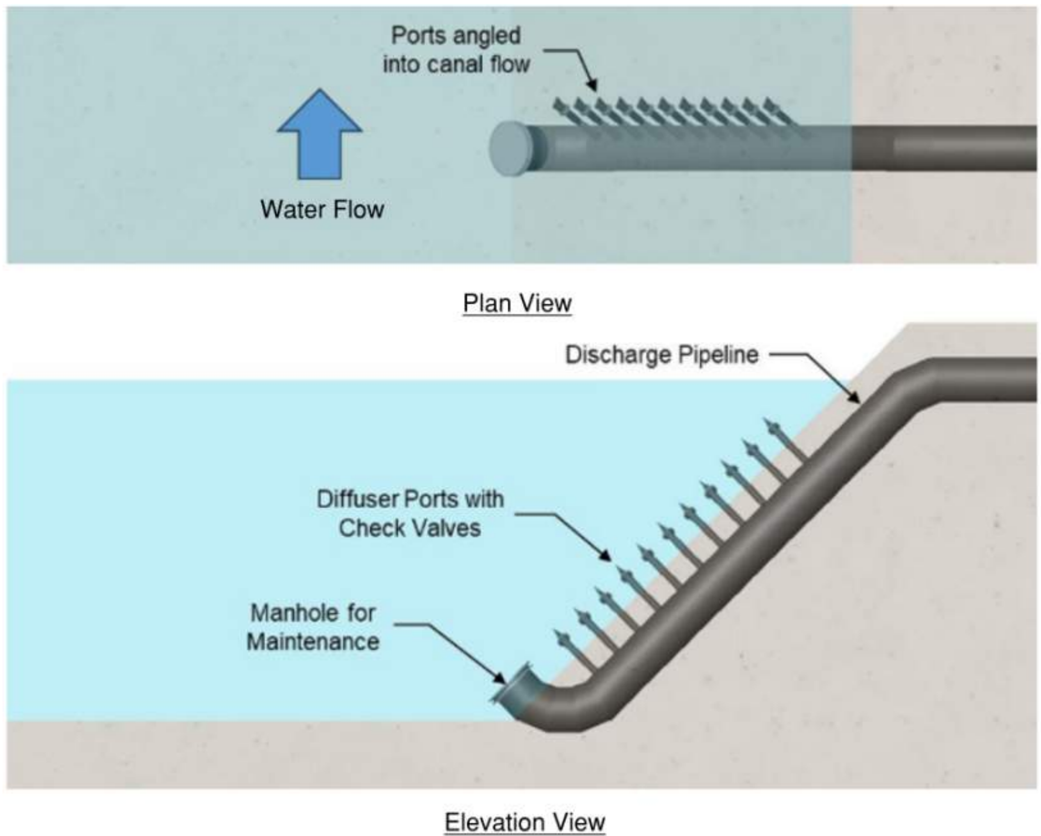


Figure 4.1.4-14: *Example diffuser configuration*

Pumps

Two sets of pumps are required for the function of this system. One set of pumps sits in the wet well and circulates the lake water from the wet well, through the heat exchangers, and out to the discharge location. The second set of pumps circulates the campus cooling water (CCW) through the heat exchangers and back to the campus Power Plant.

Three vertical turbine style pumps will be utilized for the lake water system, sized in an N+1 arrangement for full capacity delivered with only two operating pumps.

Three vertical split case style pumps will be utilized for the CCW system, sized in an N+1 arrangement for full capacity delivered with only two operating pumps.

Wet Well

A wet well is provided within the Lake Interface Equipment Building. The wet well is constructed so that it is filled by gravity with water from the lake. The lake water pumps are located within the wet well and when operating, draw down the water level in the wet well, which sees flow through the intake pipe by the natural force of gravity. The wet well is designed with consideration for the low and high lake levels, the draw down effect of the pumps, a surge effect from pump shutoff, and minimum required submergence of the pump suction.

Dissolved Oxygen Management

Dissolved oxygen is the amount of oxygen in a body of water that is available to organisms, typically measured in milligrams per liter of water (mg/L). Ecosystems rely on stable oxygen levels and numerous factors can affect them, such as temperature, depth, velocity of flow, and many others. Each fall, the average dissolved oxygen content at the intake locations is much lower than that of the Montlake Cut, near where the water will be discharged, as seen in Figure 4.1.4-15. One corrective option being explored is the use of a nanobubbler to mechanically inject oxygen into the water to ensure the dissolved oxygen content of the intake is within a closer margin of the discharge location content. The nanobubbler would be installed with an inline injection point, on the discharge side of the lake water pumps. One such option utilizes an inline nanobubble generator to target 9.5-10 mg/L, requiring an increase of 2-3 mg/L. A sample system studied required 106 lbs/hr nanobubble generator with a 40 HP air compressor. A turn-key system of this capacity requires a 40'x10'x10' (roughly shipping container sized) enclosure with 10" connections to the lake water system in a sidecar configuration. A system like this has a rough order of magnitude cost of $935,000. This cost has not been included in the project estimates as it has not yet been determined of dissolved oxygen correction will be required.

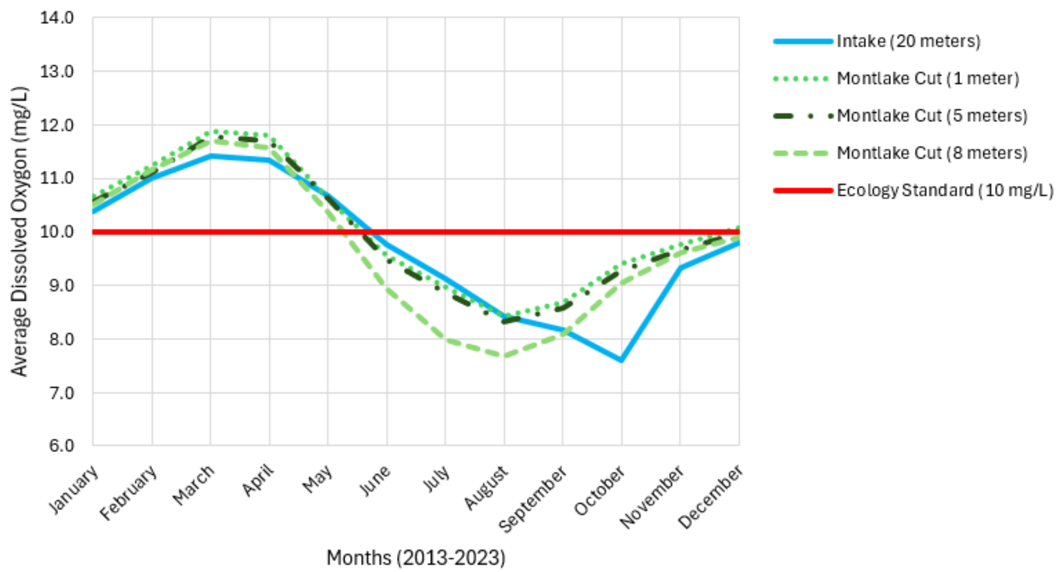


Figure 4.1.4-15: *Dissolved oxygen content at the proposed intake location and within the Montlake Cut plotted against the Depart of Ecology Standard*

Energy Potential

The energy potential of a lake water heating and cooling system is limited by the temperature of the water at the intake location. For the location studied for the lake water intake, a minimum and maximum temperature of 43°F and 49°F are observed. Refer to the Assessment section as well as Appendix 9.4 Preliminary Permitting & Environmental Considerations – Phase 2 for additional details on the expected temperatures at the lake intake.

These temperatures are not favorable for direct use of lake water as a heating or cooling source. The water is neither warm enough to directly provide heat nor cold enough to provide more than ~35% of the temperature change required in cooling mode. However, the water can be used as a heating source and a cooling sink when paired with heat recovery chillers.

Heat recovery chillers paired with a Lake Interface provide the following benefits:

- Efficiencies achieved with heat pumps in heating mode result in comparable energy costs to combustion boilers and elimination of on-site fossil fuel use in this mode of heating.
- Zero water consumption compared to standard cooling tower operation.
- Increased energy efficiency in cooling compared to standard cooling tower operation.

The lake water system capacity for this concept was sized to balance the amount of combustion or electric boiler operation after campus waste heat recovery and sewer water heat recovery are operating at their maximum capacity. Given the relatively fixed output capacity of campus waste heat and sewer water heat recovery and the high capital cost associated with the lake system, it made the most sense to right-size to the application.

The heat produced by this system was set at 77,000 MBH / 22.5 MWth. This resulted in 22,000 GPM / 50 CFS of lake water being transferred through the system.

The system could be sized larger or smaller than described in this section to the application, however the cost of the system does not scale linearly, and a smaller system would result in a higher cost per unit heat output.

Energy Efficiency

The efficiency of lake water heating and cooling is relatively constant across the year. The lake water temperature does fluctuate seasonally, though historically the pattern of seasonal fluctuation has remained relatively constant. The heating efficiency is dependent on the temperature difference between the source (lake water) and the sink (campus heating loop) resulting in an expected chiller COP of 3.2. The cooling efficiency will remain effectively constant throughout the season, though the capacity can decrease with warmer lake water temperatures.

Infrastructure Upgrades to Utilize the Source

In addition to the lake water intake and discharge piping, a connection to the existing Power Plant building is required for both CCW piping and electrical power. The Lake Interface System provides heating and cooling energy to the Power Plant via heating or cooling the Campus Cooling Water which will connect the Power Plant to the Lake Interface Equipment Building.

Campus Cooling Water must be routed direct-buried from the Power Plant to the Lake Interface Equipment building as shown in Figure 4.1.4-16. Piping will connect to new HRCs within the Power Plant.

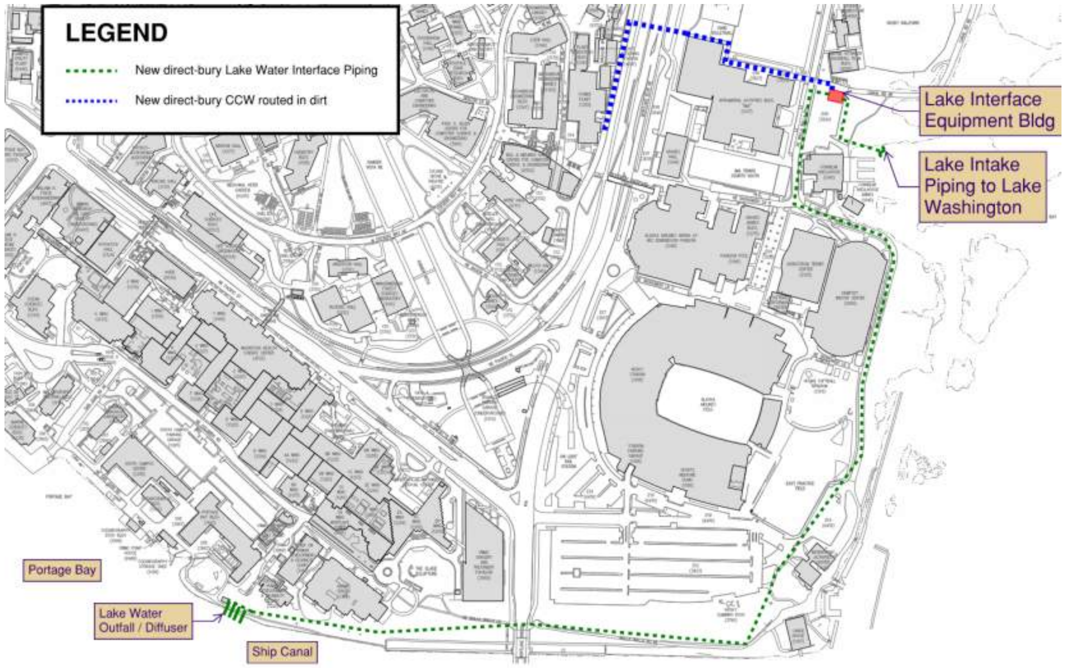


Figure 4.1.4-16: *Routing of direct-bury CCW piping from Lake Interface Equipment Building to the Power Plant building and direct-bury lake water discharge (outfall) piping from the Lake Interface Equipment Building to the proposed Outfall / Diffuser location*

Electrical power shall be fed in a 15 kV rated three-phase loop from Power Plant / East Receiving Station (ERS) to the Lake Interface Equipment Building.

Impacts to the Existing Campus Environment

During construction there is an immediate impact of the Lake Interface system. The trenching operations would include a system of barges with excavators and storage of removed materials. Several layers of turbidity curtains can be used to contain the suspended solids generated by the trench dredging activity, and so the turbidity of Union Bay and Lake Washington should not be affected. Work and the noise generated within the vicinity of Webster Point and across the Union Bay Reach / major naval corridor will certainly garner attention from the public.

Once installed, the Lake Interface system would be largely unnoticed from the perspective of the passersby. The relatively small Lake Interface Equipment Building would blend in with the sports field support buildings. The utility work for this project is extensive but is either buried when onshore or installed in a trench through Union Bay. The pipe would be visible in the shallower portions of the bay given the current proposed method does not include backfill.

Operational Considerations

Desired system life is 100 years. The major investments for this system are in the onshore and offshore piping, which can achieve system life expectancies in this range through the use of durable system materials like plastic piping systems.

Major maintenance activities would consist of:

- Cleaning the intake screen every ten years. The screen would be pulled out for cleaning and the bearings and bushings replaced. This would require a temporary barge system and divers for removal and reinstallation of the intake.
- Pigging the system every twenty years. Refer to Appendix 9.6 Section 3.7 of the Lake Water Engineering Report for more details.
- Pump and heat exchanger maintenance would follow typical annual and quarterly maintenance procedures.
- System cooling capacity would be carefully monitored during peak summer periods and controlled to limit the maximum lake water temperature delivered to the receiving body of water (Portage Bay) to 57°F or below to maintain the beneficial nature of the system as a source of cool water for salmon migration.

Risks

While the Lake Interface system is generally robust and has a low risk of catastrophic failure, there are some operational risks that should be noted.

- The proposed offshore pipe installation methods to restore the lakebed surface require further investigation. Leaving the pipe exposed creates a risk of anchor strikes / naval collision to the pipeline. It is likely that the governing agencies will require the lakebed to be returned to its original grade with an approved material.
- Environmental / invasive species – quagga and zebra mussels. Quagga and zebra mussels are considered the most economically damaging aquatic organisms to invade the United States.
    - These species are not currently identified in Lake Washington or the bodies of water surrounding the University of Washington, but should they materialize, the frequency of pigging / pipe cleaning would be increased from every 20 years to every 10 years.

For permitting / schedule risks, refer to Section 8.1 and Appendix 9.4 Preliminary Permitting / Environmental Considerations.

Emerging Technology Considerations

There are not any emerging technologies being tracked related to this work, however improvements to directional drilling that might improve the cost efficiency or reduce the risk associated with tunneling would require a re-evaluation of the trench vs. tunnel approach.

4.1.5 Air-Source Heat Pumps (ASHP)

System Overview

Air-source heat pumps consists of a refrigeration system paired with a refrigerant-to-air heat exchanger and fans to move air across the heat exchanger and a refrigerant-to-water heat exchanger for heating/cooling water delivered to buildings. The heat pump heats or cools the water system and uses the outdoor ambient air as either or a source for heat or a sink to reject heat to.

The capacity and efficiency of an air-source heat pump varies with ambient outdoor air conditions. There is a point at extreme cold temperature conditions (typically 5°F or less), where air-source heat pumps cannot provide any heat due to system limitations.

Campus-scale equipment appropriately sized for district energy applications are not available. Air-source heat pumps are not as scalable as water-to-water heat pumps since they package the outdoor heat exchanger directly to the heat pump. As the required capacity increases, the compressor technology scales in a reasonable manner but the outdoor heat exchanger scales linearly in size. To deliver heat to a campus of this size, an equipment building, and yard would be required with a campus footprint on the scale of a major University building.

Recommendations

The cost-per-unit heat output for this system may be favorable from a first cost perspective but the other options studied rely on more passive systems which have expected system life of 100 years.

Based on the low energy efficiency, high operating costs, low life expectancy, and impact to campus environment relative to the other options discussed in this section the air-source heat pump option is not included in the recommended pathway for the ERP. Should the Lake Interface become unfeasible, the air-source heat pump system could be implemented as a contingency plan.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of this project.

Key System Characteristics

ASHP Quantity and Capacity:

- 54 x 230-ton heat pumps
- 77,000 MBH / 22.5 MWth heat delivered to Power Plant
- 113,000 MBH / 33 MWth heat delivered to campus (after HRCs)
- System components:
- Pump provided per heat pump (qty. 54)
- Heat exchangers between glycol loop and CCW system
- 30% glycol-water required for freeze protection

ASHP yard size: 240' x 180'

ASHP Equipment Building: 8,000 sq ft.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included site plans, campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

Alternatives and Scenarios

Air-source heat pumps are not yet available that can directly produce 170°F which is the ideal water temperature for this campus. The most common type of air-source heat pump would be capable of producing approximately 113°F water, significantly below the desired temperature. This is a developing market, and the capabilities of these machines could increase with alternate refrigerants or advances in compressor technology.

Since the available technology cannot directly produce the required temperature, the scenario studied utilizes the air-source heat pumps positioned on the source/sink side of the campus heat recovery chiller system. This system would be in parallel with or replace the function of the Lake Interface or geothermal system. Refer to Figure 4.1.5-1 for a schematic diagram showing the arrangement of the air-source heat pumps with the campus utility plant HRCs.

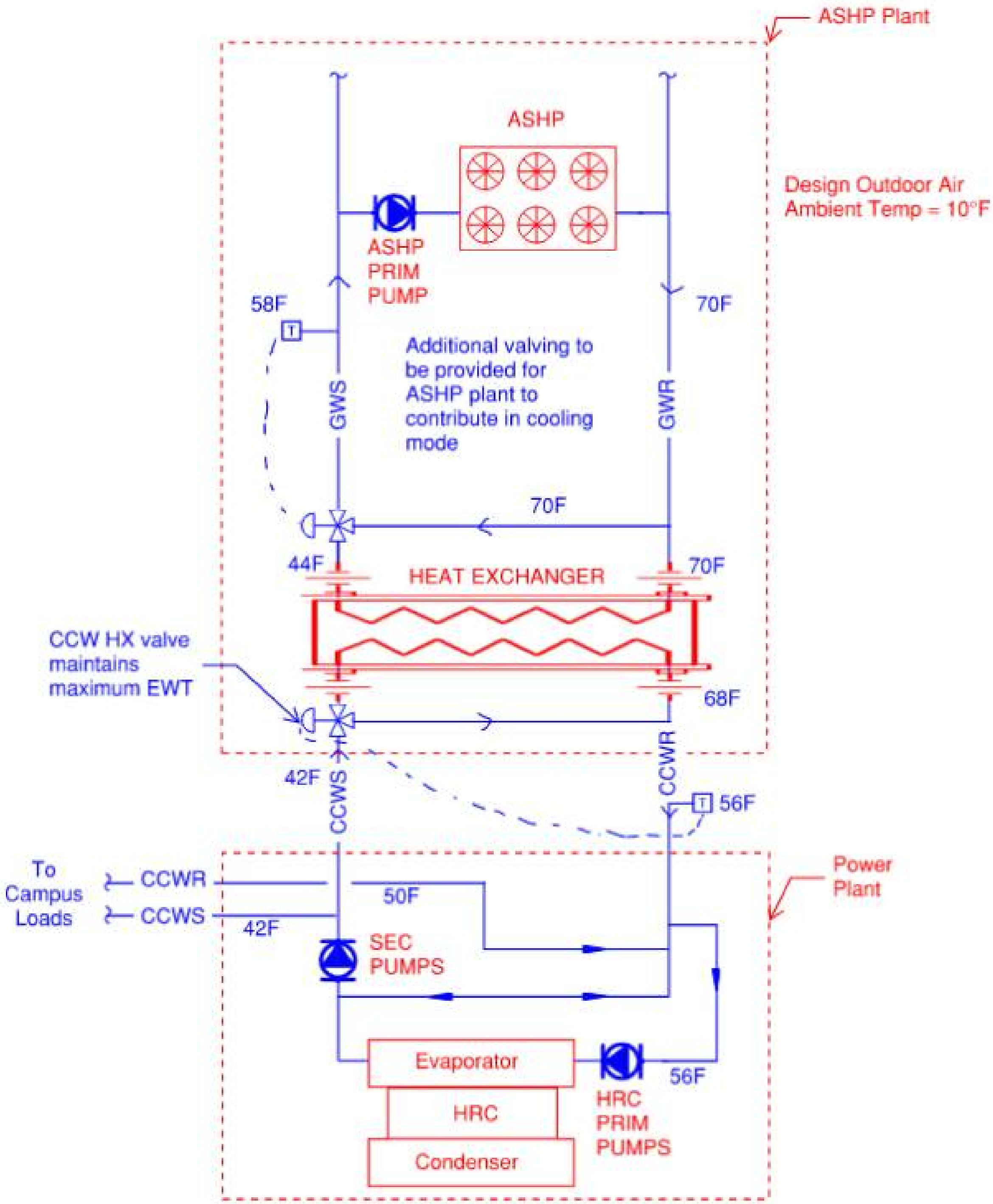


Figure 4.1.5-1: *Air-source heat pump (ASHP) and heat recovery chiller (HRC) conceptual diagram. Temperature values shown are for heating mode*

The air-source heat pump system generates warm or cool water that can be utilized by the equipment located at the Power Plant to provide heating and cooling water to the campus.

In heating mode, the air-source heat pumps produce 70°F water from the outdoor air at a design ambient condition of 10°F. This acts a false load on the chilled water system, allowing a heat recovery chiller to generate the design heating water supply temperature as if a simultaneous heating and cooling load existed.

In cooling mode, the air-source heat pumps can act as an additional source of cooling during peak load conditions, working in parallel with the other chillers at the Power Plant to directly produce campus cooling water.

Many of the typical commercial HVAC manufacturers provide an air-source heat pump equipment line. This scenario studied a nominal 230-ton air-source heat pump utilizing R-454B refrigerant and provided with a pump package for each heat pump.

An ASHP Equipment Building houses heat exchangers (separating the campus cooling water from the ASHP glycol loop) and a large electrical room with substations to supply the air-source heat pump equipment.

Energy Potential

The ambient outdoor air is considered an unlimited heat source/sink and is not environmentally limited in terms of the quantity of energy that can be used for heating or cooling.

The energy potential of this system is limited by the capacity of each heat pump which is dependent on the design outdoor air temperatures. Cooling is a by-product of this system, while heating is the determining factor for size. For this study, a winter outdoor air temperature of 10°F is assumed. This is well below the 24°F ASHRAE design temperature condition for Seattle and will cover the campus for extreme conditions.

For this study, the air-source heat pump system capacity was set to be equivalent to the heat energy provided by the lake interface system, to allow for a direct comparison to the lake interface system since the two systems would provide similar functions.

The heat produced by this system was set at 77,000 MBH / 22.5 MWth. At 10°F outdoor air temperature, this would require 53 230-ton nominal ASHPs. This system would have an operating electrical input power of approximately 7.5 MW.

The system could be sized larger or smaller than described in this section and should scale well in terms of cost per unit heat output.

Energy Efficiency

The capacity and efficiency of an air-source heat pump varies with ambient outdoor air conditions. The system has a higher capacity and efficiency during milder outdoor air conditions (40°F to 75°F). The system's capacity and efficiency decrease in the hottest and coldest periods of the year.

Under the coldest winter conditions, the ASHP system would operate at a COP of greater than 3 to produce the warmed chilled water return back to the Power Plant. When this warmed water is supplied to a heat recovery chiller, the heat recovery chiller is then able to use that heat to supply the campus with hot water. The heat recovery chiller requires additional power to do this and operates at a chiller COP of 3.2. With both the ASHP and HRC input powers factored in, the combined chiller COP is 1.9. While this is significantly more efficient than a combustion or electric boiler, it is less efficient than other heat pump sources which range from 3–5.5 COP (discussed in other sections).

The ASHP efficiency would increase during milder outdoor air conditions as noted, however the HRC efficiency would remain the same and the overall system efficiency would only increase by approximately 20%.

Infrastructure Upgrades to Utilize the Source

Beyond just siting the ASHP yard and equipment building, a connection to the existing Power Plant building is required for both CCW piping and electrical power.

Campus Cooling Water must be routed direct-buried from the Power Plant to the Air-Source Heat Pump Equipment building as shown in Figure 4.1.5-2. Piping will connect to new HRCs within the Power Plant.

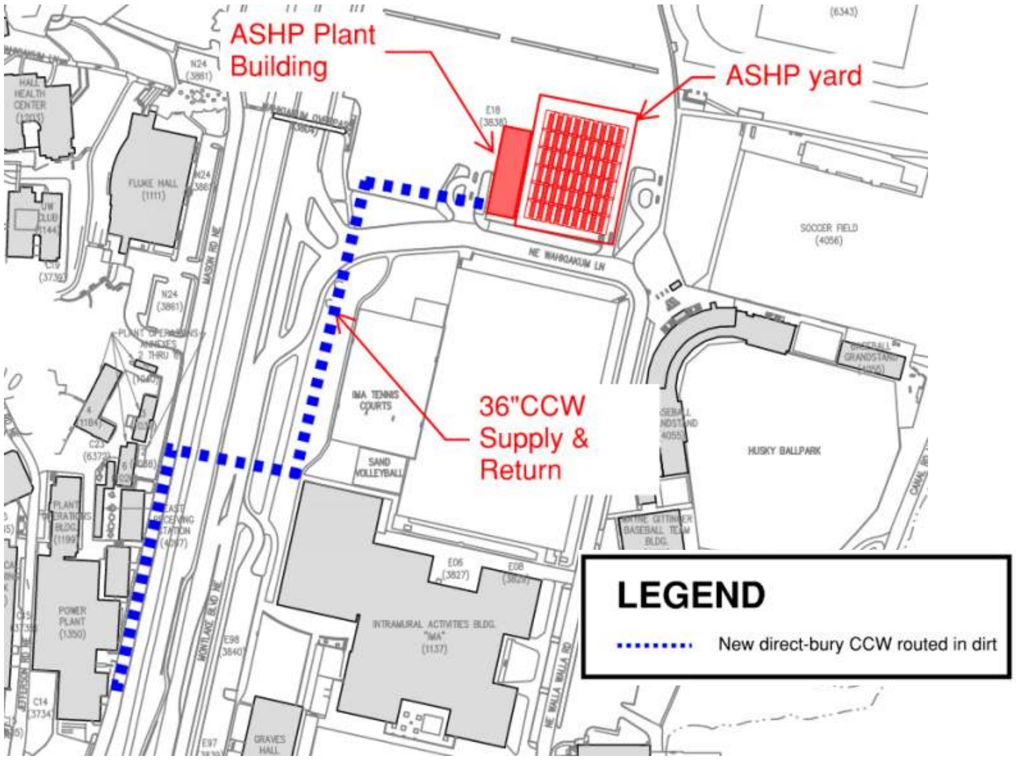


Figure 4.1.5-2: *Routing of direct-bury CCW piping from ASHP plant/yard to the Power Plant building*

Electrical power shall be fed in a 15 kV rated three phase-loop from Power Plant / East Receiving Station (ERS) to the Air-Source Heat Pump Building providing a reliable power supply.

A 15 kV rated double-ended switchgear, capable of handling up to 27 MW, will be installed within the building. The design also incorporates nine 3MW unit substations, each with a 13.8 kV primary connection and a 480V secondary output, equipped with 4,000A busses for distribution to the (54) 480V air-source heat pumps.

All electrical equipment will be located indoors within the Air-Source Heat Pump Equipment Building. Additionally, the building will include a 480V transformer to support loads such as ventilation, freeze protection, and lighting. A 208V system will provide power for controls, maintenance receptacles, and other support functions within the building.

Impacts to the Existing Campus Environment

The ASHP system is the most outwardly disruptive energy source to the campus from the perspective of passersby. It will be a source of noise within the vicinity of the yard. To deliver heat at to a campus of this size, an equipment building, and yard would be required with a campus footprint on the scale of a major University building. The mechanical equipment would be visible from the main campus in view corridors to the east.

Air-source heat pumps would be located in the East Campus near the existing fields north of the IMA building. A mechanical yard will be constructed with an enclosure acting as a security and line of sight enclosure and constructed of materials consistent with the campus aesthetic. The yard will have a footprint of roughly 240' x 180', which allows for spacing between the air-source heat pumps and an elevated rack system shall collect the flow from each heat pump into a pipe header. The ASHP Equipment Building, located adjacent to the yard, would be approximately 8,000 sq ft in area with a footprint of 50' x 160' with a structure height of 24'.

Operational Considerations

This system is operationally complex given that it requires two independent heat pump / heat recovery chiller systems to operate in together as one overall heating system. The control algorithms for this system would be complex and require special training to understand and operate.

The ASHP system provides some benefits in redundancy, where a single or even several failures of equipment would not result in the system capacity being lost.

However, there is a point of diminishing returns on redundancy and with a system of this consisting of hundreds of compressors, refrigerant circuits, valves, fans, and pumps, is likely and expected over time to have constant equipment failures. This taxes university maintenance resources and would require dedicated staff specializing in the maintenance of these systems.

Operational costs would be high relative to other energy sources considered based on the increased maintenance and energy costs discussed previously.

Risks

A heightened awareness of the global warming impact from refrigerants is starting to materialize in regulations at the State level. There is a risk that the proposed refrigerant for the ASHPs could eventually be phased out, which would not require immediate replacement but would increase operational costs and complicate equipment replacements.

Emerging Technology Considerations

There is substantial market pressure for manufacturers to provide air-source heat pump solutions for small and large systems. It is likely that the push towards electrification will result in advances in air-source heat pump reliability and efficiency.

4.1.6 Geothermal Heating & Cooling

System Overview

Geothermal heating and cooling in the context of this study refers to the practice of exchanging heat with the deep earth. Holes are drilled into the earth at depths of three hundred feet to thousands of feet, depending on regional geology and drilling technology. These holes are utilized to install a series of pipes that form a geothermal heat exchanger. Water flows through a closed circuit (no direct interface to the ground or groundwater) and is either warmed or cooled by the surrounding earth. That temperature exchange is then amplified using heat pumps to generate useful chilled or hot water for building heating and cooling. Figure 4.1.6-1 illustrates this process.

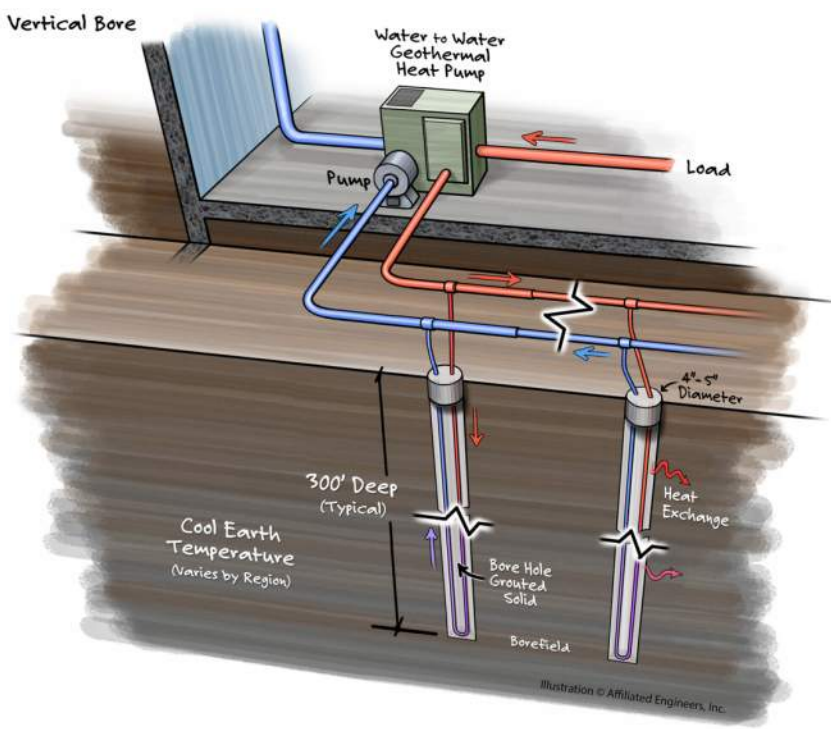


Figure 4.1.6-1: *Simple diagram of Geothermal heat pump system*

Other similar, but different, technologies include:

- Geothermal energy—largely seen in places like Iceland, which requires access to volcanic hot rock which is not the situation in Seattle.
- Open-loop geothermal heating and cooling – groundwater is extracted, heated or cooled, and reinjected into an aquifer.
- Geothermal heating and cooling systems have been in use for since the 1940's. Their use has seen a recent spike in the push to reduce fossil fuel use in heating systems since they tend to be more practical than air-source heat pumps in cold climates.
- Several campuses undergoing similar efforts to University of Washington to reduce or eliminate fossil fuel use are planning to utilize geothermal systems. Ball State, Princeton, Carleton College, and Oberlin College to name a few.
- Refer to 2017 Hot Water Conversion Study: Phase II for previous study conducted for the University of Washington on geothermal systems.

Recommendations

Though geothermal systems are being adopted by many other universities across North America, given the UW's location within an urban setting just north of downtown Seattle, the opportunity to dedicate the necessary land to provide a substantial portion of the University's heating and cooling needs through geothermal does not exist without major concessions to future campus planning.

Based on the high first cost and impact to future campus development potential in the east campus the geothermal option is not included in the recommended pathway for the ERP. Should the Lake Interface become unfeasible, the geothermal option could be implemented as a contingency plan.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of this project.

Key System Characteristics

Geothermal field area: 44 acres consisting of 4,750 bore holes

Geothermal field capacity:

- 4,750 bore holes installed at 20' o.c.
- 77,000 MBH / 22.5 MWth heat delivered to Power Plant

- 113,000 MBH / 33 MWth heat delivered to campus (after HRCs)
- System components:
  - Three geothermal pumps with VFDs - 11,000 GPM, 50 ft head, 200 motor HP each
  - Three CCW pumps with VFDs - 11,000 GPM, 70 ft head, 250 motor HP each
  - Heat exchangers between geothermal loop and CCW system
  - No glycol shall be used in the geothermal system.

Geothermal Equipment Building: 2,000 sq ft.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included site plans, campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

Future data collection recommended as part of next steps if this option is to be pursued further:

- Drill test bores in the east campus at a few locations (3-5 given the size of the site) to better understand the geology, the drilling conditions, and thermal performance.
- Further study of the areas of the east campus that were a former landfill to determine necessary precautions to be taken during installation.

Alternatives and Scenarios

A geothermal heating and cooling system consisting of a closed-loop geothermal heat exchanger would function similarly to the Lake Interface heating and cooling system.

The Geothermal System provides heating and cooling energy to the Power Plant via a piping system which will connect the Power Plant to the Geothermal System and allow the heat recovery chillers to interface with their evaporator or condensers to the geothermal system. In heating mode, the Geothermal system adds heat to chilled water supply, acting as a false load on the chilled water system to allow for generation of heating at the Power Plant Heat Recovery Chillers. In the cooling mode, the Geothermal system rejects the heat from the chiller condensers into the ground loop.

The geothermal loop would be located on the east campus and be arranged with the intent to allow for future building construction within the geothermal grid. Refer to Figure 4.1.6-2 for the area of campus studied and the size of the proposed wellfield. At existing sports fields, it is assumed a complete removal and restoration of the field would be required.

The indicated area would consist of 4,750 geothermal boreholes spaced apart from one another 20 feet on center (o.c.). This spacing is required to reduce the thermal breakthrough from one bore to another and to avoid oversaturating the field with heat over time.

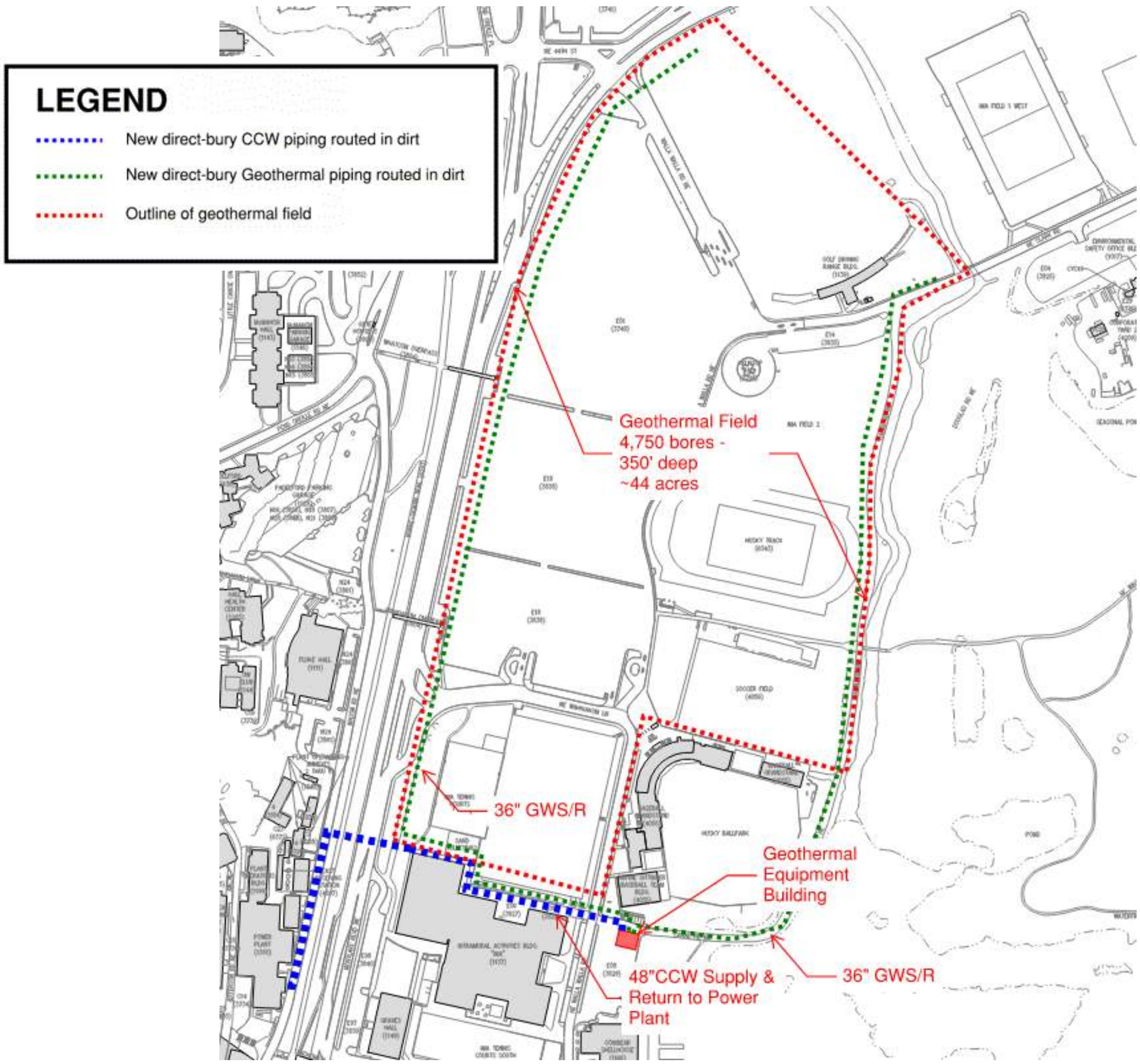


Figure 4.1.6-2: *Geothermal well field area in East Campus*

The scenario studied includes a closed-loop geothermal heat exchanger consisting of 350’ deep vertical boreholes with HDPE piping installed. The depth of wells chosen for this study is consistent with other regional projects factoring in the following:

- Geology in this region is not conductive to deep boreholes. Drilling significantly deeper can require the use of well casings and drilling techniques that dramatically increase the cost of installation.
- Depths beyond 350’ require drilling rigs that are not locally available which can be challenging to source and maintain uptime during construction.
- Deeper wells could be considered as part of a more detailed pre-design effort to reduce the quantity of wells and the impacted area of the campus, and the tradeoffs studied.

Two sets of 36” geothermal water supply and return header would be routed along each side of the field, collecting headers from underground prefabricated geothermal vaults. Below-grade geothermal field vaults would be utilized. These prefabricated cylindrical HDPE vaults contain the piping header to individual branch piping to approximately 15-20 bores per branch. Ten such vaults would be required.

A Geothermal Equipment Building would be required to house large pumps for the geothermal loop and CCW loop, heat exchangers (separating the campus cooling water from the geothermal loop), and electrical room supporting approximately 1 MW of electrical load. The building would be comparable in size to the Lake Interface Equipment Building, at approximately 2,000 square feet.

A heat exchanger system is recommended to separate the CCW system from the geothermal system to reduce the risk of contamination between either system. While not strictly required, it is best practice and would ensure regulatory compliance for systems interfacing with potential groundwater.

Alternatives considered include utilizing areas of the campus which are already established as permanent open / green space areas such as Rainier Vista. Refer to Figure 4.1.6-3 for a site map of the area of Rainier Vista considered. Rainier Vista is the largest of such areas on campus, with other notable potential areas including the Quad, Denny Yard, and Parrington Lawn. These areas represent only a small fraction of the area required for a substantial geothermal field. For this reason, these areas are not currently under consideration for locating a geothermal field.

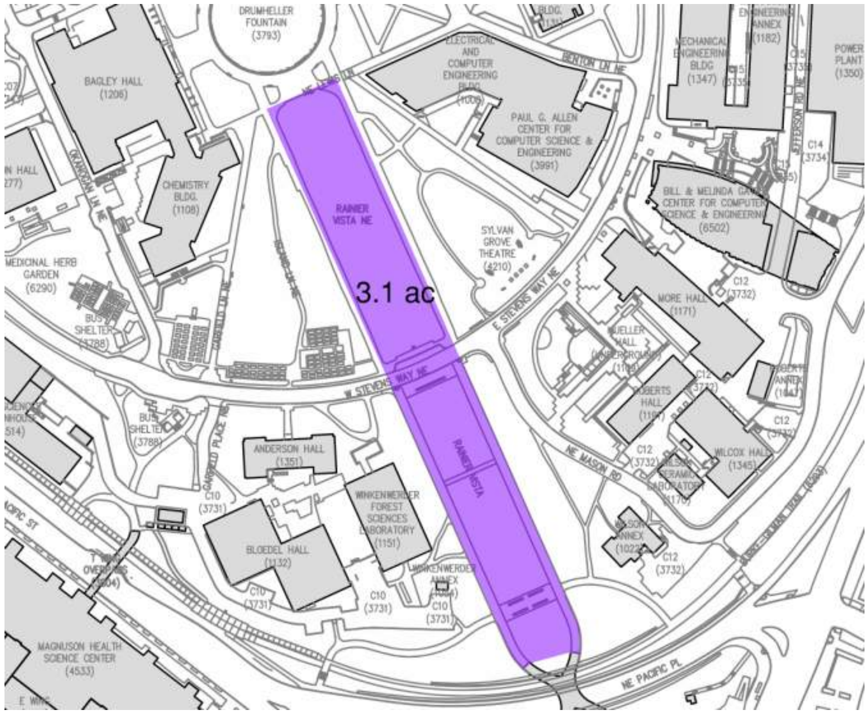


__Figure 4.1.6-3:__ Rainier vista, a permanent open green space on campus, represents 3.1 acres of area equating to only 7% of the area presented in the base scenario

Energy Potential

The energy potential of a geothermal system is limited by the available area to install the wellfield, the depth of each bore, and the spacing of the bores.

For this study, the geothermal system capacity was set to be equivalent to the heat energy provided by the lake interface system, to allow for a direct comparison to the lake interface system since the two systems would provide similar functions.

The heat produced by this system was set at 77,000 MBH / 22.5 MWth. Using 350' deep wells spaced 20' on center, a site area of 44 acres would be required.

The system could be sized larger or smaller than described in this section and should scale well in terms of cost per unit heat output.

Energy Efficiency

The efficiency of a geothermal heating and cooling is relatively constant across the year. The ground temperature remains relatively constant season to season, though it fluctuates within a season over extended periods of heat exchange in. The heating efficiency is dependent on the temperature difference between the source (the earth) and the sink (campus heating loop) of the system is comparable to the Lake Interface system, resulting in an expected chiller COP of 3.2.

In a balanced system where the heating and cooling loads are monitored and controlled to maintain an equal amount of heating and cooling seasonally, the capacity and efficiency will not change over decades.

Infrastructure Upgrades to Utilize the Source

A connection to the existing Power Plant building is required for both CCW piping and electrical power.

Campus Cooling Water must be routed direct-buried from the Power Plant to the Geothermal Equipment building as shown in Figure 4.1.6-4. Piping will connect to new HRCs within the Power Plant.

Electrical power shall be fed in a 15 kV rated three-phase loop from Power Plant / East Receiving Station (ERS) to the Geothermal Equipment Building.

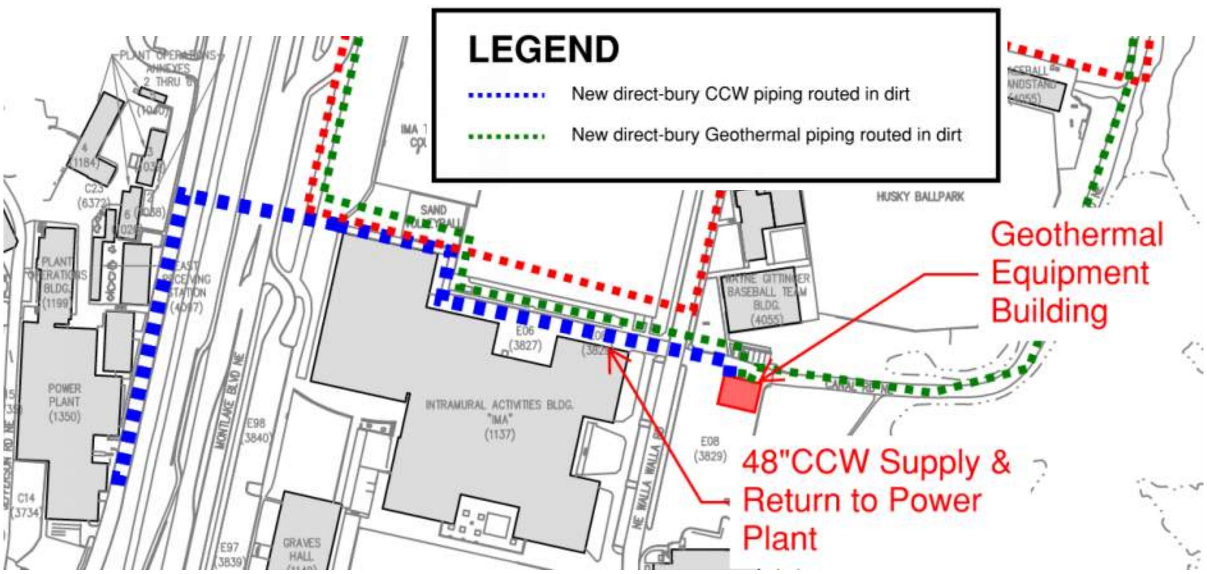


Figure 4.1.6-4: *Routing of direct-bury CCW piping from Geothermal Equipment Building to the Power Plant building*

Impacts to the Existing Campus Environment

The Geothermal system would be made up of thousands of geothermal boreholes, taking up a massive site area (~5% of Seattle campus area) and likely create an obstacle to future east campus development.

Outside of the impact to future development, the geothermal system is unnoticed from the perspective of passersby. The relatively small Geothermal Equipment Building would blend in with the sports field support buildings and the vaults located across the field would present itself as a manhole that is no different than any other buried utility across the campus.

Operational Considerations

This system is operationally simple. The geothermal component acts as a cooling tower in the summer and as a cooling load in the winter. It is not a common system for facility operators to encounter but would require relatively little training to train new operators.

The system would have redundancy in the geothermal heat exchange field through multiple headers and vaults, and through pumps and heat exchangers provided in an N+1 redundancy configuration.

Operational costs will be comparable to the lake interface system. Higher energy cost of electricity is offset by the efficiency of the heat pump heat source.

Risks

Geothermal systems are very robust and have little operational risk of system-wide failure or costly maintenance after installation.

There exists a schedule and cost risk. A system of this size would likely take 2-4 years of continuous drilling operations to install. The proposed area of campus could present construction complications due to its previous use as a landfill. The specialized nature of the work also presents a risk in workforce and equipment availability. The recent increase in popularity of this system type presents a challenge to the drilling industry to meet the demand. There will be a lot of competition for skilled drilling contractors.

Emerging Technology Considerations

There are innovations happening within the drilling and geothermal industry. Similar to the ASHP system, the market pressure of increased electrification will hopefully lead to improvements in system cost and efficiency.

Current emerging technologies to watch over the next decade or more include:

- Angled drilling (Celsius Energy) which utilizes special drilling techniques to reduce the amount of surface wells and increase the efficiency of drilling through reductions in mobilization of the rigs from bore to bore.
- Enhanced geothermal systems utilizing bores an order of magnitude deeper (2-5 km) to reach hot enough rocks to provide direct heating to without the use of heat pumps.

4.1.7 Energy Source Comparison

The energy sources described in this section each have advances and disadvantages. Table 4.1.7-1 summarizes these in a matrix format. The selected options for study in the implementation planning phase are Campus Waste Heat Recovery, Sewer Water Heat Recovery, and Lake Interface Heating & Cooling.

Table 4.1.7-1: Energy Source Advantage Comparison Matrix

	Advantage				
Rating Category	Campus Waste Heat Recovery	Sewer Water Heat Recovery (SWHR)	Lake Interface Heating & Cooling	Air-Source Heat Pump	Geothermal Heating & Cooling
Energy Efficiency	ü	ü	ü		
Greenhouse Gas Emissions	ü	ü	ü	ü	ü
Impact to Campus Environment	ü	ü	ü		
First Cost	ü				
Funding Opportunities		ü	ü		ü
Energy Cost	ü				
Maintenance Cost	ü				ü
Water Cost	ü	ü	ü	ü	ü

4.2 Plant Upgrades

4.2.1 Introduction

At the heart of the Energy Renewal Plan are major modernization upgrades to the systems within the electrical systems and campus utility plants.

The campus electrical systems must be upgraded to increase the capacity of the system to meet the demands of the proposed electrified heating systems and increased cooling system capacity, as well as improvements to system resiliency and reliability. The existing electrical system receives power from Seattle City Light through two points of connection, West Receiving Station (WRS) and the East Receiving Station (ERS), with all power provided through WRS under certain operating scenarios.

The Power Plant (PP) and West Campus Utility Plant (WCUP) currently generate campus cooling water to a connected loop that is isolated to prevent the two systems from interacting with one another. The Power Plant is the only source of steam for the campus and provides steam for building heat, domestic and lab water heating, humidification, and sterilization.

The vision for the campus is to have a connected system that can be served with heating and cooling from either plant, depending on the availability of the different heat sources discussed in Section 4.1. Figure 4.2.1-1 shows a diagram of the completed system after the improvements outlined in the ERP.

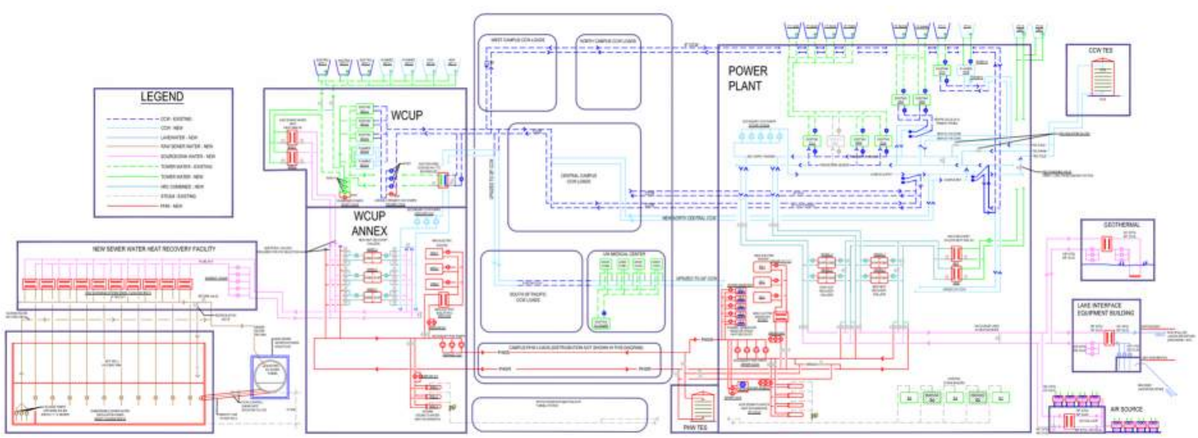


Figure 4.2.1-1: *Mechanical system diagram. Refer to Appendix 9.3 MSSD-1, Mechanical System Schematic Diagram for a larger format version of this diagram for readability.*

4.2.2 Power Plant (PP) Upgrades

4.2.2.1 Power Plant Upgrades – Mechanical

System Overview

The Power Plant houses the campus' boiler system as well as more than 70% of the campus current chilling capacity. The Power Plant building was built in 1938 and expanded over the years to add to the boiler capacity. The Power Plant transitioned from coal as a fuel source in 1988, leaving a surplus of space previously associated with storage and processing of coal. The ERP includes plans for utilization of these spaces as well as space freed up by the removal of two of the five steam boilers in installation of new electrified heating systems.

The Power Plant is planned to house the following key components of the decarbonized heating and cooling systems. Refer to Figure 4.2.2.1-1 for a system diagram of the Power Plant in its final condition.

- Heat recovery chillers
- Steam-to-water heat exchangers
- Secondary pumping systems for CCW and PHW
- Thermal Energy Storage for CCW and PHW
- Electric boilers
- Water-to-water heat exchangers for HRCs to connect to cooling towers

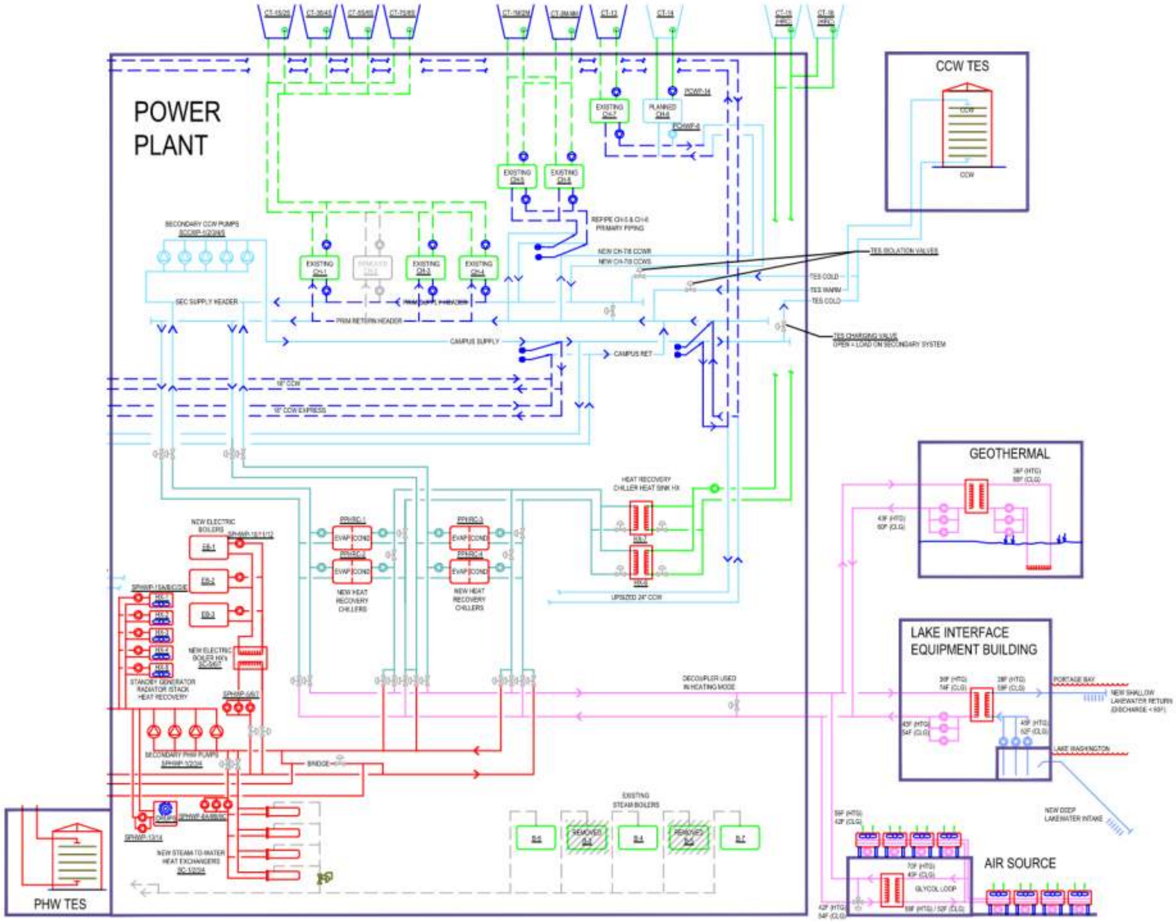


Figure 4.2.2.1-1: *Mechanical system diagram for the Power Plant. Refer to Appendix 9.3 MSSD-1, Mechanical System Schematic Diagram for a larger format version of this diagram for readability.*

Recommendations

The Power Plant has the highest concentration of recommended work since it contains much of the campus cooling capacity (current and future) as well as the critical heating systems for standby operation (combustion boilers). The following projects are recommended as part of the ERP:

- Existing system renewal, replacement, and removal
- Conversion of CCW system to year-round operation
- Power Plant controls upgrades
- Power Plant Campus Cooling Water (CCW) upgrades
- Power Plant Primary Heating Water (PHW) systems

- Power Plant electric boilers
- Emergency generator heat capture
- Thermal Energy Storage (TES)
- New chillers for peak cooling capacity/future weather

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

Key System Characteristics

Power Plant mechanical system capacity and characteristics:

- Heating capacity:
  - Normal operation: 53 MWth
  - Capacity with largest equipment out of service (N-1): 43 MWth
  - Standby capacity: 228 MWth (Combustion Boilers 4, 6, and 7)
- Cooling capacity – **without** UWMC chillers consolidated to PP:
  - Normal operation: 33,000 tons
  - Capacity with largest equipment out of service (N-1): 31,000 tons
  - Standby capacity: TES tanks discharge. Chillers not on generator power.
- Cooling capacity – **with** UWMC chiller capacity consolidated to PP:
  - Normal operation: 37,000 tons
  - Capacity with largest equipment out of service (N-1): 35,000 tons
  - Standby capacity: TES tanks discharge. Chillers not on generator power.
- Thermal Energy Storage capacity:
  - Chilled water storage: 4.2 million gallons usable / 35,000 ton-hrs / 123 MW-hrs
  - Hot water storage: 1.3 million gallons usable / 333,000 MBTU / 97 MW-hrs
- Campus Distribution Pumps:
  - CCW Secondary: 5 x 9000 GPM / 700 HP (N+1).
  - PHW Secondary: 4 x 6,300 GPM / 600 HP (N+1).

- Heat recovery chiller technology: Non-custom equipment with compound centrifugal compressor technology by domestic manufacturer.
  - R-513A refrigerant.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included record utility drawings, site plans, field investigation to develop and validate proposed modifications to the Power Plant to accommodate new equipment, campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

Alternatives and Scenarios

Existing System Renewal, Replacement, and Removal

The Power Plant has many systems that will continue to be relied upon as part of the Energy Renewal Plan. It is expected and accounted for in the Life Cycle Cost Analysis that systems that remain would be renewed as part of a trueing up of deferred maintenance. As part of that renewal, some of these systems would be upgraded to better support the future load conditions resulting from anticipated changing climate conditions. Details on those upgrades are included in this section.

The following list indicates the major systems that are planned for continued use in servicing the campus in the final stage of the Energy Renewal Plan:

- Heating System (Steam converted to Hot Water)
  - Power Plant Boilers (3 of 5 existing boilers)
    - Anticipate B-4, 6, and 7 continue to provide steam in a backup role for the purposes of hot water generation within the Power Plant.
    - Steam condensate systems would eventually be reduced since campus distribution would be eliminated.
  - Diesel fuel oil tank and fuel oil system remains for use with diesel engine generators and as a secondary fuel source for boilers.
- Cooling System (CCW)
  - Most of the campus cooling water piping system will remain and be expanded upon. Refer to Section 4.3.2 for more details on the mechanical distribution.

- Water-cooled electric-driven chillers (all) and associated pumps.
- Cooling towers (all) – end-of-life replacements would increase fan power and fill media capacity to increase tower performance under warmer wet bulb conditions (76°F wet-bulb temperature by 2050).
  - PP CT-1 thru 8, could be retrofit with larger fan motors and improved fill media (while remaining code-compliant) and achieve a 13% increase in output at the existing operating conditions or to maintain current design flow rates and temperature at an increased outside wet bulb temperature.
- Water treatment systems – retrofitted / expanded as part of Thermal Energy Storage upgrades.
- Make-up water and expansion tank systems – retrofitted and retro-commissioned to adjust system fill pressure and expansion tank capacity to new system volume and point of zero pressure change for a combined system.

The following list indicates major components of the current system which will be phased out as part of the final stage of the Energy Renewal Plan:

- Heating System (Steam)
  - Boilers 3 and 5 are planned to be demolished to allow for installation of new heating system components.
    - This work would ideally occur after the WCUP heating system improvements to allow for the boiler capacity to be replicated by heat recovery chillers, offloading the demand for steam from the Power Plant.
  - Steam and condensate distribution systems external to the Power Plant
  - Backpressure steam turbine – decommissioned once the demand for low pressure steam has decreased below the minimum operating point of the turbine or when the steam boilers are relegated to a backup/standby role
- Cooling System (CCW)
  - Chiller #2 is a steam-driven chiller primarily used to maintain demand for low pressure steam during the summer to optimize the operation of the backpressure steam turbine.
    - Once the steam turbine is decommissioned, this chiller will no longer provide a useful purpose.

    - Chiller #2 is located in a part of the plant that would make it difficult to replace with a water-cooled electric-driven chiller. This chiller is planned for removal and will not be replaced.

- Hydropneumatic/expansion tank
  - As part of the Thermal Energy Storage tank project, the TES will become the expansion tank for the combined WCUP/PP CCW system. The hydropneumatic tank at the PP will be decommissioned.

Heat Recovery Chiller Technology

There are many manufacturers and technology options that were considered for this project. The primary factors of concern were:

- Performance including:
  - Maximum hot water supply temperature.
  - Energy efficiency.
- Track record of proven installations operating in similar environments.
- Compliance with recent changes to Washington State refrigeration regulations.

The main categories of equipment that were considered included:

- Conventional heat recovery chiller technology utilizing compound compressors.
- Conventional heat recovery chiller technology in a cascade arrangement.
- Screw compressors utilizing ammonia.
- Custom heat recovery chillers.
  - Custom machines can be designed for synthetic refrigerants, CO2, ammonia, butane, among other refrigerants.

Conventional chillers offer the highest efficiency of the technologies studied, primarily due to their reliance on maintaining a lower hot water supply temperature (max 170°F). These machines are also available from manufacturers that the university has a long history with: York and Trane. The approach for each manufacturer differs with York providing a compound compressor, with compressors in series and Trane offering the cascade approach, requiring two chillers to produce the design hot water temperature. This study utilizes the York CYK chiller as the basis for the cost and energy studies, however further evaluation will be provided in the project's detailed design phase to validate the final chosen manufacturer.

Ammonia is gaining traction as a natural refrigerant with a global warming potential of zero. Ammonia refrigeration systems are not uncommon in industrial applications but have not gained much traction in the commercial / institutional space due to the concerns of creating hazardous conditions for the facility operations staff if there were a critical leak of ammonia. Manufacturers of ammonia-based screw chillers include GEA and Vilter. The industry is currently positioning these machines as packaged chillers with a heat capacity of roughly half that of the conventional machines discussed above. This leads to a higher space requirement and less scalability compared to the conventional machines. Additionally, during the course of this study several equipment representatives were contacted, and the products provided could not meet the design temperature conditions of this project due to limitations on their compressor technology.

Custom chillers have performance claims that make them very attractive to UW's unique campus characteristics, primarily around the ability to generate hot water supply temperatures of 200°F or higher. The high hot water temperature has the potential to allow for significant reductions in hot water distribution piping size, however the system has a low efficiency compared to the other technologies studied (~2.3 COP vs. 2.5-3.0 COP) and has no benefit in efficiency from reductions in the hot water supply temperature during non-peak periods. Additionally, these products are essentially one of a kind, site-built machines that were developed for the oil and gas industry. The leading manufacturer for this style of machine is MAN-ES, a company headquartered in Germany.

Conversion of CCW System to Year-round Operation

Background

The new systems will rely on campus waste heat recovery and must operate both the heating and cooling systems year-round. Currently, the Power Plant CCW system is operated only seasonally as a cooling loop and outside of that window is used as a source-sink loop for process loads.

The CCW system was originally considered a comfort cooling system, with a defined period of operation from approximately mid to late May to mid -October (this operating schedule has gradually expanded due to warmer weather.) The system has been operated as a source-sink (heat recovery) loop during the months outside the cooling window, with some select 100% outside air buildings drawing heat from the loop to preheat outside air, and other buildings discharging heat from process cooling loads into the loop. The Power Plant equipment cooling loop also discharges heat into this system. The heat balance has been maintained over the years by adding heating or cooling loads to the loop as new buildings and systems were designed-- adding heat sources if the loop was not warming or adding heat sinks if the loop temperature was rising too high. Anecdotally, the temperature of this loop rises to 70°F at its peak periods.

Proposed Modifications

Since the Power Plant chillers and WCUP chillers have not often been run in parallel (particularly at peak periods) retro-commissioning is intended to expose unforeseen hydraulic issues that arise as the two plants operate together. The retro-commissioning effort will be facilitated by the addition of a wide array of new metering /monitoring devices. These additional devices and recommended retro-commissioning activities are detailed in Appendix 9.13 Scope of Work document SOW-P-1. Additional metering hardware would include:

- Additional differential pressure sensors in the north and southeast sections of the campus to supplement the existing monitoring devices.
- Absolute pressure sensors at system low and high points.

This work would be sequenced with the Power Plant campus cooling water (CCW) upgrades discussed later in this section. Under that work, PP chilled water pumps will be converted from their current manually operated state to primary-secondary operation with fully automated variable speed capability.

Buildings with process cooling loads are typically configured as shown in Figure 4.2.2.1-2.

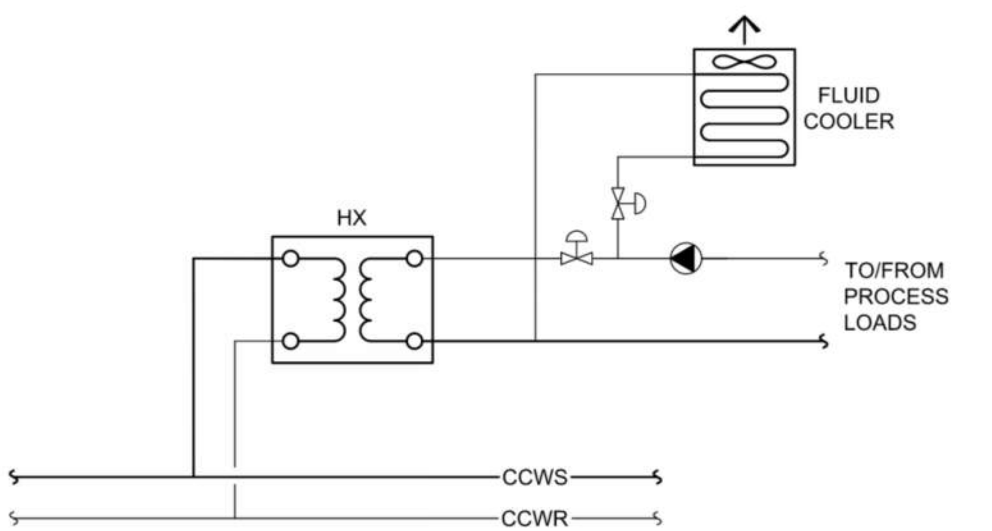


Figure 4.2.2.1-2: *Buildings Using CCW as Heat Sink in Winter (Current and Future)*

Initially, these buildings remain largely unchanged with reprogramming to use CCW as the sink when heat addition is beneficial to the system (e.g., when campus heat loads exceed campus cooling loads). Over time, as Fluid Cooler systems near their end-of-life state, they could be eliminated to reduce maintenance, provided that the process being served is not critical and does not require redundancy.

Buildings using the CCW loop as a winter heat source are typically configured as shown in Figure 4.2.2.1-3:

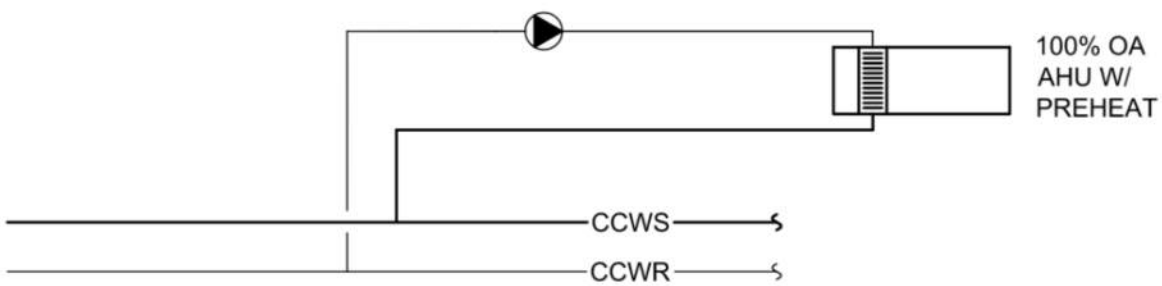
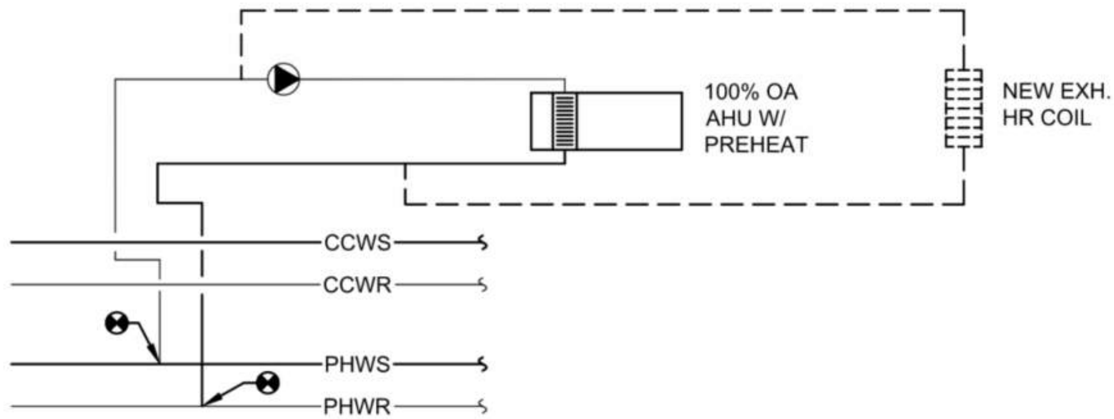


Figure 4.2.2.1-3: *Buildings Using CCW as Heat Source in Winter (current)*

If the building already includes hot water heating coils, these coils can optionally be de-commissioned and removed (to reduce pressure drop). If the building requires a new primary heating water heating (PHW) coil (i.e., it uses steam preheat now), the OA preheat coil should be evaluated for use as the new PHW coil.

As an efficiency improvement, the outside air preheat coils could be incorporated into a building runaround heat recovery loop, if a heating water coil already exists and the exhaust side of the building can accommodate a coil. This should be evaluated for feasibility on a building-by-building basis in the future.

Figure 4.2.2.1-4 summarizes the three options for addressing AHU preheat coils.



OPTION 1: FOR BUILDINGS W/O HOT WATER HEATING COIL. RECONNECT PREHEAT COIL TO NEW PHW SYSTEM.

OPTION 2: RECONFIGURE AS PART OF A NEW RUN AROUND HEAT RECOVERY SYSTEM.

OPTION 3: DEMO COIL AND PUMP, DISCONNECT FROM CCW.

Figure 4.2.2.1-4: *Buildings Using CCW as Heat Source in Winter (recommended conversion)*

Power Plant Controls Upgrades

This work will consist of the following -- upgrade Power Plant PLC-based control system to perform the following functions:

- Automate control of primary CCW pumps, chillers and cooling towers. Add VFDs to pumps where not currently present for added flexibility. Cooling tower fans all include VFDs (installed in 2012/2013 upgrades).
  - Address existing chillers, pumps and towers
  - Include integration and automation of new CH-8 and CT-14 controls.
- Automate sequencing of chillers and future heat recovery chillers for both CCW and PHW production.
  - Automate lake water pumping as a heat source to support heat recovery chiller heating mode. Automate switchover to backup cooling tower use for heat recovery chillers when cooling dominates campus loads (and conventional chillers are insufficient to meet load).
  - Automate sequencing of backup heating (whether from steam-to-hot water converters, from future electric boilers or from generator radiators when in use).

- Integrate with WCUP in sequencing of heating and cooling equipment.

Automation of the CCW system should include addition of VFDs to pumps to allow fine-tuning of flow control and to minimize energy use. New differential pressure sensors have already been defined in scope memo P-1 and will be necessary for automated control of chilled water pumping; pumps will control to maintain minimum delta-P at the worst-case point in the system currently being served.

Chillers should be staged automatically based on a combination of chiller leaving water temperature feedback, system delta-P feedback and feedback from flow meters (primarily the three existing "controlotron" BTU meters). Loss of leaving water temperature control should be the primary means of staging on a new chiller, but the system should also monitor the system's ability to meet differential pressure requirements at all monitoring points being serving and at the system's current delta-t/flow characteristics.

Cooling towers fan VFDs are currently manually enabled, but once enabled, the existing PLC system controls fan speed to maintain condenser water supply temperature. The PLC system also monitors minimum flow switches at individual tower cells and vibration switches at fans. Like the chillers, enable and disable signals to tower fan VFDs should be automated and tied to the quantity and location of operating chillers.

Power Plant Campus Cooling Water (CCW) Upgrades

Background

The CCW system at the Power Plant suffers hydraulic issues that are only likely to worsen as the plant expands with more systems feeding into the same convoluted distribution system. The manually operated primary-only pumping system is also incompatible with the future heat recovery chiller system, which will require a tighter control of flows from the plant heating and cooling equipment to maintain stability.

The current Power Plant CCW system is a manually operated primary pumping only system with dedicated pumps per chiller. The CCW header is unconventional in that it interconnects plants and loads in a way that only makes sense historically and geographically (i.e., location of multiple plants and tunnel connections). The result is a series of three CCW plant areas within the Power Plant pumping into a circuitous header in three locations with distribution takeoff points to loads occurring at various points along this header. This creates hydraulic issues that are currently addressed by operating pumps not associated with operative chillers at certain times of year to get water to flow in appropriate directions (resulting in degradation of chilled water supply temperature).

The PP CCW system is also currently designed as a primary-only supply system, which makes the chiller flowrates dependent on the system flowrate, and vice versa. Primary-secondary pumping offers more flexibility, particularly when heat recovery chillers are added to the system. Primary-secondary systems more easily accommodate thermal energy storage tanks and maintain a continuous flow of water through the heat recovery chiller which is critical to plant stability. Conversion of the PP CCW system to Primary-secondary operation is the recommendation.

Proposed Modifications

As part of this conversion, the following work will occur within the Power Plant:

- Installation of a new CCW piping header across the Power Plant, creating a true common header that interconnects all of the three existing sub-plant chiller areas (the CH-1 thru 4 area, the CH-5/6 area and the CH-7 /future CH-8 area) as well as the future heat recovery chiller locations, providing each chiller equal access to each load with no preference towards serving one load over another.
- Creation of a primary-secondary bridge/decoupler, normally incorporating the CCW TES tank as the bridge (but also with conventional decoupler capability).
- Addition of secondary pumps that will distribute CCW to loads equally.
- Disconnection of main distribution piping connections from the current circuitous header, and reconnection of main distribution piping to the secondary pumps' distribution header.
- Connection of the cold thermal energy storage (CTES) tank in two ways; the tank will have connections to the load side of the secondary distribution system for charging as well as to the primary-secondary bridge (effectively making it part of the bridge) for discharging.

The existing "header" interconnects three distinct chiller plant areas with loads interspersed between plants. The creation of the common header will involve a new 42" supply and return primary CCW headers routed in the upper coal bin area from the three existing chiller areas south to the proposed location of new heat recovery chillers in the area currently occupied by boilers 3 and 5 (to be demolished, see section on Existing System Renewal, Replacement, and Removal) and the proposed location of new secondary CCW pumps in the Shop 43 area. The location of the secondary pumps in Shop 43 will also require (1) additional 42" secondary CCWS line to be routed thru the coal bin from the secondary pumps back to the main points of distribution near existing CH-5 and 6. See Figure 4.2.2.1-5 for a potential route for these pipes. Existing concrete structure is expected to remain with structural steel framing and supports added.

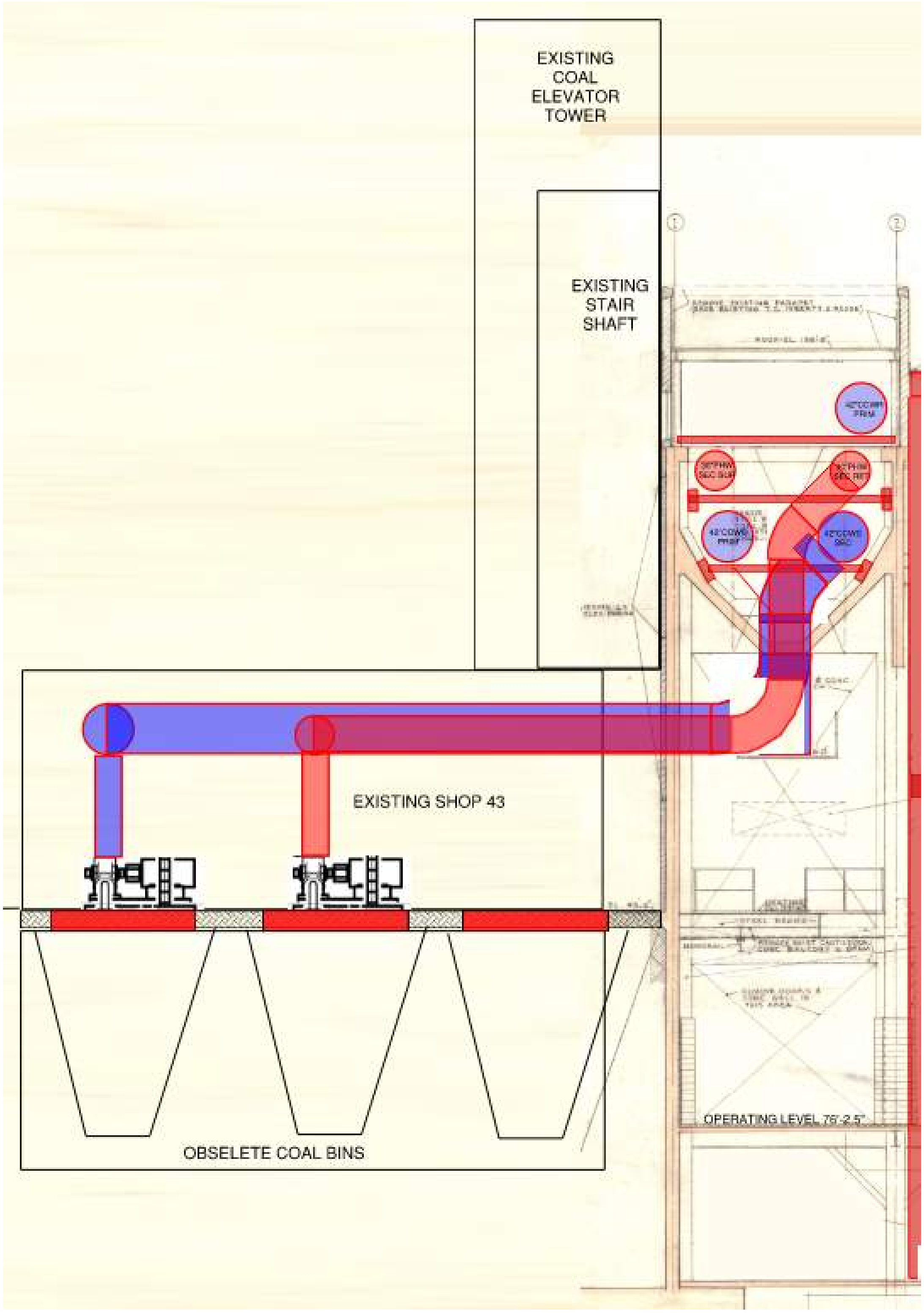


Figure 4.2.2.1-5: *East-west section looking north through Power Plant at Shop 43 area (converted to mechanical room) with new pipe header distribution through coal bin area. Refer to Appendix 9.13 Scope of Work documents for more detail.*

Secondary pumps facilitate several functions necessary for operation of a heat recovery chiller plant with thermal storage. The secondary pumps are critical in discharging the CTES tank and help to separate the variable demands of the campus from the heat recovery chillers so that stable equipment operation can be maintained.

The secondary pumps are proposed to be in the Shop 43 area, which will be modified from its current use as a shop space to become a mechanical room for the new secondary pumps and an electrical room for the gear servicing the new heat recovery chillers, pumps, and boilers.

The reconfigured CCW system and added secondary pumps are shown diagrammatically in Figure 4.2.2.1-6.

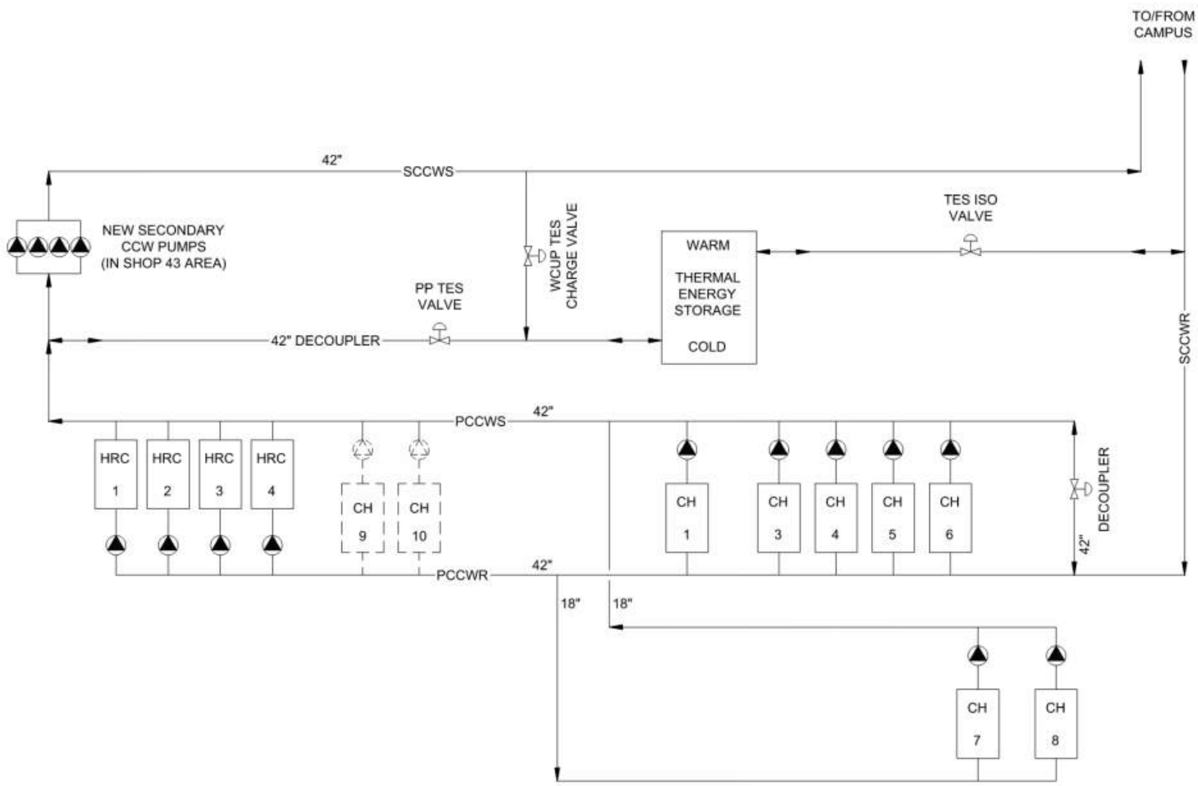


Figure 4.2.2.1-6: *Diagram of reconfigured CCW system*

Thermal Energy Storage (TES) Tanks

The Case for TES

As discussed in the Section 4.1.2 Energy Sources – Campus Waste Heat Recovery, Thermal Energy Storage tanks are integral to operation of heat recovery chillers. Heat recovery chillers are essentially fixed-speed machines that operate at the top end of what chillers are capable of (high pressure and temperature). Thermal Energy Storage tanks are integral in matching the operating capabilities of the heat recovery chillers to the varying demands of the campus.

Beyond that base requirement, TES acts as a thermal battery which can be used in multiple ways to improve:

- Resilience to utility service interruptions. TES serves the campus until plant equipment is restarted after a utility outage or significant voltage sag event (refer to Section 6.4.1 for more discussion on the campus' history of utility outages).
- Utility costs by strategically staging equipment to operate in lower utility rate charge periods. Current utility rate structures incentivize electrical use at night, but future rate structures are also likely to incentivize lowering peak electrical demand as well.

The ERP implementation plan includes TES tanks for both CCW and PHW systems for the above reasons. This is in line with the strategies used by most higher education campus systems, even those with less aggressive carbon reduction goals. The benefits to system resilience and cost savings have driven many universities towards TES tanks.

TES Sizing

The proposed TES tank capacities were evaluated and presented to the UW Energy & Utilities team. Thermal Energy Storage tank sizing is entirely driven by the intended use case. Several use cases were looked at with the corresponding volume requirement, to:

- Cover a utility service interruption at peak load.
- Cover the minimum requirement to operate Heat Recovery Chillers.
- Take advantage of time-of-day electrical utility rates.
- Maximize campus waste heat recovery with diurnal energy storage.

Various tank sizes were evaluated, as shown in Table 4.2.2.1-1, with criteria for resiliency and operations as described above. UW selected the 4.2-million-gallon CCW TES tank and 1.3-million-gallon PHW TES tank for the 1-hour utility service interruption benefit which provided the greatest benefit towards meeting the campus loads. When outdoor air temperatures approach design winter temperatures, Power Plant combustion boilers will need to be warmed to the point required for an accelerated start-up in the event of a utility service outage.

Table 4.2.2.1-1: Thermal Energy Storage Tank Benefits for CCW and PHW Systems Based on Tank Volume

		CCW Benefits				PHW Benefits			
		Resiliency Criteria	Operational Criteria			Resiliency Criteria	Operational Criteria		
Tank Volume [Gal]	Approx Tank Size	1-Hr Utility Service Interruption Capacity [tons]	HRC 4-hr Operation	Utility Peak Offset [$/yr]	Diurnal Energy Storage [$/yr]	1-Hr Utility Service Interruption Capacity [tons]	HRC 4-hr Operation	Utility Peak Offset [$/yr]	Diurnal Energy Storage [$/yr]
600k	45'D x 60'H	N/A				135,000	Yes	See CCW Benefits	$25k
900k	50'D x 70'H					202,500	Yes		$35k
1.1M	50'D x 85'H	8,250	Yes	-	$17k	247,500	Yes		$40k
1.3M	55'D x 80'H	9,750	Yes	-	$20k	292,500	Yes		$43k
1.6M	60'D x 85'H	12,000	Yes	$130k	$23k	360,000	Yes		$48k
2.4M	70'D x 90'H	18,000	Yes	$195k	$25k	540,000	Yes		$52k
3.2M	80'D x 95'H	24,000	Yes	$260k	$25k	N/A			
4.2M	90'D x 100'H	31,500	Yes	$325k	$25k				
4.8M	90'D x 110'H	36,000	Yes	$390k	$25k				

Siting

With a size determined, tank sites could be evaluated. Several sites were evaluated, however the requirement for proximity to the Power Plant allowed for a quick screening that eliminated the other options further to the north. Refer to Appendix 9.7 Site Analysis & Zoning Study for additional detail. Refer to Figure 4.2.2.1-7A, 4.2.2.1-7B, and 4.2.2.1-7C for a vicinity plan, site plan, and a section of the proposed site.

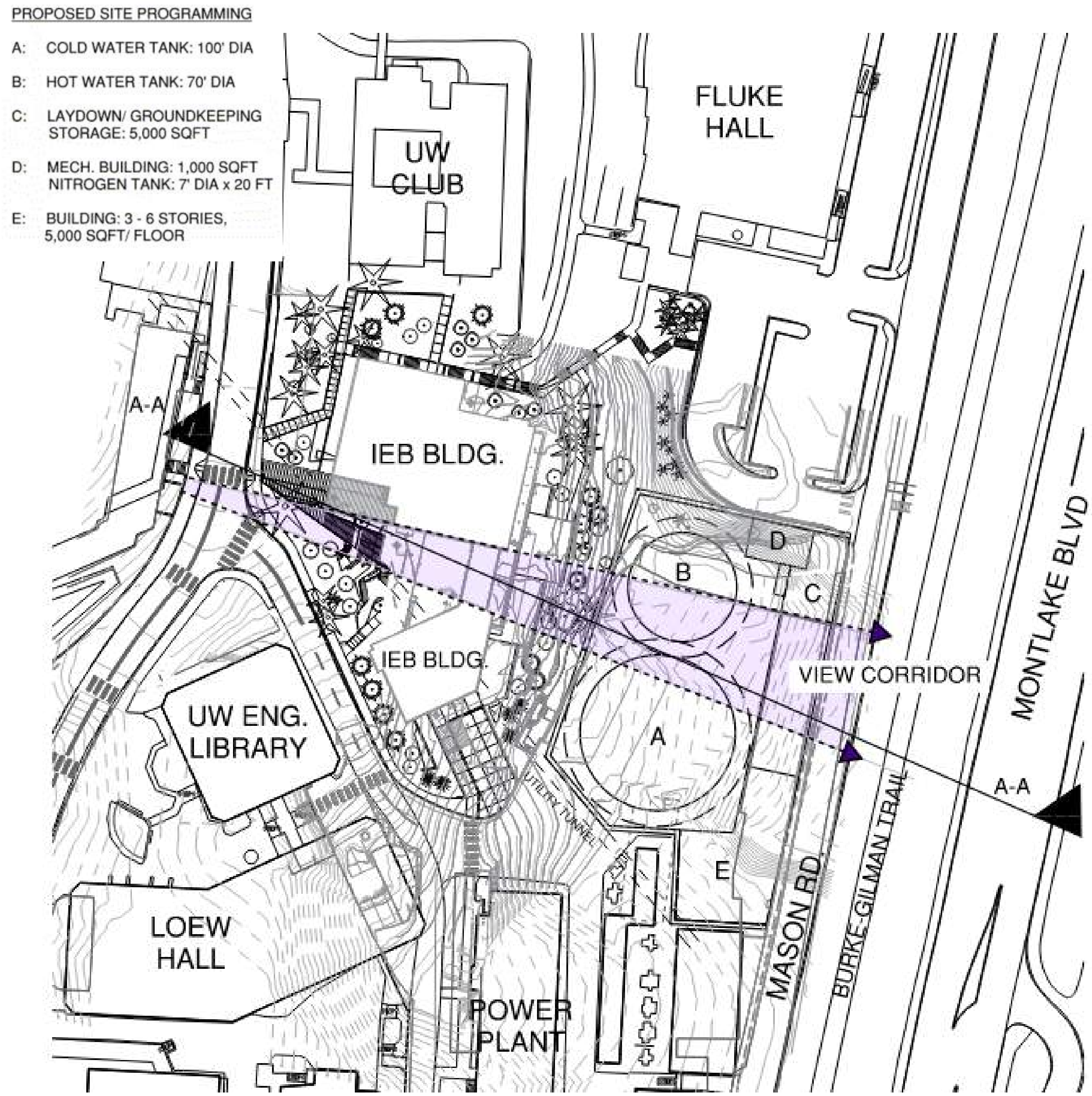


Figure 4.2.2.1-7A: *Vicinity plan showing the campus buildings within the vicinity of the proposed TES site*

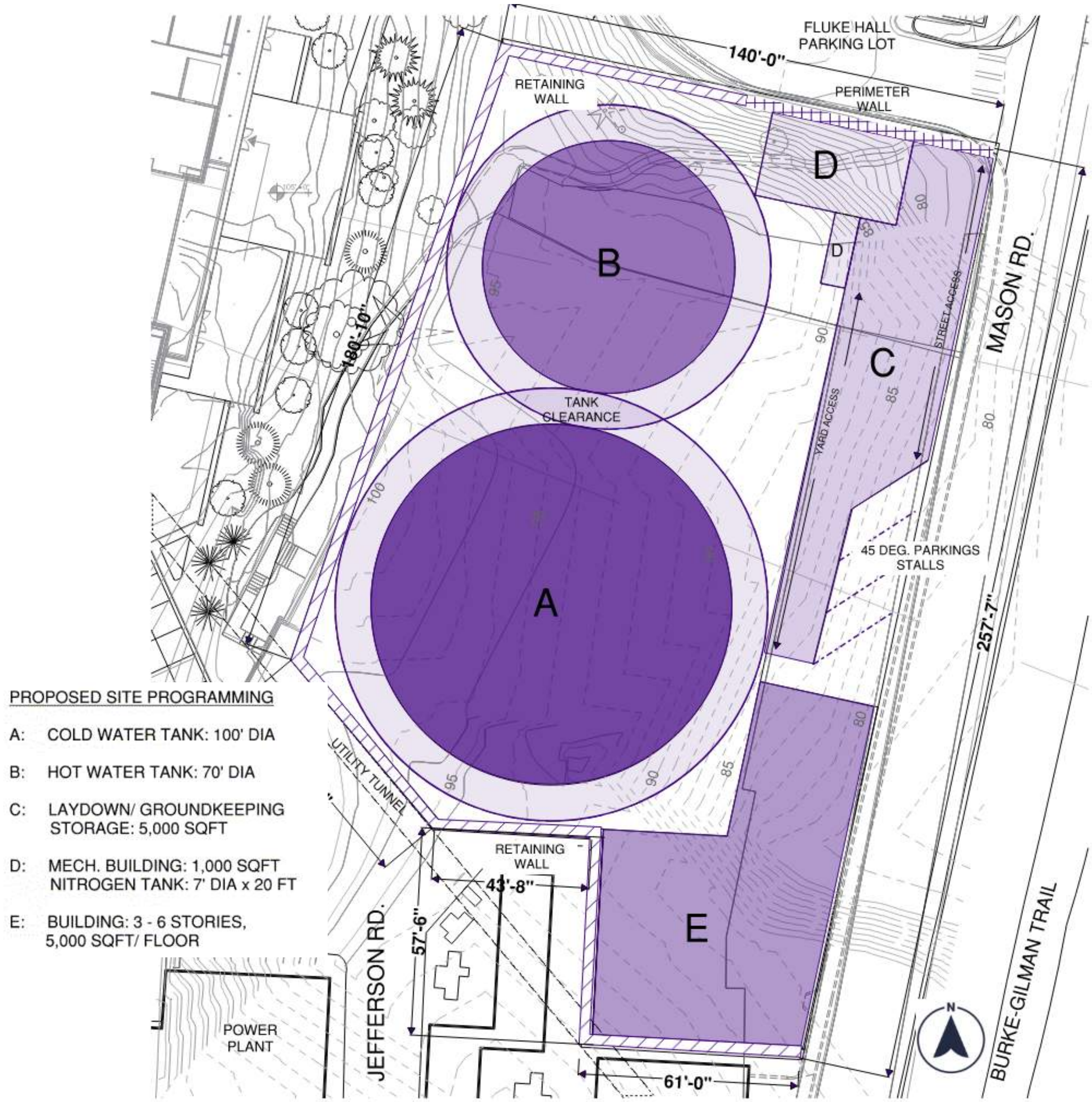


Figure 4.2.2.1-7B: *Site plan of TES tanks and Facilities Services building*

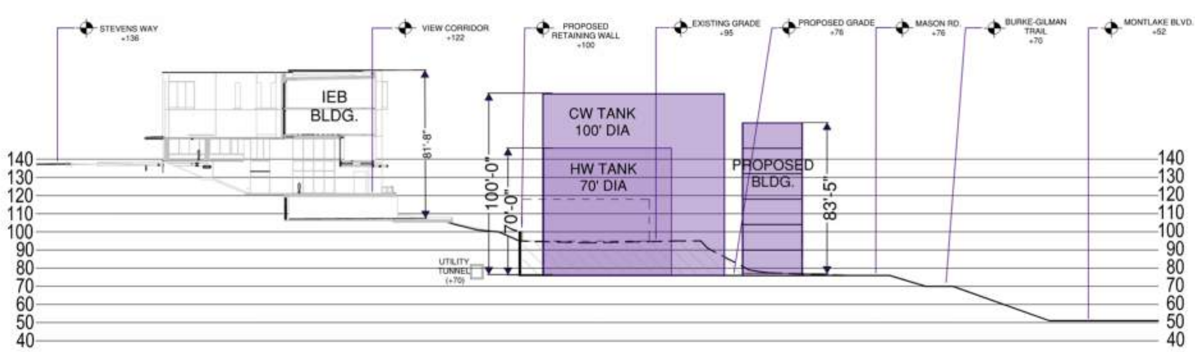


Figure 4.2.2.1-7C: *Section of the proposed TES site*

The proposed site currently is home to the Plant Operations Annex 2, 3, 4, and 6 buildings which houses groundskeeping, UW's Campus Controls group, UW's Facility Services Engineering group, and other facilities service personnel. These Annex buildings will be demolished, and the site excavated and re-graded to match the current elevation of Mason Road to the east. These groups would be displaced with the plan to relocate the office personnel to other campus surplus space and provide new space for the groups that need to continue to be in this location via new Facilities Service building on the proposed site. Refer to Appendix 9.13 SOW-P-5 for additional detail.

Scope Considerations

The addition of TES tanks to the existing CCW system triggers additional work in the system. Among other concerns, the tanks are open to the atmosphere (non-pressurized) and so act as the expansion tank for the system. Portions of the existing system that are at an elevation above the TES tank water height must be addressed to reduce the pressure experienced by the tank. The following is a summary of the work that would be done to prepare the system for the new TES tanks:

- Eleven buildings will require a new set of pressure sustaining valves and pumps as indicated in Figure 4.2.2.1-8 to protect the new TES tank from over pressurization. The number of buildings impacted is determined by the height of the tank, so a shorter tank than proposed would require more buildings to be modified. Refer to Appendix 9.13 SOW-B-1 for the specific buildings impacted.
- PP CCW system upgrades (refer to previous section) – primarily the need for the existing CCW header to be reworked and the addition of CCW secondary pumps which will be the way that the CCW TES is discharged.

- Water treatment system expansion – the existing system must be expanded in capacity since the system volume (currently estimated at 1.5 million gallons) is increasing by a factor of four.

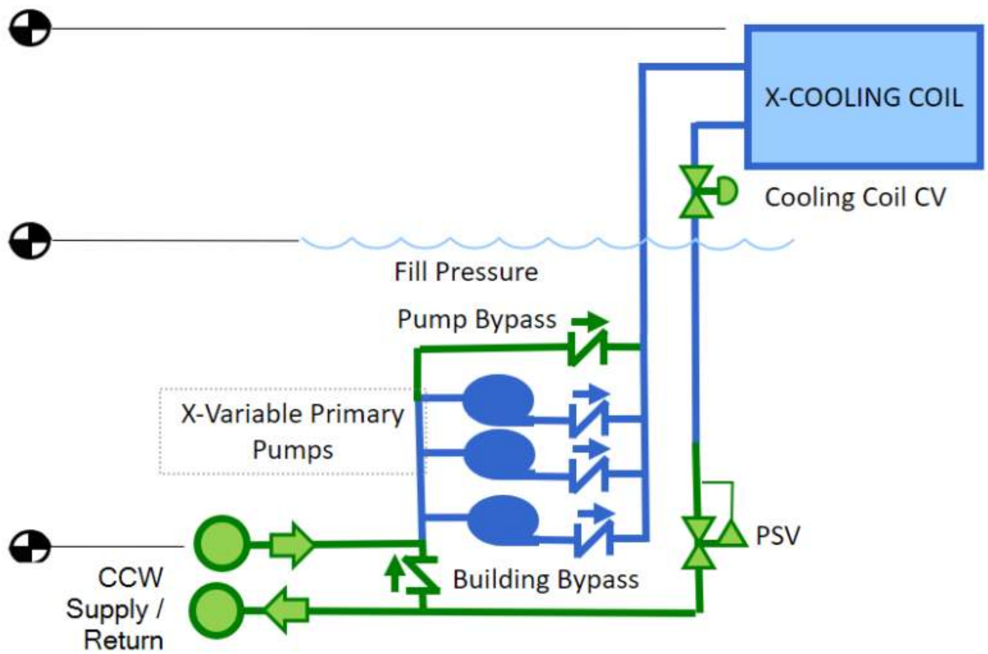


Figure 4.2.2.1-8: *Diagram showing a building with cooling coils located above the system fill pressure that would require a new pressure sustaining valve (PSV) and building pumps*

The TES tanks associated with the new PHW system will not trigger additional work within the buildings, however this tank will require a nitrogen generator and pressure maintenance system. Hot water systems operate at an elevated temperature and are more likely to entrain oxygen which can be detrimental to the new steel pipe system. The nitrogen pressure maintenance system provides a blanket of nitrogen at the exposed surface of the water and maintains the tanks at roughly atmospheric pressure.

New diesel engine generators will be provided to serve the secondary pumps (CCW, PHW) during a power interruption. The generators are necessary to allow for the stored water within the TES tanks to serve the load until standby systems can be ramped up (in the case of combustion boilers) or until utility service is restored (in the case of cooling).

Power Plant Primary Heating Water (PHW) Systems

Background

The PP currently provides steam for the entire campus. With its proximity to the Lake Water Interface energy source, the PP is the logical place for locating the heat recovery chillers that will be used for Lake Water Heating & Cooling.

First Phase – Steam to Primary Heating Water

It is envisioned that the initial phase of the campus heating water system originating at the Power Plant would begin with the addition of steam-to-water heat exchangers and campus PHW secondary distribution pumps. This will allow the PP to begin to serve buildings with hot water, generated through steam. Ultimately, the PHW system will connect both the WCUP and Power Plant. The steam-to-water aspect of this system is a phased solution. In the interim period before the heat recovery chillers and electric boilers are in place, the steam-to-water heat exchangers will be the primary source of heating for the PHW system. In the final condition, the steam-to-water heat exchangers will be part of the standby power system operation and allow for heat from the combustion boilers to be used during campus electrical utility outages.

The steam-to-water heat exchangers and PHW pumps will be located in the place of Boilers 3 & 5 on an elevated platform above the heat recovery chillers, refer to Appendix 9.13 Scope of Work document SOW-P-10.

Second Phase – Heat Recovery Chillers

The next phase of the campus heating water system will involve installation of the heat recovery chillers and associated cooling towers and heat exchangers as detailed in the Appendix 9.3 MSSD-1 Mechanical System Schematic Diagram and Appendix 9.13 Scope of Work document SOW-P-8. The heat recovery chillers will connect to the CCW, PHW, Lake Water, and cooling tower systems allowing for operation in any of the following modes:

- Campus waste heat recovery
- Lake water interface (heating or cooling)
- Cooling-only mode with heat rejection through cooling towers

Prior to installation of the PHW Thermal Energy Storage tank, the PP heat recovery chillers would be carefully staged to prevent short cycling. Once the TES tanks are in place, the operation of the PP heat recovery chillers will be optimized, increasing energy efficiency, and simplifying system operations, as their runtime will not be as dependent on the campus load.

The four heat recovery chillers will be located in the space formerly occupied by boiler 3 & 5. Each heat recovery chiller will be served by a primary VFD-driven PHW and CCW pump, located on the basement floor below each chiller. The heat recovery chillers will be configured as a primary-secondary pumping system, with secondary distribution pumps in the Shop 43 area.

As discussed in the Section 4.1.4 Energy Sources - Lake Interface (Heating & Cooling), water discharge to Portage Bay must be limited to 57°F or less. If Lake Water intake temperature rises above 51°F, the heat recovery chillers will be supplemented by cooling towers.

Proposed Modifications

The following work will occur within the Power Plant:

- Installation of steam-to-water heat exchangers and associated pumps.
- Installation of four heat recovery chillers and associated pumps.
- Installation of a new PHW piping header across the Power Plant.
- Installation of secondary PHW pumps.
- Installation of two cooling towers and associated pumps
- Creation of a primary-secondary bridge/decoupler, normally incorporating the PHW TES tank as the bridge (but also with conventional decoupler capability).
- Connection of the PHW Thermal Energy Storage tank in two ways; the tank will have connections to the load side of the secondary distribution system for charging as well as to the primary-secondary bridge (effectively making it part of the bridge) for discharging.

Power Plant Electric Boilers

Since heat energy sources during peak heating conditions are limited, and in some cases variable (sewer, campus waste heat), electrode boilers will be used to provide supplemental peak heating capacity. Electrode boilers will be deployed in the later stages of the ERP implementation as a tool to reduce or eliminate the last ~10% of annual fossil fuel used for campus heating. Electrode boilers are essentially a back-up plan to other strategies of full decarbonization, which may include:

- Building energy efficiency and load reduction measures that reduce the campus peak heating to within a range that can reliably be handled with heat pumps and TES.
- Emerging technologies – refer to Emerging Technologies section.

During the interim period before electrode boilers are provided, the campus will rely on the fossil fuel combustion boilers for peak heating. Combustion boilers will be prepared for operation seasonally using weather forecasting to predict peak heating periods where the boilers would be required.

Electrode boilers located in the former Boiler 3 & 5 area provide trim heat for new PHW system beyond what the heat recovery chillers can provide under peak load scenarios. Electrode boilers create steam using high voltage electricity, and heating hot water is created with steam-to-hot water heat exchangers. These heat exchangers are tied into the primary heating water system with a sidecar piping/pumping system. The electrode boiler system requires a feedwater system to supply hot water to the boilers, likely to be a skid-mounted system provided by the manufacturer.

Electrode boilers are proposed over electric resistance boilers since they are available in voltages that are compatible with the high-voltage campus power (13.8 kVA) which results in reasonable feeder sizes to the boilers. Electric resistance boilers are not currently available in voltages above 4,160V which would result in an additional level of transformation and massive electrical feeders across existing areas of the plant buildings. It should be noted that both electrode and electric resistance boilers require very large electrical disconnects (comparable in size to switchgear), generally located adjacent to the boilers.

The proposed scope includes:

- 3 x 6-MW electrode boilers.
  - Provided in a redundant arrangement. Only two boilers are intended to operate under peak load scenario.
  - Large electrical controllers, comparable to switchgear, which are required for boiler capacity modulation / staging.
- Packaged feedwater skid for boilers, provided by boiler manufacturer.
- Steam-to-water heat exchangers at each boiler.

Emergency Generator Heat Capture

As the final stage of the ERP implementation, the plant transitions from heat generation with fossil fuel combustion boilers to electric heat generation. At this point, the ability to provide heat on demand during an electrical utility service interruption will become more challenging.

In its current condition, the plant operates combustion boilers and upon a loss of electrical power, a Diesel Rotary Uninterruptible Power Supply (DRUPS) provides power to the critical controls associated with the boilers and operation continues. In the future state, the combustion boilers would not be firing and, if relied upon for heat under these scenarios, will require an amount of time to bring up to capacity. This is discussed in more detail under the Operational Considerations section.

Since the emergency generators that will be used to provide backup power also produce a large amount of waste heat, heat exchangers will be provided to extract heat from the engine jacket water at the five 2 MW diesel engine generators. Heat exchangers will be valved in parallel with existing remote radiators with water redirected to new heat exchangers when generators are operating, and heat is required for campus operation. Each generator rejects approximately 750 kW to jacket water. This generation capability could also be extended to the DRUPS unit, which rejects approximately 700 kW. The total heat capture is ~4 MWth which is <5% of the campus heating load but will work to slow the decline of the PHW system during the outage.

The proposed scope includes:

- Water-to-water plate & frame heat exchangers and pumps at each genset.

New Chillers for Peak Cooling Capacity/Future Weather

The Power Plant includes space for a single additional conventional chiller, a 2,000-ton machine plus the associated pumps and cooling tower. The 2000-ton machine and its associated VFD are shown in Figure 4.2.2.1-9. Refer to Appendix 9.13 SOW-P-2 for additional details.

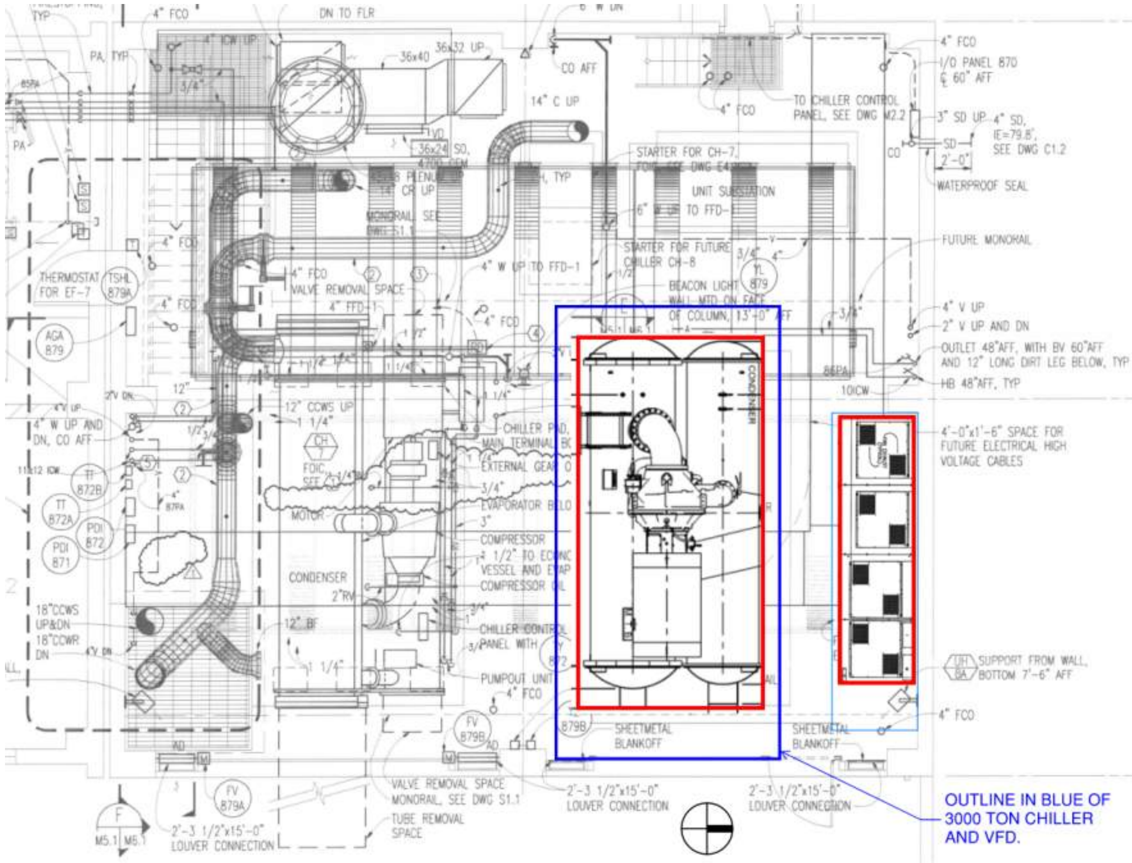


Figure 4.2.2.1-9: *Floor plan showing the location of a new 2,000-ton chiller (CH-8) within the northern most chiller room in the Power Plant. Optional 3,000-ton chiller footprint shown for reference.*

The addition of this chiller to the plant brings the Power Plant capacity to 14,000 tons. That total reduces to 13,000 tons with the absorption chiller (CH-2) removed as discussed in the Existing Systems Renewal, Replacement, and Removal section. The addition of heat recovery chillers and their associated energy sources / cooling towers will bring this capacity to 21,000 tons.

With the increased cooling capacity associated with the consolidation of distributed chillers into the central system (5,500 tons), addition of buildings without cooling (2,515 tons), UWMC cooling (4,350 tons), and the impact of future weather conditions (4,500 tons), the campus peak load will reach 35,000 tons. The UW team instructed the ERP team to plan for the ability for the plant to deliver these loads to the campus but not to include the full buildout within the ERP plan. The ERP implementation plan includes the scope associated with a peak load of 31,000 tons which represents either a lower than predicted future weather condition or the continued segregation of UWMC chillers from the campus plant. The distribution system (discussed elsewhere in Section 4.3.2) is planned for the 35,000-ton future peak.

To meet the future cooling condition, the Power Plant would require the addition of 4,000 tons of cooling which would likely come as a result of the following:

- Replace CH-1 (1,000 tons) with a larger chiller (2,000 tons).
- Demolition of Boiler B-4 and installation of 2 x 1,500-ton chillers, cooling towers, and associated pumps.

Impacts to the Existing Campus Environment

A significant portion of the work within the Power Plant will go unnoticed by the campus.

The TES tanks will have an impact on campus aesthetic along the Burke Gilman Trail and as viewed from Montlake Boulevard and adjacent campus buildings. The elevation and height of the tanks was reviewed with Campus Architecture with the intent to mitigate the impacts as much as feasible, to the views from the new Interdisciplinary Engineering Building and the Husky Union Building. TES tanks are often highlighted on university campuses with campus branding or with appropriate treatments that highlight the importance of energy efficiency and sustainability. Figure 4.2.2.1-10 provides examples from other campuses. Refer to Appendix 9.7 Site Analysis & Zoning Study for conceptual renderings of the TES tanks.

Figure 4.2.2.1-10: *Thermal Energy Storage tanks at Daytona State (left) and North Carolina State Raleigh (right)*

Operational Considerations

Operational Complexity of Electrified Heating Systems

Refer to Section 6.2.2 for discussion on the increased complexity of electrified heating systems and the impact that will have on operator technical expertise, training, and automation.

Campus-level Sequencing Across Power Plant and WCUP

Currently the Power Plant and WCUP systems are operated largely independent of one another. The CCW systems are segregated under normal operation and the Power Plant handles all of the campus' district heating needs.

Once the CCW and PHW systems are connected, the sequencing of heating and cooling equipment will require synchronized operation of the two plants. The system's optimal sequencing will be based on the state of the two Thermal Energy Storage tanks located at the Power Plant. Because of this, the Power Plant should act as the lead for determination of equipment sequencing. Algorithms will be developed to allow the two plants to operate independently in the event of an outage or loss of communication between the two plants, but this should not be the normal mode of operation.

Heating During Electrical Utility Service Interruptions

Once the campus conversion is complete, the campus will be dependent on the electrical system to achieve its peak heating output. This is already the case in cooling mode in the current campus.

In a partial loss of electrical utility service (utility maintenance) where system capacity is reduced but not fully disrupted, heating needs may be addressed via the most efficient means of heating available; likely heat recovery chillers connected to the sewer – due to the highest typically available source temperature and load curtailment at non-critical buildings. If the remaining heat recovery chiller capacity is inadequate for campus load at that time of year, combustion boilers will be relied upon.

In a full loss of electrical utility service due to a regional outage the plant will revert to operation of combustion boilers. The DRUPS provides power to the critical controls associated with the boilers. Initially, the combustion boilers would not be firing and, will require an amount of time to bring up to capacity.

The ERP includes two measures for handling the campus heating demand during the time that the combustion boilers require to start from their idle state. The first measure is discharging the PHW TES tank (with secondary pumps powered by new generators dedicated to that purpose), which at the proposed size is anticipated to be able to satisfy the anticipated load for just over an hour. The second measure is to capture heat from the PP generator radiators by directly heating the PHW system with the heat from the radiators.

It is assumed that a full loss of electrical utility service will also see a reduction in the load on the PHW system since the majority of buildings do not have air handling units or pumps on generator backed power and thus the realized load at the plants would be significantly reduced.

Risks

Plant Seismic/Structural Improvements

This study does not address the structural scope of the project. Significant structural evaluation will be required to determine the feasibility of the proposed equipment and distribution arrangements. Demolition and modifications to the existing structures will be required to accommodate the proposed design.

Key considerations with regard to structural elements on the project include:

- Evaluation for new equipment and large diameter piping throughout the Power Plant facility and across the roof not previously designed for such loads.
- The work within the abandoned coal bunkers should assume selective demolition of the concrete bunkers. The hoppers (slopped portion of bunkers) may be entirely removed with the vertical concrete walls and beams remaining.
- New structural slab and supports located over the existing coal unloading hoppers for new equipment.
- Demolition of the floors, access platforms and equipment supports located in the area of the existing boilers.
- New floors, access platforms, supports for elevated equipment including chillers, boilers, pumps, etc., and roof-mounted cooling towers location in the area of the existing boilers.
- Reinforcement and retrofit of existing framing members for new arrangements and loading.
- New foundations for building columns and equipment located at grade.

The scope of the project assumes an allowance for structural work associated with the plant upgrades.

Conversion of CCW system to year-round operation

Since the Power Plant and WCUP have only occasionally been operated together in the past, and only for limited periods of time, it is critical that the new monitoring devices recommended be installed and appropriate commissioning performed prior to full implementation.

Power Plant Campus Cooling Water (CCW) upgrades

The reconfiguration of the CCW header is a huge and invasive, but also a very necessary, effort. The reconfiguration will be disruptive to normal Power Plant operation and must be scheduled and sequenced to allow continuous operation of the CCW system.

Thermal Energy Storage (TES) Hydraulics

Introduction of a large thermal energy storage tank into the existing CCW system shifts the hydraulics of the campus system by establishment of a new point of zero pressure change at the tank itself, making other expansion tanks in the system obsolete. The proposed tank site at the Power Plant Annex area minimizes these impacts, but full system commissioning and appropriate use of pressure sustaining valves at select buildings above the tank level will be necessary.

At each building with a pressure sustaining valve (PSV) care must be taken to implement a fail-safe operation that disables the building's CCW pumps on a failure of the building's PSV.

Emerging Technology Considerations

In general, two areas that should be watched for impact of emerging technologies include availability of new and improved refrigerants, and availability of heat recovery chillers with higher lift and better turndown capability, higher overall efficiency, etc.

Emerging technologies described in the Section 4.1 would also have cascading impacts to the plant systems.

Development of high-voltage electric resistance boilers would provide a simpler technology than electrode boilers. Resistant boilers are not yet available in favorable voltages (13 kVA) for the campus.

4.2.2.2 Power Plant Upgrades – Electrical

System Overview

The Power Plant electrical systems include the East Receiving Station, five diesel-engine generators (2.0 MW / 4,160V), and a Diesel Rotary Uninterruptible Power Supply (DRUPS) (2.160 MW / 4,160V). The East Receiving Station receives most of its power from the West Receiving Station and a smaller amount of power from SCL. The ERS serves campus loads, including the Power Plant CCW system and the SCL service feeds a majority of the cooling loads at the power plant. The SCL feed is normally kept separated from the rest of the ERS via a normally open circuit breaker. The diesel-engine generators provide primary service to the UW Medical Center (UWMC) as well as to critical equipment (which does not include any CCW equipment) at the Power Plant. The DRUPS was installed in 2022 and ensures that the Power Plant critical equipment loads including the steam boiler equipment and controls remain operational during a voltage sag or loss of electrical service.

A backpressure steam turbine system with a capacity of 3MW was put in service in 2023. A previous steam turbine was replaced but was not in service during the metering interval that was used for this report. This system is provided for energy efficiency and cost savings and is not part of the critical campus electrical infrastructure.

Recommendations

Electrical scope in and around the Power Plant includes the following key components of the ERP electrical systems. The power plant scope includes expanding the medium voltage distribution system to feed new loads at the power plant, lake interface building, and TES. The upgrades include the installation of a new express feeder set from WRS to ED Main and removal of the existing SCL service. The upgrade provides additional capacity to the East of the campus and provides medium voltage distribution to nearby projects. New 13.8 kV distribution switchgear in shop 43 will serve new powerplant loads, the lake interface equipment, and the thermal energy storage system.

New generators serving Power Plant distribution pumps associated with the Thermal Energy Storage system will provide standby power to distribute stored energy. Appendix 9.3 EOD-1, Electrical One-Line Diagrams shows the proposed electrical equipment to be installed.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

It may be advantageous to maintain the operation of the existing SCL service and SCL transformer that feeds the sectionalizing cabinet. The SCL service can serve as a partial back-up source of power. It would be crucial to isolate the ED Bus in this scenario to limit fault current contribution similar to how the bus is operated currently.

Key System Characteristics

Power Plant electrical system capacity and characteristics:

- New electrical demand
- New electrical ring bus capacity

Assessment Data

Metering data summarized in Table 4.2.2.2-1 indicates the existing peak demand from the year 2023. The steam turbine (TG3) was energized and commissioned in November 2023 while the peak demand occurred earlier in the year in August 2023. For this reason, the contribution of the turbine was not fully realized in the data. A power factor of 0.9 pf was assumed. The loads are generally balanced between the feeders.

Table 4.2.2.2-1: ERS Peak Annual Demand Load From the Year 2023

ERS Source	Metered Load	Date
EA Main (fed from WRS WA2)	3,996 KVA	08/15/23
EB Main (fed from WRS WB2)	4,130 KVA	08/16/23
EC Main (fed from WRS WC2)	4,234 KVA	08/16/23
ED Main (fed from SCL)	4,205 KVA	08/15/23
Sum (of EA, EB, EC, and ED)	**16,425 KVA**	**08/15/23**

Alternatives and Scenarios

Feeder Capacity

The existing electrical spare capacity on the existing express feeders from the WRS to the ERS is substantial and is sufficient for the project upgrades. However, the existing switchgear in the ERS only has two spare breakers and utilizing these spares would leave the University with no spare breaker spaces for the future or a change in project direction without significant upgrades. The proposed modifications introduce enough spare breakers in the new EE Bus for the next 50 years while also providing additional redundancy and capacity at the power plant.

The existing electrical demand is 687 amps (16.4 MVA) on a 1200 A, 13.8 kV, 3Ph, switchgear configured in an N+1 redundancy setup. The current infrastructure consists of three feeders, with the combined capacity of any two feeders providing approximately 57 MVA (N+1), while the total capacity across all three feeders is 86 MVA (in N configuration).

The proposed system upgrade includes adding a fourth feeder set to enhance the redundancy by providing a ring bus within the power plant. Under normal operating conditions, the load will be balanced across all four feeders, ensuring both efficiency and reliability in the system's performance. But also unlocks additional capacity and adds spare medium voltage breakers for the future.

Existing System Renewal and Replacement

The existing 13.8 kV electrical switchgear in the ERS is within its lifespan and contains three spare circuit breakers. The proposed new mechanical equipment will require more breakers than is available. To meet the University’s standards and good practice, the project should leave spare breakers for future growth, equipment, and unforeseen electrical loads. The intent is the installation should be providing a minimum of 50 years of service without significant modifications or increases to capacity.

The proposed electrical upgrades at the ERS consist of adding a new feeder from the WRS, new 15kV rated switchgear, 13.8 kV circuit breakers for new ERS loads, and spare 13.8 kV circuit breakers for future use.

Normal Power

The East Receiving Station receives four sources of normal power. Three of the sources come from the West Receiving Station by express feeders and the fourth source comes from an SCL utility feeder and SCL transformer in the ERS yard.

The existing SCL feeder to the ERS supplies primary cooling loads at the power plant. The SCL feeder is a single radial feed from their distribution level service which means it does not have redundancy. If the feeder experiences an outage, the Power Plant (and campus) loses a majority of its cooling capacity and equipment until the UW facilities team can divert power from elsewhere to the equipment. Depending on the time of day and time of year (outdoor temperature) the plant may not catch up to the cooling load for up to a day.

Electrical Feeders from WRS to ERS

The three sets of ERS feeders coming from the WRS are in acceptable condition and are routed in the west trunk tunnel from the WRS to the ERS. The breaker sources and mains are described in Table 4.2.2.2-1.

Consideration should be given to routing the new express feeders by an alternate path to provide protection from a physical disruption in the west trunk from de-energizing the power plant.

Generator Power

The Power Plant houses the diesel generators that provide backup power for the Medical Center and many of the campus buildings. There are five existing 2 MW / 2.5 MVA diesel generators. There is a small amount of spare capacity on the generators, but not enough to support significant new loads.

The thermal energy storage tanks are designed to be used to provide capacity to the campus heating/cooling system during a power outage. To pump the stored energy, the pumps should be powered by generator (standby power). Thus, the project provides new generators for the CCW and PHW secondary pumps which discharge the water from the TES tanks to the campus.

It includes the addition of new generators (2 x 2 MW) to provide standby power capacity for CCW TES operation during a utility outage. Location options include the new facilities support building for the TES tank yard (indoor), the yard space for the TES tanks (outdoor), the Power Plant roof, or the high-bay area in the Power Plant that currently houses the turbine generator. Placing generators in the turbine generator High-Bay is not ideal because the turbine was recently installed and installing generators on the roof involves significant structural upgrades and opens the project to complexity with the fire department.

The preferred locations for the two new generators are either the TES yard (outdoor) or the TES yard support building (indoor).

The generators will require a new paralleling switchgear and automatic transfer pair to feed a new main-tie-main switchboard which distributes power to the CCW and PHW secondary pumps.

Impacts to the Existing Campus Environment

The project will involve several scheduled shutdowns of the ERS switchboard to accommodate the installation of new conductors. These shutdowns will impact both the EA Bus and the ED Bus. De-energizing the EA Bus will temporarily disrupt house power, Chillers 3 and 4, and certain heating steam loads. This operation requires careful coordination to minimize the impact on critical systems.

The ED Bus shutdown, necessary for decommissioning the SCL service, will involve Seattle City Light (SCL) removing their transformer and primary metering equipment. Modifications to the ED Bus to feed the new EE Bus will also result in brief interruptions to Chillers 1, 5, 6, and 7, as well as associated support pumping equipment and the Kirsten Wind Tunnel. It is recommended that this work be scheduled during the winter months when cooling demand is at its lowest.

The installation of new express feeders from WRS to ERS will require work in the west trunk but is not expected to disrupt above-ground circulation.

The installation of the new EE Bus in Shop 43 will necessitate the displacement of the shop area, which will be relocated to the new support building near the TES tanks.

Operational Considerations

The main operational considerations include additional equipment, a new medium voltage bus configuration in the power plant, and additional generator sets with paralleling switchgear.

One of the key proposed modifications involves transitioning the existing multi-ended main-tie switchgear configuration in the ERS to a ring bus arrangement within the medium voltage bus system. This reconfiguration is designed to enhance operational flexibility and system reliability.

The proposed new operation includes normally closing the ECD breaker, which connects the EC Bus and ED Bus but is currently kept open to separate the SCL service from the rest of the ERS. It is understood this is kept open to limit fault current contributions to the ERS bussing.

Risks

Increased fault current introduced by closing the breaker between EC Bus and ED Bus Mitigation measures include increasing impedance of the transformers or installing line reactors at the UW Substation to limit the available fault current contribution from the utility.

Feeders that share a common path between the receiving stations present an operational risk. Alternative paths within the tunnels exist but add significant length to the conductors.

Emerging Technology Considerations

In the event of a power loss from Seattle City Light (SCL), the CCW and PHW pumps for the Thermal Energy Storage (TES) tank can transition to operate as a microgrid, utilizing the new generators as an island. This allows the plant to draw down stored thermal energy. This ensures that the campus can maintain its heating and cooling capacity for a short duration, typically an hour to a few hours depending on outside air temperature, effectively bridging the gap during the power outage until external power is restored, and the heat recovery chillers or boilers can re-energize.

4.2.3 West Campus Utility Plant (WCUP) Upgrades

4.2.3.1 WCUP Upgrades - Mechanical

System Overview

The WCUP houses the campus' segregated CCW system serving critical facilities in the south of Pacific Street region. The WCUP was built in 2017 with the capacity to expand its chilling capacity as well as add heat recovery chillers. The ERP includes plans to build out the future chilling and engine generator capacity of the WCUP and expansion of the building with a new structure to house heating equipment and support space for operators.

The WCUP is planned to house the following key components of the decarbonized heating and cooling systems. Refer to Figure 4.2.3.1-1 for a system diagram of the WCUP in its final condition.

- Heat recovery chillers
- Steam-to-water heat exchangers
- Secondary pumping systems for CCW and PHW
- Electric boilers
- Water-to-water heat exchangers for HRCs to connect to cooling towers

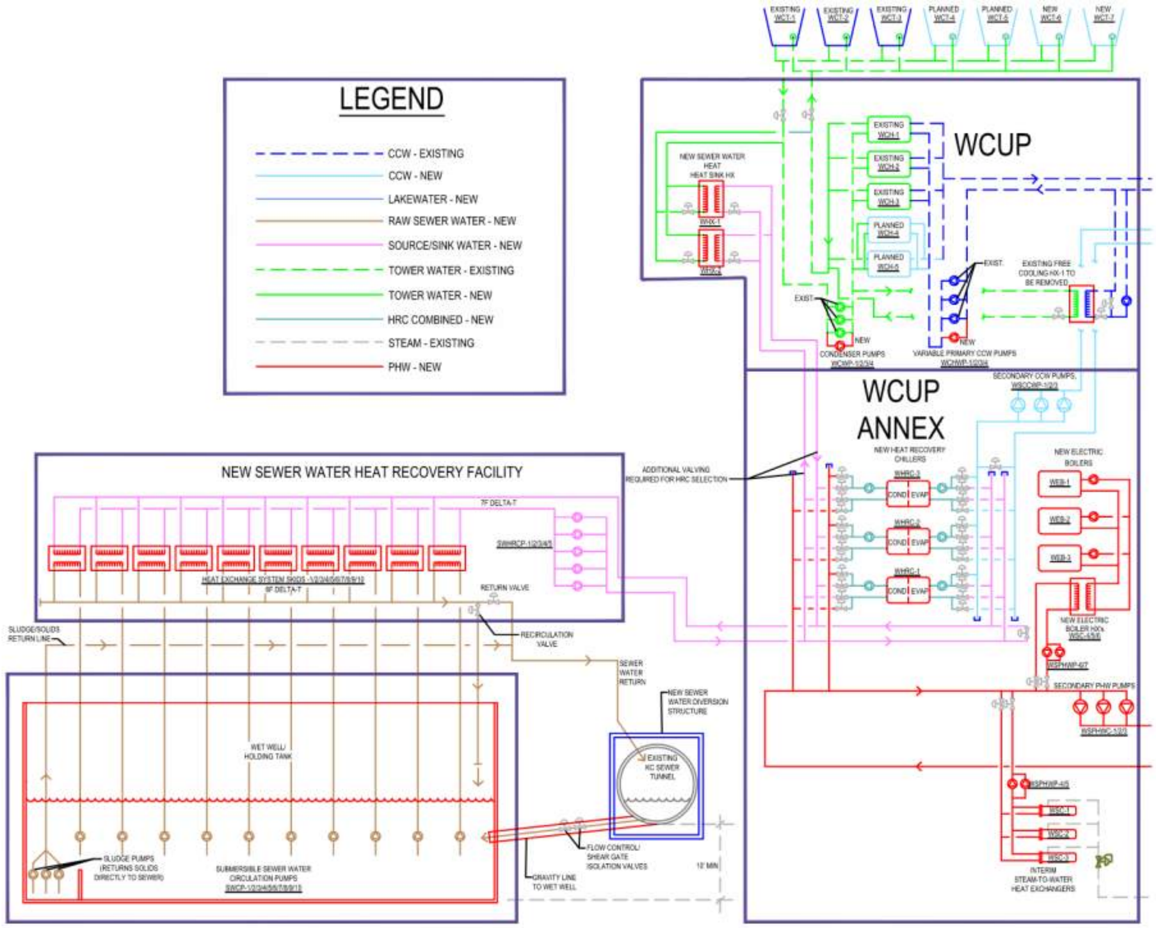


Figure 4.2.3.1-1: *Mechanical system diagram for the WCUP. Refer to Appendix 9.3 MSSD-1, Mechanical System Schematic Diagram for a larger format version of this diagram for readability*

Recommendations

An expansion of the WCUP to the south is proposed to locate new heating and cooling equipment associated with the new sewer energy source as well as providing the fully built out CCW capacity.

The following projects are recommended as part of the ERP:

- Expansion of the WCUP footprint for added equipment and operator space
- WCUP Primary Heating Water (PHW) systems
- WCUP electric boilers
- New chillers for peak cooling capacity/future weather

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

Key System Characteristics

WCUP system capacity and characteristics – completion of ERP:

- Heating capacity:
  - Normal operation: 35 MWth
  - Capacity with largest equipment out of service (N-1): 28 MWth
  - Standby capacity: n/a – WCUP heating systems not on generator power.
- Cooling capacity:
  - Normal operation: 12,000 tons
  - Capacity with largest equipment out of service (N-1): 10,500 tons
  - Standby capacity: 3,000 tons (no change from current)
    - WCUP chillers / cooling tower capacity on generator power could be increased with fully built generator capacity, however this is not a focus of the ERP.
- Campus Distribution Pumps:
  - CCW Variable-Primary: 3 x 4,500 GPM / 400 HP (existing) + 1 x 4,500 GPM / 400 HP (new).
  - CCW Secondary (new): 3 x 4500 GPM / 500 HP (N+1).
  - PHW Secondary: 4 x 3,900 GPM / 400 HP (N+1).

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included record utility drawings, site plans, field investigation to develop and validate proposed modifications to the WCUP to accommodate new equipment, SkySpark monitoring data for flowrates, temperatures, and pressures, campus heating and cooling load profiles, local outdoor ambient temperature data, and predicted future weather data.

Alternatives and Scenarios

Existing System Renewal, Replacement, and Removal

The WCUP facility was originally designed for 9,000 tons (N+1) cooling capacity. A project is currently underway to install a WCH-4 (1,500 tons) which will bring the cooling capacity of the WCUP to 4,500 tons (N+1).

The major components of the cooling system at WCUP are either new (WCH-4) or not passed the halfway point of its expected useful life. These systems will continue to be integral to the WCUP. The ERP implementation includes the installation of WCH-5/WCT-5 (discussed in a later section).

The fuel oil system that currently supports four rooftop diesel engine generators was designed for the full buildout of six generators and will be utilized to serve the additional generators noted in Section 4.2.3.2 WCUP Upgrades – Electrical.

The only systems within the WCUP that will be removed and not replaced as part of the ERP are:

- Waterside economizer and associated pumps
  - Waterside economizers are intended to save energy by allowing direct cooling of chilled water via cooling towers, without chiller operation. The existing economizer is used only in low-load winter scenarios since the load drops below the minimum turndown capacity of the chillers.
  - Waterside economizers reject heat from the chilled water system to the atmosphere during winter and low outside air temperature conditions. In the ERP system configuration, this heat will instead be recovered to the heating water system with heat recovery chillers.
  - The waterside economizer was integral to the Code compliance strategy for the WCUP at the time of construction. As part of the heat recovery chiller system project, the design team will validate the Code compliance strategy to allow replacement of the waterside economizer with heat recovery chillers.
- Expansion tank
  - As part of the Thermal Energy Storage tank project, the TES will become the expansion tank for the combined WCUP/PP CCW system. The expansion tank at the WCUP will be decommissioned.

WCUP Expansion

Background

When the WCUP was designed and constructed, it was intended to include up to seven chillers, five of which would be water-cooled conventional cooling-only chillers and two would be water-cooled heat recovery chillers capable of generating hot water heat to a new hot water system.

At the time of construction, only three of the conventional cooling-only chillers and cooling towers were installed, with future provisions included for the remaining chillers. The design documents from that project do not clearly show the intent for the heat recovery chiller system and associated hot water system.

Several test fits of the existing plant were performed with current heat recovery chiller technology from various manufacturers and were unable to find a satisfactory layout for more than one heat recovery chiller within the space that would remain after the fifth cooling-only chiller is installed. Chiller sizes have increased for the same capacity due to refrigerant regulations requiring lower global warming potential (GWP) refrigerants that are less effective and require more refrigerant per machine, increasing the volume of the equipment.

The space available in the basement mechanical room is not adequate for the new pumps associated with the hot water distribution system and primary pumps required for the heat recovery chillers. A path within the mechanical room to enter the tunnel is also not clearly provisioned for.

Another factor in the decision to expand the WCUP is that the plant was originally intended to be remotely monitored and controlled, with no regular operational staff. In reality, operational staff must be present at the plant for regular operational supervision and preventative maintenance activities. The staff are currently provided with temporary offices and break area in the space provisioned for future chillers.

In summary, the WCUP expansion will provide the following:

- Support space for WCUP operations staff.
- Mechanical rooms for:
    - Heat recovery chillers.
    - Pumps.
    - Electric boilers.

  - Steam-to-water heat exchangers.
- Electrical rooms supporting the new mechanical equipment.
- Connection to the utility tunnel system.

Siting

Due to the lack of space for future heat recovery equipment and operations support, the ERP team proceeded with evaluation of options to create new space. A new plant or expansion of the existing WCUP was needed.

The area of campus that the WCUP is located in sits on the edge of the future Portage Bay Crossing development which means that the real estate surrounding the plant has a high development value. Similar to the efforts to locate a new substation (discussed in Section 4.2.4 UW Substation), there was determined to be no properties with suitable adjacency and availability to the WCUP to allow for a new building to be constructed outside of the footprint of the existing site. See Figure 4.2.3.1-2 for a vicinity plan showing adjacent properties bordering the existing WCUP facility.

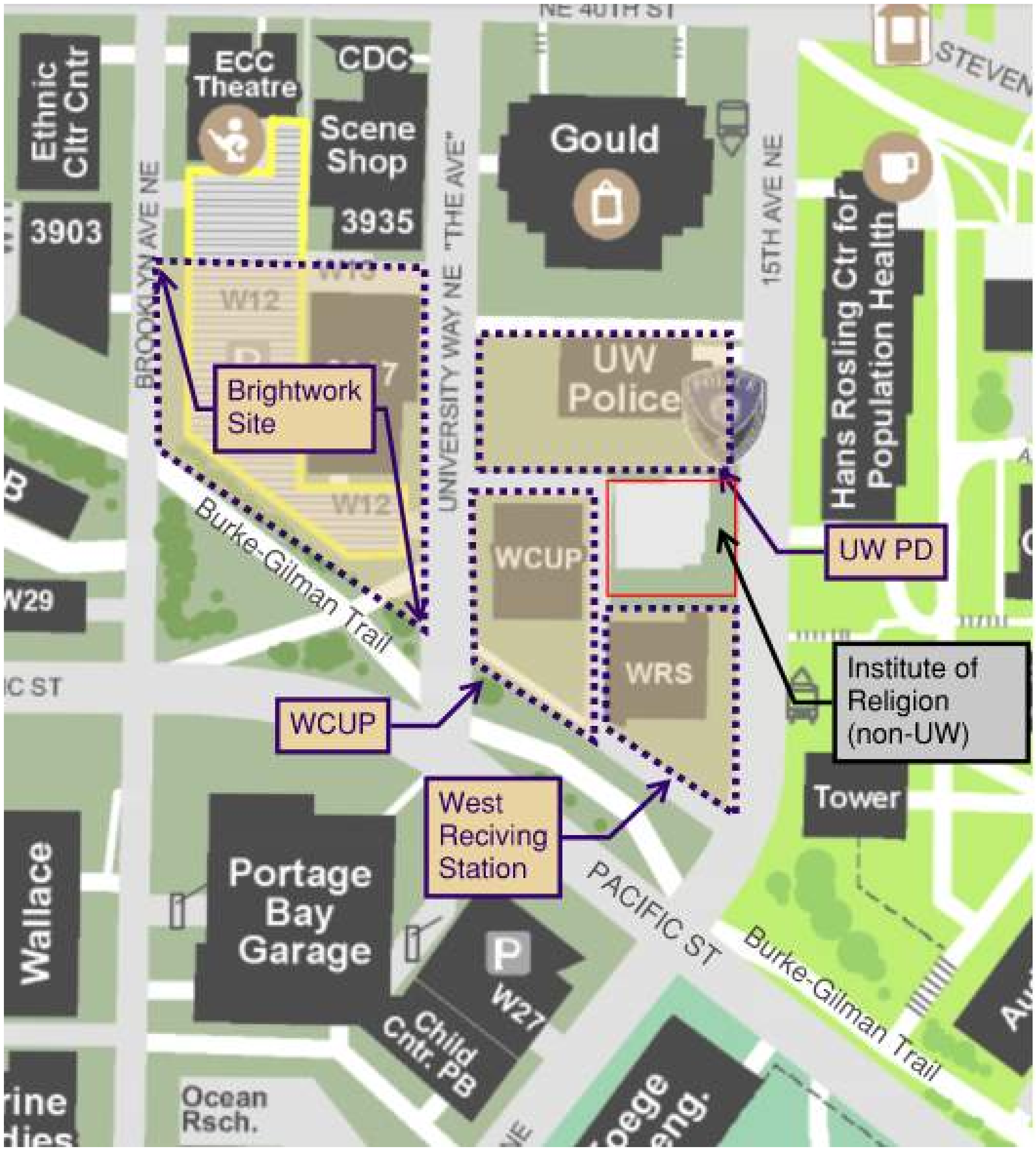


Figure 4.2.3.1-2: *Vicinity plan of adjacent properties to WCUP*

With no available adjacent properties, the team explored what options existed to expand the footprint of the existing WCUP within the footprint of the site. The site is built to the lot lines to the north, east, and west. The south face of the WCUP is setback from the Burke-Gilman Trail. The Burke-Gilman Trail is owned by the UW through this section of campus. The easement to the trail has preliminarily been determined to not prevent the construction of a building adjacent to the trail. There is precedent of this with the Life Sciences Building. Expansion of the WCUP to the south appears to be technically feasible from a Code and Land Use standpoint (to be confirmed), however it will be a sensitive topic and negotiation of the extent to which the new WCUP expansion could approach the Burke-Gilman Trail have not been started as part of this process.

For the purposes of this study, it is assumed that the WCUP facility can be extended to within a few feet of the trail. Several options were developed for the size and shape of the building, with different levels of setback evaluated. Refer to Appendix 9.7 Site Analysis & Zoning Study for additional detail.

Building Characteristics

The new WCUP expansion is planned to make the maximum use of the space available. The basement and first floor would be set to the same structure height as the existing structure; however, the building will include two additional floors, providing enclosed space where the current structure currently has a large, enclosed roof area. Figure 4.2.3.1-3 shows a section of the expansion adjacent to the existing structure.

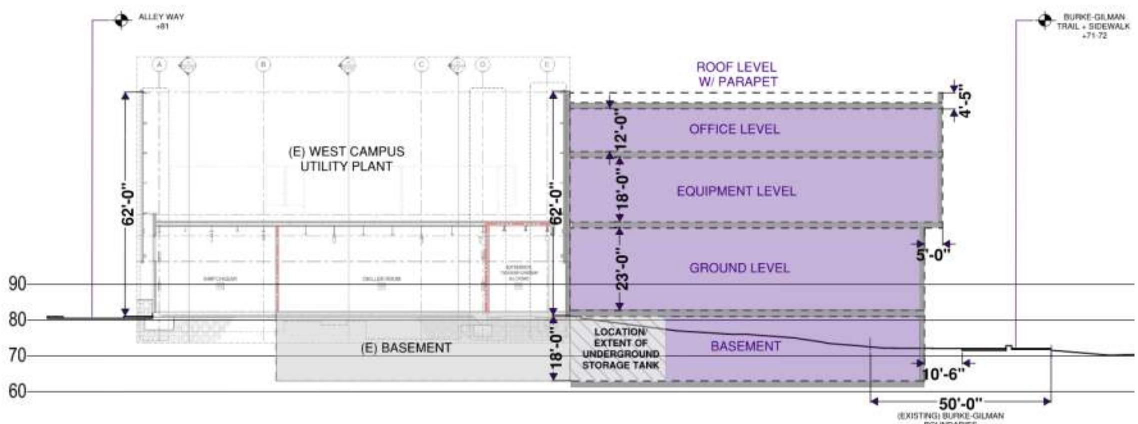


Figure 4.2.3.1-3: *Section showing the new proposed WCUP facility in purple adjacent to the existing WCUP. Refer to Appendix 9.7 Site Analysis & Zoning Study for additional detail.*

The estimating effort for this study conservatively assumes the largest footprint expansion, labeled as Option 2 in Appendix 9.7 Site Analysis & Zoning Study. This option provides the maximum space and flexibility for equipment which has not been fully designed or selected at this time. Options 1 & 3 provide more favorable setbacks from the trail.

Option 2 has a total usable area of 26,895 sq ft, which is more than double the area of the existing facility, largely due to the additional two stories provided in the expansion. The footprint of the expansion is 6,739 sq ft compared to 8,600 sq ft of the existing WCUP.

Considerations for the Expansion

The following items weighed in the consideration of the expansion:

- Proximity to the Burke-Gilman Trail.
- Underground fuel oil storage tank to the south of existing WCUP and access to exterior electrical transformers must remain. Footprint of new expansion does not extend over the storage tank.
- Existing underground electrical utilities from Seattle City Light to the West Receiving Station and a UW-owned duct bank will be relocated as part of this project but would otherwise be necessary to relocate as part of the UW Substation project.
- The expansion must make connections to the existing CCW and steam/condensate systems and distribute a new hot water system to the campus. These connections will be made via a connection to a new utility tunnel that intersects the WCUP expansion basement.

WCUP PHW System

Background

The WCUP currently only provides CCW to the campus. With its proximity to the King County Sewer energy source, the WCUP is the logical place for locating the heat recovery chillers that will be used for Sewer Water Heat Recovery.

First Phase – Steam to Primary Heating Water

It is envisioned that the initial phase of the campus heating water system in west campus would begin with the addition of steam-to-water heat exchangers and campus PHW secondary distribution pumps. This will allow the WCUP to begin to serve buildings within its region with hot water, generated through steam from the Power Plant. Ultimately, the PHW system will connect both the WCUP and Power Plant. The steam-to-water aspect of this system is an interim solution as the steam system connecting PP to WCUP will eventually be decommissioned and removed to allow the installation of PHW piping in the tunnel.

The steam-to-water heat exchangers and PHW pumps will be located in the WCUP expansion, refer to Appendix 9.13 Scope of Work document SOW-P-4.

Second Phase – Heat Recovery Chillers

The next phase of the campus heating water system will involve installation of the heat recovery chillers and associated cooling towers and heat exchangers as detailed in the Appendix 9.3 MSSD-1 Mechanical System Schematic Diagram and Appendix 9.13 Scope of Work document SOW-P-7. The heat recovery chillers will connect to the CCW, PHW, SWHR, and WCUP cooling tower systems allowing for operation in any of the following modes:

- Campus waste heat recovery
- Sewer water heat recovery (heating or cooling)
- Cooling-only mode with heat rejection through cooling towers

Prior to extension of the PHW system to the Power Plant for access to the PHW Thermal Energy Storage tank, the heat recovery chillers would be carefully staged to prevent short cycling. Once the PHW and CCW systems are integrated with TES tanks in place, the operation of the WCUP heat recovery chillers will be optimized, increasing energy efficiency and simplifying system operations, as their runtime will not be as dependent on the campus load.

WCUP Electric boilers

As described in Section 4.2.2.1 Power Plant Upgrades – Mechanical, electrode boilers will be deployed in the later stages of the ERP implementation as a tool to reduce or eliminate the last ~10% of annual fossil fuel use for campus heating.

Electrode boilers located in the new WCUP expansion provide trim heat for new PHW system beyond what the heat recovery chillers can provide under peak load scenarios.

The proposed scope includes:

- 3 x 6-MW electrode boilers.
  - Provided in a redundant arrangement. Only two boilers are intended to operate under peak load scenario.
  - Large electrical controllers, comparable to switchgear, which are required for boiler capacity modulation / staging.
- Packaged feedwater skid for boilers, provided by boiler manufacturer.
- Steam-to-water heat exchangers at each boiler.

New Chillers for Peak Cooling Capacity

The WCUP includes space for additional conventional cooling-only chillers including the associated pumps and cooling tower. Refer to Appendix 9.13 SOW-P-3 for additional details.

The addition of the fifth chiller (WCH5) to the plant brings the WCUP cooling capacity to 7,500 tons in cooling-only mode. The addition of heat recovery chillers and their associated energy sources / cooling towers will bring this capacity to 12,000 tons (1,500 tons of sewer heat rejection and 3,000 tons of cooling tower operation). The heat recovery chillers replace the function of the sixth and seventh chiller that were identified as part of the original WCUP build and that space could be allocated for additional chilling capacity, however the distribution system leaving the WCUP is not sized for this load increase. Hence, that space remains available for future projects.

Impacts to the Existing Campus Environment

Given the WCUP's adjacency to the Burke-Gilman Trail and the proposed expansion to the south that will reduce the setback from the trail considerably, there is a prominent impact to this region of the campus and its relationship to the trail.

As outlined in the Siting section, there are various options developed for further study that aim to achieve a moderate impact to the trail.

Construction activities associated with the WCUP will be disruptive. This will be a continuation of the work already occurring in the Portage Bay Crossing area, particularly associated with the Brightwork project immediately to the west of the WCUP.

Operational Considerations

Operational Complexity of Electrified Heating Systems

Refer to Section 6.2.2 for discussion on the increased complexity of electrified heating systems and the impact that will have on operator technical expertise, training, and automation.

Campus-level Sequencing Across Power Plant and WCUP

Refer to Section 4.2.2.1 Power Plant Upgrades – Mechanical for discussion on the importance of sequencing equipment across the Power Plant and WCUP.

A specific consideration for the WCUP is that it does not have direct access to the Thermal Energy Storage system unlike the equipment at the Power Plant. Careful automated sequencing will need to be developed to intentionally load and unload the CCW and PHW systems at the WCUP through control of the secondary pumps across the two plants. As much as possible, the WCUP will seek to match the flow of primary (chiller) flow to the secondary (campus) flow to efficiently load the heat recovery chillers. For example, when a new chiller is staged on at the WCUP, the secondary flow at the WCUP will want to increase proportionally, requiring an equal decrease in the Power Plant secondary flow rate given a constant demand from the campus.

Heating During Electrical Utility Service Interruptions

Once the campus conversion is complete, the campus will be dependent on the electrical system to achieve its peak heating output. This is already the case in cooling mode in the current campus.

In a partial loss of electrical utility service (utility maintenance) where system capacity is reduced but not fully disrupted, heating needs must be addressed via the most efficient means of heating available; likely heat recovery chillers connected to the sewer – due to highest typically available source temperature and load curtailment at non-critical buildings. If the remaining heat recovery chiller capacity is inadequate for campus load at that time of year, combustion boilers will be relied upon.

In a full loss of electrical utility service due to a regional outage the campus will rely on the Power Plant to be the single source of heat for the campus. The WCUP would operate in a cooling mode during this outage to provide cooling to critical campus loads.

Cooling Load Curtailment During Electrical Utility Service Interruptions

The WCUP currently serves a segregated area of the campus, primarily made up of buildings requiring critical cooling. In the near future as part of the ERP, the WCUP CCW system would be interconnected with the Power Plant CCW system. The complexities of this conversion are discussed in Section 4.2.2.1.

From the perspective of the WCUP, the WCUP will still need to serve its critical loads in a utility outage. This is complicated by the fact that the WCUP will now be connected to a CCW system that serves many more buildings and the behavior of those buildings in a utility outage has the potential to impact the WCUP's ability to deliver cooling where it is needed.

As part of this work, each building connected to the CCW system will need to be evaluated for its behavior during a utility outage. The primary concern is any non-critical building that would not fail to a closed position on a loss of power. Additionally, intentionally placed automatic control valves within the CCW loop may be required to allow the WCUP to isolate its flow to critical buildings during a utility outage.

Risks

Refer to Section 4.2.2.1 Power Plant Upgrades – Mechanical section for risks that are shared between the interaction of WCUP and the Power Plant.

The expansion of the WCUP to the south has not been formally discussed or approved with the University of Washington Campus Architecture & Planning, City of Seattle, or Seattle City Light. The final direction for the expansion must be approved by each of these groups. Should the expansion not be approved at all, another property would be required and the connectivity between the existing WCUP and new building would require a significant rethinking of the energy and utility systems. If the expansion is approved at a smaller size than shown, there may be consequences to the quantity and type of equipment able to be provided and would be likely to have impacts to the annual GHG emissions of the campus.

Emerging Technology Considerations

Refer to Section 4.2.2.1 Emerging Technologies for the Power Plant Upgrades – Mechanical systems as these would equally apply to the WCUP Mechanical systems.

4.2.3.2 WCUP Upgrades - Electrical

System Overview

The electrical scope in the WCUP comprises of two major components: generator additions and the WCUP annex. The generator scope includes the installation of two 4160V gensets in existing spare provisions to achieve full generator capacity at the WCUP for campus generator power loads.

Recommendations

The annex entails the installation of three new medium voltage feeders at 26 kV from the new UW substation, as described in Section 4.2.4, serving a connected load of 27 MVA. These feeders will be routed below grade in new duct systems utilizing surface street utility right-of-way construction (pathway installed as part of UW Substation work described in section 4.2.4). The feeders will then rise to Level 3 above grade and terminate in 35 kV class switchgear.

The medium voltage switchgear will provide main sections for each incoming feeder and tie breaker sections, supporting switching configurations similar to primary selective operation. Two 4,160V unit substations rated at 10 MVA will serve three heat recovery chillers and a step-down transformer. Three electric boilers will be connected to the switchgear at medium voltage (26 kV).

Low voltage cooling and ancillary mechanical equipment operating at 480V will be served from two unit-substations rated at 3000 kVA, serving Main-Tie-Main switchgear. Low voltage distribution will also be overhead, using conduit and wire.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

Key System Characteristics

WCUP electrical system capacity and characteristics:

- New electrical demand: 27 MVA.
- Three new 26 kV medium voltage feeders.

Diagrams of the electrical systems are shown in the figures below.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included record drawings, field investigation to develop and validate proposed modifications to the WCUP to accommodate new equipment described in Section 4.2.3.1.

Alternatives and Scenarios

Electrical upgrades to support mechanical heating systems include installing a 26 kV ring bus as described above. With distribution to four unit-substations and three boilers.

The project proposes installing two new 2 MW generators at the WCUP. The generators would be installed in future provisions made available in the original buildout of the electrical system. The existing 4,160V switchgear has two spare circuit breakers intended for two new generators (#5 and #6). The WCUP roof area also has space for the footprints of these new generators. New scope would consist of procuring and installing the new generators, along with new feeders from the generators to the existing switchgear.

Impacts to the Existing Campus Environment

The footprint of the WCUP annex impacts the existing SCL service feeders to the WRS and the project would involve relocating these feeders around the WCUP. It is anticipated these feeders will become owned by UW, but coordination with SCL may be involved.

Operational Considerations

The WCUP upgrades bring two additional generators into the plant which will require routine maintenance. The WCUP upgrades also introduce a major amount of electrical equipment and capacity to the plant. The switchgear and transformers will become a critical part of the day-to-day heating and cooling operations.

Risks

Risks include increased fault current contribution from installing generators #5 and #6 which should be further studied.

The expansion of the WCUP directly impacts four existing underground SCL feeders which feed the West Receiving Station. Relocating the conductors will require SCL coordination, design, and assistance which inherently introduces risk to the project schedule. The intent is for the relocated feeders and conduit bank to be of the size and quantity as needed to refeed the WRS from the new substation described in Section 4.2.4. The sequence of construction will need to be carefully scheduled and phased so that only one of four SCL service feeders is de-energized at a time while being relocated, re-fed around the new WCUP footprint, and re-energized.

The project assumes the UW substation is built and there is a source of 26 kV available for the short-term build-out; however, the UW substation may not be completed before the WCUP needs to be energized. There may be a need for a temporary transformer to be installed with a 13.8 kV primary fed from the adjacent WRS in lieu of the UWS to power this scope. A second option includes feeding the project from a primary tap on the WRS transformers at 26 kV through applying for a new service with Seattle City Light.

4.2.4 UW Substation

System Overview

This section recaps a series of discussions between the University and Seattle City Light (SCL) between February 2024 and August 2024. The concept for the new substation is formally documented in Appendix 9.14.1 – UW Substation Design Concept Memo – Rev 2.

The ERP, coupled with future campus expansion, is expected to significantly increase electrical demand on SCL from 52 MW to 114 MW. To meet this increased demand, UW is pursuing the development of a new electrical substation with SCL, which will support the existing campus, new ERP-related loads, and future campus needs.

The University of Washington's new substation project was formally communicated to SCL, highlighting its capacity, redundancy, reliability, resiliency, layout, location, and design requirements. Figure 4.2.4-1 provides a rendering of the new substation concept. The intent is to use this information in SCL's comprehensive system impact study to verify the feasibility of the new substation. While the project details reflect the current understanding based on discussions, the University remains open to alternative options that may offer significant benefits to both organizations.

***Figure 4.2.4-1**: Rendering of new substation at the Northlake Building Site. Refer to Appendix 9.7 Site Analysis & Zoning Study for additional architectural and site details*

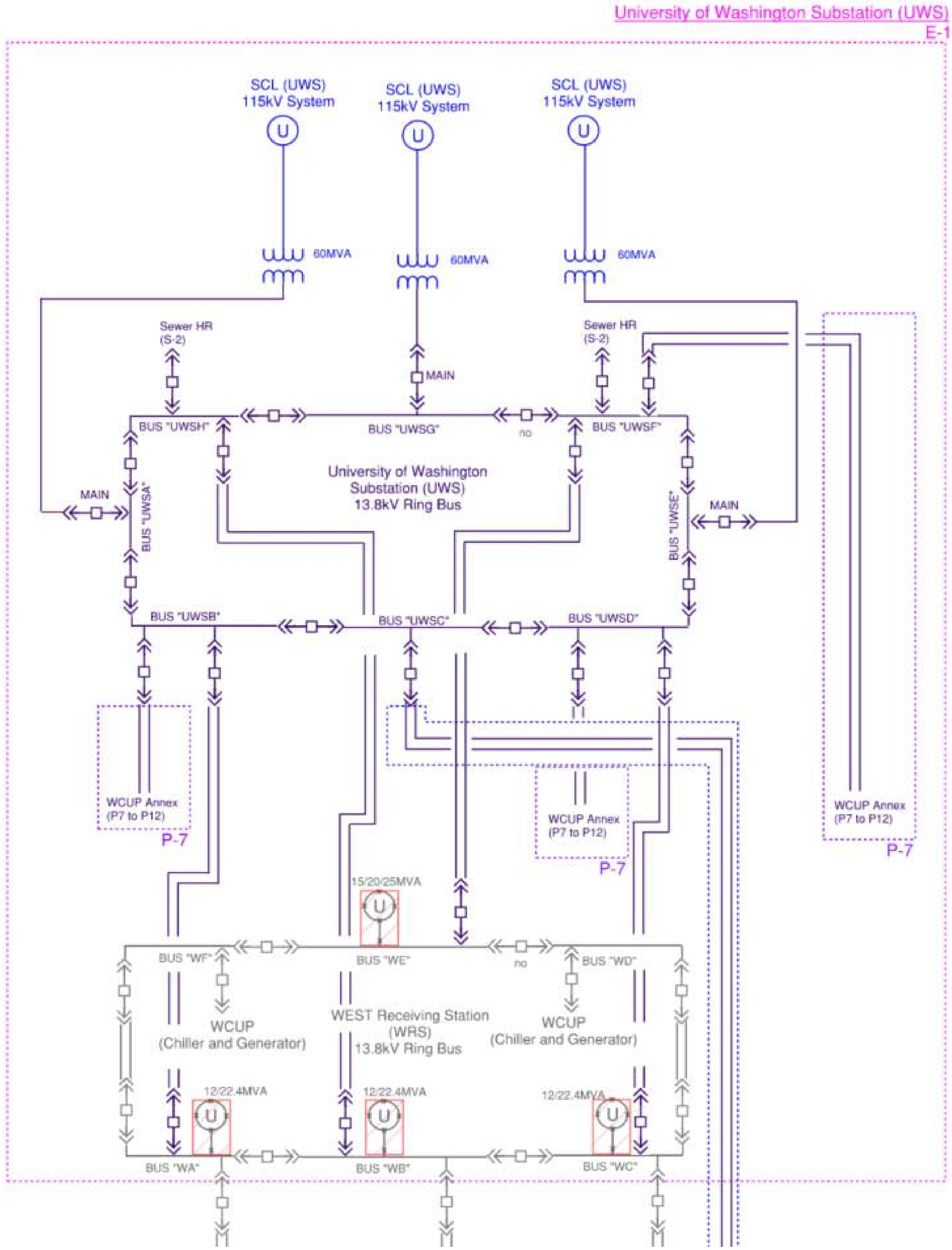
Recommendations

To address the increased system capacity from decarbonization, plan for the future of the UW campus, and improve the reliability of the electrical system a new substation is recommended. The new substation, referred to in this report as the UW Substation, would be located at the site of the existing Northlake Building and would be provided with transmission level service from Seattle City Light.

The project should incorporate the following features:

- Transmission line level service with redundancy comparable to the existing SCL University Substation.
- Separation of UW feeders from other customers in SCL vaults.
- Reduced maintenance impacts through new equipment with extended lifespans.
- Increased power quality, minimizing voltage sags.
- Transformers in a minimum of N+1 configuration.
- Physical protection of the substation yard.
- Underground transmission lines.
- Separate paths for transmission lines for physical protection (preferably with one city-block spacing).
- Adaptation for climate changes and future campus growth.
- Design adherence to SCL's standards.

The configuration of the new UW Substation is outlined in Figure 4.2.4-2.


University of Washington Substation (UWS)
E-1
SCL (UWS)
115kV System
U
60MVA
Sewer HR
(S-2)
MAIN
BUS "UWSH"
BUS "UWSG"
no
BUS "UWSF"
University of Washington
Substation (UWS)
13.8kV Ring Bus
BUS "UWSA"
BUS "UWSE"
BUS "UWSB"
BUS "UWSC"
BUS "UWSD"
WCUP Annex
(P7 to P12)
P-7
15/20/25MVA
BUS "WF"
BUS "WE"
BUS "WD"
WCUP
(Chiller and Generator)
WEST Receiving Station
(WRS)
13.8kV Ring Bus
12/22.4MVA
BUS "WA"
BUS "WB"
BUS "WC"

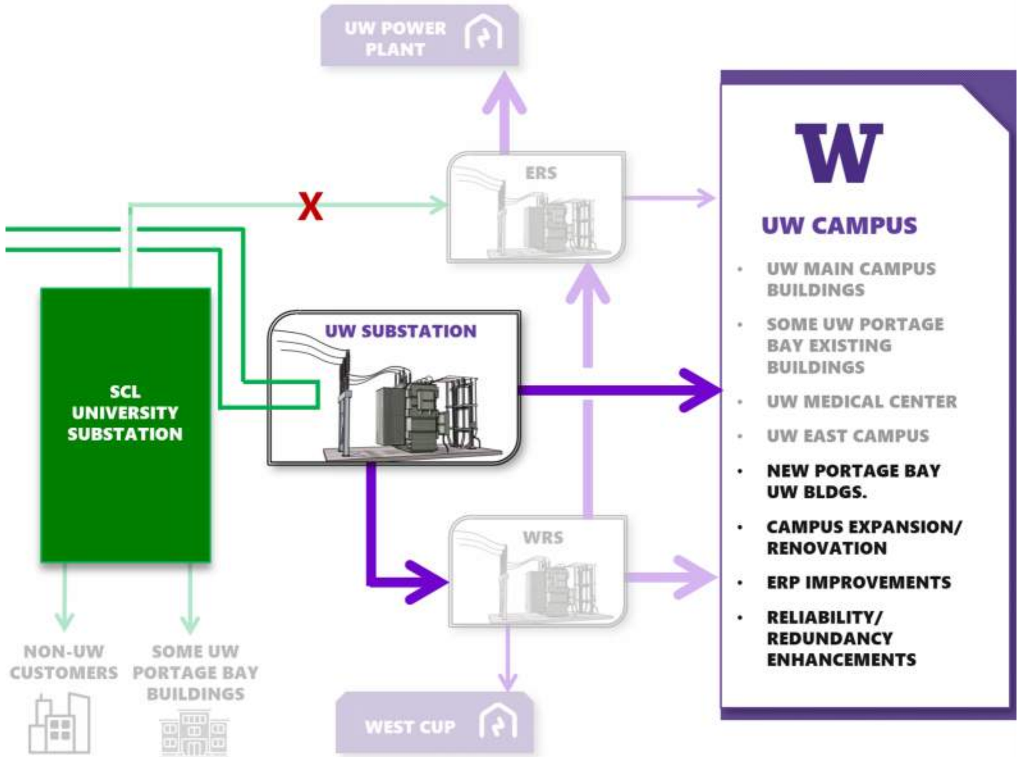


Figure 4.2.4-2*: Proposed configuration of UW Substation. New work is in purple. Refer to Appendix 9.3 EOD-1, Electrical One-Line Diagrams for a more detailed engineering diagram.*

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of this project.

Key System Characteristics

New and existing loads are shown in Figure 4.2.4-2 and Table 4.2.4-1. The existing demand is based on the metered peak demand from SCL's Meter Watch and through discussions with SCL and the University. The project should design around a campus load of 52 MVA at a 1.0 power factor, accounting for the base campus demand. Future ERP loads include heat pump heating, lake cooling/heating, sewer heat recovery, electric boilers, and consolidation of distributed cooling, among others.

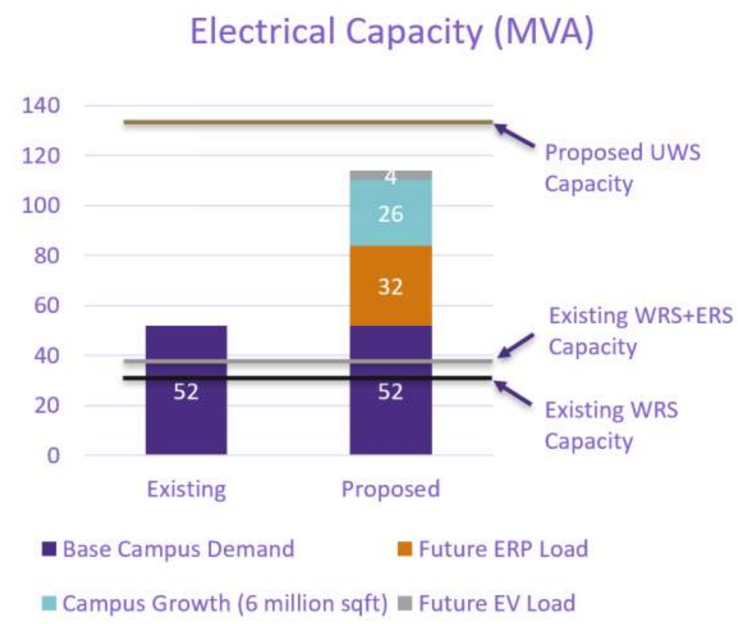


***Figure* 4.2.4-2**: *Existing and proposed electrical demand*

Table 4.2.4-1: Design Elements, Parameters, and Equipment Properties of the New UW Substation

Design Element	Value
Minimum Capacity (in ONAN mode)[1]	120 MW
Transformer Quantity (in N+1)	(3) Minimum
Transformer Size	60 - 100 MW
Transformer Cooling	ONAF[2]
Transformer Primary Voltage	115 kV
Transformer Secondary Voltage	26.4 kV
Primary Transmission Bus Configuration	Ring Bus
Secondary Distribution Bus Configuration	Ring Bus

Comments:

1. The intent is to size the transformers based on passive cooling capacity. Forced air cooling options shall be provided, but only to allow additional capacity in the future. ONAN = Oil filled (O), with natural convection (N), air cooled (A) with natural convection (N).

2. ONAF = Oil filled (O), with natural convection (N), air cooled (A) with forced air (F).

Assessment Data

Electrical System Capacity

The existing and future expected post-decarbonization campus demand curves are shown in Figure 4.2.4-3. Future decarbonization system demand includes heat pump heating, lake cooling/heating, sewer heat recovery, electric boilers, and consolidation of distributed cooling. Future decarbonization system demand includes future climate adaptation and addition of cooling to historic buildings. Some portage bay campus buildings are fed directly by SCL and not by the WRS. No credit is being taken for future addition of building solar PV.

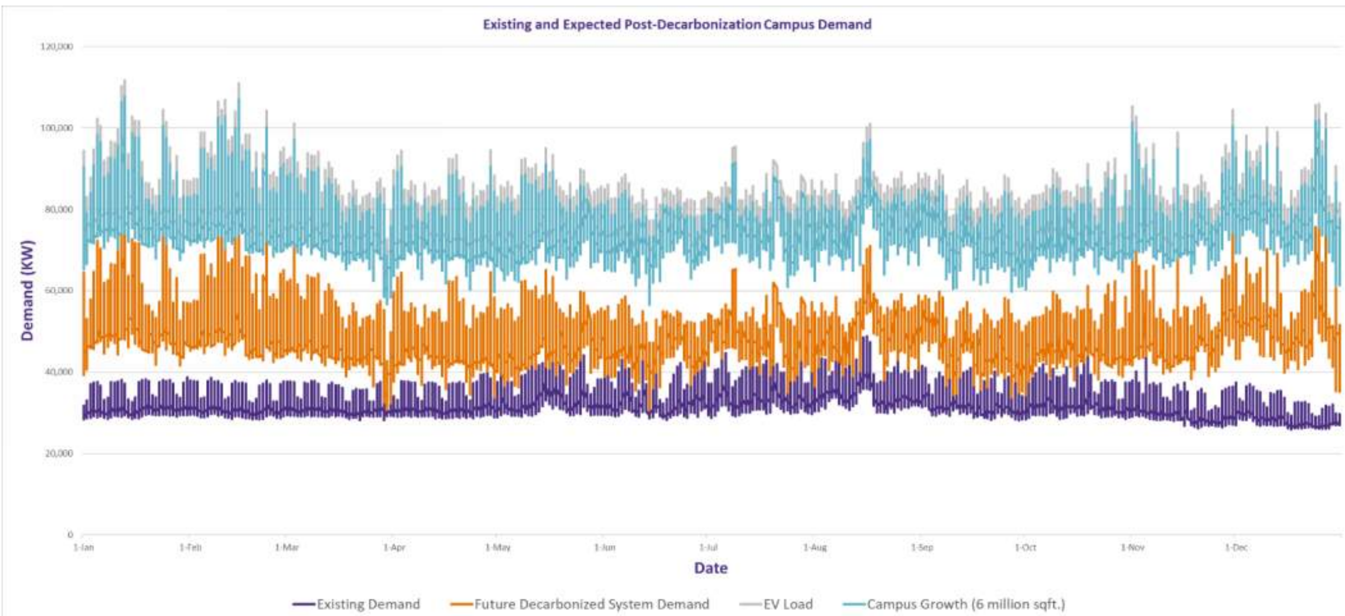


Figure 4.2.4-3: *Annual campus demand shown in 8,760-hour format*

Power Quality

The new substation must ensure continuous, uninterrupted power to critical facilities, preventing outages that could disrupt operations. As UW hosts essential programs, including a leading medical center and Tier 1 research facilities, reliable electrical power is crucial. Any power disruption could impact patient care, interrupt medical procedures, and hinder research activities, making power reliability a key element of the Energy Renewal Project.

The University currently experiences monthly voltage sags that disrupt operations, likely due to shared cables with non-UW customers and overhead lines feeding nearby neighborhoods. Refer to Section 6.4.1 for more discussion on existing power quality issues. The new substation should provide redundancy at least equal to the existing SCL service, if not better. This redundancy will cover routine maintenance and unplanned system impacts without reducing or losing power to campus operations.

Alternatives and Scenarios

Siting

The preferred site for the new substation is the property at 814 NE Northlake Place, owned by the University. This site, which will involve demolishing the existing Northlake Building, is ideally located between the existing University Substation and the WRS. Although expansion to combine with an adjacent University-owned lot is feasible, it is not preferred. Figure 4.2.4-4 shows a number of sites that were studied for the site of the UW Substation. The site was evaluated by the team for several factors including square footage, distance to SCL and UW, and future development potential/value. Several sites were eliminated because they were insufficient in size while others were eliminated because they were prioritized for development goals. The site that was selected provides reasonable transmission line routing and access to distribution to the UW while also being West of the university bridge which separates it from the bulk of the portage bay crossing development plans.

Figure 4.2.4-4: *Vicinity map showing the potential sites that were studied for siting of the UW Substation highlighted in magenta*

Modifications to the Northlake building site include demolishing the existing building and grading the site. Proposed impacts to the site are noted in Figure 4.2.4-5. The property provides good access to the existing underground distribution and the elevated site allows access to the underground portion of equipment in a two-level design. The property is also appropriately located between the University Substation and the WRS as shown in Figure 4.2.5-7

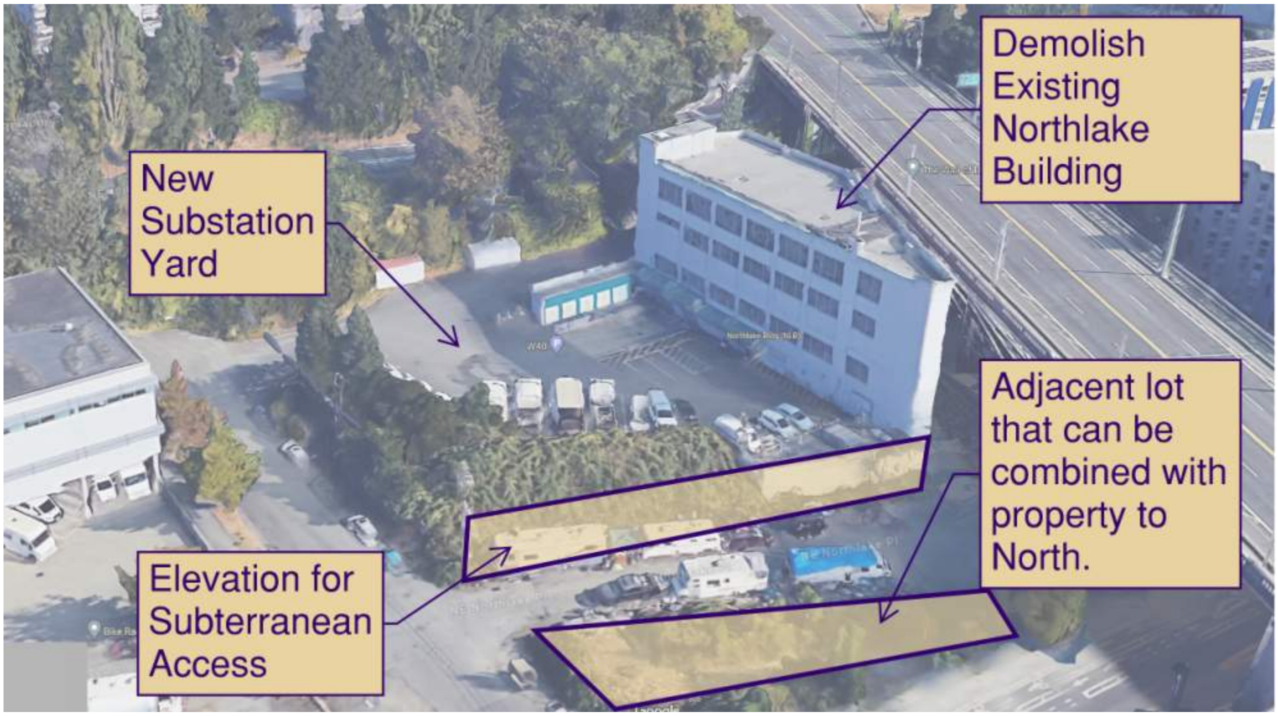


Figure 4.2.4-5: *Northlake Building site modifications*

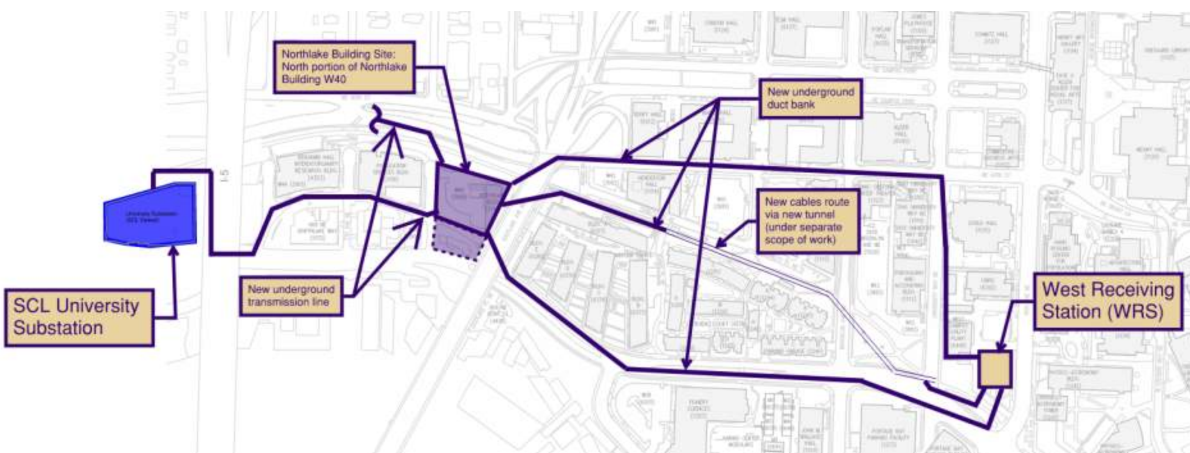


Figure 4.2.4-6: *Location of Northlake Building site in relation to the University Substation and WRS*

UW Substation Layout Options

The University and SCL is considering several substation layouts, including single-level and dual-level constructions, as well as air-insulated and gas-insulated gear. The system impact study being performed by SCL will inform this direction. The substation yard will be designed to SCL standards and will include essential equipment such as transformers, capacitor banks, inductance, control rooms, and distribution switchgear.

Alternatives to a New Substation

The University and SCL have considered alternative solutions to building a new substation. Studied alternatives include expanding the existing university substation, the use of superconducting feeders, and express feeders from the North Substation (SCL). Most of these options were estimated to have similar costs to an entirely new substation but have limited capacity, introduce risk, or do not provide a significant long-term solution to the University (minimum of 50 years). The investigation and main conclusion of the alternatives is listed below.

Expanding University Substation

University Substation has many challenges to address. The University Substation has reserve transformer capacity available for expansion. However, the capacity is stranded due to constraints in the size of the yard and feeder getaway configuration. Seattle City Light confirmed to the University of Washington that there is no ability to provide additional capacity from the University Substation to the existing West Receiving Station due to space constraints in the underground distribution.

The satellite image in Figure 4.2.4-7 further illustrates the space constraints at University Substation. It is effectively boxed in from four sides with the Burke-Gilman trail to the North, I-5 to the East, and buildings to the South and East.

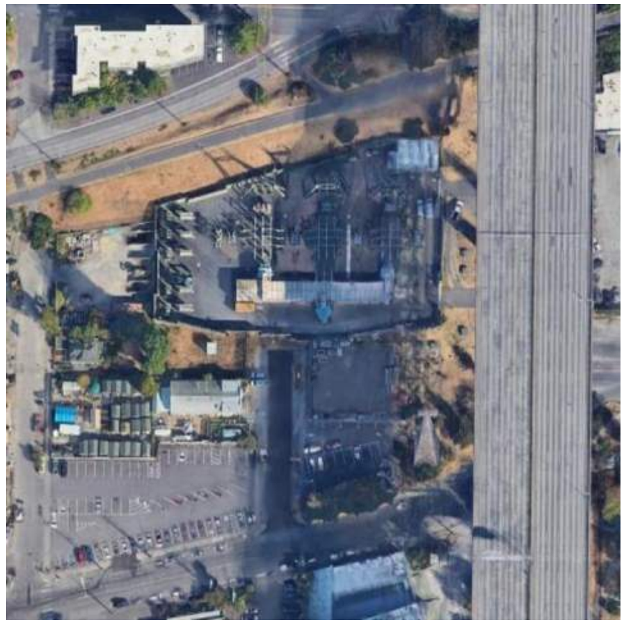


Figure 4.2.4-7: *University Substation satellite view*

Rebuilding either the transmission or distribution buses at University Substation will be expensive and challenging. Rebuilding getaways at University Substation is a significant challenge to overcome regardless of whether SCL builds new transmission lines or a new distribution feeder. The duct banks have multiple crossings, are too close together, and they contain too many cables. Thermal modeling of the duct banks has revealed severe limitations to the cable ampacities. There is no room left in the ground or in the existing duct banks to construct new feeders. If SCL builds an additional feeder(s) into the existing system, they would have dramatically reduced ampacity and will reduce the ampacities of the existing cables in the vicinity. The existing substation also has no spare circuit breakers for new distribution feeders.

This option does not resolve the highly loaded feeders out of University substation and the University Network still shares breakers with the feeders that serve the West Receiving Station, significantly decreasing the reliability of the system and the capacity limits during SCL maintenance events that can be triggered by non-UW SCL customers.

Express Feeders from North Substation

This solution requires expanding the distribution bus at North Substation and routing two new feeders to the University. Figure 4.2.4-8 shows the relative location of the North Substation to the West Receiving Station. It requires approximately 24,000 feet of overhead construction and 3000 feet of underground civil construction. The overhead routes are exposed to vehicular traffic and exposed to outages from vehicle collisions with utility poles, tree branches, or birds. This solution does relieve some of the thermal loading in University substation getaways and reduces the fault duty at the University.

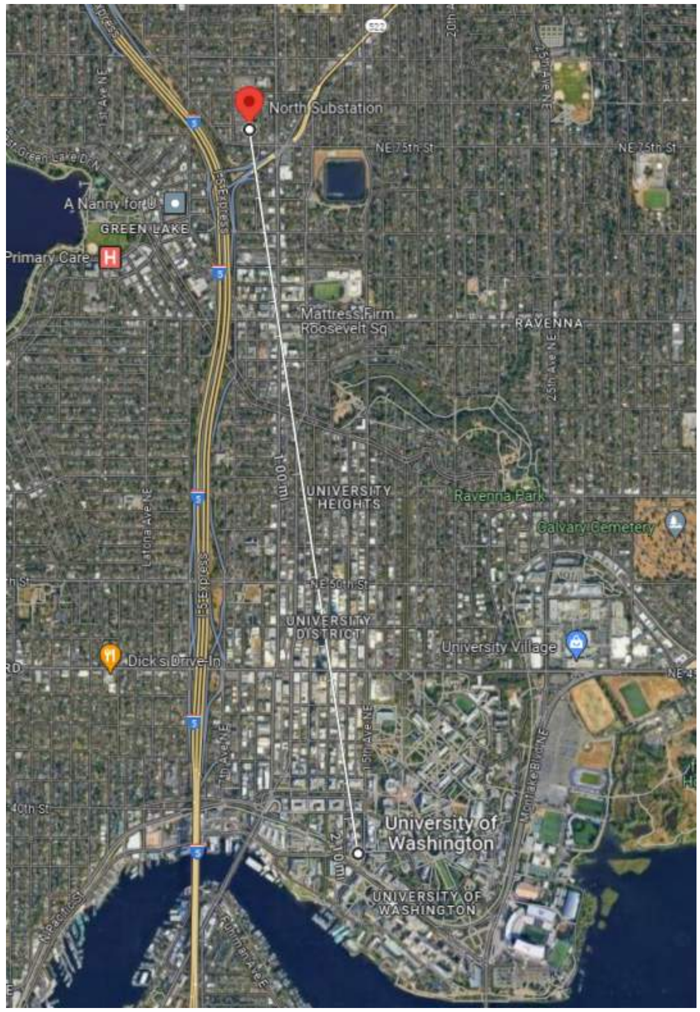


Figure 4.2.4-8: *Location of North Substation in relation to the University, approximately 2.1 miles in distance*

Due to the complexity, distance, and estimated cost, routing new feeders from the North substation is not as beneficial to the University as an entirely new substation.

Superconductors from University Substation to WRS

Refer to the Emerging Technologies section for a discussion of superconductors. Ultimately, not selected due to their unproven use in similar applications and non-fail-safe design relying upon mechanical cooling systems.

Impacts to the Existing Campus Environment

The preferred site for the new substation is the property at 814 NE Northlake Place, owned by the University. This site is located between the existing SCL University Substation and the UW West Receiving Station (WRS) making it an ideal location from a routing perspective. Although expansion to combine with an adjacent University-owned lot is feasible, it is not preferred. While this site is identified as one of UW's potential west campus development sites, its development value is perceived to be lower than other potential sites due to its adjacency to the University Bridge which separates it from the rest of the west campus.

Modifications to the site include demolishing the existing Northlake building and grading the site. Proposed impacts to the site are noted in Figure 4.2.4-9. The property provides good access to the existing underground distribution and the elevated site allows access to the underground portion of equipment in a two-level design. The property is also appropriately located between SCL's existing University Substation and UW's West Receiving Station as shown in Figure 4.2.4-7.

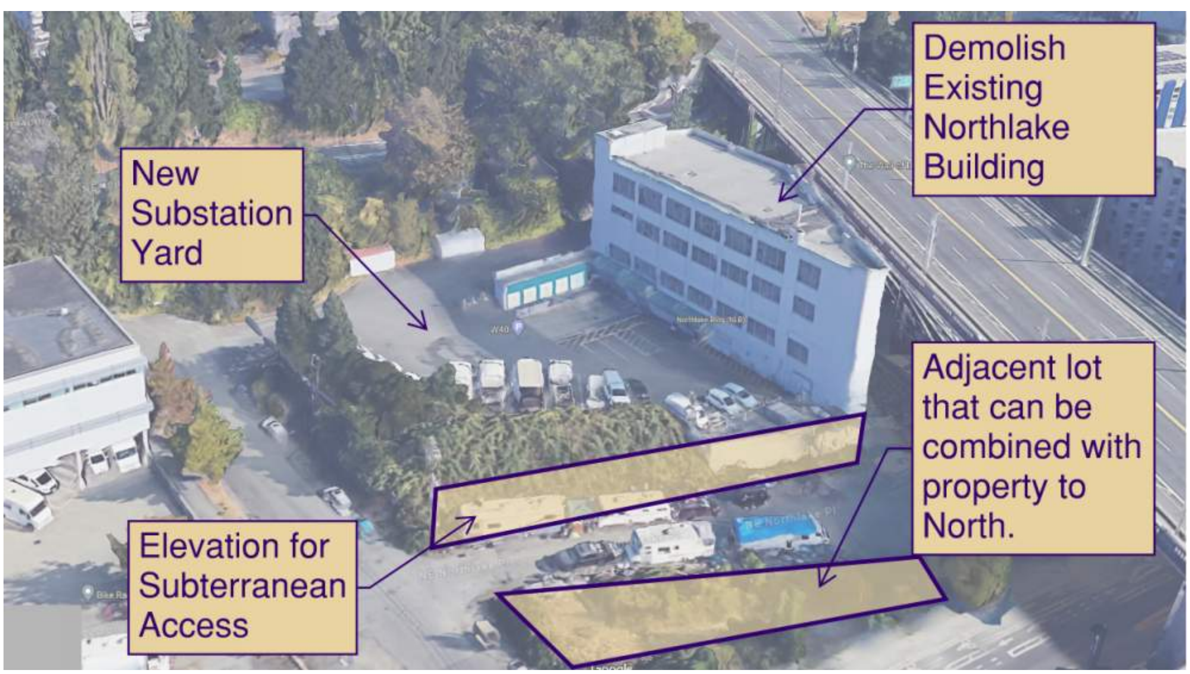


***Figure 4.2.4-9**: Northlake Building site modifications*

The project will cause temporary closures and traffic impacts to the Burke Gilman Trail, NE 40th Street, Lincoln Way, University Way NE, and NE Pacific Street.

Operational Considerations

To ensure continuous power supply, the substation will have built-in redundancy with multiple power sources, backup systems, and robust switching capabilities to reroute power during faults or maintenance activities.

The SCL and UW team prefer a ring bus configuration on the primary side (115kV) of the substation. The primary switching configuration will be further documented in the next project phase.

Ensuring that operational staff are properly trained to manage and troubleshoot the new substation is essential. This includes familiarity with the specific equipment, safety protocols, and emergency procedures.

The ownership of the electrical equipment within the UW Substation has not been defined. It is likely that Seattle City Light will own and maintain the 115 kV side of the equipment since UW does not currently have electricians certified for maintaining that equipment and would be pulling from the same labor pool as Seattle City Light to recruit staff.

Risks

The project introduces 115 kV transmission level service to the campus. 115 kV equipment will require new considerations for safety (clearance) and procedures for all who access the substation yard. It is anticipated SCL will own and maintain the 115 kV equipment, however, the substation will have shared access to both SCL and UW personnel. So, the UW facilities team should be informed and trained on the potential dangers of the system.

The substation should be designed in a way that protects it from physical damage and intentional damage. The intent is that cables are installed underground to provide them protection. The yard should have high-walls and should be secured from unauthorized access. Where possible, equipment shall be indoors or protected from objects being thrown from above and the equipment should be designed in a way that it is not subject to flooding. The elevation of the University Bridge above and adjacent to the site will be a consideration during design.

Existing breaker space at the WRS is becoming limited and loads on the WE and WD bus should be considered for relocation to the UW Substation in future projects. Migrating the existing loads will require new transformers to be installed with 26 kV primaries to replace the existing 13.8kV primaries.

Emerging Technology Considerations

Superconductors

The project briefly explored the use of superconductors at 26.4 kV, but due to concerns over the technology being relatively new, increased initial costs, potential excessive maintenance costs, and unproven reliability, it was ultimately decided to utilize traditional copper feeders instead.

Gas Insulated Switchgear (GIS)

GIS is being considered for the project due to its ability to significantly reduce the required space compared to traditional switchgear systems. However, GIS comes with a higher upfront cost and introduces sulfur hexafluoride (SF^6), a potent greenhouse gas with significant environmental impact. SCL is evaluating the potential of incorporating this technology into the project, with plans to manage and maintain the equipment responsibly to mitigate environmental concerns.

Solid State Transformers (SST)

The use of solid-state transformers can improve energy efficiency and allow for better integration with renewable energy sources in the future.

Battery Storage

Energy storage solutions, like lithium-ion batteries, provide backup power and peak shaving capabilities to enhance grid stability but require significant real-estate, maintenance, initial cost, and offer short duration ride-through.

4.3 Utility Distribution

4.3.1 Introduction

As part of the major modernization upgrades to the central energy and utility systems, the connection of those utilities to the campus buildings represents the largest effort in terms of cost, schedule, and disruption to the campus environment.

The campus steam heating and cooling systems are currently installed within an expansive set of utility tunnels. This section describes approaches to replacement of the steam heating system with a primary heating water (PHW) system and expansion of the CCW system through a combination of existing utility tunnels, new utility tunnels, and new segments of direct-bury piping. Example photos of tunnel installations and in-progress direct-bury piping installations are shown in Figure 4.3.1-1.

***Figure 4.3.1-1**: Photo of an existing campus utility tunnel (left) and an in-progress shot of direct-bury piping installation from another campus (right)*

The campus electrical systems must be re-fed from the new UW Substation to the two points of connection to campus, the West Receiving Station (WRS) and the East Receiving Station (ERS). This distribution work will largely take place within existing utility tunnels, however there will be buried duct banks between the new substation and WRS. An example photo of an in-progress installation of a buried duct bank is shown in Figure 4.3.1-2.

Figure 4.3.1-2: *Photo of a previous electrical duct bank installation through Burke Gilman Trail*

The distribution options discussed in this section were reviewed with representatives from UW Campus Architecture & Planning and Campus Energy, Utilities, and Operations in a series of workshops.

4.3.2 Mechanical Distribution

System Overview

One of the desired outcomes of the campus energy renewal is to provide reliable and efficient heating and cooling from the campus energy systems to all campus buildings that are currently connected to the central system, or where a new building connection is determined advantageous due to proximity or significant energy and operational benefits. The framework for proposing projects for the distribution system is directed by the following goals:

- Transition the campus from steam heating to hot water heating.
- Expansion of the Campus Cooling Water (CCW) System to incorporate buildings with distributed building level chillers.
- Continuation of steam service to critical process and humidification loads.
- Maximizing the existing tunnel infrastructure utilization.
- Expansion of the tunnel infrastructure where feasibility and value-add align.
- Making connections to buildings with new Primary Heating Water (PHW) piping, revised or new CCW piping, or revised steam/condensate piping.

Recommendations

Projects

The following projects are recommended as part of the utility distribution expansion and rollout:

- Maximize reuse of existing tunnels. Incrementally remove steam piping in tunnels and replace with PHW to the greatest extent possible.
- Provide PHW piping in a looped arrangement strategy with the intent to allow all buildings to be served from two different directions for redundancy.
- Utilize direct-bury piping where existing tunnels are at capacity.
    - Align routing with areas of campus that require surface improvement projects.
    - Where feasible, avoid routing through areas of campus with recent surface improvements.
- Upsize CCW piping in locations where increased load is anticipated.
- Decommission the campus steam and condensate distribution system in a phased manner.
    - Provide local steam plants to supply critical steam loads, described in Section 4.4.4, Local Steam Plants.

Advancements Beyond the ERP

- Develop hydraulic models for both PHW and CCW systems. Refine hydronic routing and sizing.
- Further consider phasing related to construction, using local steam plants, and maintaining selected Power Plant steam into near future.
- Review constructability and end-used layout of tunnel installations. In some sections of tunnel/campus a hybrid (tunnel + direct bury) may be necessary.
  - A hybrid approach between maximized tunnel reuse and maximum direct-bury may be determined as part of project pre-design efforts.
  - Full direct-bury approach is not sensible as it would leave the North Tunnel empty, and the West Trunk tunnel only half utilized.
- Fully understand the shutdown requirements in South-of-Pacific Zone and other critical buildings. Develop installation and shutdown strategy for these areas.
- Identify potential staging areas, tunnel access points, and vertical pipe shafts.
- For buildings served by Power Plant CCW: aggressive monitoring and retro-commissioning program to improve delta-T.

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects. For a zone-by-zone breakdown of the distribution system projects, refer Appendix 9.15 Detailed Distribution Descriptions.

Key System Characteristics

PHW Distribution

- Approximately 8 total miles each of PHWS/R piping mains (16 miles of total piping), approximately 2 miles of which is direct bury, remainder is in tunnel.
  - Reuse of tunnels requires piping support modification to accommodate installation of PHW piping.
- Additional branch PHW piping for an estimated 129 buildings. Most of these branch lines are installed in branch tunnels. Some mechanical rooms are located on upper levels of buildings and require work inside the building itself.
- PHW piping is sized for 30°F delta-T.
- Provide PHW piping in a looped arrangement strategy with the intent to allow all buildings to be served from two different directions for redundancy.

CCW Distribution

- Connections of the CCW to approximately 41 buildings that have distributed chillers, which will be consolidated into the CCW system. Some of these buildings already have CCW connections that may require being upsized. Refer to Distributed Chiller Replacements Section 4.4.3.
- Tees and valves for approximately 34 buildings to be added to the CCW system in the future.
- Future consolidation of the UW Medical Center CCW load onto the Campus CCW system. Assumption is that the S-1 chiller plant will be decommissioned.
- Approximately 3500' of CCW pipe upsizing (demolish and replace with larger pipe) in the SW, WT and SE tunnels.
- CCW delta-T is assumed to be 14°F for the entire system. Discussion of CCW delta-T is located later in this section.

Tunnel Expansion / Additions

- Vault expansions or vertical shaft at all tunnel/direct bury interfaces.
- Approximately 1500' of new tunnel (with vaults) in West Campus adjacent to the WCUP. Tunnel section at the south end of the W27 development is a mined tunnel.

Steam / Condensate Distribution

- Phased steam and condensate piping removal.
- Steam/condensate piping for local (satellite) steam plants. See also Section 4.4.4 Local Steam Plants.

Additional Piping Services on Campus

- Approximately 2000' of direct bury Sewer Water Heat Recovery Piping between the WCUP and the Sewer Water Heat Exchange Facility on NE Northlake Pl.
- Existing services to remain, relocation may be required: Compressed Air(CA), Emergency Lake Water(ELW).
- Removal of abandoned piping services: Pond Water, Abandoned Lake Water, Well Water, Sump Pump Piping.

Assessment Data

Relevant data for this analysis include record utility drawings, site plans, and field investigation to validate proposed routing against existing surface features. Tunnel space availability was determined through a series of site visits, drawing review, and use of the FARO Sphere web application. The FARO Sphere application allows for general measurements, and these were used to develop sketches showing possible PHW installation layouts. These are located in Appendix 9.15 Detailed Distribution Descriptions.

Temperature and flow rate data for the CCW system as seen from both the Power Plant and WCUP. This was used to estimate temperature differentials to analyze and size the piping system.

Alternatives and Scenarios

Baseline Piping Main Distribution Scheme – Maximizing Tunnel Reuse

The University has a longstanding commitment to using walkable underground utility tunnels for its infrastructure. These tunnels provide easy access for campus staff, allowing for both preventative and emergency maintenance that would be difficult with buried utilities. Therefore, the preferred strategy for achieving distribution goals is to maximize the reuse of existing tunnels. Although this approach ensures the most accessible final installation, it presents challenges related to space, phasing, and constructability. A detailed description of the entire tunnel system using this "tunnel maximization" approach can be found Appendix 9.15 Detailed Distribution Descriptions. Refer to Exhibit A in Appendix 9.5 for a map showing the direct bury piping in the baseline option.

Alternate Distribution Scheme (Maximized Direct-Bury Piping)

An alternate distribution scheme utilizing direct bury piping for the majority of the PHW mains was also laid out. This approach increases the direct bury routing to approximately 17,000’ of trench length for the main pipes. In addition, branch line requirements would be several thousand feet. Refer to Exhibit B in Appendix 9.5 for a map showing the direct bury piping in the maximum direct bury option. Additional detailed information is available in Appendix 9.15.3 Detailed Distribution Description – Alternate Option – Direct Bury.

Both of these schemes have their advantages and disadvantages, and it varies widely throughout campus depending on several factors, including the size of the existing tunnel, the density of loads present (bigger/smaller pipes), the presence of critical steam, and buildings shutdown requirements.

Campus Cooling Water (CCW) Distribution

The WCUP and Power Plant currently operate as isolated CCW piping systems under normal operating conditions. Only during maintenance events are isolation valves manually opened and the two systems allowed to communicate. The CCW system is distributed to 74 buildings through utility tunnels with a few limited sections of buried piping. The most significant known hydraulic bottleneck in the CCW distribution system is between nodes SW-1 and SC-7 between Ocean Sciences and K wing, however this situation should be alleviated by upcoming CCW piping installation in those tunnel sections (anticipated to occur prior to the ERP implementation). No other major distribution bottlenecks are currently identified. Condition of the CCW piping system has not been evaluated, but anecdotal reports from plant operators indicate that the capacity of the existing piping systems is likely to be impaired due to the age and condition of the pipe.

For purposes of analyzing the existing CCW distribution piping system, a delta-T had to be determined to estimate the capacity of the piping system. Looking at data representing CCW supply and return temperatures at the WCUP (Figure 4.3.2-3), a delta-T near 14°F appeared to be a reasonable target. Although the delta-T's drop much lower many hours throughout the year, during hours of high load conditions the delta-T tends to be well over 14°F, acts as a sizing buffer. Refer to Figure 4.3.2-4, below.

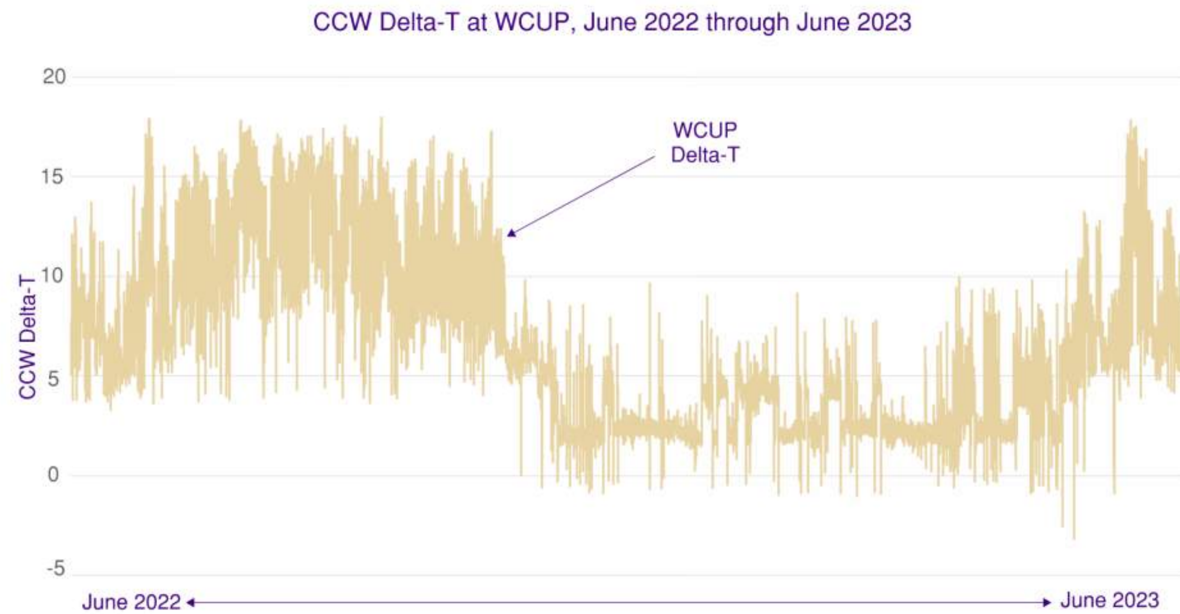


Figure 4.3.2-3: *WCUP CCW Delta-T – June 2022 through June 2023*

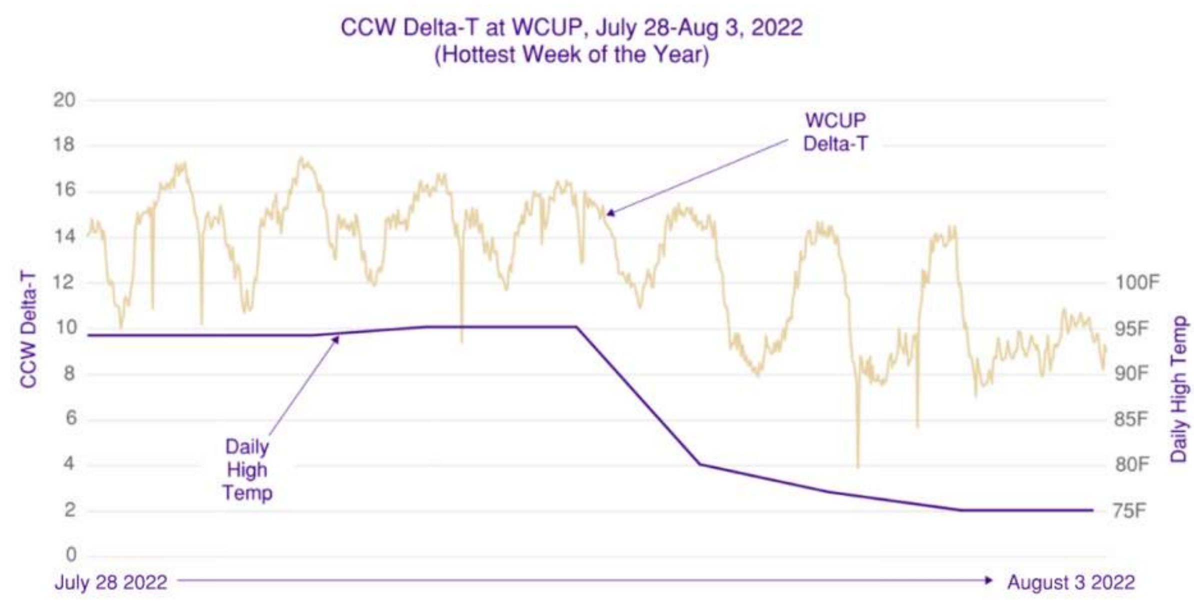


Figure 4.3.2-4: *WCUP CCW Delta-T – Hottest Week of 2022*

Currently the WCUP serves buildings that tend to be newer and higher performing from a CCW delta-T standpoint. Once the WCUP and Power Plant CCW systems are combined, this sizing buffer would allow the WCUP to serve some lower-performing buildings as well. Looking at data representing CCW supply and return temperatures at the Power Plant, the delta-T's paint a slightly different picture, with roughly 3-4°F lower delta-T than that seen at the WCUP (refer to Figures 4.3.2-5 and 4.3.2-6), below. This is likely due to poor CCW performance at the buildings served by the Power Plant (typically older buildings), and possibly due to extra bypass that occurs out in the system due to the primary-only pumping operation at the Power Plant. It is recommended that any problem buildings go through a controls/coil upgrade and retro-commissioning effort to increase delta-T. This will be an important continuous activity, particularly as the summer temperature extremes continue to climb. It is anticipated that converting the power plant to a primary/secondary pumping system will also help to increase the CCW delta-T, due to the reduced bypass. For this reason, a 14°F delta-T was used in the CCW piping distribution analysis in this report for the combined CCW system.

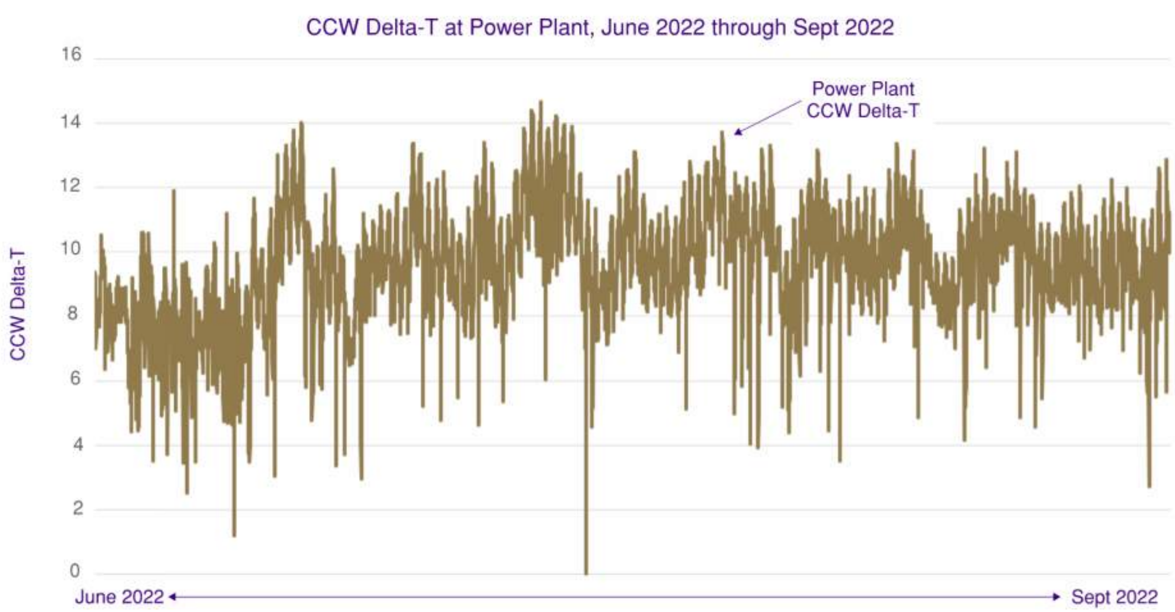


Figure 4.3.2-5: *Power Plant CCW Delta-T – Cooling Season of 2022*

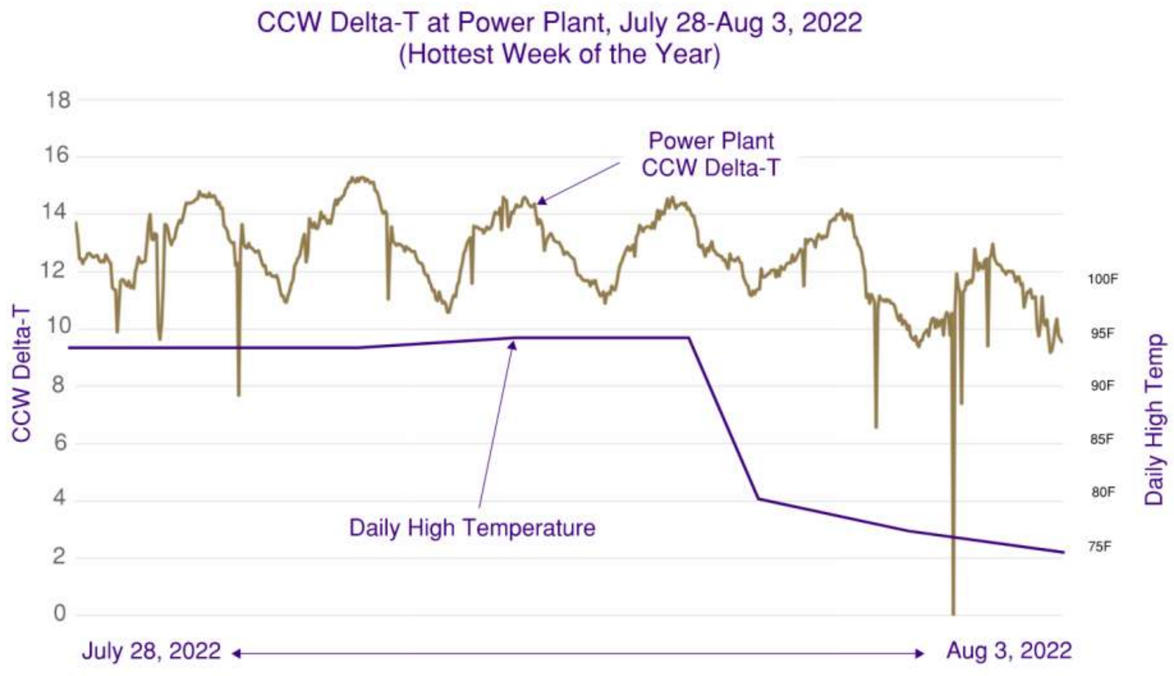


Figure 4.3.2-6: Power Plant CCW Delta-T – Hottest Week of 2022

The CCW distribution system total capacity will be increased by over 50% as a result of distributed building chillers being replaced with connections to the CCW system and also considerations for future weather. To account for predicted future weather conditions, a 15% increase in CCW load was added to the baseline total to arrive at a peak load condition. This factor was determined based on the predicted load increase discussed in Section 3.2.4. The system was analyzed at peak load conditions to observe where bottlenecks occur, and where piping may be required to be increased in size. For the purposes of this study, at maximum velocity of 10 FPS was used to determine allowable pipe sizing. For new piping installations, 7-8 FPS was used as the target velocity during peak flows for sizing. Without building a complex hydraulic model using software, an attempt was made to split up the CCW system into two parts, one served by the Power Plant, and another served by the WCUP.

A "CCW Bottleneck Map" was developed to indicate flow rates though the distribution network and can be found in Appendix 9.3 - Large Scale Distribution Maps, CCWM-1, CCW Bottleneck Map.

Key Takeaways from the CCW piping analysis:

- CCW piping to remain as-is in most of the tunnel system.
- CCW upsizing was determined to be required in three locations:
  - SW tunnel, from WT5 (WCUP) to SW1 from 22" to 28"
  - SW tunnel, from SW1 to SW3 from 22" to 26"
  - SE/SC tunnel, from the Power Plant to SC2 from 20" to 24"
  - WT tunnel, from WT1 to WT2 from 20" to 22"
- To relieve the WT tunnel and provide additional loop piping, a new direct bury loop is installed between the Power Plant and tunnel node NE6. This loop provides service to 18 buildings in North Central Campus with CCW (and PHW) and intersects the tunnels at three locations to facilitate access to building mechanical rooms.

Steam and Condensate (HPS/LPS/PC/GR) Distribution

Reduction of fossil fuel-based steam usage is an integral part of the decarbonization effort, and with the reduction, and eventual elimination, of the central steam distribution on campus, the inefficient steam distribution system can eventually be decommissioned, as well.

Building a complete parallel PHW heating system would require the distribution system to be direct-bury, which is not preferred as discussed earlier in this section. Without a parallel PHW heating system in place, the extensive steam and condensate system will be required to be systematically and strategically removed from the distribution system as the PHW system is incrementally expanded through the tunnels across campus. Parts of campus that only use steam for heating can, theoretically, go through this transition during the summer months without major disruptions. Many buildings in the North Campus fit into this category. The majority of campus, however, will require steam for heating, water heating, or process needs during continuous operation. These parts of campus will require higher degrees of coordination, temporary feeds, bypasses, or alternate services. The planning and phasing portion of this project is part of the Phase III effort.

Although the steam piping analysis is less involved than CCW, it is important to understand it is distribution as portions of it start to be removed to make way to PHW piping installation; can the existing steam piping that remains during project build-out serve the remaining heating and process loads? Of particular interest are the flow rates in the two West Trunk steam lines, which would provide steam to the WCUP to provide heat to the PHW system in the initial stages of the project. Of the two available flow meters, one is currently being commissioned, and the other (FT-136E) tops out at 62,000 PPH meter reading. It is recommended to increase the range of this meter at this location. Even without perfect meter data, based on extrapolation inferences it has been determined that the West Trunk steam lines should be able to handle the additional load the WCUP will require for the first stage of PHW rollout.

Existing steam and condensate piping was not considered for use as temporary or permanent PHW piping, due to the age and condition of the of the existing steam/condensate system.

Primary Heating Water (PHW) Distribution

The PHW distribution system is completely new system. The velocity used for sizing PHW piping was 7 FPS in most cases. In instances where tunnel reuse forced smaller sizes, velocities may be as high as 10 FPS. While some of the tunnels offer enough room to easily convert steam piping to hot water, many of the tunnel installations are already spatially challenged, and adding large PHW piping was not feasible (SE tunnel, for example). In these cases, a direct bury approach was taken to achieve the distribution goals. It was assumed that valves would be located at every branch line.

Installation of PHW into the tunnel system in and around UW Medical Center and UW Medical Center appears to be particularly challenging. There are ~25 mechanical rooms, each of which currently using steam for heating, refer to Figure 4.3.2-7. Many of these mechanical rooms also house steam PRVs for process loads. There is ample space in some of the mechanical rooms to easily house a new PHW to HHW and PHW to DHW skid, but many of the mechanical rooms will require an amount of relocation of other services to create adequate space. Although the labyrinth of piping in the MHSC is complex and oftentimes contains tight installations, there are opportunities to be had for back-feeding in order to integrate the mechanical rooms into the new PHW system.

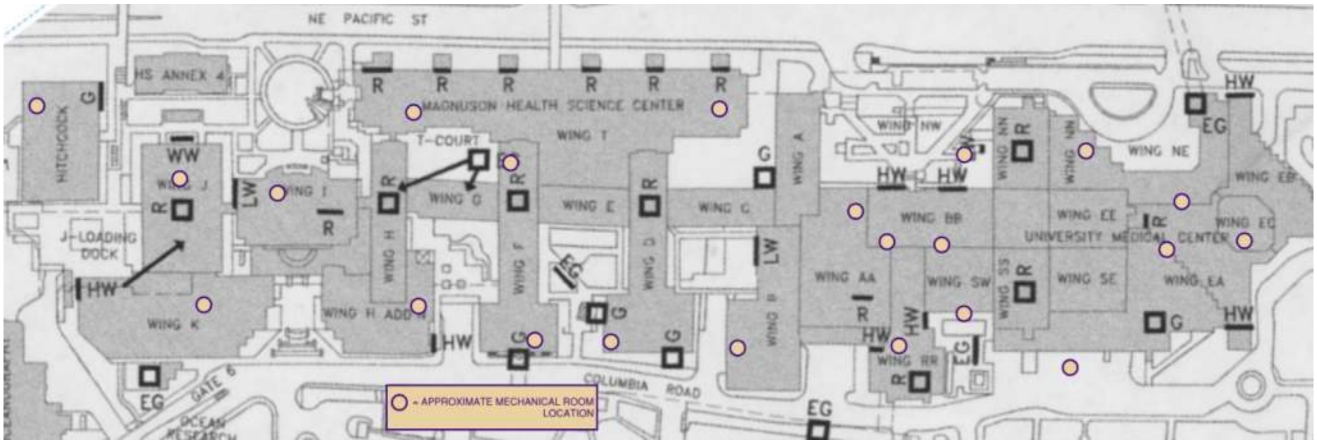


Figure 4.3.2-7: *Vicinity Map of MHSC and UWMC with mechanical room locations identified in plan view*

Additional Piping Services on Campus

- Compressed Air: Shall remain operational throughout the project. In many cases throughout the tunnel system, it will be required to be relocated.
- Well water: Located in the area adjacent to SC4, is available to be removed to facilitate additional piping installation.
- Emergency Lake Water: This system originates near the S-1 plant and serves the Power Plant boiler makeup water in emergency scenario if the local supply line goes down. This system is required to remain.
- Lake Water: Portions of this system located inside the tunnel are abandoned and can be removed to facilitate additional piping installation.
- UWMC Condenser Water: This system is required to remain.
- Pond Water: Located in the ST tunnel, this pipe is available to be removed to facilitate additional piping installation.

Pipe Material

Various piping materials for the PHW, CCW, SWHR and Lake Water systems were considered, with the two main types being steel or plastic. Criteria for considerations are:

- Pressure ratings at system operating temperatures.
- Longevity including leak detection methods.
- Ease of installation.
- Industry standardization.

At the UW campus, the primary pass/fail concern in evaluation of different piping materials is the high static pressure of the system due to the significant elevation difference between the low and high points in the system. If plastic piping were to be used for the PHW system, it would require a very thick-walled system (3.5" pipe wall thickness at the larger pipe sizes) to maintain adequate pressure ratings. At these sizes/dimensions, plastic piping no longer becomes a significant cost saver, since the comparable steel pipe would deliver the same flow at 1 or 2 nominal pipe sizes smaller. For the CCW system, although there exists a higher static pressure regime because of campus installations, the lower system operating temperatures allow for the ability to operate at higher pressures and remain within the acceptable ratings of plastic materials. In addition, the scope of work for direct bury CCW piping is limited to upper campus, where static system pressures will be lower. The SWHR piping system, operating at moderate pressures and temperatures, has even more options. Anticipated temperature and pressure ranges are listed in Table 4.3.2-2.

After performing a high-level screening process of available piping systems, and considering the operating temperatures and pressures, three types of piping systems emerged as viable options for this project: standard carbon steel, thin-wall steel (EN 253), and HDPE. Refer to Figure Table 4.3.2-1 for pros and cons with each system type.

Table 4.3.2-1: Comparison of Three Pipe Materials Studied for The UW Campus

Carbon Steel		Thin Wall Steel (EN 253)		HDPE	
Direct Bury or Tunnel		Direct Bury Only		Direct Bury Only	
Pros	Cons	Pros	Cons	Pros	Cons
Robust System	Thermal expansion requires anchors, bends, and bolster pads	Relatively fast installation	Thermal expansion can be achieved with sand backfill; no anchors required	Can be installed without expansion loops	Thicker walled pipe makes for wide trench requirements
High familiarity with installing this material	More time required for installation	Valves are factory installed, improving longevity	Less familiarity with this material, requires specialized welding	100-year life span	Less familiarity with installing this material
Leak detection is available	Cathodic protection required	Leak detection comes standard with engineered systems	Thin walls make corrosion a concern		Less ideal for above ground installation, support concerns
	Difficult to maintain integrity of valves in soil		Water chemistry cost increase due to corrosion mitigation		
			Cathodic protection required		

Carbon Steel Piping

Welded carbon steel piping is the most robust system available and is used in the legacy piping systems on campus. However, it is also the most expensive to install, as all joints must be welded, and more fittings are required due to its lower flexibility compared to thin-walled piping. Additionally, carbon steel piping requires standard anchoring and expansion loops or expansion joints, which limits its flexibility in dense campus environments. It can be provided as a complete engineered system or fabricated on-site. Leak detection can be added as an ancillary system. Although not ideal for direct bury in this project, carbon steel piping is a reasonable choice for tunnel installations, where the pipe runs are generally straight and tunnel support spacing is already established.

Thin-Walled Steel Piping

Thin-walled piping systems popular in Europe offer several advantages. They are quick to install, require fewer fittings due to their flexibility, and handle expansion compensation more easily than standard carbon steel pipes. These are generally installed as engineered systems, with factory installed insulation and leak detection. These systems can operate at higher temperatures and pressures compared to plastic alternatives, though their thinner walls make them more susceptible to corrosion. Because of this, water treatment is of utmost concern and can drive up installed and operational costs. Even with the water treatment concerns, thin-walled steel piping is a reasonable choice for the PHW direct bury piping on this project, given the relative ease of installation vs carbon steel and its capacity to withstand the higher pressure**s and temperatures seen in that system.**

HDPE Piping

HDPE piping was determined to be a better direct bury CCW piping solution than either steel piping option due to superior corrosion resistance, lower material cost, and less installation time. The direct bury CCW installations are located in the upper part of campus where the pressures are in acceptable range for this product. Due to the pressures and temperatures seen in the PHW system, HDPE was not an option. HDPE, while being perfectly suited for the direct bury SWHR and Lake Water piping, requires a shorter span for piping supports, which does not favor its use in the tunnel system. HDPE installations are considered to have a 100-year life span.

Table 4.3.2-2: Piping System Materials Summary

Category	PHW	CCW	SWHR	Lake Water
Anticipated Design Temperature Range	130°F-170°F	42°F-70°F	36°F-85°F	36°F-57°F
Anticipated Design Pressure Range Lower Campus	225-275 psig	225-275 psig	80-100 psig	80-100 psig
Anticipated Design Pressure Range Upper Campus	175-200 psig	175-200 psig	NA	NA
Tunnel Piping Material for Project Scope	Welded carbon steel piping, 2" insulation with jacket, mounted on rollers.			
Direct Bury Piping Material for Project Scope	EN253 pre-insulated steel piping, 2" insulation with jacket. With leak detection.	HDPE SDR 11, rated for 200psi in cold water applications, 1.5" insulation with jacket. With leak detection. (DB CCW only occurs in Upper Campus)	HDPE SDR 11, rated for 200psi in cold water applications, 1.5" insulation with jacket. With leak detection.	HDPE SDR 11, rated for 200psi in cold water applications, 1.5" insulation with jacket. With leak detection.

Impacts to the Existing Campus Environment

Surface disruptions for the baseline distribution approach will be related to the construction of ~2 miles of direct buried pipe trenches, 1700' of new tunnel construction, and staging areas to accommodate these efforts.

Direct bury scope is located in the North Central, South Central and West Campus Zone. See Figures 4.3.2-8 to 4.3.2-10, below.

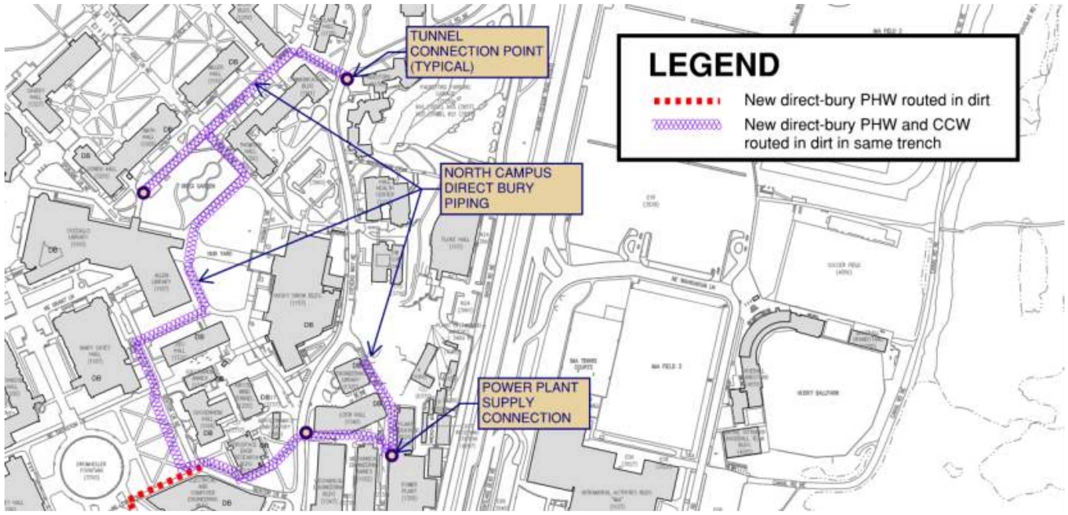


Figure 4.3.2-8: *North Campus direct-bury scope*

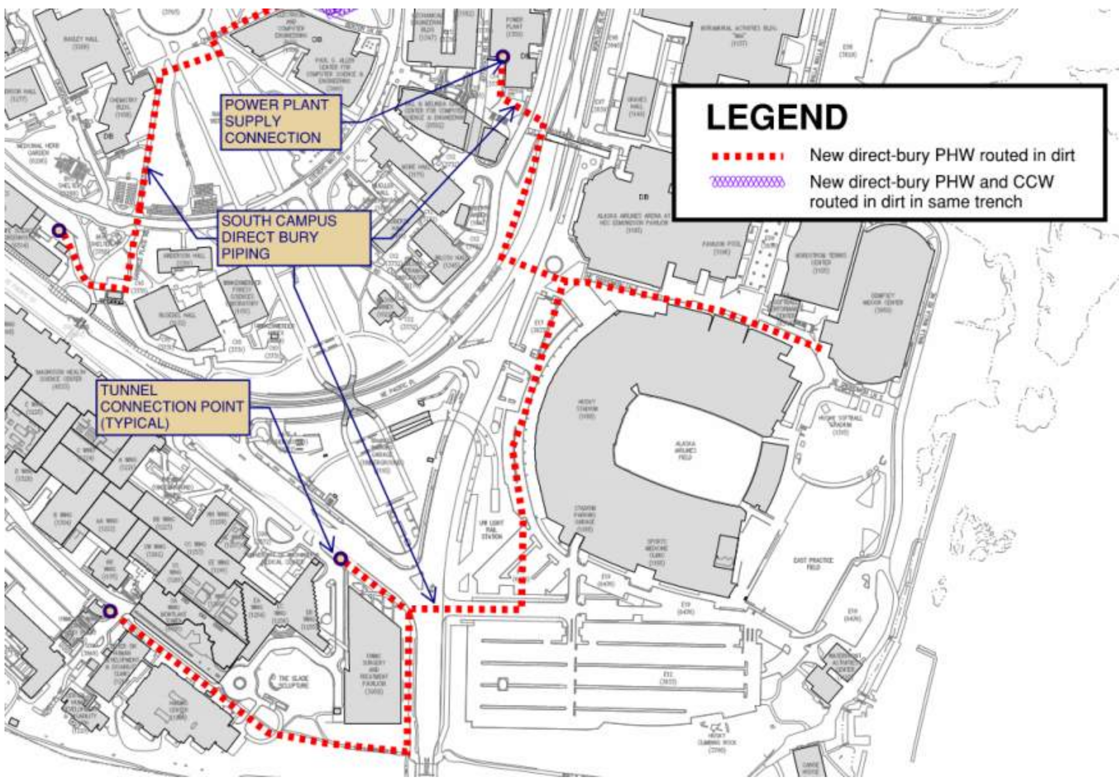


Figure 4.3.2-9: *South Campus direct-bury scope*

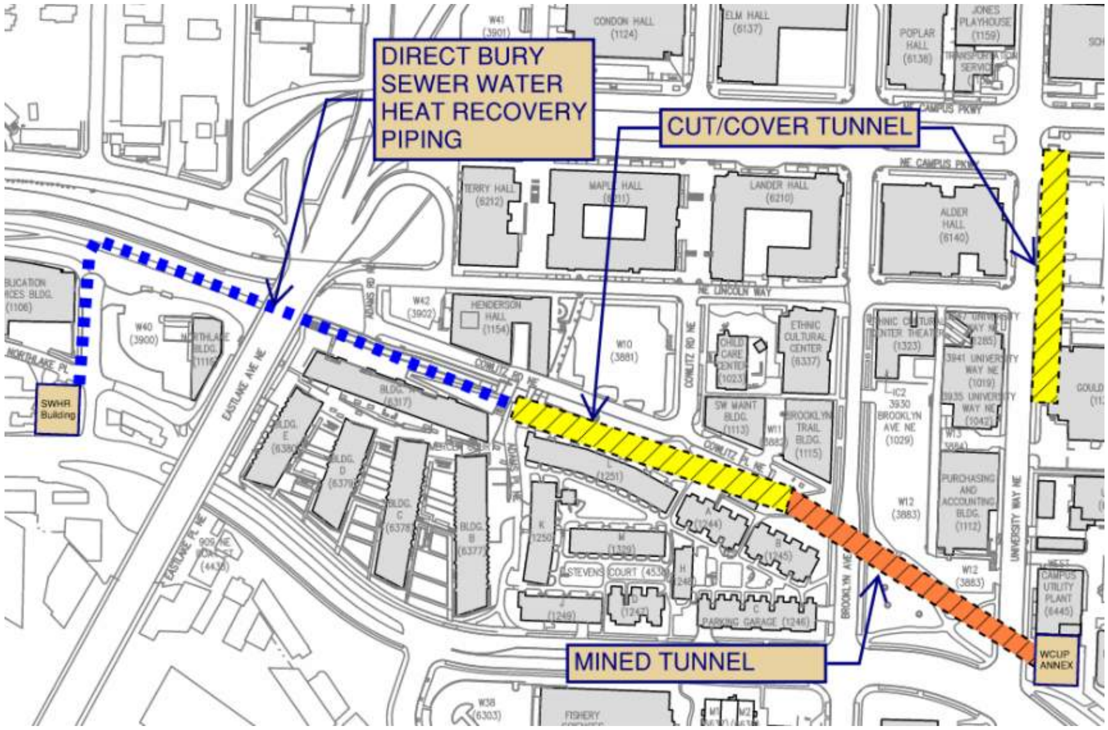


Figure 4.3.2-10: *West Campus direct-bury scope-1*

Whenever possible, direct bury routes were chosen to align with future campus projects relating to surface improvements. Pipe routes along Skagit Lane, Lewis Lane and South of Loew Hall were chosen as routes in order to avoid doubling-up of surface improvement projects. Refer to Figure 4.3.2-11 for the highlighted routes.

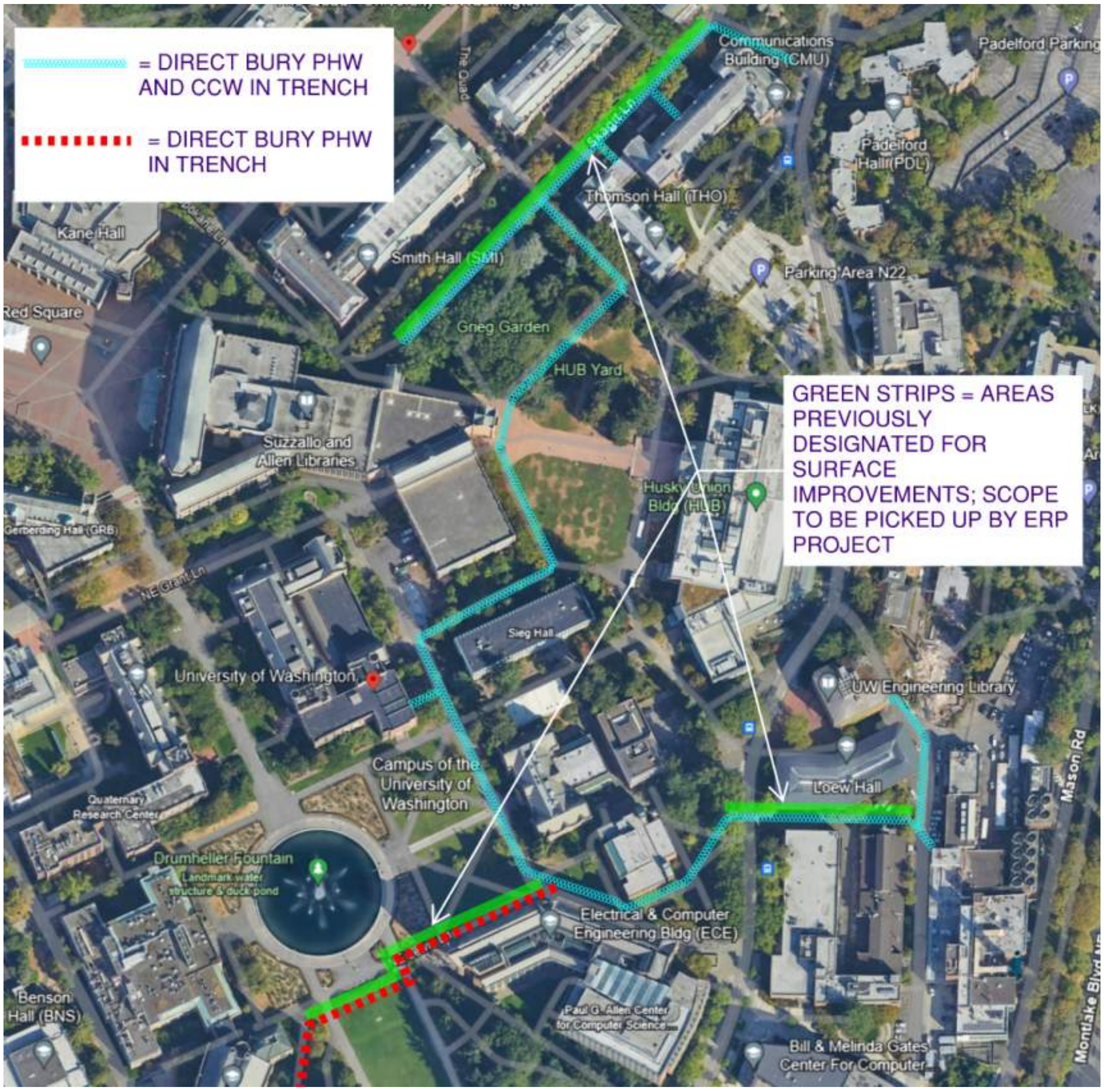


Figure 4.3.2-11: *Direct Bury Route Alignment with Surface Improvement Projects*

The maximized tunnel re-use approach, while reducing the amount of surface disruption, will still require significant staging areas at grade during construction.

Installation of piping inside the tunnel will likely require a staging zone (~2000 SF) adjacent to the tunnel access vaults, in addition to a large lay-down yard that would be in the range of 25,000 SF.

Surface staging area estimates are provided in the constructability commentary in the Appendix 9.13 Scope of Work Documents located.

Operational Considerations

Some of the utility tunnel installation layouts are extremely cramped, requiring asymmetrical piping installations and/or requiring complex support structures and branch takeoff connections. Steel inserts in existing tunnels may not be in locations conducive to building supports required. The limited space and awkward installation configuration could impede maintenance and repair work, making it difficult to service the pipes or perform any modifications. The cramped conditions can exacerbate issues related to heat dissipation and ventilation. In some cases, a hybrid solution of direct bury and tunnel may be preferred to a severely tight installation where maximized tunnel reuse is achieved. Refer to Figure 4.3.2-12 for tunnel section drawn between WT5 and SW3, which is likely the tightest installation. It is recommended that cost benefit analysis of the tunnel reuse philosophy be considered for the tightest (and likely most expensive) tunnel sections, notably the SW, SC and WT tunnels.

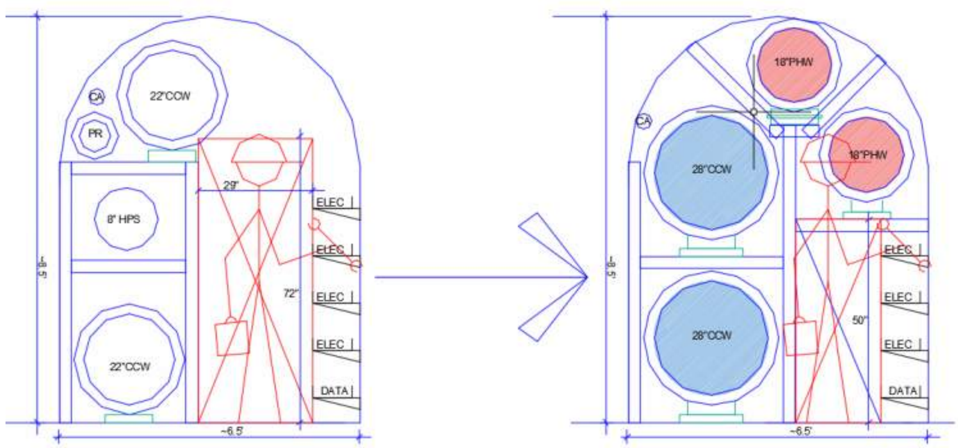


Figure 4.3.2-12: *Utility tunnel section in the WT-5 to SW-3 tunnel*

Risks

The removal of existing utilities (steam, condensate, CCW) and subsequent installation of new utilities (PHW, CCW) represents one of the most significant areas of risks of outages and unforeseen conditions. The effort will need to be done in a carefully sequenced manner, and the likelihood of schedule delays due to complications in working in confined tunnel spaces around existing services is high.

Many piping installations may want to occur during an off-season (CCW work done in winter, PHW/steam work done in summer), as it provides more flexibility and could potentially reduce the amount of temporary heating or cooling required. Schedule creep could potentially be a problem if the project is not completed before the season change occurs, or students return to campus in the fall.

There is risk of unintended damage to systems meant to remain and be active during construction, which could result in unplanned outages. Extreme care must be taken when working within tight spaces around existing live utilities.

Performing at least a portion of the distribution work with the direct bury approach could alleviate some of these risks, allowing existing system to remain active as another system is installed in parallel.

Refer to Section 7.4 for additional Risk Assessment.

Emerging Technology Considerations

The main aspects that drive the size of the pipe distribution systems are the capacity carried by the pipe and the temperature difference between the supply and return (delta-T). There are heat pump technologies, discussed elsewhere in this report, that claim to have the capability of delivering high temperature water (200°F+) at a high delta-T (40°F -60°F) which, if used for this project, could dramatically reduce the size of the new PHW systems. However, these technologies do not have any proven installations in North America and would likely be the first of their kind in terms of scale and expected reliability if applied here. With the expected timeline of this project, it is not anticipated to be a technology that could be used but is mentioned for the sake of understanding how the proposed solution was arrived at. The impact of reduced pipe size has not been studied as it would not only decrease material/labor cost but could also enable alternative routings.

4.3.3 Electrical Distribution

System Overview

The electrical distribution consists of new transmission lines from Seattle City Light to the primary side of the UW Substation described in Section 4.2.4 and secondary distribution feeders from the UW Substation to the West Receiving Station (WRS) and East Receiving Station (ERS).

The transmission lines will route along two different paths. The first will be along the Burke Gilman Trail and NE 40th street while the second line will route along NE Northlake Place. The distribution feeders (secondary side) are routed via three new conduit duct-banks installed in Burke Gilman Trail, NE 40th Street, Lincoln Way, University Way NE, and NE Pacific Street. Refer to Figure 4.2.4-7 for routing details.

The project runs a new set of express feeders from the West Receiving Station, through existing tunnel node WT-4 and then through the west trunk to the power plant. Refer to Section 4.2.2.2 for additional information on the feeder and switchgear scope.

Recommendations

Feeders From University Substation to UW Substation and WRS

The transmission lines will route along two different paths. The first will be along the Burke Gilman Trail and NE 40th street while the second line will route along NE Northlake Place. The distribution feeders (secondary side) are routed via three new conduit duct-banks installed in Burke Gilman Trail, NE 40th Street, Lincoln Way, University Way NE, and NE Pacific Street. Refer to Figure 4.2.4-6 for routing details.

Express Feeders Between WRS and ERS

The project runs a new set of express feeders from the West Receiving Station, through existing tunnel node WT-4 and then through the west trunk to the power plant. Refer to Section 4.2.2.2 for additional information on the feeder and switchgear scope.

The recommendation is to install new express feeders in a cable tray with dividers between each feeder. The installation should provide space for a third cable to facilitate replacement of a cable in the future with minimal interruptions. The intent is that a replacement cable can be installed adjacent to the other two cables while one or both of the existing cables is de-energized and load to be transferred to the new cable. The path through the existing west trunk was verified in the field with the contracting team during this phase of the project.

Medium Voltage Feeders to Plant and Source Equipment

The projects at the WCUP, Power Plant, UW Substation, Lake Interface Building, and Sewer Heat Recovery building include additional details on medium voltage cabling and distribution equipment. Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

Key System Characteristics

The primary side transmission line will be designed by SCL but is understood to be an underground, oil-insulated cable. The three distribution duct banks consist of a 3x3 conduit bank in each route, shown in Figure 4.3.3-2. The total quantity of distribution conduits will be (27). The intent is that there is sufficient space for Day-1 cables as well as enough spare conduit for the future needs of the campus for a minimum of 50 years.

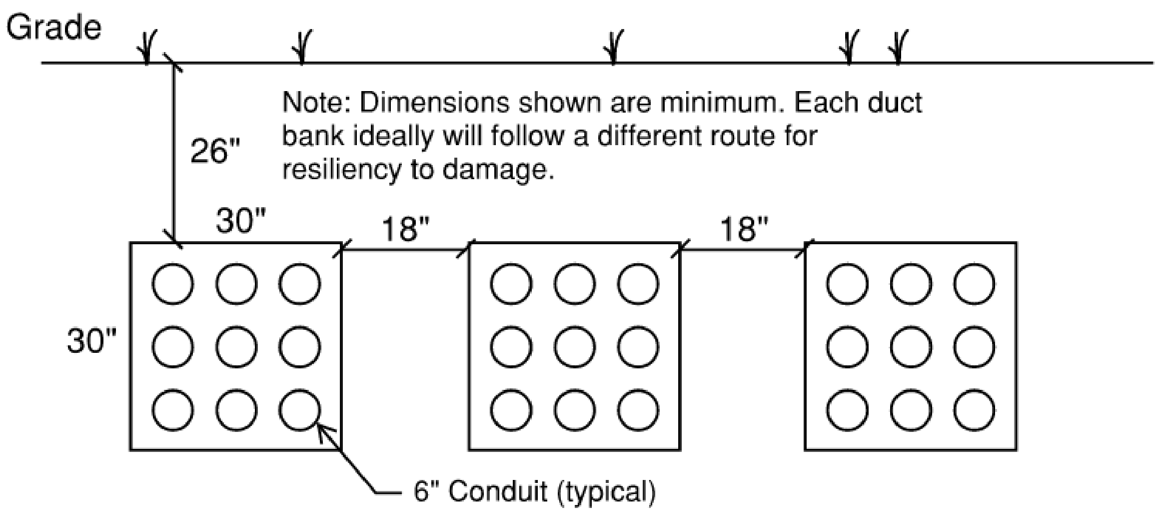


Figure 4.3.3-2*: Electrical duct bank elevation concept between UWS and WRS*

Assessment Data

Assessment data included field investigations of the routing from WT-5, through the West Trunk, and into the ERS/Power Plant. The path across the Powerplant from the ERS to Shop 43 and the new EE Bus was also verified in the field.

Alternatives and Scenarios

Feeders From University Substation to UW Substation and WRS

There is potential to re-use portions of existing SCL conduit banks and vaults and the specific application should be further studied. Re-using the SCL duct banks would involve acquiring permission from SCL. The conduits would approximately trace the existing SCL service which is being decommissioned and replaced.

Express Feeders Between WRS and ERS

An alternative route for the express feeders from the WRS to the ERS is along the Burke Gilman trail, paralleling Pacific and Montlake. The route through the West Trunk Tunnel was selected primarily because it is a significantly shorter distance and is more accessible meaning installation would require less labor and coordination than trenching along the Burke Gilman Trail.

Feeder Configurations

Burial depth of distribution feeders and de-rating impacts the quantity and size of the distribution feeders. As burial depth and number of conductors increases, temperature and therefore impedance of the feeders increases. The program Ampcalc4 was used to determine the feasibility of various duct bank configurations including 2x5, 5x2 and 3x3. The proposed conduit bank configuration is shown in Figure 4.3.3-3 The project briefly considered using a 2x5 bank because it would utilize existing SCL conduit banks that could be re-used in the project. However, it was determined that the 2x5 duct banks do not allow sufficient dissipation of heat below the top row of conduits for the size, type, and quantity of conductors that would be installed in the bank. The top row of conduits in the existing SCL banks may be useful for new conductors.

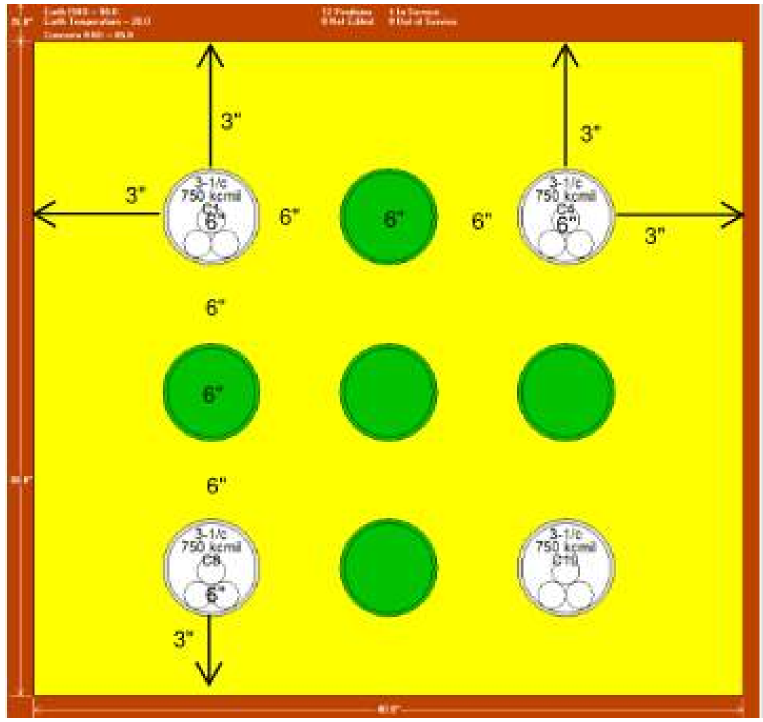


Figure 4.3.3-3: *Proposed conduit bank configuration for distribution feeders between UW Substation and WRS*

Impacts to the Existing Campus Environment

Impacts to the campus are minimal within the main campus.

Conductors installed in the Burke Gilman Trail will require an extended shutdown and temporary trail traffic detour of a couple thousand feet of the trail. But installation of new cables in the tunnels will not have an impact on the main campus.

Operational Considerations

Spare conduits are included in the duct banks for future installation of medium voltage cables.

Vaults will be installed along the conduit bank path which will require occasional access or maintenance.

Risks

The route identified for the express feeders from the WRS to the Power Plant through the West Trunk Tunnel crosses steam piping in several locations, mainly in the nodes and occasionally blocks access to sections of mechanical piping. This does not meet the University's design standards for routing medium voltage cables in the tunnels and would need to be a calculated risk to the ease of future maintenance. Consideration will need to be given to derating the cables due their proximity of the steam piping in areas in relation to the cable insulation due to higher ambient air temperatures. Derating of conductors may be required for the period of time that the steam lines remain in service.

All feeders from the West to East which power the loads in the East pass through the same tunnel (the West Trunk). This introduces risk to the electrical system because a physical disruption to the tunnel could interrupt plant operations. An alternative path within the tunnels exists to the north but adds significant length to the conductors. Similarly, another path exists in the Burke Gilman Trail which also adds significant length to the conductors.

Emerging Technology Considerations

The project can consider a smart grid system, which enables real-time monitoring and optimization of energy usage. Incorporating advanced fault detection and automated restoration can significantly reduce downtime during outages.

4.4 Building Systems

4.4.1 Introduction

An extensive effort within the campus buildings to accommodate the transition and modernize building systems is anticipated. This section will review in detail:

- Building Hot Water Conversions
- Distributed Chiller Replacements
- Local Steam Plants
- Cooling Added to Buildings Without Cooling
- Building Energy Efficiency & Load Reductions
- Building Control System Upgrades
- Comprehensive Metering Upgrades

4.4.2 Building Hot Water Conversions

System Overview

More than 120 buildings on the UW campus are connected to the existing steam system to serve for building heating and domestic water heating, with a portion of those also requiring steam for humidification, lab water heating, or sterilization / process demands.

The building systems across the campus vary, and with that variance comes differing levels of complexity in converting the system from steam to hot water heating.

Generally, primary heating water (PHW) will be routed to each building (as discussed in Section 4.3.2 Mechanical Utility Distribution). From there, the PHW will be routed to the building's mechanical room and a new water-to-water heat exchanger will be provided for each building system, including:

- Building heat
- Domestic water heating
- Lab water heating

Buildings that have steam distribution extending beyond the mechanical room will require additional work within the building including PHW piping routed to existing loads and/or replacement of steam humidification or process equipment with local electrified or gas-fired steam generators (refer to Section 4.4.4 Steam Plants for additional detail).

The difficulty of converting each building depends on the existing systems in place. Building hot water conversions were separated into the following categories:

- Low Difficulty
- Moderate Difficulty
- High Difficulty

Given the quantity of buildings and systems impacted by these conversions, this effort represents some of the highest risk in terms of cost, schedule, and disruption to the campus operations.

Recommendations

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of the building hot water conversion projects.

Connection Methods

The method of connection between the buildings and district PHW system will be made with water-to-water heat exchangers with pumps to circulate the building hot water.

Buildings that currently have steam coils in air-handling units with a high percentage of outside air will need to provide an element of freeze protection, as discussed in the Risks section.

Heat Exchanger Type

Plate & frame heat exchangers will be used due to their high performance and maintainability. Multiple heat exchangers per system will be provided, where feasible, to allow for partial or full redundancy in the event of equipment maintenance or failure.

Shell and Tube heat exchangers were evaluated but could not provide the required delta-T performance.

Project Sequencing

The building hot water conversion can occur either before or in conjunction with the installation of the primary heating water piping. This effort should be paired with the building-level chiller replacements discussed in Section 4.4.3 and building control systems upgrades discussed in Section 4.4.7 for an efficient construction schedule.

This work is best completed during the summer months to minimize building heating disruptions and limit the magnitude of temporary systems required to maintain building occupancy.

Key System Characteristics

Heating hot water capacity and characteristics:

- 127 buildings converted from steam to hot water.
  - There may be some variance in this number depending on how buildings in the South of Pacific region (MHSC, UWMC) are counted.
  - Connection method: Heat exchanger provided between PHW and building systems.
  - Heat exchanger type: Plate & frame gasketed heat exchanger.
  - Design conditions:
    - Temperature – Design Day worst case buildings:
      - PHW: 162°F entering / 142°F leaving.
      - Secondary hot water (SHW) : 160°F leaving / 140°F entering.
    - Temperature – Reset condition:
      - PHW: 145°F entering / 135°F leaving.
      - SHW: 140°F leaving / 130°F entering.
    - Pressure drop: 10 psi SHW and PHW.
- Heating load capacities vary from building to building.
  - See the Building Conversion Summary Table attachment as part of Appendix 9.13 Scope of Work Documents for capacities and equipment requirements for each building.
- Electric water heaters will be used in buildings with DHW loads <24 kW.
- Scope within buildings typically includes, at a minimum:

- New water-to-water plate & frame heat exchangers.
- New storage tanks for Domestic Hot Water and Lab Hot Water.
- Scope within buildings may include, depending on difficulty rating:
  - New or replacement PHW pumps.
  - PHW piping throughout building.
  - Replacement of steam coils at Air-handling units.
  - Replacement of room-level terminals (steam radiators).
  - Addition of stand-alone steam generators (refer to Section 4.4.4 Local Steam Plants).

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included building record drawings, Resource Conservation Program audit reports, building heating and cooling load profiles, local outdoor ambient temperature data.

Alternatives and Scenarios

Building to District PHW System Connection

Several methods of connection and quantity of heat exchangers (HX) between the building's systems and the district PHW system were studied:

- Option 1: Direct use of Primary Hot Water (PHW) within building.
  - Building pumps circulate secondary hot water (SHW) within building.
  - HX only provided for DHW and LHW.
- Option 2: Isolate PHW from existing and new systems with building heat exchangers.
  - HX per system - SHW, DHW, LHW.
- Option 3: Isolate PHW from existing and new systems with building heat exchangers.
  - Single HX to PHW. Downstream HX's to DHW, LHW.
- Option 4: Isolate Existing SHW systems + Direct Use of PHW for New Piping any AHUs

Diagrams depicting each of the Options above are provided in Figures 4.4.2-1, 4.4.2-2, 4.4.2-3, and 4.4.2-4.

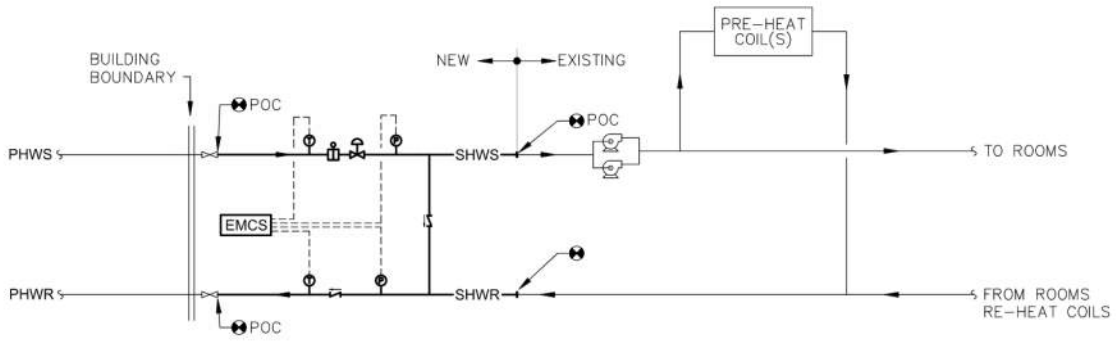


Figure 4.4.2-1: *Option 1 – Direct use of PHW within the building for the building secondary hot water loop. Heat exchangers to DHW & LHW services not shown*

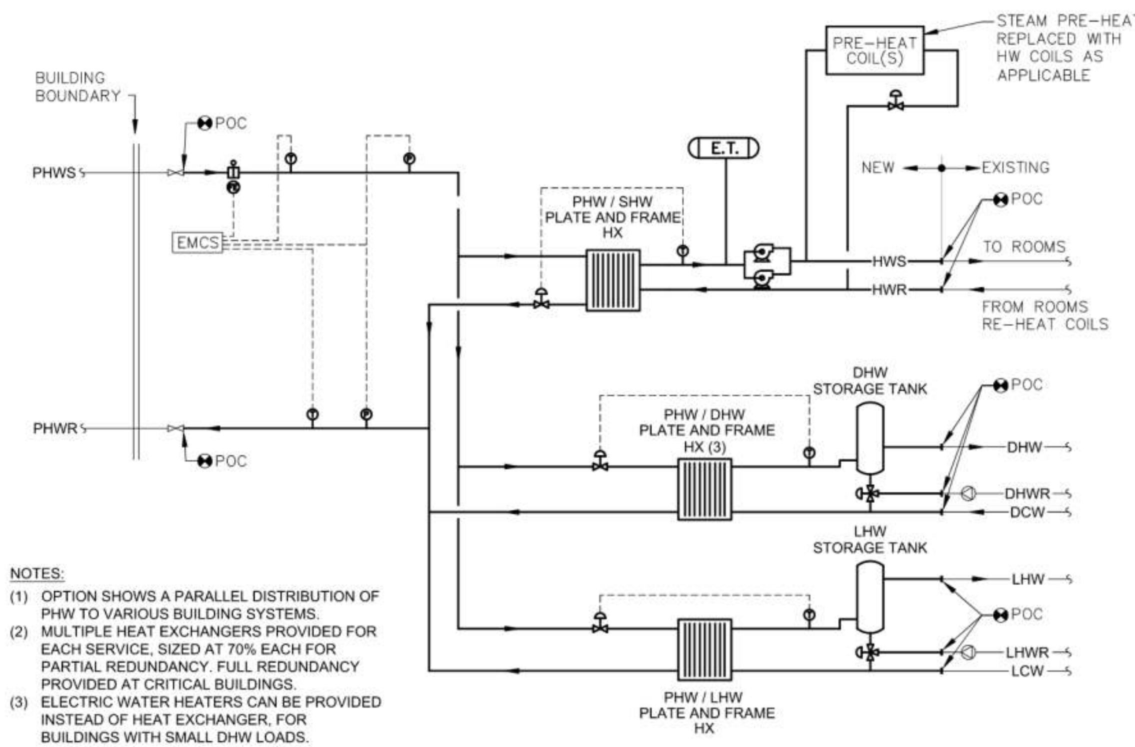


Figure 4.4.2-2: *Option 2 – Isolate PHW from existing and new systems with building heat exchangers. Heat exchangers are provided for each system*

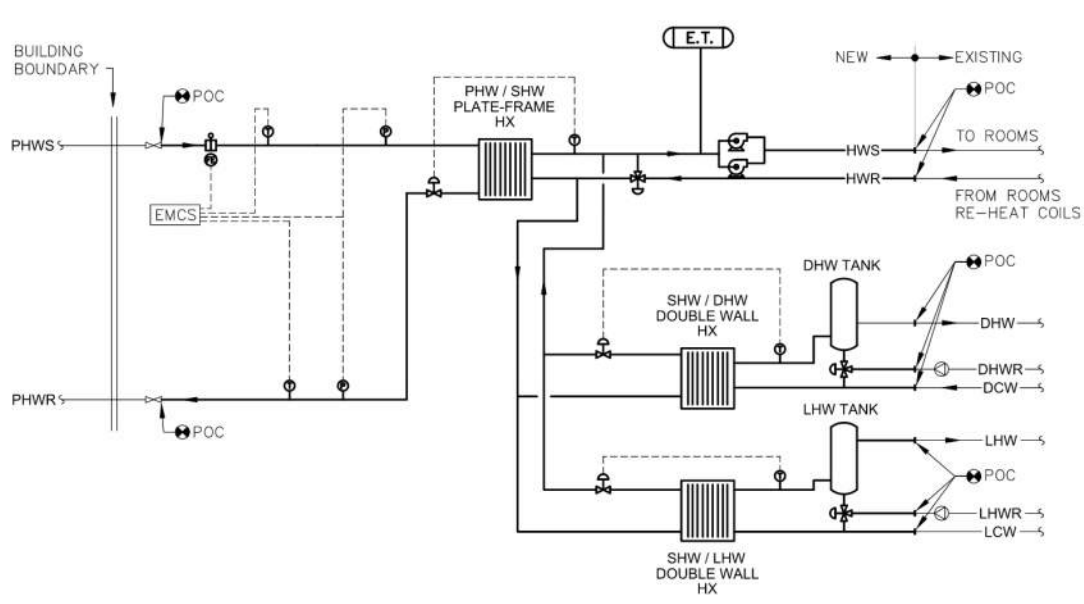


Figure 4.4.2-3: *Option 2 – Isolate PHW from existing and new systems with building heat exchangers. A single HX is provided between the PHW and building systems, with downstream HXs provided for DHW and LHW*

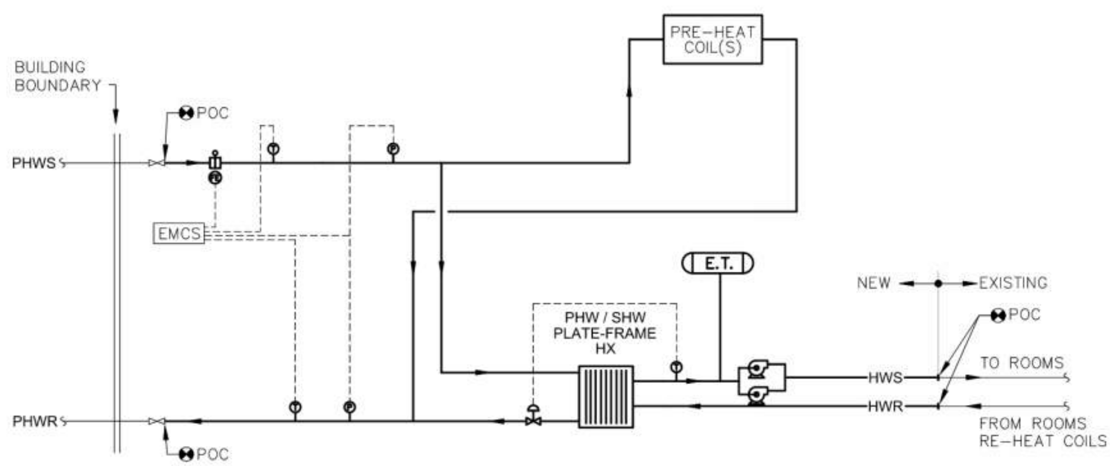


Figure 4.4.2-4: *Option 4: Isolate Existing SHW systems + Direct Use of PHW for New Piping any AHUs*

A decision criteria matrix was created to rate the advantages of each of these methods. Rated across the following factors, Option 2 - isolating the PHW from the existing and new systems with individual HXs per system scored the highest:

- Reliability
- Maintainability

- Footprint / space fit
- Operational complexity
- Energy efficiency
- Impact of system pressure on existing components

Heat Exchanger Type

A similar effort to the building to district PHW system connection method was performed to determine the recommendation for the type of heat exchanger to be used across the campus.

Three heat exchanger types were looked at:

- Plate & frame gasketed heat exchangers.
  - Provide a tight temperature approach capability (2°F-3°F) for energy efficiency.
  - Can be disassembled and cleaned.
- Brazed plate heat exchangers.
  - Same approach capability as plate & frame.
  - Cannot be cleaned. Effectively a throw-away product.
- Shell & tube heat exchangers.
  - Poor approach capability – unable to meet the system design conditions.
  - Requires single tube, counterflow design.
  - Large footprint and high cost.
  - Essentially do not require maintenance. Less likely to experience issues due to the large flow area.

A decision criteria matrix was created to rate the advantages of each of these heat exchanger types. Rated across the following factors to the building connection type, plate & frame gasketed heat exchangers scored the highest:

- Maintainability.
- Footprint / space fit.
- Vendor flexibility.
- Energy efficiency.

Building Conversion Difficulty Assessment

There are 127 buildings that are required to be converted based on their existing connection to the district steam system, including the UW Medical Center at Montlake and numerous research labs.

All buildings were divided into three categories based on the level of involvement required to make these upgrades: low, moderate, and high. The assessments were made using the following resources:

- Site visits – discussed in the Baseline Assessment Report.
- Desk review of record drawings and Resource Conservation Program audit reports.
- AEI/UW staff knowledge.

Low Difficulty

The buildings in the low difficulty category have minimal steam services. These buildings have existing hot water distribution systems in place and have steam-to-water heat exchangers to building heating and water heating systems.
Figure 4.4.2-5 shows a simple diagram of a Low Difficulty building conversion.
Characteristics of a low difficulty building include:

- Existing heating water distribution system.
- Steam-to-hot water heat exchanger located at basement.
- Steam does not extend past mechanical room.

Examples of buildings in this category include:

- Condon Hall
- Gould Hall
- Mary Gates Hall

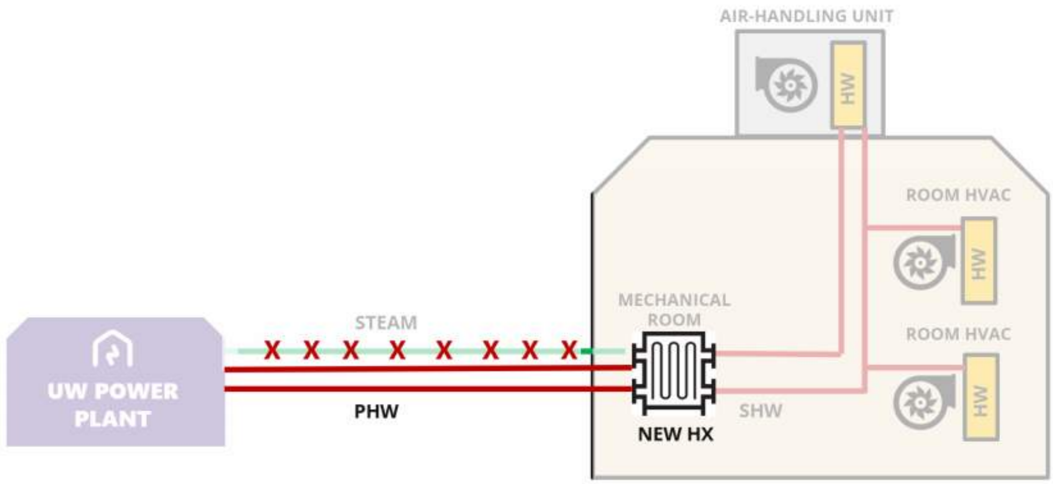


Figure 4.4.2-5: *Simple diagram of a Low Difficulty hot water conversion. Bold lines indicate new work*

The existing shell-and-tube heat exchangers will be replaced with new plate & frame water-to-water heat exchangers. Steam services will be shut-off and removed. For these buildings, building secondary hot water systems already exist and no new hot water loads are added. This allows for the existing building pumps to be reused without modification. The existing hot water distribution piping remains as-is for both lab hot water systems, domestic hot water systems, and heating water systems.

The main modification to existing systems in these projects will be the addition of a storage tank for buildings with moderate to high LHW and DHW systems. Buildings will with small water heating loads will utilize electric water heaters instead of heat exchangers when the system size does not justify connection to the district heating system.

Low difficulty buildings will have minimal electrical or architectural impacts. Since pumps are expected to be reused, the only electrical work will be for low voltage controls upgrades, and possibly the addition of a Variable Frequency Drive (VFD) for pump speed control.

In cases where there is not space for both the existing and new equipment in the mechanical room, additional mechanical room space may need to be created through conversion of an adjacent space.

Moderate Difficulty

The moderately difficult building category includes buildings that have steam-to-water shell and tube heat exchangers for hot water service and steam piping service for the heating coils in the building's air handling units. Some buildings also have steam loads for process items such as humidification and sterilization. These process loads will either be served from a new point-of-use electric generator or a regionalized steam plant proposed in Section 4.4.4. Figure 4.4.2-6 shows a simple diagram of a Moderate Difficulty building conversion. Characteristics of a moderate difficulty building include:

- Existing heating water distribution system.
- Steam-to-hot water heat exchanger located at basement.
- Steam routes to central air-handling units (AHUs).
- Limited process steam loads.

Examples of buildings in this category include:

- Johnson Hall.
- Kane Hall.
- William H. Gates Hall.

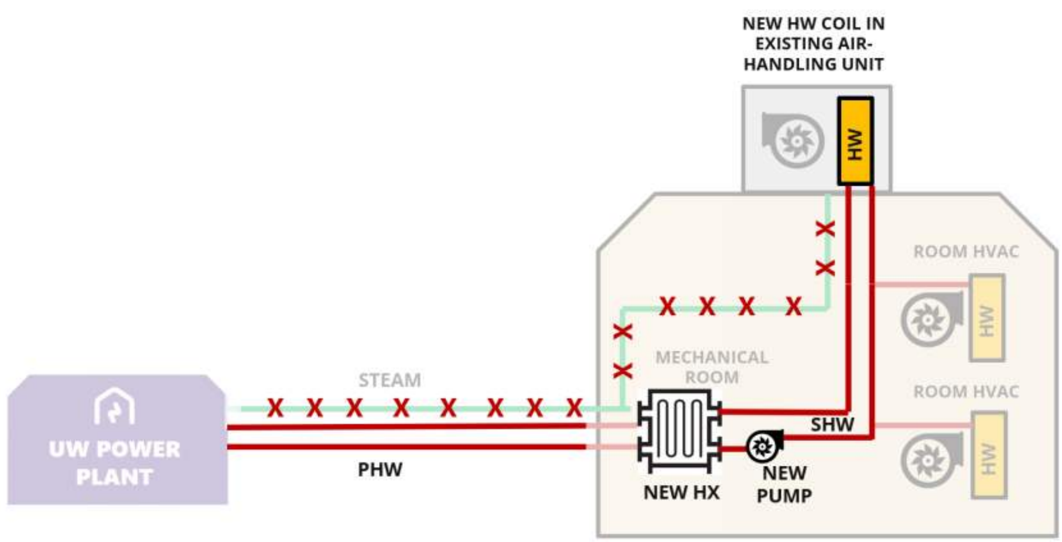


Figure 4.4.2-6: *Simple diagram of a Moderate Difficulty hot water conversion. Bold lines indicate new work.*

The existing shell-and-tube heat exchangers will be replaced with new plate & frame water-to-water heat exchangers and new pumps. The existing hot water distribution piping shall remain as-is for both Lab Hot Water systems and Domestic Hot Water systems. Additionally, the heating coils in the air handling units for each building will be replaced and circulation pumps will be provided. The piping will be extended from the existing system piping to make this connection. The added flow from changing the AHU coils requires the replacement of the heating water pumps and variable frequency drives. Moderate difficulty building design will include a storage tank for LHW and DHW systems. Some buildings will use electric water heaters instead of heat exchangers when the system size does not justify a heat exchanger. Any steam process loads would be replaced with stand-alone electric systems or connection to a new local steam plant (refer to Section 4.4.4).

Moderate difficulty buildings are more likely to have electrical or architectural impacts. Pumps will be replaced with larger motor sizes and new VFDs, which will result in more substantial electrical work.

In cases where there is not space for both the existing and new equipment in the mechanical room, additional mechanical room space may need to be created through conversion of an adjacent space.

High Difficulty

The highly difficult building category includes buildings that have steam-to-water shell and tube heat exchangers for some hot water services and steam piping service for the heating coils in the building's air handling units and room/zone level terminal unit heating functions. High difficulty buildings may also have substantial steam loads for process items such as humidification and sterilization. These process loads will either be served from a new point-of-use electric generator or a regionalized steam plant proposed in Section 4.4.4. Figure 4.4.2-7 shows a simple diagram of a High Difficulty building conversion. Characteristics of a high difficulty building include:

- No heating water distribution system exists.
- Steam utilized throughout building for room level heating and AHU pre-heat.
- Significant process steam loads (sterilizers, cage wash).

Examples of buildings in this category include:

- Suzzallo Library
- Bagley Hall
- Hutchinson Hall

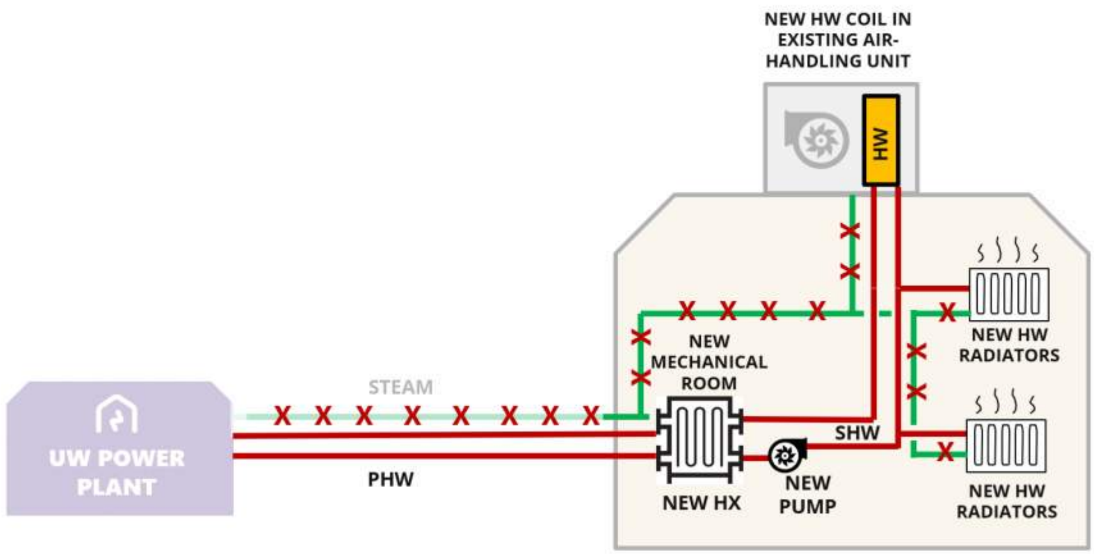


Figure 4.4.2-7: *Simple diagram of a High Difficulty hot water conversion. Bold lines indicate new work.*

A new mechanical room is likely required in each high difficulty building, as there the existing steam system uses minimal space and did not require heat exchangers or pumps for building heat. The new mechanical room would ideally be located within basement level / back-of-house space to minimize the architectural impact.

An entirely new building secondary heating water system would need to be created, with new piping routed throughout the building to existing AHUs and to each room level heating device (typically in the form of radiators located at the building perimeter). All building heating coils would be replaced with new hot water coils. This will be a very invasive and disruptive task to the building.

Like the other difficulty categories, high difficulty building design will include a storage tank for LHW and DHW systems. Some buildings will use electric water heaters instead of heat exchangers when the system size does not justify a heat exchanger.

High difficulty buildings will have the most significant electrical and architectural impacts. New pump systems will require new electrical panels and feeders.

Integration with the Building Renewal Plan

New and renovated building work completed within the timeframe of the ERP implementation will be provisioned future connection in a way that allows a simple transition from steam to PHW with minimal-to-no interruption in building heating service.

Space will be provisioned for the new water-to-water heat exchangers and tie-ins provided for this future connection. When planned for properly, the switch in steam to PHW service would happen over a weekend with no impact to building operation.

Other Distributed Heating Systems

The University has several facilities with building-level heating systems using either electricity or fossil fuel as the heating source. These systems are not planned for integration into the campus systems. The electric systems are primarily of the VRF or electric resistance type, typically associated with the Housing & Athletics branch of the University. The gas systems are typically located on the outskirts of campus and represent <5% of the campus peak heating demand.

For further discussion on these systems, refer to Section 3.1.4 of the Baseline Assessment Report.

Impacts to the Existing Campus Environment

There will be moderate to significant impacts to individual building operations for buildings categorized as moderate and high difficulty, as work is required within the building to connect new piping to existing AHU and room level heating devices.

From outside of the buildings, temporary heating systems are likely required where shutdowns extend beyond a weekend or for buildings requiring continuous service. These systems would likely be a trailer-mounted diesel-fired boiler and pump system, which will require staging space outside of the building and will be a source of noise.

After the work is complete there is no noticeable difference from the perspective of building occupants.

Risks

Construction risks include unforeseen circumstances within existing buildings which have the potential to increase the project scope and schedule.

Operational risks include a higher risk of freeze protection in heating water coils exposed to outdoor air. While steam coils are typically perceived as a lower freeze risk, in practice, they have a comparable rate of coils bursting in a winter freeze. Potential methods of mitigating the risk include:

- Coil pumps for maintaining constant water flow through coils which increases controllability and reduces risk of freezing coils.
- Generator power for freeze protection elements.
- New coils provided with burst protection – a pressure relief system that prevents coil damage before a coil freezes.
- Glycol on dedicated hot water loops to AHU coils.

4.4.3 Distributed Chiller Replacements

System Overview

Nearly 50 buildings on campus utilize some amount of distributed building-level chillers. Of these, 20 buildings are not connected to the existing central cooling water system and will require a new connection.

Multiple benefits are realized by eliminating these distributed chillers:

- Increased energy efficiency and reduced demand on the electrical system through higher-efficiency, centralized chillers.
- Increased ability to recover campus waste heat with heat recovery chillers.
- Eliminate deferred and ongoing maintenance associated with distributed chillers, cooling towers, and fluid coolers.

Recommendations

Refer to Appendix 9.13 for Scope of Work documents outlining the specifics of each of these projects.

Connection Methods

The recommended method of connection between the buildings and the campus CCW system is made with water-to-water heat exchangers with pumps, or a pressure sustaining valve and pumps, to circulate the building's chilled water.

Existing buildings that are not currently connected to the CCW system are assumed to be able to be provided with a new heat exchanger and pumps. Buildings currently connected to the CCW system will not be provided with new heat exchangers.

Existing buildings that are currently connected to the CCW system and exceed the maximum elevation allowed determined by the CCW Thermal Energy Storage tank are to be provided with new pressure sustaining valves and building pumps to mitigate the pressure impact on the TES tank while not reducing the effectiveness of the building cooling system that would come with the addition of a heat exchanger.

Project Sequencing

The building-level chiller replacements effort will be paired with the building hot water conversion discussed in Section 4.4.2 and building control systems upgrades discussed in Section 4.4.7 for an efficient construction schedule.

Each building will be assessed upon construction to confirm the increased load to the district cooling system is as expected for the Campus Utility Plants' planned capacities.

Key System Characteristics

Distributed chiller conversion to campus cooling water capacities and characteristics:

- 49 distributed chillers eliminated.
  - Connection method: Heat exchanger OR pressure sustaining valve.
  - Heat exchanger type: Plate & frame gasketed heat exchanger.
  - Design conditions:
    - Temperature – conservative assumptions for worst case buildings:
      - CCW: 42°F entering / 56°F leaving.
      - Building Chilled Water: 44°F leaving / 58°F entering.
    - Pressure drop: 10 psi.
- CCW load capacities vary from building to building.
  - See the Building Conversion Summary Table attachment as part of Appendix 9.13 Scope of Work Documents for capacities and equipment requirements for each building.
- Scope within buildings typically includes, at a minimum:
  - New water-to-water plate & frame heat exchangers OR pressure sustaining valves.

- Scope within buildings may also include replacement or addition of building chilled water pumps where buildings are currently served by the CCW system. In case where CCW was already connected, the CCW connection pipe may require being upsized.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included building record drawings, Resource Conservation Program audit reports, building heating and cooling load profiles, local outdoor ambient temperature data.

Alternatives and Scenarios

Connection Methods

Several methods of connection to the CCW were evaluated, including:

- Buildings isolated by heat exchanger.
  - Example: Population Health.
- Buildings directly connected to CCW with building pumps.
  - No current examples on campus.
- Buildings directly connected to CCW with no building pumps (flow provided by campus pumps):
  - Example: LSB, Bill & Melinda Gates Center for CSE, ARCF.

UW Facilities Engineering's stance is to recommend isolation provided by a heat exchanger. There are many examples of direct connections across the campus, but on recent projects Facilities Engineering has pushed for this approach for the sake of keeping the building's water chemistry isolated from the central system.

Due to the impact a heat exchanger has to the temperature provided to the building (typically 2°F warmer than the water supplied to from the campus), installation of a heat exchanger at existing buildings would adversely affect the performance of systems within the building.

Where existing buildings are already connected to the CCW system, the direct connection without a heat exchanger is planned to remain. This ensures that cooling coils within the building will not need to be replaced.

Where the CCW system is not currently connected to the building, it is assumed that a heat exchanger can be provided without requiring replacement of cooling coils within the building. An evaluation at each such building will need to be made, since the building chillers could have designed for a lower supply water temperature than can be achieved with a heat exchanger.

CCW System Pressure Relative to Thermal Energy Storage

The Thermal Energy Storage tanks proposed for this campus are open to atmospheric pressure and thus are the determining factor for the maximum height and pressure of the CCW system on campus. The relative height above or below the TES tank will determine the maximum pressure seen by buildings.

Where existing buildings are already connected to the CCW system and the building is at an elevation that would exceed the maximum allowable pressure at the CCW TES tank, the building will be provide with a pressure sustaining valve and building pumps. Refer to Section 4.2.2.1 discussion on Thermal Energy Storage tank Scope Considerations for details on this arrangement.

Chillers Connected to Generator Power

An evaluation of the distributed building chillers connected to generator power has not been provided as part of this study. Buildings that include generator backed chillers will need to be evaluated as part of the load assigned to the WCUP during a utility outage and ensure that adequate generator-backed cooling capacity exists in the WCUP, and that the distribution system has the capacity to deliver that load from the WCUP to the building.

The UW Medical Center as a group represents a significant amount of generator backed cooling load. There is currently 2,830 tons of chillers at UWMC which if all of that cooling is truly required to be on generator power, would roughly double the amount of generator backed cooling that would need to be provided at the campus level. This would all come from the WCUP as the PP chillers are not backed by generator power.

For this reason, as well as other utility discussions around the relationship between UWMC and UW Main Campus, the ERP implementation planning effort **will not** include the consolidation of UWMC chillers into the central systems. The distribution system sizing recommendations are made with the plan to integrate the UWMC into the campus utilities however the plant equipment associated with this load is not included. A future study would need to evaluate the impact of this consolidation and how the required generator-backed cooling would be provided and delivered to the UWMC through the system.

Other Distributed Cooling Systems

The University has several facilities with building-level cooling systems that rely on refrigerant or air to distribute cooling, through unitary direct-expansion units or variable refrigerant flow (VRF) systems. These systems represent approximately 900-tons of cooling and are not planned for integration into the campus systems.

For further discussion on these systems, refer to Section 3.1.4 of the Baseline Assessment Report.

Impacts to the Existing Campus Environment

Similar to the Building Hot Water Conversions, there will be moderate impacts to individual building operations as work is required within the building to connect new piping to point of connection of the removed chiller, typically on the roof.

From outside of the buildings, temporary cooling systems are likely required where shutdowns extend beyond a weekend or for buildings requiring continuous service. These systems would likely be a trailer-mounted chiller and pump system, which will require staging space outside of the building and will be a source of noise.

After the work is complete there is a minor positive difference in the elimination of the existing chiller from the perspective of building occupants, depending on the location of the chiller that is being removed. A source of noise / visual impact may be removed.

Operational Considerations

Building operations and maintenance will be simplified by the removal of distributed chillers, which require regular annual maintenance and refrigeration technicians to maintain. In some cases, distributed chillers are part of a winterization program that requires drain down of the system annually, which is another maintenance activity that can be eliminated.

Risks

Risks of building cooling outages should be lessened by the redundancy inherent in a central cooling system.

4.4.4 Local Steam Plants

System Overview

Research facilities located in the South-of-Pacific (SOP) zone and the UW Medical Center require steam for day-to-day functions and cannot tolerate any steam system shutdowns. Providing local satellite steam plants to serve the requirements of these facilities allows the steam-fired equipment to remain operational while allowing the steam service from the Power Plant to be disconnected and decommissioned, which also frees up tunnel space for PHW piping to be installed.

The worst-case minimum flow rate that the existing Power Plant steam boiler system can deliver is around 60,000 lb/hr, far higher than the estimated total process load of ~20,000-25,000 lb/hr. The load associated with steam process demands can be highly variable, which also presents a problem with serving the load with large combustion boilers. A smaller steam system will eventually be required to serve process loads once the entire campus has been converted to PHW service.

Recommendations

The proposed method to address the steam process demand both in the temporary and final condition includes:

- Dedicated electric steam generators for buildings with a small quantity of process equipment demands.
- New local gas-fired steam plants located within existing buildings that distribute steam centrally through existing buildings and portions of the existing tunnel network for buildings and regions of the campus with a high quantity of process equipment demands.

This process will require refinement of the required steam load located in South-of-Pacific region to allow for segregating into a handful of Local Steam Districts.

Strategic locations will be identified to house local steam plants and construct these in the early stages of the PHW distribution rollout.

Natural gas-fired steam boilers will be provided to supply medium pressure (80-90psi) or high pressure (185 psi), depending on the local equipment requirements and availability of PRV stations.

Proposed Local Steam Districts are:

- One plant located on the west side of the SOP Zone to pick up loads at ARCF, Hitchcock and Foege.
  - The location of the to-be-removed chiller in the basement of Foege was identified as a possible location for this plant. The existing abandoned generator stack could possibly be used as the exhaust stack for that plant. Piping can either be run direct bury between Foege and ARCF or routed through J/K loading dock and underground infrastructure.
  - Plant capacity: 15,000 lb/hr.
- One plant located in central SOP Zone to serve G/H/I/J/K/T-Wings.
  - A plant location for this zone has not been identified, but a location near the J/K loading dock could provide adequate access, structural requirements and intake air requirements.
  - Plant capacity: 10,000 lb/hr.
- One plant located at the UW Medical Center to serve sterilizers.
  - The plant location could be an adjunct to, or in place of, the existing S-1 chiller plant.
  - If space is available, the existing steam piping in the tunnel and UWMC could potentially be re-used since the PHW piping in that neighborhood is planned to be direct bury.
  - Plant capacity: 6,000 lb/hr.

Steam-fired equipment north of Pacific Ave (dishwashers, autoclaves, etc.), will be transitioned to electric.

Several point-of-use steam requirements in South-of-Pacific may not lend themselves to be connected to any of the new local steam systems. These pieces of equipment will need to be transitioned to electric steam generators before steam piping in the tunnels can be fully decommissioned.

Key System Characteristics

Local Steam Plant characteristics:

- Three local steam plants, serving medium- or high-pressure steam.
- Boiler systems shall be natural gas-fired, in an N+1 arrangement.

- Full boiler plant includes combustion air intake, stack vents, steam relief piping, condensate handling, water treatment. This may require revisions to interior of existing buildings.
- Envisioned boiler system includes full system skid, with boilers, makeup water system, control panels and condensate handling all provided in a single package.
- Refer to Scope of Work Documents in Appendix 9.13 for additional information.

Assessment Data

Estimates of steam process loads were developed using the equipment inventory lists provided by the UW and UWMC.

Alternatives and Scenarios

Steam Process Equipment Identification and Load Estimates

Approximately 140 total appliances - sterilizers(autoclaves), rack/tunnel washers, humidifiers - were itemized/located, and most of these are in the SOP Zone. Approximately 15 steam-fired pieces of dishwasher equipment are located on campus, heavily concentrated in the northeast corner of campus. Although a fairly comprehensive inventory list was provided, a complete survey of the entire Health Sciences and UWMC was not performed. See Figure 4.4.4-1 for a map of the South-of-Pacific region and the indicated quantity of steam process equipment.

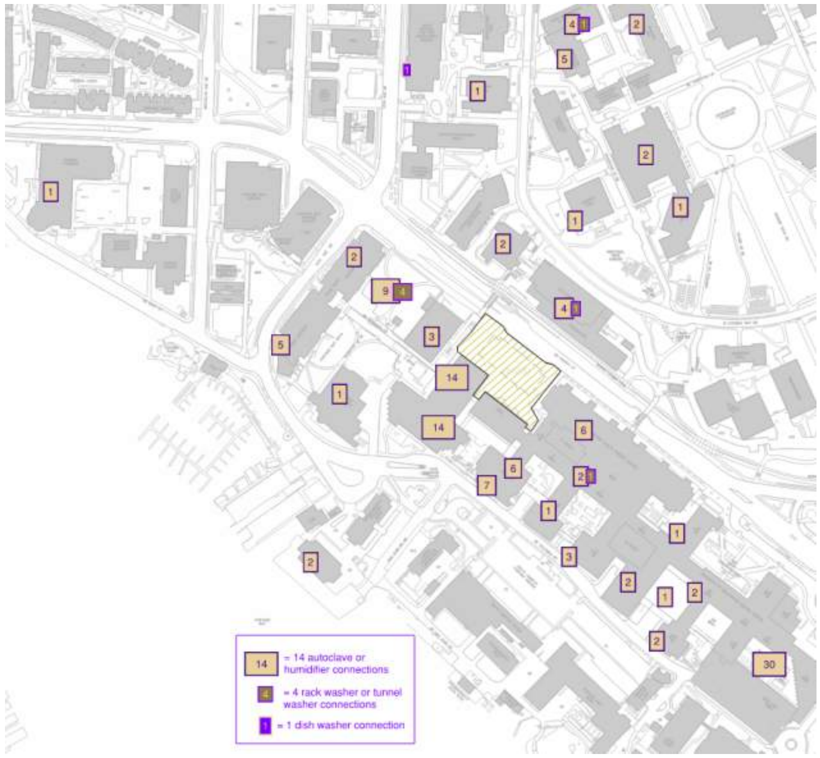


Figure 4.4.4-1: *Process steam connection map. Numbers indicate quantity of connection in that general area.*

Through a combination of site visits, document research and communication with equipment vendors, sizes of potential satellite steam plants were estimated. To best understand the steam requirement and shutdown constraints, a full audit of the steam-fired equipment must take place to validate system size estimates as part of the project identification phase of these projects.

Steam Generation by Combined Heat & Power (CHP) Systems

In lieu of generating steam by steam boilers, the option of a combined heat and power(CHP) system was explored. CHP systems simultaneously generate steam and power that can be fed back into the UW electrical system.

At the sizes required for these local steam plants, the smaller steam turbine generators generally considered for this application are expensive, maintenance intensive and have trouble passing emission requirements. Steam turbine generators that are in the range of acceptable emission are generally too large to be practical (~18,000 PPH on the small end). Given the variability of the process steam loads (high peaks and valleys) and the vision of smaller local steam plants, these CHP turbine systems do not appear to be an appropriate solution.

Reciprocating engine CHP was investigated as well. However, these machines are generally more suited for continuous duty, versus variable loads. The turndown requirements that will be involved in these smaller local steam plants precludes a system such as this from being a viable alternative.

Impacts to the Existing Campus Environment

The new local steam plants will have several impacts. Square footage will be required to house these boiler rooms; likely in the 1000-2000 square foot range. In addition to the footprint of the boiler room itself, the boiler will be required to have combustion air intake louvers that communicate with the outside, boiler vent ducts and relief vent piping that need to go the roof. Routing these vent lines to the roof may require modifications throughout the building.

Operational Considerations

The boiler skids envisioned utilize 2-3 boilers operating together to maintain header pressure. It is anticipated that the turndown with multiple boilers will be sufficient for the variable steam needs of the neighborhood.

Local steam plants will be in isolated locations, requiring staff to physically travel to each location for inspection/maintenance. A complete boiler system by a single manufacturer could be provided with a service contract included, potentially reducing the burden on the facilities staff.

Risks

Operational risks include a natural gas service outage. These local steam plants do not have access to diesel fuel oil like the Power Plant historically has, so any interruption in gas service would result in a loss of steam for the processes served by gas-fired steam plants. Natural gas resiliency to be investigated in Phase III, likely to involve new fuel oil storage at each location.

Unknown / unforeseen conditions are a risk in work like this where undocumented equipment discovered during the design or construction process could lead to large scope changes to add a new steam generator or extended steam line late into a project. When re-using existing steam lines within buildings, these risks can be lowered since the connectivity to existing systems will remain in place.

Introducing gas-fired equipment into buildings that do not currently have gas service can lead to more staff time required to address odor complaints within facilities. A common complaint in hospitals and labs is the smell of natural gas, which can be misattributed to many other causes. However, in buildings that have natural gas service, these complaints must be responded to responsibly.

Emerging Technology Considerations

Steam heat pumps are a developing market (potentially operating at COPs of 1.5-2.0 depending on the heat source) but are unlikely to be a near-term solution. Steam heat pumps would be challenged both on turn-down and responsiveness required for serving steam process loads.

4.4.5 Cooling Added to Buildings Without Cooling

System Overview

As discussed in Section 3.2.4, the impacts of future climate conditions are driving college campuses in milder climates to provide cooling in regions that previously could forego it. This can also be attributed partially to a desire for higher utilization of university campuses throughout the summer.

There are many existing buildings on campus that were not provided with cooling as part of their original design but now suffer during the summer, becoming effectively unusable for academic or administrative purposes with temperatures in the building rising above 80°F.

There are challenges with adding cooling to these buildings including the cost of the improvements, disruption to the building, and Building Code requirements that are triggered by adding cooling to a building that did not previously have it.

However, the biggest obstacle by far to adding cooling to these buildings has been the access to the campus cooling water system. It is challenging to add stand-alone systems to buildings, especially historic ones, since those systems would require some way to exchange heat to the outdoors via a large roof space or adjacent space for at-grade equipment. The goal of this project is to extend the CCW distribution system to the buildings identified as requiring cooling and provide a set of tees and valves to allow for connection to the campus cooling system as part of a future building renovation project.

Recommendations

Thirty buildings were identified to be provisioned for the addition of future cooling as part of this study. This project will extend CCW distribution through regions of the campus that do not currently have access to cooling. Piping mains will include tees with capped valves at locations within the proximity of the tunnel branches towards the identified buildings. Refer to Figure 4.4.5-1 for a map of the campus buildings that are provisioned for the future addition of cooling.

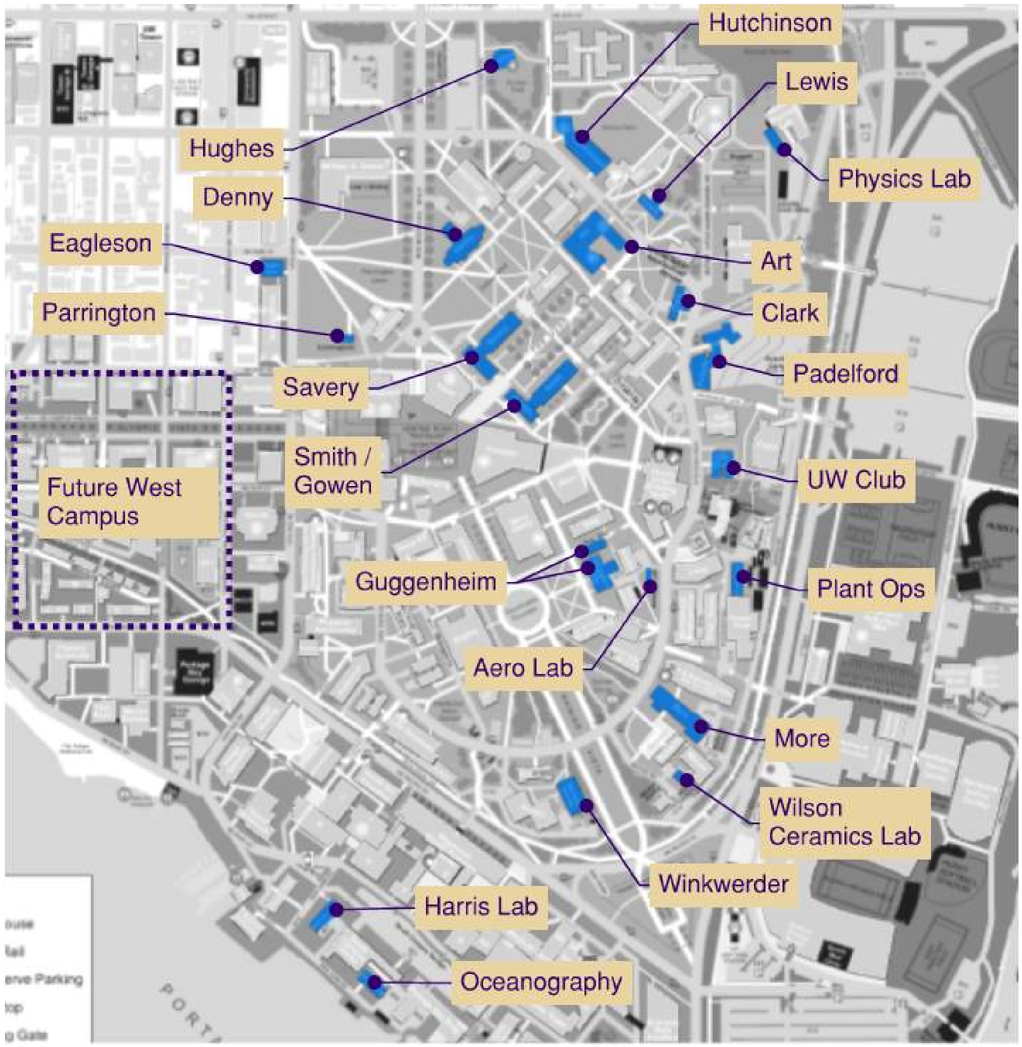


Figure 4.4.5-1: *Campus map indicating buildings that are provisioned for the future addition of cooling.*

Addition of cooling to the buildings is outside of the scope of the Energy Renewal Plan and would be funded under specific building renovation projects.

Key System Characteristics

- 30 buildings provisioned for the addition of cooling as part of future projects.

- Approximately 2,300 tons / 8 MWth additional cooling provisioned within the plant equipment and utility distribution to accommodate the future buildings.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included building record drawings, Resource Conservation Program audit reports, building heating and cooling load profiles, local outdoor ambient temperature data.

Alternatives and Scenarios

The addition of cooling to existing buildings will have different levels of difficulty based on whether there are central air distribution systems that already exist. Adding cooling to buildings without an existing central ventilation system (for example, to buildings that have historically been naturally ventilated) will require significant architectural improvements and planning to deliver cooling to the building. Many buildings would look to utilize room level cooling devices with retrofits to the central air system to create a dedicated outside air system.

The addition of cooling to a building would be an opportunity to address future climate conditions. The building's new cooling systems should account for the future weather conditions discussed in Section 3.2.4 so that building level systems are prepared to accept higher rates of cooling provided by the district cooling system.

4.4.6 Building Energy Efficiency & Load Reductions

System Overview

Building energy efficiency and load reduction measures present opportunity to reduce energy consumption and utility costs, reduce operational carbon emissions, and reduce peak loads on campus utility infrastructure which saves cost and further improves energy efficiency.

With a campus building portfolio of this size, a comprehensive study of building level upgrades would be a massive undertaking. This project aims to focus on campus energy systems to provide the highest value impact to the campus.

While building upgrade measures were not extensively studied, the two highest impact measures to the campus systems are discussed in this section:

- Air-to-air energy recovery.

- Elimination of simultaneous heating and cooling systems.

Recommendations

The building energy efficiency and load reduction strategies discussed in this section are not part of the ERP implementation plan due to the significant cost and logistics associated with implementing these measures at a campus scale to the point of a significant reduction in campus heating demand.

The outlined measures should be applied on a case-by-case basis as opportunities for building and system retrofits occur naturally through other maintenance and capital project opportunities.

Assessment Data

Relevant data for this analysis collected during the Baseline Assessment phase included building record drawings, Resource Conservation Program audit reports, building heating and cooling load profiles, local outdoor ambient temperature data.

Alternatives and Scenarios

Air-to-Air Energy Recovery

Ventilation air typically represents the most significant component of the peak heating load for a campus of this size. The UW campus includes high ventilation rate lab, healthcare, and assembly spaces. Air-to-air energy recovery systems, typically consisting of an energy recovery coil located in the exhaust air paired with another coil located in the outside air intake can effectively reduce the peak ventilation load by 50-60% on a system-by-system basis.

The opportunity for increased adoption of these systems across the campus will come in the form of building renovations and modernizations or targeted HVAC retrofit projects for the purpose of energy savings and load reductions.

The UW Medical Center has 270,000 CFM of 100% outside air AHUs that do not have heat recovery. Assuming a 50% energy recovery system, this represents a load reduction potential of 2 MWth (~2% of campus peak).

While the potential is high, the effectiveness of systematically achieving these load reductions would not align with the schedule goals of the project and would not be as cost-effective as the alternate energy source proposals discussed elsewhere in this report.

Simultaneous Heating & Cooling System Retrofits

UW buildings built in the 1960's to early 1970's (28 buildings representing 2.6 million square feet within the ERP scope fit this description) typically include either a dual-duct or constant volume terminal reheat system. These systems supply a constant volume of air to a space continuously, regardless of the load, and through a combination of mixing hot air with cold air or reheating cold air, deliver the required temperature to the space. These systems are incredibly wasteful as they employ simultaneous heating and cooling to the same space at any time that the loads are less than the peak design condition.

Buildings with this type of system typically run annual energy use intensities of 100-300 kBTU/sf-yr which significantly exceeds the maximum values allowed for the campus per the Clean Building Performance Standard. A few example buildings and their associated EUIs are provided below:

- Sieg Hall – constructed 1960 / 310 kBTU/sf-yr EUI
- MHSC RR-wing – constructed 1960 / 483 kBTU/sf-yr EUI
- Oceanography Teaching Building – constructed 1969 / 169 kBTU/sf-yr EUI

The difficulty in remedying these systems is similar to the level of difficulty required for the High Difficulty Hot Water Conversions discussed in Section 4.4.2, with changes needed at both the system and room level, likely requiring invasive construction efforts throughout the entire building. These systems are best handled with significant whole-building renovations and are unlikely to significantly dealt with until the Building Renewal Program addresses these buildings.

4.4.7 Building Controls & System Analytics

4.4.7.1 Introduction

The University of Washington (UW) has integrated the AVEVA PI System, implemented in 2021, to enhance data visualization and historical data management. At the West Campus Utility Plant (WCUP), SkySpark is utilized as a Fault Detection and Diagnostics (FDD) program, with its primary focus on ensuring plant reliability and energy optimization as a secondary benefit.

UW utilizes three building automation systems (BAS): JCI, Alerton, and Siemens. Additionally, it also employs two other data storages in limited capabilities: ABB data historian in the power plant and FactoryTalk Historian in the WCUP.

To further expand the reliability and efficiency of campus operations, it is recommended to either expand the existing SkySpark FDD system or consider deploying a standalone FDD solution. Expanding the current SkySpark system could capitalize on existing investments and seamlessly integrate advanced analytics, thereby optimizing energy use across the campus. Alternatively, a standalone FDD tool can complement the existing system, providing coverage across the campus.

A framework was developed to capture key elements of various FDD vendor tools to distinguish the functionality and potential application of one offering from another. [Characterization and survey of automated fault detection and diagnostics tools | FlexLab. (n.d.). https://flexlab.lbl.gov/publications/characterization-and-survey-automated | https://live-lbl-eta-publications.pantheonsite.io/sites/default/files/lbnl-2001075.pdf]

Expanding the PI System is also recommended to enhance its integration capabilities across the campus. By expanding this system, additional points can be polled from new buildings with JCI, Alerton, and Siemens BAS and metering data. This broader integration would enable more comprehensive data analysis and visualization, leading to better insights, improved decision-making, and greater efficiency across the campus.

4.4.7.2 Building Controls

The Building Controls Upgrades, identified in Appendix 9.13 as scope of work SOW-B-7, involves a modernization of the existing building control systems across multiple buildings. The primary objective is to transition pneumatic control systems to Direct Digital Control (DDC) systems. Additionally, it also includes the conversion of partial control systems to full control systems and their subsequent integration with the PI System for data collection, monitoring, and analysis, as well as the integration with SkySpark or other Fault Detection and Diagnostics (FDD) tools for fault detection and to optimize system performance.

4.4.7.3 Comprehensive Metering Upgrade

As part of the ERP, expansion of the UW's existing metering capabilities is recommended. A Comprehensive Metering Upgrade is identified in Appendix 9.13 as scope of work SOW-B-6, including the addition of new electric, chilled water, and steam flow meters to fill the gaps within the campus buildings.

All new meters associated with existing systems or with the new plant, distribution, and building conversion work will be integrated with the UW's System Analytics program.

4.4.7.4 System Analytics

PI Historian

The University of Washington is currently upgrading its existing pneumatic control systems to Direct Digital Control (DDC), transitioning from partial to full controls. This upgrade includes integrating the new systems with the PI System to enhance data collection, monitoring, and analysis. Data shall be archived for a minimum of 10 years.

Table 4.4.7.4-1 shows the costs that the University of Washington is currently paying for PI System. The cost structure is shown in Table 4.4.7.4-2.

Table 4.4.7.4-1: University of Washington PI System Costs

SKU	Description	Upfront Cost	Annual Maintenance
GS-PI-SERVER-1K	PI Server Software - 1,000 Data Stream Unit	$1,368.00	$222.30
GS-PI-PSA-1K	PSA Unlimited Data Access Add-on Software for PI Server - 1,000 Data Stream Unit	$351.00	$57.04

The UW is also paying maintenance for four interface types (BACnet, Modbus, UFL, and OPC DA) and cost for PI DataLink and PI Vision for 15 users.

Table 4.4.7.4-2: UW PI System Cost Structure.

Type of Costs	USD/Point
Base Cost	1.70
Annual Recurring Maintenance Cost	0.28
PI Interfaces (BACnet, Modbus, UFL, OPC DA)	$2,970
PI Data Link (15 users)	$780
PI Vision (15 users)	$2,244

The scalability of the PI system is designed to accommodate the addition of more data points, with the primary consideration being the associated costs. This scalability can be achieved either by adding more servers or by upgrading the specifications of existing servers. Currently, the PI system collects data from three BAS (JCI, Alerton, and Siemens), which are responsible for polling data from 25 buildings. Each building contributes approximately 1,100 data points, resulting in a total of 28,000 points currently being monitored. With the planned expansion of the PI system across the campus to include around 500 buildings, it is assumed with the inclusion of 66% data points redundancy, an additional 600,000 points are anticipated.

The total anticipated cost for PI System is shown in Table 4.4.7.4-3.

Table 4.4.7.4-3: Total Anticipated Cost for PI System

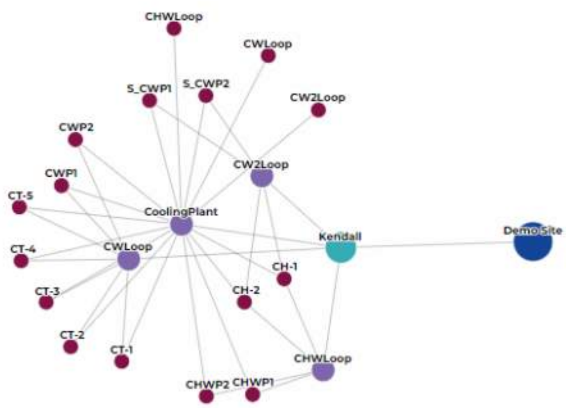
PI System Base Cost	$1,020,000
PI System Annual Recurring Maintenance Cost	$167,400
PI Interfaces (BACnet, Modbus, UFL, OPC DA	$2,970
PI DataLink (15 users)	$780
PI Vision (15 users)	$2,244
Additional Points	600,000

Fault Detection and Diagnostics

At the West Campus Utility Plant (WCUP), SkySpark is employed as a plant reliability program focused on enhancing overall plant reliability, with energy optimization as a secondary benefit. To broaden the scope of active energy management and Fault Detection and Diagnostics (FDD) functionality across all buildings, it is recommended to either scale the current FDD tool or install a new one. FDD tools are highly effective in identifying and diagnosing equipment faults, inefficiencies, and operational anomalies, which can lead to significant energy savings. In the industry, FDD systems have been proven to enhance the efficiency of building operations by detecting issues early, reducing energy waste, and minimizing downtime. Implementing or expanding an FDD tool can optimize energy management across the campus, ensuring consistent and reliable performance while driving down energy costs.

FDD Platform Capabilities

- Poll live data from the BAS or sync to stored BAS trend data at regular intervals via BACnet, or other data connectivity methods, to store historical data for analysis by the platform.
- Provide for the organization of all equipment as a hierarchical structure of assets, representing all structure and equipment. Multiple rules or fault detection logic will be supported for each asset.
- Structured views and a very robust data tagging and organization approach can solve the hierarchical structure of assets. For visualization, the asset instance can be duplicated in multiple places and for analytical relationships, there are input rules that assign relationships. Various ways include singular and one-to-many. The tools also have of complex loops (ring duct architecture) to combine derived inputs.



Source: Clockworks Analytics

- Utilize tagging to model and describe data and support the use of open-source tagging guidelines developed by Project Haystack.
- Include a rule execution engine that monitors all available data and alarms, executing logic to determine or predict equipment operational or efficiency faults, and calculates KPIs.
- Display active faults and KPIs via graphical interfaces, with drill-down features for further analysis. Analyze all referenced inputs continuously to calculate and display all possible causes of the fault and the probability of all possible causes.

Data Organization

- Data organization refers to the value added to raw data whereby data transformation, analytics, and visualization can be streamlined. This value includes adding descriptive information and defining how data relate to each other.
- Smart building platforms with robust data organization features leverage semantic data modeling, expert meaning, and data restructuring to deliver enhanced analytics.
- The semantic data model shall describe the data integrated within the platform and define their interrelationships. This model shall be at the core of all analytic services, whether internal or external to the platform.
- The semantic layer shall support user-guided tagging processes via a Graphical User Interface (GUI) and automated semantic application using profile definitions, pattern analysis, and model-based approaches with ML algorithms.
- Marker tags standardized by Project Haystack's open-source initiative shall be supported. This standard set shall be included in the platform's default tagging dictionary, and users shall be able to extend this dictionary to apply custom tags.
- BACnet Protocol's Structured View objects, or equivalent shall be supported. These objects define building information in logical containers with multi-level hierarchies to convey structures including buildings, geo-locations, systems, and sub-systems.
- The structural organization shall represent inherent interdependencies such as air systems depending on heating water systems, terminal units depending on primary ventilation, and rooms belonging to areas and levels in a building.

Data Connections Requirements

- Provide physical or virtual gateways, as required, to connect to BAS data, including any additional gateways for access where proprietary BAS protocols are used.
- Provide power and data for the FDD gateway, as required.
- Coordinate network requirements for the FDD gateway with BAS vendor and Owner.
- Ensure single-direction secured outbound data transfer from BAS to FDD software platform.

- Make all BAS devices and points available to the FDD platform via BACnet/IP, Haystack, or other methods using standard service requests, properties, and object types.
- Provide all necessary licensing for ten years for the FDD platform to integrate with the BAS data.
- Ensure all necessary ports for connection to the BAS are open to the FDD platform.
- Owner shall provide the FDD vendor with remote access to FDD Gateways as allowable in compliance with Owner's IT security policies, for the purpose of managing the FDD software.

Software Functionalities

- Integrate the following building subsystems with the BAS: HVAC, Electrical Systems, Power Monitoring, SCADA/EPMS, CMMS, etc. All data is pulled from BAS to FDD platform for analysis.
- Provide analytic tools that apply to any data types available from building subsystems.
- Present all views and data visualizations in a standard web browser without requiring plug-ins or Java. Support the use of the current version of industry-leading browsers as a minimum.
- Include a suite of built-in views to present analytic results. Views are automatically generated when issues are found by analytic rules without the need for programming or development.
- Support third-party API visualization application programs.
- Calculate performance penalty costs for specified faults and KPIs using static or dynamic variables.
- Prioritize or sort faults and KPIs by level of cost, energy, comfort, location, or maintenance impact.
- Ingest data manually or via various formats, including Excel or CSV files.
- Grant or restrict access to buildings, functions, and features based on user credentials and rights.
- Store data for a minimum of ten years.
- Issue generated fault notifications via email, text, or through the work order management system.

BAS Requirements for FDD Functionality

- Automate backups of all devices where possible.
- Ensure BAS graphics represent the actual engineered configuration of each equipment and system.
- Adopt or develop a consistent standard naming convention to deploy across systems, equipment, device controllers, and their connected points.
- Adopt or develop a consistent BACnet Instance (i.e., Device ID) numbering scheme to deploy across a given BACnet network's associated device controllers.
- Ensure that, in addition to normal BAS requests and workloads, in-scope FDD-selected BAS devices both at the IP supervisory and field bus layers have the ability and are configured to support a minimum five-minute interval polling from all points required for FDD through common BAS protocols (BACnet/IP, Haystack, etc.).
- Allow for outbound traffic, configuring firewalls as needed, to the FDD platform.

Key Performance Indicators

- Number of faults per week, month, year, or user-defined time period.
- Number of faults per floor or area.
- Most costly equipment based on faults.
- Total avoidable energy cost available.
- Total avoidable energy cost addressed (energy savings).
- Ability to drill down into types of savings (cooling, heating, electric).
- Number of comfort, maintenance, energy issues.
- Repeat offenders (equipment with multiple faults).
- Repeat offenders (recurring faults).
- Number of work orders by time/category priority.
- Average time to resolution for work orders and/or faults.
- Amount of energy lost due to unfulfilled work orders or faults.
- Comparison of trended temperature and humidity readings against setpoints per floor.

- Measure of optimal start sufficiency (whether a building reaches design temperature by the start of the business day).
- Number of hot/cold calls for different areas of the building.
- Total number of occupied hours where space is considered uncomfortable.
- Total site solar energy generation and building energy profile breakdown with respect to percentage of total load and effectiveness provided by photovoltaics.
- Total carbon dioxide emissions and offsets provided by site renewable energy sources (photovoltaics).
- Total utility (electric, domestic water, chilled water) consumption rates and costs.
- BAS graphic depicting all chilled and hot water valve positions within the building to analyze if the differential pressure reset strategy is properly functioning.
- BAS graphic depicting all terminal unit damper positions within the building.
- BAS graphic depicting consumption-based heat maps for electrical and water utility usage over time within the building.

Cost Modeling

Table 4.4.7.4-4 shows the median base cost for FDD setup which is 0.06 USD/sqft (9 USD/point), while median annual recurring cost is 0.02 USD/sqft (4 USD). In addition to the technology costs, the labor hours it takes for in-house facility engineers to support technology set up and configuration and to use the tool to identify and follow up on issues is 12 hour per building for FDD which included commercial buildings and a campus with 116 buildings. After two years of implementation, organizations using FDD tools achieved a 9% median annual energy savings. [*Nibler, V.; Crowe, E.; Granderson, J. Building Analytics Tool Deployment at Scale: Benefits, Costs, and Deployment Practices. Energies 2022, 15, 4858. https://doi.org/10.3390/ en15134858*]

Seattle City Light Existing Building Commissioning (EBCx) program offers incentives for retro-commissioning (RCx) and monitoring-based commissioning (MBCx) to improve building systems for enhanced occupant comfort and energy efficiency. The program has three phases: Assessment, Commissioning, and Performance Verification. MBCx (Path B) uses Energy Management Systems and Fault Detection and Diagnostic (FDD) software to continuously monitor and optimize building automation controls. The software identifies inefficiencies (“faults”), which are addressed to improve operations. Once corrected, the system is monitored to maintain efficiency. MBCx also meets some compliance requirements for Seattle’s

alternative building tune-up process.
[https://www.seattle.gov/Documents/Departments/CityLight/EBCxReqs.pdf]

Table 4.4.7.4-4: Median Base Technology Cost and Median Annual Recurring Technology Cost for FDD Tools

Type of Costs	USD/SQFT
Base Cost	0.06
Annual Recurring Software Cost	0.02

The total anticipated cost for FDD, considering a total area of approximately 17.5 million square feet, is provided in Table 4.4.7.4-5.

Table 4.4.7.4-5: FDD Cost Model

Base Cost	$1,050,000
Annual Recurring Software Cost	$350,000
Building Area	17,500,000 sqft

Fault Detection and Diagnostics and PI System Details

The following provides a summary of the typical points requirements associated with the Fault Detection and Diagnostics (FDD) and the PI System for HVAC and electrical systems.

Table 4.4.7.4-6 provides a list of typical points associated with the FDD and PI System for the HVAC system.

Table 4.4.7.4-6: HVAC Typical Points

System	Points
AHU	• Discharge Fan Status or Command • Cooling Valve or Stage • Heating Valve or Stage • Chilled Water Pump (optional) • Dehumidification Mode (optional) • Discharge Temperature • Mixed Air Temperature (fallback options available) • Face Bypass Damper (optional) • Outside Damper Status or Command • Outside Airflow (optional) • Outside Airflow Set Point (optional) • Minimum Outside Airflow (optional) • Occupancy • Heat Exchanger Valves (optional)

Table 4.4.7.4-6: HVAC Typical Points

System	Points
	• Return Air Temperature or Zone Air Temperature • Discharge Air Temperature • Outside Air Temperature
Zone	• Zone Occupied Cooling Set Point • Zone Occupied Heating Set Point • Zone Unoccupied Cooling Set Point • Zone Unoccupied Heating Set Point • Zone Damper • Zone Damper Discharge Temperature • Zone Damper Position • AHU Cold Deck Discharge Temperature • Zone Air Temperature • Zone Effective Set Point or Zone Heating/Cooling Set Point • Occupancy (optional) • Fan Status (optional)
Terminal Unit	• AHU Discharge Fan Status or Command • Discharge Airflow • Discharge Airflow Set Point • Discharge Airflow Maximum Set Point (optional) • AHU Discharge Temperature • Heating Valve or Stage • Discharge Temperature
Heat Exchanger	• Pump Status • Water Temperature • Water Temperature Set Point • Summer Winter Mode (optional) • Heat Exchanger Valves (optional)
Pump	• Pump Status or Command
Domestic Water Booster Pump	• Status (on/off) • Operating Hours • Lead/Lag Assignment • System Pressure (PSI) • Heat Detector Status, Temperature • Status Indicators (available, not available, activated, etc.) • Modes of Operation (Occupancy, Un-occupancy, Emergency)

Typically, Points such as Electrical Demand (kW), Electrical Consumption (kWh), Apparent Power Demand (kVA) and Voltage & Current for all Phases (A, B & C) are monitored. However, Table 4.4.7.4-7 provides a list of typical points for Electrical Power Monitoring and Control for a much higher level of analysis of the electrical system.

This high-level information is valuable for assessing overall amperage usage, helping to determine how much spare capacity is available especially useful during renovations or additions. Monitoring voltage can also reveal undervoltage or overvoltage conditions that may impact equipment performance.

Understanding harmonics is crucial for diagnosing power quality issues. If left unaddressed, these issues can lead to premature equipment failure or improper operation. However, advanced meters are required to measure harmonics.

Depending on the facility and its power consumption, different utility rate structures may apply. Exceeding certain usage thresholds can result in penalties, making it important to track metrics like "Over kW demand."

With the increasing use of electronic power supplies in LED fixtures and variable frequency drives (VFDs), buildings are experiencing higher levels of harmonics. Facilities such as research labs or healthcare centers, which utilize high-end, expensive equipment, could greatly benefit from harmonic monitoring.

Table 4.4.7.4-7: Electrical Power Monitoring and Control Points

System	Points
Waveform Data	• Phase voltages, phase currents, and residual current • Overlay of three-phase currents and overlay of each phase voltage and current • Waveforms ranging from two cycles to five minutes • Disturbance and steady-state waveforms up to 512 points per cycle • Transient waveforms up to 83,333 points per cycle on a 60 Hz base • Calculated waveform on a minimum of four cycles of data including: • THD (Total Harmonic Distortion) – rms magnitudes – Peak values – Crest factors – Magnitude of individual harmonics
RMS Real-Time Measurements	• Current: Each phase, neutral, average of three phases, percent unbalance • Voltage: Line-to-line each phase, line-to-line average of three phases, line-to-neutral each phase, line-to-neutral average of three phases, line-to-neutral percent unbalance • Power: Per phase and three-phase total • Reactive Power: Per phase and three-phase total • Apparent Power: Per phase and three-phase total • Power Factor: Per phase and three-phase total • Displacement Power Factor: Per phase and three-phase total • Frequency • THD: Current and voltage • Harmonic Power: Per phase, three-phase • Phase rotation • Unbalance: Current and voltage • Harmonic Magnitudes and Angles for Current and Voltages • Accumulated Energy: Real kWh, reactive kVARh, apparent kVAh (signed/absolute) • Incremental Energy: Real kWh, reactive kVARh, apparent kVAh (signed/absolute) • Conditional Energy: Real kWh, reactive kVARh, apparent kVAh (signed/absolute)
Alarms	• Over/Undercurrent

Table 4.4.7.4-7: Electrical Power Monitoring and Control Points

System	Points
	• Over/Undervoltage • Current Imbalance • Phase Loss, Current • Phase Loss, Voltage • Voltage Imbalance • Over kW Demand • Phase Reversal • Digital Input Off/On • End of Incremental Energy Interval • End of Demand Interval

Table 4.4.7.4-8 provides a list of frequency of data poling for the FDD and PI System analytics.

Table 4.4.7.4-8: Data Collection Frequency

PI Points	Frequency
Electric Meter	1 minute
Chilled and Hot Water BTU Meter	15 minutes
Building DHW BTU Meter	15 minutes
HVAC Data from BAS	15 minute

5.0 Cost Estimates

5.1 Introduction

The ERP team includes a general contractor with experience in planning and construction of several campus utility projects of this nature and a professional services and consulting firm with experience in advising non-profit clients with financial modeling and funding support.

The Whiting-Turner team was provided with the Scope of Work documents in Appendix 9.13 to define the elements of the project to a specific enough level to provide planning level cost estimates and schedules. As part of their review, Whiting-Turner provided constructability commentary (see Appendix 9.12) which will be factored into the implementation planning for the final report.

In Phase II, a financial model was developed in preparation for the implementation planning phase, ensuring that the model was aligned to the capital and operational expenses that would be provided in Phase II. An updated preliminary analysis of funding opportunities has been provided.

5.2 Project Costs

The Whiting-Turner team has provided detailed cost estimates for projects based on the coordination to date and project scopes of work identified in Appendix 9.13 Scope of Work Documents. Refer to Appendix 9.10 Detailed Cost Estimates.

See Table 5.2-1 for a summary of costs by project type. These costs will be used in Phase III to develop the Implementation Plan, outlining the recommended sequencing of projects based on project technical, schedule, and funding constraints.

Table 5.2-1: Cost summaries for projects within each project category.

Description	ROM Cost ($)
Energy Sources	
Lake Water Interface System	$134,801,640
Sewer Heat Recovery System	$49,637,618
Subtotal:	$184,439,258
Plant & Electrical System Upgrades	
Power Plant Improvements	$160,504,714
WCUP Improvements	$153,655,735
Thermal Energy Storage System	$67,533,943
UW Substation and West Receiving Station Upgrades	$168,827,118
East Receiving Station Upgrades	$13,431,848
Subtotal:	$563,953,358
Site Distribution	
Mechanical Site Distribution	$492,211,569
Subtotal:	$492,211,569
Building Upgrades and Conversions	
Building Heating System Conversions	$260,097,167
Building Chiller Replacements	$20,573,390
Local Steam Plants	$59,241,421
Building Controls, Metering, and System Analytics	$187,652,738
Subtotal:	$527,564,716
UW ERP Project Cost Total:	$1,768,168,902

***Project schedules have not yet been determined. Amounts do not account for escalation.**

5.3 Federal and State Reimbursement

University of Washington has set a financial goal to fund the projects associated with the ERP campus energy transformation with 100% external resources.

The primary source of funding identified will be funding from the State legislature which is expected to have more funding than in previous years available through the Climate Commitment Act (see Section 8.2.1 for more details). These projects will pursue financial reimbursement through other state, federal, and utility incentive programs at the completion of the project, which can act as a rolling funding source as projects continue to be implemented by the University.

Refer to Appendix 9.8 for an updated report on Potential Funding, Financing, and Incentive Programs.

6.0 Operational Considerations

6.1 Introduction

The Energy Renewal Program will introduce many challenges to campus operations involving the temporary disruptions associated with construction and transition of systems as well adapting to the new systems and functional priorities.

6.2 Operational Staff Considerations

6.2.1 Operational Staff Resources

An assessment of UW's staff resources has not been completed as part of this effort. The additional full-time employees (FTEs) that will be required has not been quantified.

It is understood that the current operations staff do not have experience with the new systems (115 kV electrical, heat recovery chillers, electric boilers, thermal energy storage) utilized in district energy applications and will require training.

The specific cost value of additional FTEs required to operate and maintain the new systems associated with the Energy Renewal Plan is not provided. Operations & maintenance costs that will be utilized in the life cycle analysis will be rough estimates based on previous study efforts with other university and institutional clients, based on the relative cost of maintenance to cost of equipment. Additionally, feedback from the CE&U team has been used to estimate the increased direct payroll costs associated with the additional staff required for the ERP systems.

6.2.2 Operational Complexity of Electrified Heating

Any potential increase in effort and responsibility for operations staff is very important to the University to understand, who like most campuses is already overextended maintaining the current systems.

There are aspects of the transition from fossil fuel combustion boilers to electric heat recovery chillers, boilers, and thermal energy storage that provide tangible maintenance benefits:

- Heating water piping and associated terminal air handling systems require less maintenance than steam piping.
- Reduced wear and tear on combustion boilers relegated to only providing peaking and standby power operation.

However, the complexity of operations for a heating plant relying primarily on heat pumps is significant. The steam system historically used on campus is very simple to operate from the standpoint of staging of equipment with a single primary goal of maintaining steam pressure located in only one campus utility plant. Equipment relying on compressors is not nearly as robust as gas-fired equipment when it comes to changing system conditions and part-load operation. Additionally, the new proposed systems may operate under different goals depending on the season or regulatory environment. Some of these challenges are offset with adequate thermal energy storage to allow heat pumps to operate at their ideal run condition for an adequate amount of time to avoid short cycling and the issues that come with that. Furthermore, the proposed heating systems will also provide a more distributed approach to heating, transitioning from a single centralized heating system to a distributed system consisting of many different heat sources including heat recovery, lake heating/cooling, sewer heating/cooling, electric boilers, air-source heat pumps, geothermal, and management of thermal energy storage tank capacities.

Heat recovery chillers are a double-edged sword when it comes to their ability to operate in multiple modes (heating, cooling, heat recovery). This flexibility comes at a cost of operational and controls complexity. Automated control valves and different pumping and flow criteria are required as the heat recovery chiller moves between operational modes. These machines are more sensitive since they are typically running at near full load.

There will likely be several years, if not a decade, where legacy heating and cooling equipment will be required to operate alongside these new systems. Even with the best commissioning process, this interim period is likely to present unknown issues that will be dealt with by operational staff as they arise.

Additionally, the campus's chemical water treatment program will need to be re-evaluated with respect to the significant added system volume associated with large campus scale Thermal Energy Storage tanks (potentially adding 4 million gallons of water to the system).

The proposed primarily heat pump driven heating system will require a significant shift in UW staff which are currently trained to operate a very simple heating system. This will require more staff, additional training of the current staff, and a complete reimagining of how things have been done in the past.

6.2.3 Maintenance Considerations

6.2.3.1 115kV Electrical Systems

The ownership of the electrical equipment within the UW Substation has not been defined. It is likely that Seattle City Light will own and maintain the 115 kV side of the equipment since UW does not currently have electricians certified for maintaining that equipment and would be pulling from the same labor pool as Seattle City Light to build that staff up.

6.2.3.2 Year-Round Campus Cooling Water

The impact of switching the CCW system from a seasonal “comfort” cooling system to a year-round critical cooling system has implications to the standard of criticality of plant CCW operations that the Power Plant operations staff has not had to work under. This will lead to more training of Power Plant operators to spread the specialty knowledge of chiller operation across a broader group of operators to help in response time to issues. More staff may be needed to maintain CCW system operation to acceptable standards during continuous operation of the plant.

6.2.3.3 Heat Recovery Chillers

Due to the flexible modes of operation that heat recovery chillers can be utilized for, they tend to be operated more throughout the year. Heat recovery chiller maintenance will need to be scheduled during the shoulder seasons rather than in the peak of winter or summer, since the HRCs will need to be fully operational during either peak period.

Heat recovery chillers are comparable to the conventional cooling-only chillers used at the PP and WCUP but include additional compressor stages and economizers that will require additional training for maintenance staff.

Heat recovery chillers are regularly run at near their peak load capability and the tuning period for a system of this scale will be lengthy. Operators will need to be familiar with assessing equipment faults and preventing them through adjustments to the PLC system control setpoints.

6.2.3.4 Electric Boilers

Electric boilers are relatively low maintenance compared to combustion boilers. Water chemistry within the closed loop circuit between the electrode boiler and the associated heat-exchanger is an isolated system that is within the control of the operators compared to attempts to maintain water chemistry in the CCW loop which extends throughout campus and even into buildings.

Electrode boilers are vertically configured and are quite tall (greater than 16' at the size of boiler being investigated), requiring access platforms to service the electrode elements and internal nozzle header/electrode strike plate at the top of the unit.

6.2.3.5 Sewer Water System

Large sewer water heat recovery facilities are a new feature in district-level heating systems. As such, there is a dearth of information available regarding maintenance efforts required to keep these systems running beyond scheduled factory-recommended preventative maintenance. Given the fact that the system is handling raw sewage from a large system known to occasionally carry solids as large as wrenches and bicycles, it can be expected that this system will require a conscientious maintenance program.

Although the types of submersible and sludge pumps used in wet well environments are generally regarded as highly robust and are specifically manufactured for heavy-duty operations, they will require scheduled and situational maintenance. The sewer water circulation pumps and sludge pumps will be located in the wet well at least 20' below grade, necessitating access via panels at-grade and ladders or stairs. Access to the wet well will follow safety precautions associated with a confined space including a temporary ventilation system to provide a safe and reasonable working environment. If a Huber system is used, it will require additional wet well access and maintenance due to their use of their proprietary RoK4 filtration/auger units located there. A semi-annual maintenance cycle on wet well components would be a prudent approach. A Huber system has a different filtration approach, their RoK4 filtration/auger units in the wet well.

The heat exchange skids themselves are located in the Sewer Water Heat Exchange Facility, a clean and conditioned environment. The SHARC skids require a quarterly inspection (performed by a SHARC-certified technicians) and semi-yearly or yearly technician to perform any required maintenance on the heat exchanger, auger/solids pump of motor, belts, gearboxes, and the SHARC unit itself. Their heat exchangers, and other components. The Huber RoWin heat exchanger skid located in the SWHR Facility consists of a custom plate-frame type heat exchanger with a cleaner carriage device to periodically clean the surface of the heat exchanger. Published recommended Huber equipment maintenance requires exchangers require quarterly visual inspection, with annual scheduled maintenance on all motors and cleaner carriage. Both SHARC and Huber have service contracts that are packaged standard with their equipment.

SHARC and Huber have large scale projects being installed during the summer of 2024, and may provide a fortuitous opportunity; site visits to facilities with either of these heat exchange systems could be an invaluable way to garner knowledge of these nascent technologies.

6.2.3.6 Lake Interface System

The Lake Interface System circulates lake water from the depths of Lake Washington to the Lake Interface Equipment building on the shoreline of Union Bay, and ultimately discharges water to Portage Bay. This system includes large pumps associated with the lake water and campus cooling water, a wet well, over a mile of offshore piping within Union Bay/Lake Washington, and a mile of buried piping between the Lake Interface Equipment Building and the discharge location in Portage Bay.

The following maintenance activities are anticipated as part of this system:

- Intake screen cleaning:
  - For the automated brush cleaning intake screen recommended in this report, the screen must be removed from its location ~65 ft below the water level every 10 years to replace bearings and brushes.
- Pipeline cleaning:
  - Referred to as “pigging”, see Appendix 9.6 Lake Water Engineering Report Section 3.7.
  - Required once every 20-30 years, barring invasive mussel species becoming prevalent in Lake Washington which would decrease the interval to once every 10 years.

- Wet well cleaning:
  - Seasonal drain down and cleaning is recommended to remove sediment.
- Standard maintenance activities that the UW is familiar with:
  - Heat exchangers.
  - Pumps.

6.2.3.7 Power Plant Combustion Boilers and Steam Turbine

The role of the Power Plant combustion boilers, currently used for steam generation, after all systems are installed, operational, and commissioned will become that of a backup heating system. Wear and tear will be reduced with the system operating very few hours of the year, however the critical nature of the system to supply heating to essential facilities in the event of a power outage is unchanged. This will mean maintaining the same level of quality preventative maintenance on equipment that is not running under normal operating conditions. New testing procedures will need to be developed to ensure that the start-up procedures for the system is well understood and that all enabling measures to ensure a timely initiation of standby boilers are in place and well understood by plant operators.

6.2.3.8 Building Systems

Maintenance impacts on the building side are relatively small compared to the changes seen at the campus level.

The biggest common element between all buildings served by the new systems is the addition of plate & frame heat exchangers which replace steam-to-water shell and tube heat exchangers. Plate & frame heat exchangers have a much higher potential to act as a filter due to the small tight channels within the heat exchanger. Poor water chemistry will require more frequent cleaning of the system. It is understood that the currently the building maintenance schedule does not include any cleaning of the shell and tube heat exchangers, so this will be an entirely new maintenance activity at each building.

Some benefits that will be seen at buildings include:

- Distributed building chillers being removed eliminates maintenance.
- Elimination of steam and condensate maintenance elements (condensate receivers, steam traps).

6.2.3.9 Local Steam Plants

The proposed steam plants discussed in Section 4.4.4 consist of packaged steam boiler and feedwater systems. These systems will require regular maintenance associated with gas-fired boiler and steam equipment. The only building that currently has a gas-fired boilers is the Plant Services Building. Heat is typically provided by the district heating system.

The local steam plants are currently scoped out as skid-mounted boiler package, complete with boilers, feedwater system, water treatment and boiler controllers. Feedback from local vendors indicate a time commitment of approximately 40 hours per year per boiler skid for preventative maintenance. These systems will require 24/7 monitoring, which is expected to be accomplished with remote monitoring capabilities from the Operations Center at the Power Plant.

More onerous, however, are the blowdown and water treatment activities associated with this equipment. These maintenance operations are required on a more frequent schedule, and it can be assumed that some form of monitoring or adjustment would need to occur on a daily basis.

If new steam distribution systems are included to support the new local steam plants, maintenance of additional steam traps, located in tunnels system or buildings, would also be required.

6.2.3.10 System Analytics and Fault Detection Diagnostics

The system analytics tools, including Fault Detection Diagnostics (FDD) discussed in Section 4.4.7 are anticipated to aid the maintenance activities discussed above by providing active monitoring of equipment conditions that can lead to more proactive maintenance.

6.3 Construction Logistics

6.3.1 Tunnels Accessibility and Working Conditions

The extensive tunnel system extends for over 6 miles around campus and contains nearly 100 “nodes” or vaults. These vaults oftentimes have an access hatch/panel at grade level, either open to atmosphere through a grate, or covered with a concrete lid. With the extensive amount of tunnel work in the piping projects that are defined as part of the ERP, the access to, and working space in the tunnels will be a factor in the cost, duration and complexity of the distribution portion of the projects.

Tunnels access is likely best accomplished through the tunnel nodes. Not all nodes are created equal; some have ample space adjacent for parking and staging, others have existing utilities blocking the opening to grade level, and yet others have new structures built over them. SW3 vault, for instance, has it all; adjacency to a large parking area, an enormous anteroom adjacent to the vault that is tailor-made for pipe installation, and a spacious working condition. (See Figure 6.3.1-1, below, and TVM-1 Tunnel Vault Map in Appendix 9.3 Large Format Drawings/Diagrams) Most vaults on the rest of campus, however, do not provide such amenable access and working space conducive to installation of large piping systems.

Any vault that is used as an access point for piping installation would require a 2,000 to 4,000 sq ft lay down yard, and roadway-accessed location for trucks and crane to operate in order to drop pipes down into the shaft. This staging space is in addition to a large lay down yard that is in the neighborhood. Refer to constructability commentary in Appendix 9.12.

The tunnels are also home to several miles of steam and condensate piping, which are continuously radiating directly to the tunnel environment. Heat rises, and as one walks to the north end of the tunnel system, the temperature increases significantly and is well over 100°F. It is typical practice for UW crews to wear ice vests when they work in the northern tunnels. Plans are formulated to add more fans to the tunnel system, under a separate scope of work, especially in the north.

On-site verification of tunnel access locations in the context of the overall project rollout will be further considered as part of the Phase III portion of the project.

Figure 6.3.1-1: *SW3 tunnel bode access*

6.4 Resiliency Strategies

6.4.1 Power Interruptions – Voltage Sags

Historically, several voltage sag events have occurred and interrupt campus facilities and operations. These events are typically triggered by SCL equipment opening and re-closing. Several outside factors can also affect when an event is triggered including issues with neighboring overhead power lines, rising ambient temperatures, fires, or other natural causes. A list of undervoltage events has been consolidated into graphs sorted by date, month, day, and time is shown in Figure 6.4.1-1. Events are triggered by any undervoltage of 15% or more for more than one cycle (Any L-N voltage lower than 11,730 V where 13,800 V is normal voltage). This list of events is taken from 01/04/2023 to 08/01/2024 taken from the "WA MAIN" switchgear fed from SCL at the West Receiving Station. Data is sourced from EATON Power Xpert Meters.

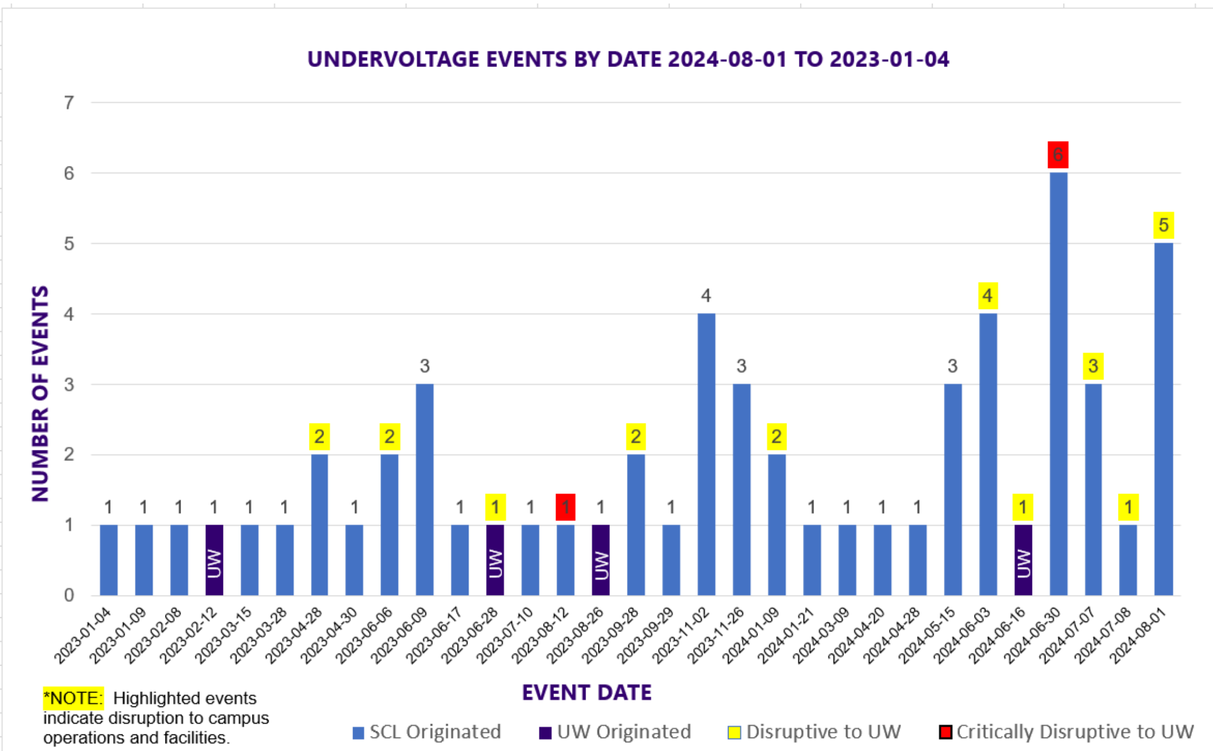


Figure 6.4.1-1: Undervoltage events sorted by date

Within Figure 6.4.1-1, the events are sorted by the date of occurrence and the quantity of events that occurred. The events noted in purple are events initiated within UW's system while the ones in blue were initiated by SCL. The values highlighted in yellow are events that caused disruption to the UW. A disruption includes restarting building equipment, a UW work-order is generated, or a UW incident report is generated. Red highlighted events are events that were critically disruptive at the UW. These are defined as events where UW took emergency action to curtail campus load to prevent overloading the system, accompanied by a UW incident report. It is noted that June 30th had the most recorded events within one day due to an external incident causing multiple disruptions to the internal system.

Figures 6.4.1-2, 6.4.1-3, and 6.4.1-4 provide a breakdown of events by day of the week, month, and hour of the day. Note that this Figure 6.4.1-3 only includes events recorded in 2023 for the months of October–December, while the remaining months have events from 2024 and 2023 included in the data. It can be seen in these Figures that there is a trend of an increase of voltage sag events during the summer months, particularly in June. This could be due to an increased usage of cooling equipment to combat the hotter weather. With a move towards electrified heating in the City of Seattle, these events may become more common in the winter. Events in which the current increases and there is a surge, are acknowledged and assumed to be an internal issue independent of SCL.

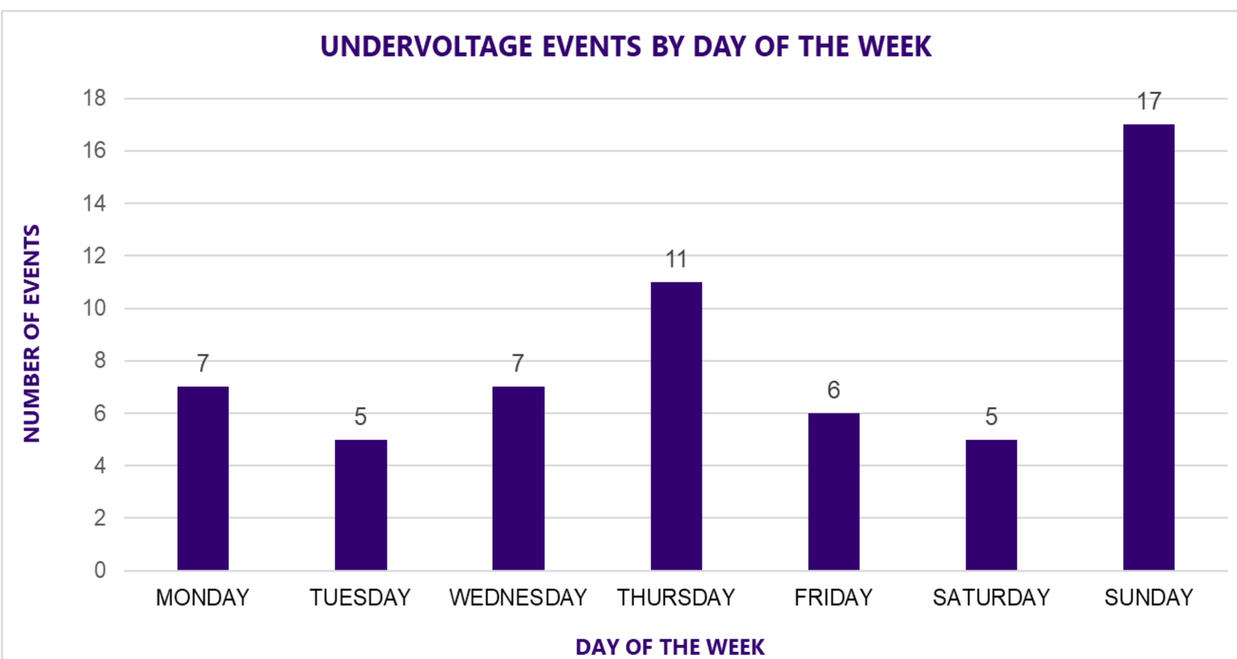


Figure 6.4.1-2: *Undervoltage events sorted by day*

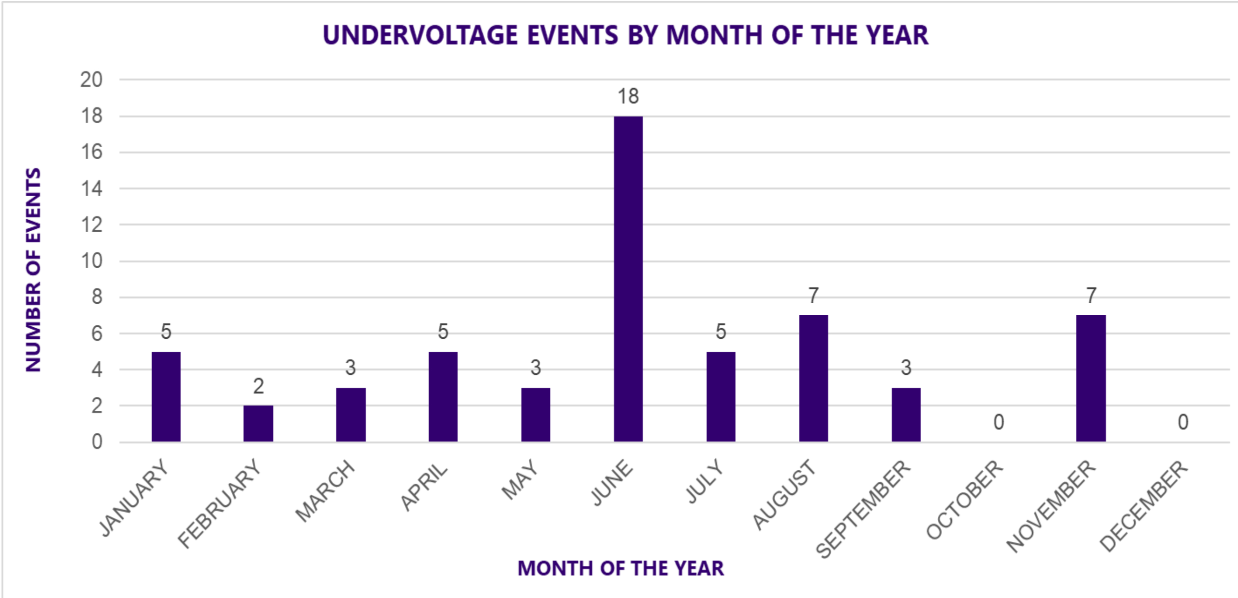


Figure 6.4.1-3: *Undervoltage events sorted by month*

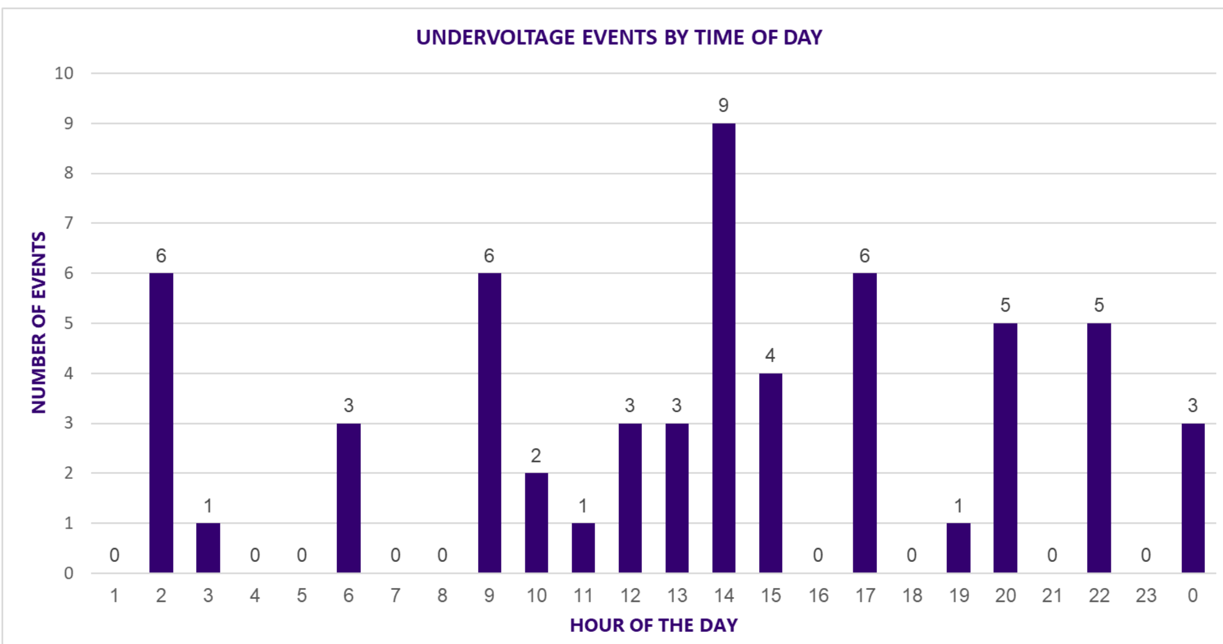


Figure 6.4.1-4: *Undervoltage events sorted by time*

Table 6.4.1-1: Known causes of interruptions based on system level.

Event Type	Quantity
Transmission	10
Distribution	47
Unknown	1

6.4.2 Power Outage

6.4.2.1 Current Campus Response to Power Outages

Refer to Appendix 9.14.2 for a detailed description of outages that had occurred during the recent period around the time that this report was generated. The events highlight the need for a redundant, reliable, and resilient substation that is separated from outside factors. Factors like shared vaults with non-UW customers and aging equipment are planned to be eliminated from the design of the new SCL substation.

6.4.2.2 Generator Power Capacity for District Heating and Cooling Systems

Generator power for pumps associated with the TES is intended to allow the university to ride through a short power outage by utilizing stored energy in the TES system. This would be provided through new generators, dedicated for this purpose.

The addition of the final two planned WCUP generators provides additional capacity to the campus during a power outage and also provides some mechanical capacity in the form of WCUP chillers and heat recovery chillers which are connected to the generator bus.

The Power Plant Diesel Rotary UPS (DRUPS) is existing to remain and was designed to run through brief power outages as well as voltage sags. This system will remain in the final stages of the ERP as part of the campus' response to power outages during winter to allow for combustion boilers to be utilized as a heat source.

6.5 Redundancy for Equipment Failure

The UW campus' current redundant capacity to withstand primary heating and cooling equipment failures is as follows:

- Steam (building heat, domestic water heat, and process): N+2
  - Load can be met with the two largest boilers (B-4 and B-6) be out of service.
- Cooling: N
  - Load cannot be met with all chillers operating.

It is the goal of the ERP to provide a comparable system in terms of redundancy for heating and to improve upon the current redundancy in the cooling systems.

With the systems proposed described in Section 4, the heating system will be redundant in an N+1 configuration, with the combustion boilers available as further backup not included in the N+1 configuration noted above. A loss of the largest heat recovery chiller would be remedied by the remaining chillers and an additional electric boiler within the plant that has the chiller out of service. The combustion boilers effectively make the system N+2 redundant under normal operating circumstances.

The cooling systems are also provided in an N+1 configuration, able to withstand the loss of the largest chiller size.

7.0 Looking Forward – Phase III Implementation Planning

7.1 Phasing/Project Schedules

The Whiting-Turner team has provided preliminary milestone schedules for projects based on the coordination to date and project scopes of work identified in Appendix 9.13 Scope of Work Documents. Refer to Appendix 9.11 Project Preliminary Milestone Schedules.

These schedules will be used in Phase III to develop the Implementation Plan, outlining the recommended sequencing of projects based on project technical, schedule, and funding constraints.

7.1.1 Integration with Building Renewal Plan (BRP)

The Building Renewal Plan has recently completed their efforts of categorizing buildings for renovation, renewal, removal, and replacement. These categories will be used in the Implementation Planning phase to guide the timing of ERP projects in areas where synergies can be identified to avoid rework of ERP and BRP projects.

Buildings identified for renewal, removal, or replacement represent an opportunity to address the energy efficiency and load reduction measures discussed in Section 4.4.6 with regards to addressing energy recovery on high outdoor air ventilation systems and removal of aged HVAC systems that rely on simultaneous heating and cooling.

7.2 Life Cycle Cost Analysis

Initial energy, utility costs, and greenhouse gas emissions are presented here, foreshadowing the full life cycle cost analysis (LCCA) effort that will be presented in Phase III. These results reflect the fully electrified plant along with all distributed building chiller loads added to the CCW system and are based on the weather data for the 2020 decade.

The heating generation curve is shown in Figure 7.2-1 showing how the utilization of heat sources varies based on the magnitude of the demand. The figure shows the quantity of hours over a year where the heat generation is at least the value shown. The impact of thermal energy storage (TES) is included, and the campus heating load demand curve is shown, illustrating how the TES shifts load from peak times to lower demand hours, thereby allowing for more utilization of the heat recovery chillers and minimizing the use of the backup boilers. Some hours with minimal heating demand during the summer are eliminated completely because of the daily discharge of the heating TES.

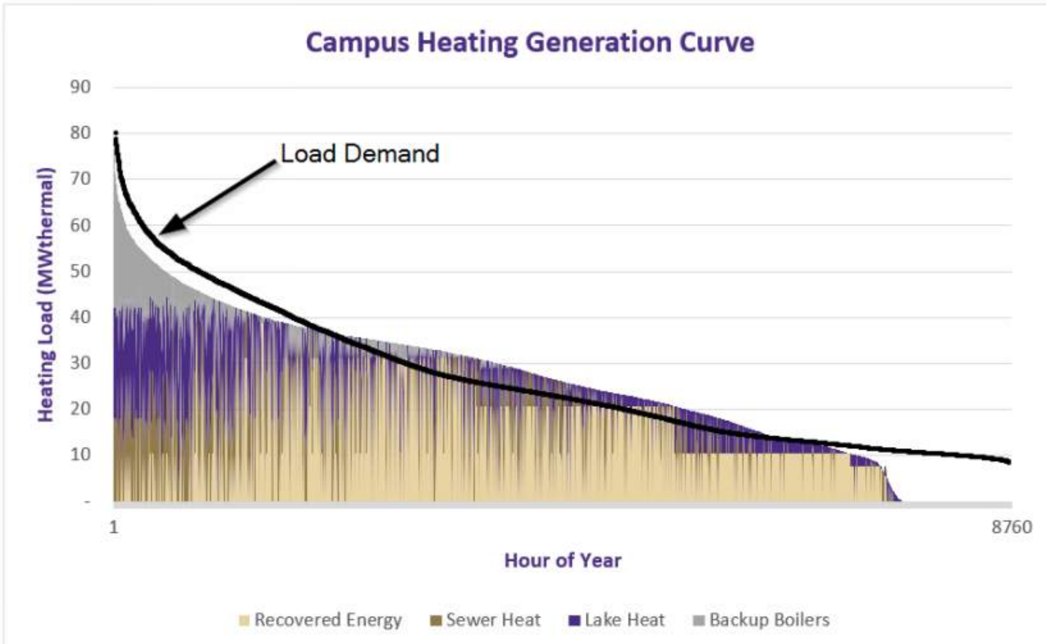


Figure 7.2-1: *Campus heating generation (plant equipment) curve and campus load demand curve.*

Table 7.2-1 summarizes the annual heating energy performance of the electrified heating system. Process steam generation was assumed to be all-electric for these model results and is a significant energy consumer. HRCs handle 44% of the hot water load running in simultaneous heating and cooling mode while only 7% of the hot water is generated from trim boilers. Together, simultaneous and sewer source produce 69% of the annual heating load while lake source heating is 24%. The HRCs have improved performance when utilizing the sewer because it is a higher temperature heat source, while using the lake yields the lowest performance relative to simultaneous or sewer.

Table 7.2-1: System Heating Energy Performance Summary

	% Annual Heating Output	Energy MWH	% Energy	Peak MW	Average Heating COP	Combined COP	Run Hours
Process Steam		64,178	44%	7.3			8,760
Simultaneous	44%	31,837	22%	12.6	3.1	5.2	5,774
Sewer	25%	14,958	10%	5.6	3.7		4,046
Lake	24%	18,218	13%	7.9	3.0		5,510
Trim	7%	15,690	11%	24.0			1,430

Analogous to the heating summarized in Figure 7.2-1, a cooling generation curve is shown in Figure 7.2-2. Lake source cooling is not explicitly broken out but is captured under the water-cooled chiller mode of operation. Lake water is used for cooling the condenser water loops of the water-cooled chillers via heat exchangers, which improves overall energy efficiency of the water-cooled chiller plant and saves a large amount of water.

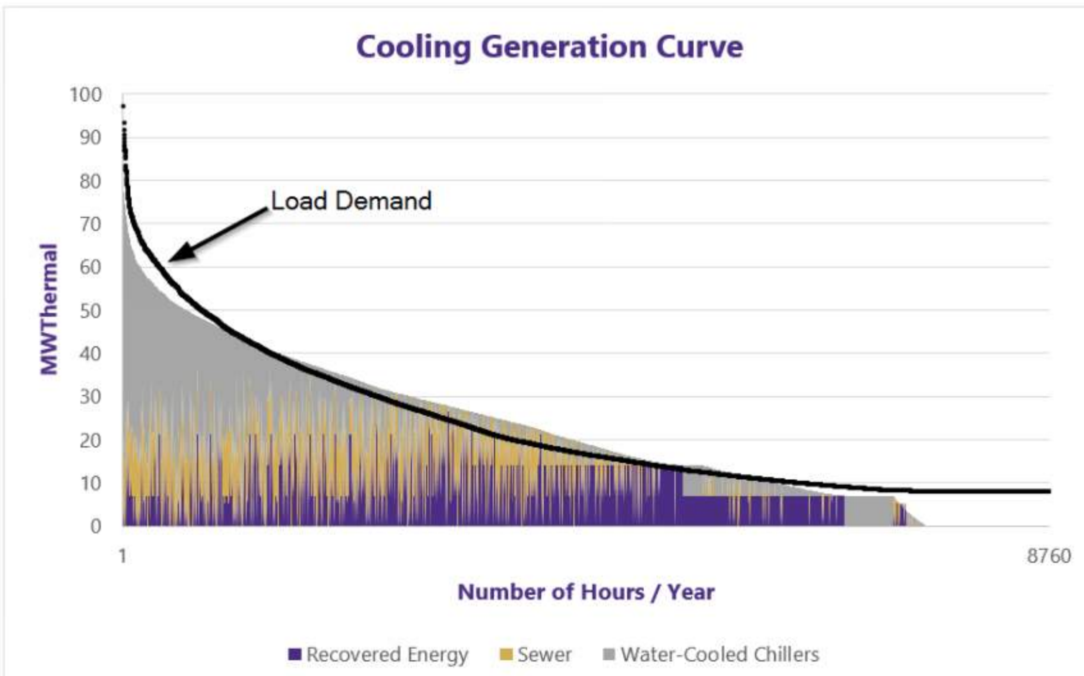


Figure 7.2-2: *Campus cooling generation (plant equipment) curve and campus load demand curve*

Analogous to the heating summarized above, cooling is summarized in Table 7.2-2 illustrating how different cooling sources are utilized based on the annual cooling demand.

Table 7.2-2: System Cooling Energy Performance Summary

	% Annual Cooling Output	COP	Run Hours	Energy MWH	% Energy	Peak MW
Simultaneous	34%	2.1	5774			
Sewer	27%	7.3	4227	7152	38%	7.7
Conventional Water-Cooled Chillers	38%	5.9	6405	11755	62%	10.9

	% Load	COP	Run Hours	Energy MWh	% Energy	Peak MW
Simultaneous	34%	2.1	5774	Energy is associated with heating; cooling is free		
Sewer	27%	7.3	4227	7152	38%	7.7
Conventional Water-Cooled Chillers	38%	5.9	6405	11755	62%	10.9

Simultaneous heat recovery and the sewer source handle 62% of the annual cooling demand. The HRCs have improved performance when using the sewer because the temperature is generally lower than that of the water-cooled chiller condenser water loops. The impact of lake source cooling is captured in the water-cooled chillers and improves the performance beyond what traditional cooling tower operation would provide.

Anticipated campus daily electrical peak demand is shown in Figure 7.2-3 both for a business-as-usual (BAU) case and for the electrified scenario. The BAU is a baseline that reflects the campus operation today, utilizing the existing natural gas steam system and conventional water-cooled chillers for heating and cooling. It includes the energy demand and consumption of the building level chillers as well. The BAU has a peak campus electrical demand of 49MW while the electrified scenario has a peak of 82MW, resulting in delta of 33MW to fully electrify the campus heating and cooling systems. The baseline data is based on measured data from Seattle City Light meters in 2023.

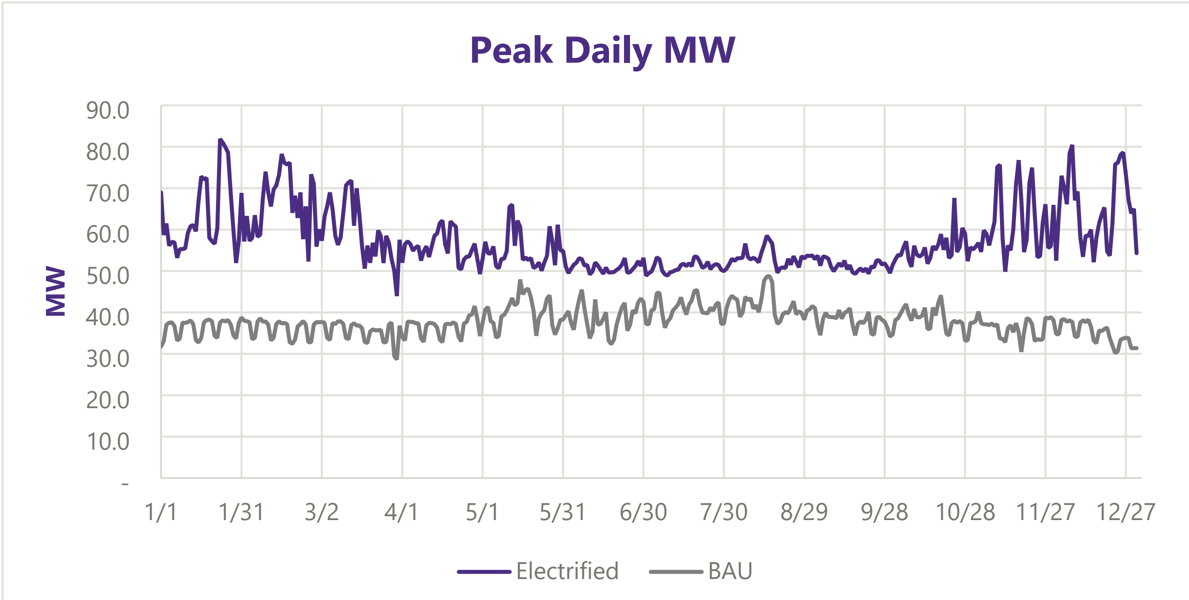


Figure 7.2-3: *Existing campus electrical demand, calculated as the peak demand over 15-minute intervals, compared to the calculated future electrified scenario*

The total energy consumption of the electrified plant is given in Figure 7.2-4 broken down by equipment. Process steam consists of 36% of the annual energy consumption for campus cooling, heating, and process steam. This analysis assumed that process steam would be electrified but it is likely that part of this load would be served by a combustion-based steam system; the CO_2 emission impacts of process steam are summarized at the end of this section. The HRCs make up 41% of the energy consumption utilizing heat pump technology while trim boilers make up 9% of the annual energy consumed.

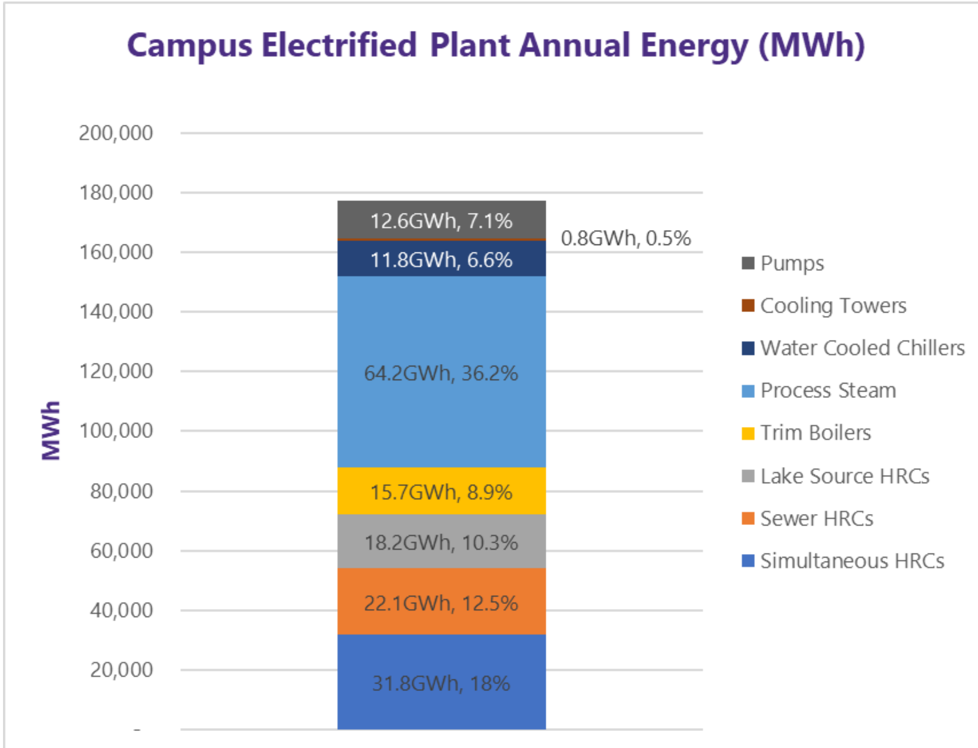


Figure 7.2-4: *Campus electrified plant annual energy by end use category*

The annual utility cost of the electrified option and the business-as-usual baseline (BAU) is shown in Table 7.2-3. The business-as-usual which continues to use natural gas steam boilers has lowest utility cost because natural gas is significantly cheaper than electricity per unit of input and the process electric steam boilers contribute to a significant portion of the annual utility cost in the fully electrified plant scenario. These are preliminary operational energy costs for a single year. A full life cycle cost analysis will be performed in the final phase of this study.

Table 7.2-3: Annual Utility Cost Summary

Costs are Normalized Against 13,700,000 Sf of Buildings Connected to WCUP And PP

	Annual	$/sf
Electrified Plant	$ 17,528,622	$ 1.28
BAU	$ 15,224,843	$ 1.11

Utility rates used for energy cost come from Seattle City Light for electricity and Puget Sound Energy for gas are summarized in Table 7.2-4. The calculated blended rate is $0.0977 / kWh including demand charges.

Table 7.2-4: Utility Rate Summary

		High Demand
Per kWh	Peak	$ 0.10
	Off-Peak	$ 0.06
Per kW	Peak	$ 4.88
	Off-Peak	$ 0.31
Per Therm		$ 0.70
Per Mmbtu Sewer		$ 0.05

A comparison of the CO2 emissions before and after electrification is given below in Table 7.2-5. The emissions rates are 0.0064 lb CO2 / kWh for SCL and 11.7 lb CO2 / Therm natural gas. Emissions are shown for the plants, contiguous campus which includes the building level gas systems, and the process steam. The process steam is a large annual load and leaving all of it on natural gas would greatly diminish the buffer between campus emissions post-electrification and the 25,000 MTons CO2e target for the climate commitment act. If the process steam is left on the natural gas system and the building level gas systems are left in place the emissions would be roughly 29,400 MTons CO2e per year.

Table 7.2-5: CO2 Emissions Summary

	Annual MTONs CO2	Notes
Electrified Plants	490	Emissions from WCUP and PP Only
BAU Plants	85,695	Emissions from WCUP and PP Only
Electrified Campus	9,795	Contiguous campus (includes building gas systems)
BAU Campus	95000	Contiguous campus (includes building gas systems)
Process Steam - Natural Gas Boilers	19,644	Impact of keeping process steam (25,000 pph) on natural gas boilers; includes steam distribution and makeup loss of 23% total

7.3 Funding and Financing Strategies

More detailed funding and financing analysis as well as guidance related to tax credits and incentives will be provided in Phase III. The analysis will include considerations for timing and bundling of projects to optimize the application for funding / reimbursement opportunities as well as a financial model that will provide scenarios and sensitivities relating to potential short-term and long-term financing options. The financial model will also consider the timing of tax credits – whose proceeds will not be paid until after an eligible project has reached commercial operations - and strategies to monetize such credits and help address up-front project funding sources and funding gaps.

7.4 Risk Assessment

The risk register in Table 7.4-1 outlines a series of high-level risk associated with the work proposed in this report.

Table 7.4-1: Project Risk Register

Risk Category	Risk Title	Risk Type	Risk Description
Energy Sources	Lake Water Permitting	Regulatory	Numerous permits and stakeholder are involved in approving the lake water use and constructions. Any single entity opposing may impact viability.
Energy Sources	In-lake Construction	Community	Temporary construction activities may be opposed by area residents.
Energy Sources	Sewer Water Bldg. Locations	Planning/ Financial	Final location of buildings and systems to support sewer water heat recovery not finalized. Each potential site has issues to address.
Plant Upgrades	WCUP Expansion	Planning	WCUP expansion has not been fully approved. Without expansion, space is not available to house necessary Heat Recovery Chillers and related equipment.
Plant Upgrades	Power Plant Upgrades	Space, Financial	Significant upgrades are required in the Power Plant to improve operational control and house additional equipment.
Plant Upgrades	UW Substation	Planning	UW Substation site at Northlake building site has not been fully approved by UW or Seattle City Light. Without this site, another location between the University Substation and WRS must be chosen. Most other options have a higher lost development opportunity.
Distribution	Direct Buried Pipe Routing	Financial	Unforeseen underground obstacles could cause significant cost increases to piping installation.
Distribution	Direct Buried Pipe Routing	Campus Operations	Installation of underground piping will impact flow of students and staff during construction activities. Temporary road closure in areas is also anticipated.

Table 7.4-1: Project Risk Register

Risk Category	Risk Title	Risk Type	Risk Description
Distribution	Piping in Tunnels	Logistic/ Financial	The desire to reuse tunnels for PHW distribution requires complex logistical control and potential for utility outages at buildings.
Building Systems	Building Conversion work	Logistic/ Financial	Building conversion work is historically the most difficult element to estimate in a hot water conversion project. Estimates may vary from those shown herein and logistical impact may occur in affected buildings.
Cost Estimating	Escalation	Financial	Given the anticipated length of the of the implementation period (+/- 10 years) for the project accurately predicting escalation costs in is difficult.
Cost Estimating	Accuracy	Financial	Estimates prepared are based on pre concept design information. Detailed design activities may identify additional requirements that increase costs.
Funding	CCA Repeal	Financial	Repeal of the CCA in Washington is a ballot initiative in November 2024. If repealed a significant funding source would be eliminated.
Funding	IRA Funding	Financial	The implementation of the IRA is in its early stages and many IRS interpretations are yet to be finalized. Assumption on available funding from this source may be impacted.
Funding	Public Response	Community	The total cost of the ERP is a significant departure from the scale of past funding.

8.0 Regulatory Compliance

The scale of the Energy Renewal Plan includes systems that will be governed by many different regulatory agencies. This section provides a summary of the major regulations impacting the proposed project work, with details expanded upon within appendices as noted in each section.

8.1 Lake Water

The interface with Lake Washington and the Ship Canal is anticipated to be the largest regulatory hurdle facing the Energy Renewal Plan. There are many agencies with jurisdiction over the lake given it is a Water of the United States, a navigable water, a water of the state, habitat for federally listed species, a Shoreline of Statewide Significance, state-owned aquatic land, and in some areas a federal works project. In addition to the natural environment considerations, the lake and Ship Canal provide important functions for commerce, navigation, and recreation. The multi-agency approval process will be lengthy, and approval is not guaranteed.

There are currently no known large non-residential uses of Lake Washington as a source of heating, cooling, or consumptive uses. The University of Washington Medical Center has an existing surface water right for use of Lake Union / Portage Bay for heating and cooling, which is not directly useful for this endeavor, but shows a previous allowance for institutional use of a natural body of water.

The approach for agency approval is to demonstrate that the proposed system will, at a minimum, “do no harm.” Some of the options for the outfall of the lake water may even present a potential benefit to environmental conditions and the University would be willing to consider operating the system in a way that enhances the environmental benefit if it were proven to exist. These claims may be difficult to prove so care must be taken to demonstrate that the complexities and relationships of ecological, hydrological, and chemical effects of the project are understood, and adverse effects are appropriately avoided, minimized, and finally mitigated.

Refer to Appendix 9.4 Preliminary Permitting & Environmental Considerations – Phase 2 for additional details.

8.2 State Regulations

8.2.1 Washington State Climate Commitment Act (CCA)

Recent State of Washington legislation (in effect as of Jan 1, 2023) referred to as the Climate Commitment Act (CCA) caps and reduces greenhouse gas (GHG) emissions from Washington's largest emitting sources, which includes the University of Washington's Seattle Campus.

As a covered entity, the University must purchase GHG emission allowances to cover at least 30% of their 2023 emissions by November 2024. With each subsequent year requiring the same allowance up to November 2027, at which point the remaining 70% of emissions must be covered, inclusive of all emissions 2023 and later. UW's present approach to compliance with CCA is to purchase 100% of its expected annual allowances in the respective year that the emissions occurred. Purchasing of emissions allowances is done in a quarterly auction format, with special provisions for public entities that provide a flat price not available to the private industry. Recent CCA auction pricing is shown below in Figure 8.2.1-1 with one allowance being equal to one metric ton of carbon dioxide-equivalent emissions.

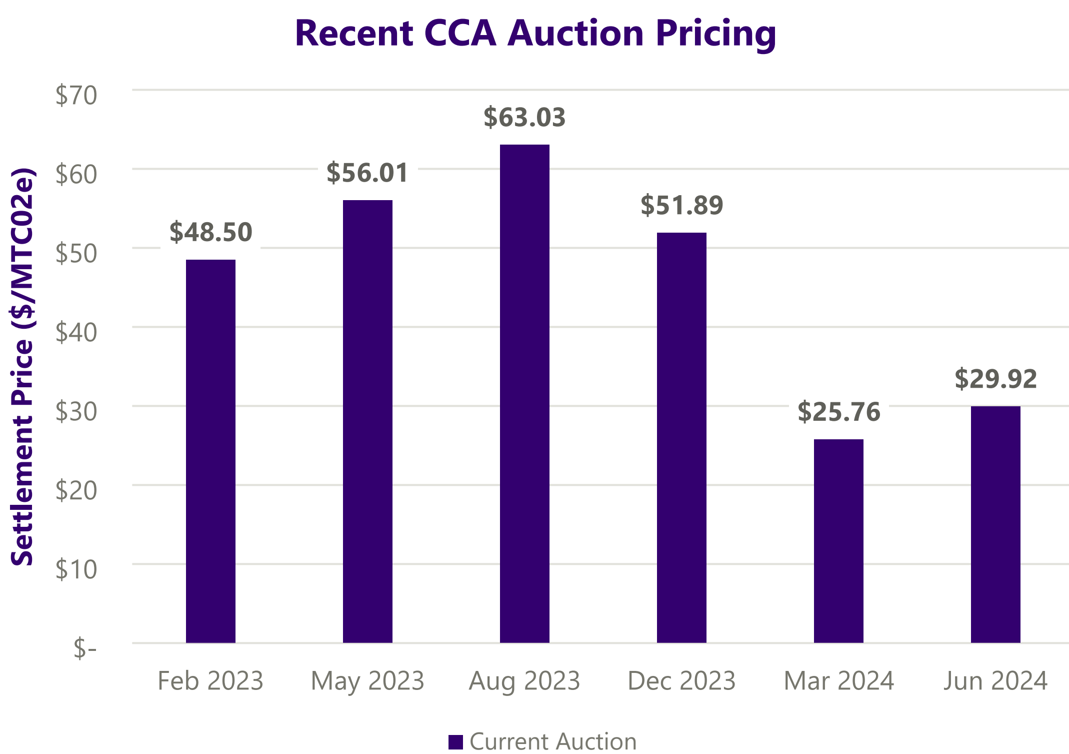


Figure 8.2.1-1: *Recent Climate Commitment Act (CCA) auction pricing for carbon emission allowances*

Known as the Cap-and-Invest program, the money collected by the State is circulated back to CCA covered entities through the legislature and is expected to act as a source of funding for projects associated with the ERP for the University.

If the University reduces its carbon emissions below the threshold of 25,000 equivalent metric tons of CO2 per year, then they would no longer be a covered entity and would be exempt from these regulations. This is expected to happen during the path towards full decarbonization, though the estimate on when this will occur has not yet been determined.

8.2.2 Washington State Clean Buildings Performance Standard

Washington state passed the Clean Buildings Act (HB1257) in 2019 which created the Clean Buildings Performance Standard (CBPS) and requires existing commercial and state-owned buildings to comply with energy usage targets based on building type. The State has released an overlay of ASHRAE 100 – 2018 for this standard. Compliance is staggered based on building floor area with larger buildings having to comply earlier. The thresholds and deadlines for compliance are given below:

- Greater than 220,000 sf – June 1st, 2026
- 90,000 to 220,000 sf – June 1st, 2027
- 50,000 to 90,000 sf – June 1st, 2028

Building owners must submit their buildings for compliance every five years for the foreseeable future with energy use targets becoming more stringent over time. Newly constructed buildings (defined as buildings permitted to the 2015 Seattle Energy Code or later) must be 15% more efficient than the EUI targets established in the standard. Buildings that are served by a campus district energy system will comply differently as discussed in the section below.

While the original intent of the standard was for buildings to comply based on EUI targets for individual building types (office, educational, retail, etc.) the Standard has been updated such that buildings on university campuses may comply with the College/University EUI target which includes classrooms, libraries, laboratory classrooms, offices, cafeterias, maintenance facilities, arts facilities, athletic facilities, and residential areas. Research laboratories where the primary activities are of scientific research, measurement, and experiments are performed can utilize the Laboratory building type.

The University of Washington intends to submit for campus-level compliance using a mix of building types that include College/University, Laboratory (research), and

Hospital. The University has communicated with Department of Commerce to establish the UW "Montlake Campus" which is a collection of buildings in Seattle that will be covered under campus-level compliance with the Clean Buildings Performance Standard. A single Energy Management Plan (EMP) and Operations & Maintenance (O&M) plan can be submitted for the entire campus if it captures the attributes of all buildings on campus. These plans shall be submitted based on the original compliance dates, beginning June 1st, 2026, and may be further developed and/or implemented in an incremental fashion to cover all buildings on campus.

8.2.3 Washington State House Bill 1390 – District Energy Systems

Another recent legislative provision known as House Bill 1390, effective July 2023, concerns state-owned campus district energy systems. The CBPS has been updated to include a compliance pathway under Normative Annex W for district energy system decarbonization.

Owners of a state campus district energy system must develop a decarbonization plan that provides a strategy for up to 15 years for the decarbonization of the district energy system by 2040. This plan must begin development no later than June 30, 2024, and be submitted to the Department of Commerce no later than June 30, 2025. Subsequently, every five years after the plan is submitted, the plan must be resubmitted along with a progress report on status of implementation. The final report of the Energy Renewal Plan will inform contents of the House Bill 1390 Decarbonization Plan; however, it is not anticipated to be directly used for that purpose.

Decarbonization in this context relates to replacement of fossil fuels and reducing operational carbon emissions for district heating, cooling, or heating and cooling systems. Fossil fuel or electric resistance sources may account for a maximum of 10 percent of a district energy system heating plant's annual output.

The campus-level compliance pathway for College/University is allowable under CBPS Normative Annex W for district energy system decarbonization and may include both buildings connected to the district energy system and standalone buildings. An approved decarbonization plan extends energy target compliance for all buildings on the campus to the 15-year decarbonization plan timeline. The campus-level energy management and operations and maintenance plan must still be submitted based on the original compliance schedule for CBPS (2026-2028). The University intends to submit the UW Montlake Campus for campus-level compliance under this district energy system decarbonization pathway.

8.3 City Regulations

8.3.1 Seattle Department of Construction and Inspections (SDCI) – Substantial Alterations

The City of Seattle requires existing building projects that meet the requirements of a Substantial Alteration to fully upgrade the building to the current building energy code. Substantially extending the useful physical and/or economic life of the building is a common definition that gets applied. Capital funding for substantial alterations is rarely available to support the viability of the original existing building project which can become a roadblock to phased implementation of district energy infrastructure and building system improvements.

The Building Renewal Plan will include a wide variety of renovations from full building gut and remodels, to minor improvement projects, to everything in between. There will also be thermal conversion projects at almost all buildings as part of the Energy Renewal Plan implementation including district energy system connections and building HVAC system modification in many buildings.

The University, as part of the BRP and ERP efforts, is seeking to develop a memo of understanding with SDCI to support the permitting of necessary upgrade projects to address deferred maintenance, comply with Washington State legislature, and comply with City of Seattle codes and standards, wherein projects that are implemented as part of the ERP (and relevant BRP projects) do not get classified by SDCI as Substantial Alterations and can be implemented in a phased and logical manner. UW with assistance from the BRP and ERP teams and other consultants specializing in permitting within the City of Seattle will aim to reach an agreement prior to work commencing for these projects.

Permits for building, mechanical, electrical, and structural work may each be required on a building-by-building basis depending on the extent of the conversion work for each building. After preliminary reviews of the codes and non-project specific discussion with City of Seattle Energy Code Advisor, projects that are solely being done to execute the energy renewal/decarbonization plan are not expected to trigger Substantial Alterations provisions, which would incur significant cost and disruption. Additionally, exceptions exist for district energy systems under the provisions of the Energy Code that would normally require addition of new building level heating and cooling equipment. The memo of understanding will aim to address this.

By the end of the campus conversion project, there will be hundreds of permits required to be processed by SDCI for the work within the buildings and tunnels. Another outcome of the memo of understanding with SDCI is to streamline this permitting process and to find and discuss any surprise provisions before they appear on the critical path of project work.

SDCI will also require structural permits for any new underground walkable tunnel sections.

8.3.2 Seattle Department of Construction and Inspections (SDCI) – Seattle Building Emissions Performance Standard

Passed by the Seattle City Council and Mayor's office in 2023, the Seattle Building Emissions Performance Standards (BEPS) is meant to complement the state's energy performance standard (CBPS) with a GHG emission standard to decarbonize existing buildings in Seattle. The goal is to reach net-zero emissions by 2045-2050 with 5-year reporting periods and emissions targets that decrease over time. The City's next phase is to develop the Director's Rule which will contain details such as required documentation, processes for compliance, and other key elements. This technical rulemaking is currently underway with a timeline of Q2 2025 for publishing of the adopted final rule.

Covered buildings that are subject to and comply with the requirements under RCW 70A.65 Climate Commitment Act are exempt from compliance with the Seattle BEPS, which includes University of Washington since the University is currently a covered entity under the CCA. If the University falls below the 25,000 MTC02e threshold for CCA covered entities, the University may be required to comply with the Seattle BEPS in the future. However, achieving this level of decarbonization under the CCA threshold would mean the University is well positioned for compliance with Seattle BEPS.

The current rulemaking process includes representative from Department of Commerce to provide consistency between CBPS, state district energy system decarbonization, and Seattle BEPS. The ordinance says building owners with a building portfolio, district campus, or connected buildings may use an aggregate standard greenhouse gas emissions intensity for compliance. This approach under Seattle BEPS would be like the campus-level approach under CBPS which includes a mix of greenhouse gas intensity targets for College/University, Laboratory, and Hospital. Additionally, the current rulemaking indicates a compliance pathway for multiple buildings under district campus decarbonization compliance plan where a district campus that can demonstrate that upgrades to the district campus plant will generate cumulative emissions reductions from 2028-2050 that are equal to or greater than the cumulative emissions reductions that would be achieved by meeting standard or alternate greenhouse gas intensity targets under Seattle BEPS.

8.3.3 Seattle Department of Transportation (SDOT) ROW

Installing direct buried district energy system piping and buried electrical duct banks on the UW campus will not require city permits unless walk-through tunnels are proposed, which will require a building (-CN) permit from the Seattle Department of Construction and Inspection (SDCI).

Permits will be required, however, for direct buried mechanical or electrical systems or tunnel systems in public right-of-way (ROW). These permits will be issued by the Seattle Department of Transportation and require two separate permits outlined below:

- Long term annually renewable permit. This Term Permit needs to be approved by the City Council. Refer to SDOT AG 1088: Private Utility Infrastructure - Transportation (available on SDOT's website) for an outline of the permitting process.
- Right-of-Way Utility permit also known as a Utility Major Permit (UMP). This permit is for the construction of direct buried utilities and is only approved after the long-term permit passes through council and is approved by SDOT. Refer to SDOT Utility Work in the Right of Way – Transportation (available on SDOT's website) for an outline of the permit requirements.

Refer to Appendix 9.5 Civil Engineering Technical Report for more discussion on permitting of utilities in the public right-of-way.

8.4 King County Sewer

Interfacing with the King County sewer main as a source of low-grade heat for the campus will require coordination and permitting approval from local agencies, including:

- King County's Wastewater Treatment Division (WTD)
- Seattle Department of Transportation (SDOT)

King County WTD is, at the time of this report, accepting applications for two additional projects across its system to allow the use of the sewer as a source for heating and cooling. The pilot project is a test run for wider use of this strategy across their system. King County WTD requires a 30% Design Review document set to begin the process for application into their sewer heat recovery pilot program and will be involved throughout the design and construction process to review and approve all work related to the connection to their pipeline and transference of sewer water to and from the pipe.

In order to make the connection to the sewer pipe, private utilities will need to be run in the SDOT right-of-way which requires multiple permits to be granted by SDOT with annual renewal. Refer to Section 8.3.3 above for additional details on SDOT compliance.