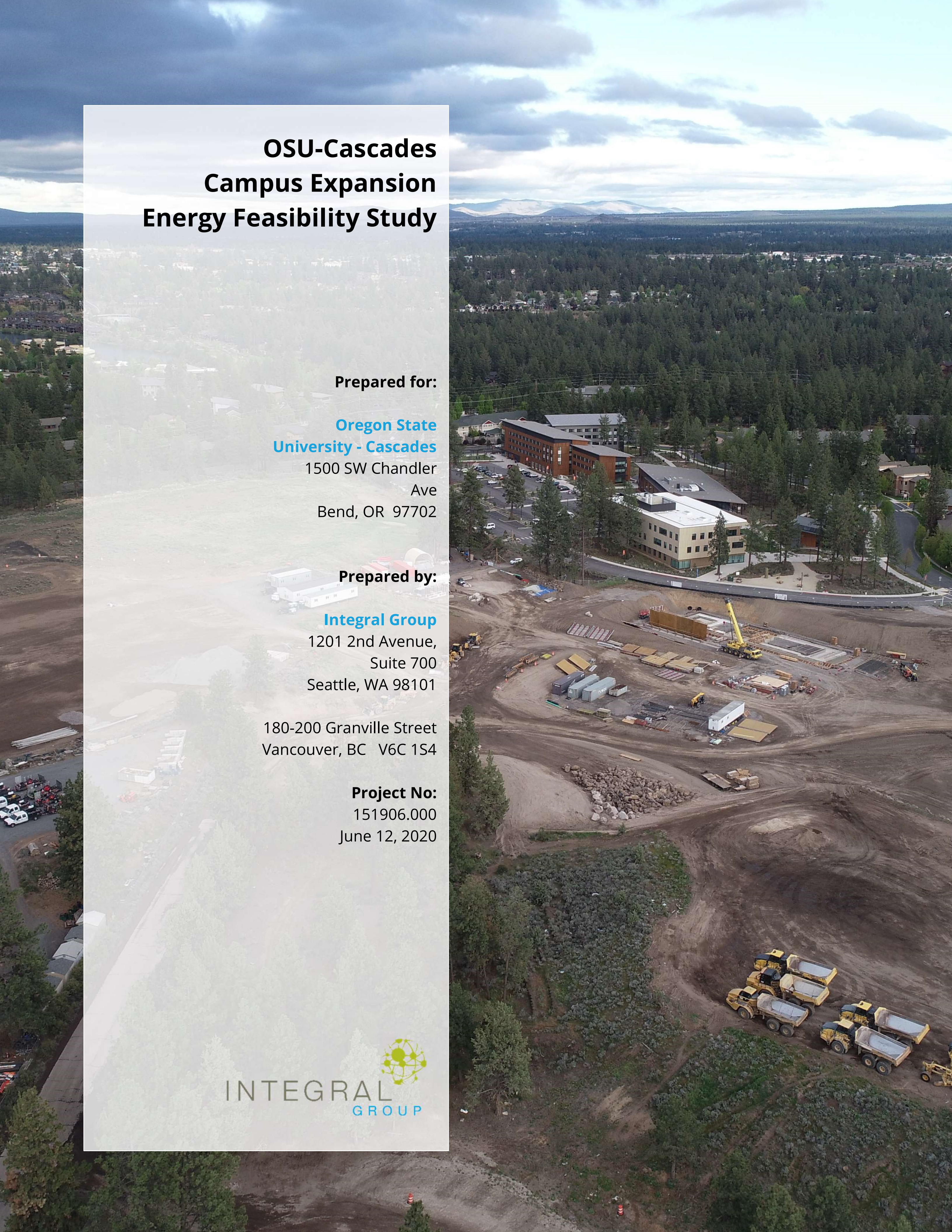

OSU-Cascades Campus Expansion Energy Feasibility Study

Prepared for:

Oregon State University - Cascades
1500 SW Chandler Ave
Bend, OR 97702

Prepared by:

Integral Group
1201 2nd Avenue, Suite 700
Seattle, WA 98101

180-200 Granville Street
Vancouver, BC V6C 1S4

Project No:
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INTEGRAL GROUP

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We would also like to acknowledge the contribution of JMB Consulting Group for developing the original Class D cost estimates upon which Integral Group based the cost analysis for this study.

AUTHORSHIP

This report was prepared by the following members of Integral Group:

- Vladimir Mikler, M.Sc., P.Eng., LEED AP, Principal in Charge
- John Weale, P.E., Principal
- Justin T.K. Chin, P.Eng., M.Eng., CPHD, Associate
- Natalie Bragg, B.Eng. (Hons), Senior Mechanical Engineer

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REPORT ISSUED

Revision	Date	Description
Revision 0	12 June 2020	Final report, issued for client comment.

EXECUTIVE SUMMARY

Oregon State University Cascades Campus (OSU-C) has set a goal to become a net-zero energy campus at full buildout. Integral Group was retained by OSU-C to conduct an energy feasibility study to review potential renewable energy sources and complementary energy conversion technologies and to develop recommended campus energy system solution that will help OSU-C with achieving this goal. Several feasible system options were developed at concept level and analyzed from technical and economical viability perspectives. The recommended thermal energy system best meeting these objectives will be also coupled with an on-site renewable electricity generation with solar photovoltaic (PV) system.

The scope of this study is a continuation of the initial recommendations and concepts outlined in the campus's previously completed Long-Range Development Plan (LRDP). In this study, Integral Group analyzed and evaluated the following renewable thermal energy technologies:

- Biomass cogeneration and trigeneration,
- Open-loop geo-exchange, and
- Vertical Closed-loop geo-exchange

Initially, each of these technologies was reviewed individually to determine if they could be implemented in a system capable of meeting the campus's key objectives and performance criteria. Technologies that were not able to meet these objectives or performance criteria were eliminated. The remaining technologies were compared under different system configurations before narrowing down the most viable thermal energy system options to the following three:

- Central heat-recovery plant with an open-loop geo-exchange system,
- Three Nodal heat-recovery plants with an open-loop geo-exchange system, and
- Distributed building-level water source heat pump plants with a closed-loop geo-exchange system.

The subsequent portion of the study included in-situ testing to confirm site specific geology and hydrogeology to confirm which version of the geo-exchange system would be the most viable and cost-effective option. The testing included installation of a 500 ft deep well followed up with groundwater pumping and water quality tests to confirm the available groundwater yield and water quality. The test results for both parameters were favorable and confirmed the technical viability of an open-loop version of the geo-exchange system at the OSU-C campus.

The financial analysis of all thee options considered not only the overall capital costs, but also the overall long-term energy, operating and maintenance costs as well as the required deployment of the capital cots to implement each option.

Based on the overall results of Integral Group's technical and financial analysis, the nodal-plant configuration with three nodal plants coupled with an open-loop geo-exchange system has been recommended as the campus energy system option best meeting the OSU-C's objectives. This option is now being developed into a detailed design and progressing into implementation phase.

Adding to this recommended, electric-based, campus thermal energy system option, Integral Group developed complementary solar PV system to offset the campus's annual electrical demand by on-site generated renewable electricity. Two system configurations were reviewed:

- Solar PV system, and
- Solar PV system with campus microgrid.

Based on the modeling and analyses, Integral Group recommended implementing 13 MW solar PV system across the campus, to be installed on selected building rooftops, canopies over outdoor parking lots and ground-mounts, to meet the OSU-C's goal of achieving a net-zero energy campus. The solar PV system can be complemented with battery storage and a campus microgrid if resilience and independence from the local power grid is a priority, or if the utility has limited capacity to accept excess electricity generated by the solar PV system. At full buildout, OSU-C's solar PV infrastructure would be one of the most notable, and likely the one of the largest, behind-the-meter solar PV installations in the Pacific Northwest.

Near the end of the study, Integral Group issued a Request for Information (RFI) to the industry to seek feedback on the potential for third-party investment for both campus thermal energy and on-site solar PV systems. Feedback was positive for the PV system. However, based on the RFI responses and uncertainties created by the COVID-19 pandemic, it is unlikely that the OSU-C will be able to secure third-party investment for the thermal energy system in the near future.

Based on the study results, Integral Group recommends the following next steps for the OSU-C campus:

- Develop detailed design and construction documents for the recommended campus thermal energy system with three nodal plants coupled with an open-loop geo-exchange system and proceed with the initial phase of its implementation,
- Review the current OSU-C campus infrastructure design package to identify synergies between the proposed thermal energy system and the campus infrastructure construction scope, and
- Proceed with detailed design of a solar PV system on the roof of the selected existing campus buildings and AB2 and seek opportunities for third-party investment for the system,
- Update campus LRDP and develop technical guidelines for future building design to ensure compatibility with the recommended campus nodal open-loop geo-exchange system.

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LIST OF ABBREVIATIONS

BTU	British Thermal Unit
CEDI	Cooling Energy Demand Intensity
CHW	Chilled Water
COP	Coefficient of Performance
DHW	Domestic Hot Water
DOAS	Dedicated Outdoor Air System
EUI	Energy Use Intensity
FTC	Formation Thermal Conductivity
GHG	Greenhouse Gas
GHX	Geo-exchange
GSF	Gross Square Feet
GW	Ground Water
HRCH	Heat Recovery Chiller
HW	Heating Water
HX	Heat Exchangers
LRDP	Long Range Development Plan
LCOE	Levelized Cost of Delivered Thermal Energy
LTHW	Low-Temperature Heating Water
MBH	Thousand British Thermal Units per Hour
MMBTU	Million British Thermal Unit
NPV	Net Present Value
OSU-C	Oregon State University Cascades
PPA	Power Purchase Agreement
PV	Photovoltaic
RFI	Request for Information
TCOO	Total Cost of Ownership
TEDI	Thermal Energy Demand Intensity
WSHP	Water Source Heat Pump

1. INTRODUCTION

Oregon State University Cascades (OSU-C) is one of two Oregon State University (OSU) campuses and is located on the west side of Bend, Oregon. The campus currently enrolls 1,215 undergraduate and graduate students, with plans to increase enrollment to 5,000 students in the future.

To support this growth, OSU-C has plans to expand their existing 10-acre campus to 128 acres of development, including new onsite energy systems, through multiple phases by the year 2034. As part of the campus expansion, OSU-C has set a goal to become a net-zero energy campus at full buildout, by implementing highly energy-efficient climate-responsive buildings, complemented with a new campus-scale thermal energy system that uses onsite renewable energy sources and technologies.

In March 2018, OSU-C issued the Long Range Development Plan (LRDP) which summarizes the university's long-term master planning project to date. It outlines the intended future high-level space needs of the campus, a planning framework to outline guiding principles to direct campus growth, and guidelines to facilitate the achievement of the campus's long-term goals.

Two of the campus's planning framework principles, sustainability and resiliency, relate directly to the design of the thermal energy system and infrastructure. The LRDP states that the intention is for the campus to be "developed in the most sustainable way possible" which includes investing in "flexibility, redundancy and low-resource systems". An example of how this intention is translated into priorities for the campus is its triple environmental goal of being a net-zero energy, net-zero water and net-zero waste campus. It is understood that this may take several years to implement, particularly since the expansion will be phased over 15 years.

1.1 Study Objectives and Key Criteria

The scopes of this study were to conduct a feasibility analysis of potential campus energy systems in continuation from the initial concepts outlined in OSU-C's Long Range Development Plan (LRDP), investigate multiple thermal and electrical energy system options that will enable the campus to meet its net-zero energy goal, review and evaluate these systems and develop the recommended solution.

Developing an optimal thermal and electrical system solution for the OSU-C campus represents a complex endeavour. It involves thorough evaluation of a multitude of elements while carefully considering their interrelationships. Some of these elements can interact in a synergistic and complimentary manner, while some can be in direct contradiction with each other. Therefore, it was crucial to establish not only a clear objective, but also a clear set of decision-making criteria and constraints, as well as their respective hierarchies right at the onset of the analysis.

Based on the review of the LRDP and feedback from the university, the following key criteria and constraints were identified and used to evaluate all key aspects of the thermal and electrical system options, in the following hierarchy:

- Cost-effective deployment of capital when developing the new campus energy infrastructure,
- Phased deployment to suit campus development plans outlined in the LRDP and updated by OSU, and
- Potential for third-party utility ownership or partnership.

1.2 Site Context

The OSU-C site can be broken into three parcels: the existing campus, the former pumice mine and the former Deschutes County landfill. The existing 10-acre campus site represents the initial development of the university with construction since 2015. It includes Tykeson Hall (academic center), Obsidian Hall (dining/academic building) and Residential Hall (residential building). The adjacent 46-acre parcel is a former pumice mine with an excavation depth of up to 100 ft. The mine will require reclamation prior to future development. The adjacent 72-acre parcel is the former Deschutes County construction and demolition landfill. This will require remediation and reclamation prior to future development. Refer to Figure 1.2.1.

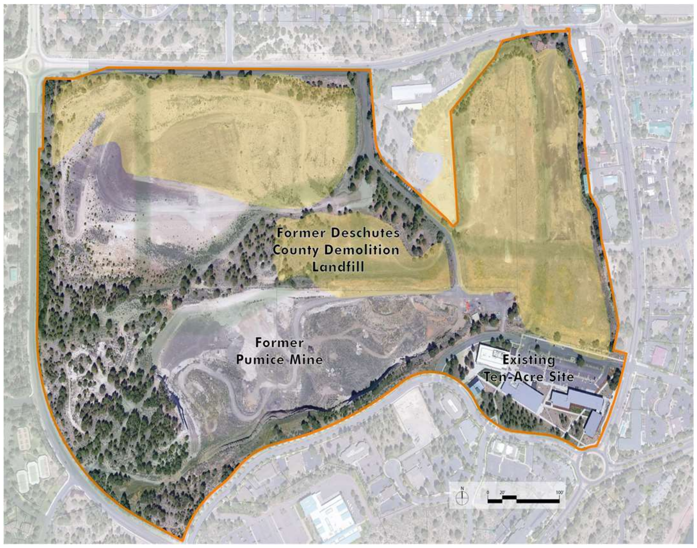


Figure 1.2.1 Existing OSU-C Site

Remediation and reclamation of the former landfill and pumice mine will be conducted in phases and to different degrees. Landfill in areas 1 and 2, identified in Figure 1.2.2, will be fully excavated, sorted, fill material processed and backfilled to allow the development of multi-storey buildings. In contrast, area 3 will retain its regulatory capacity as a landfill and will simply be remediated and graded (or capped). There will therefore be development limitations in area 3, though it will be suitable for uses such as surface parking, recreation fields and energy infrastructure such as a ground-mounted PV system.

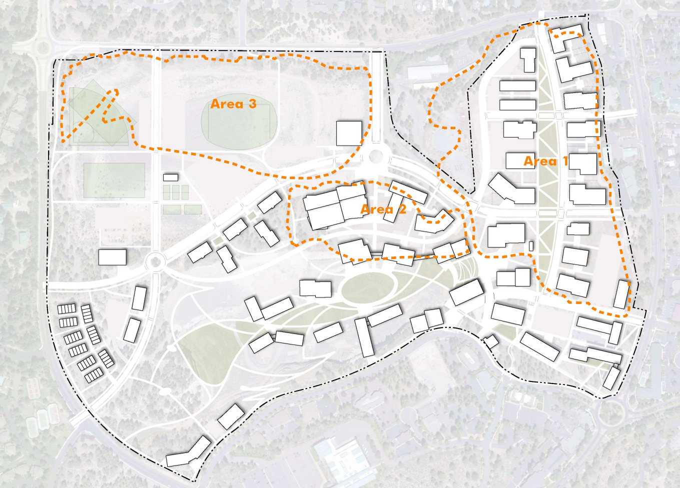


Figure 1.2.2 – Landfill Remediation Areas

The site conditions described above have several implications for a campus-wide thermal energy system. Firstly, there is an impetus to utilize the southern and eastern portions of the campus, the pumice mine, area 1 and area 2 for campus buildings. While the energy infrastructure can be accommodated amongst the current campus layout in these areas, ideally any standalone energy solution, such as a central utility building, will be in area 3.

Secondly, as the reclamation work progresses, new site conditions or constraints can surface. An example of this is the geological fault zone identified in early 2019, to the west of the current pumice mine. This resulted in the relocations and phasing adjustments for several campus buildings.

Finally, the phasing of the campus remediation and reclamation does impose some constraints on the construction of the campus energy system. As with the campus development, the timing of the remediation work must be considered when planning the infrastructure phasing in order to minimize capital costs and maximize construction efficiency.

2. APPROACH & METHODOLOGY

This section outlines the approach and methodology applied in this study, within the context of the concepts and outcomes in the Long Range Development Plan (LRDP), and the study objectives and criteria noted in the section above.

To narrow down multiple possible energy system options, we developed and followed a systematic approach by first quickly evaluating and screening the options based on their abilities to meet the key objectives and requirements. Options that were not able to meet all key objectives were quickly eliminated. The remaining best three or four options that satisfy the requirements were further developed and evaluated in a much more comprehensive manner against the key criteria. Using this approach and methodology, the final option that best satisfies the key drivers and criteria was identified.

This broad approach and methodology is shown graphically in Figure 2.0.1 below.

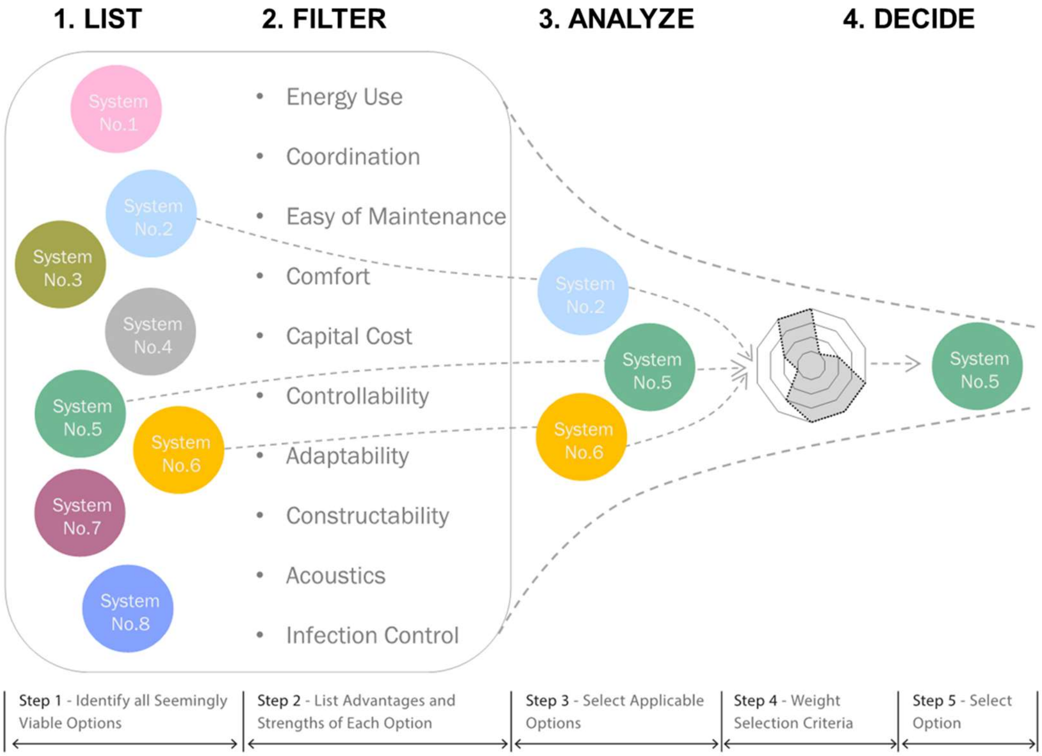


Figure 2.0.1 – Campus Energy System Options Screening Methodology

The detailed description of the methodology, including specific steps and sequences, used in this specific feasibility study is outlined below:

Review Campus Goals, Priorities, Energy Performance Targets

- Review LRDP and identify key campus priorities, constraints, proposed building energy performance targets. Benchmark proposed building energy performance targets against national and industry standards. Delineate or distinguish energy use intensity (EUI) targets into two categories: energy used to satisfy thermal energy demands and energy used to satisfy non-thermal demands.

Develop Campus Thermal Demand Profile

- Based on LRDP priorities & EUI targets for each building type, develop thermal energy demand intensity and cooling energy demand intensity targets for all campus buildings. Develop hourly space heating, cooling and domestic hot water heating demand profiles for the proposed campus buildout.

Consider & Evaluate Four Approaches to the Campus Thermal Energy System

- Centralized vs. distributed systems.
- High exergy vs. low exergy systems.

Review and Screen Available Thermal Energy Sources & Technologies

- Review all available thermal energy sources and complementary energy conversion technologies within the specific context and considerations of the OSU-C campus. Eliminate options that do not meet campus key objectives.

Develop Specific Thermal Energy System Options

- Develop three to four configurations of the thermal energy system, with the sources and the best-suited complementary technologies. Review and develop the net-zero energy strategy within the specific context and considerations of the OSU-C campus.

Evaluate Thermal Energy System Options & Recommend the Best Option

- Evaluate and screen different thermal energy system options based on the key objectives, criteria and constraints described in previous sections.

Review Renewable Electricity Generation Technologies

- Review electricity generation technologies within the specific context and considerations of the OSU-C campus. Eliminate technologies that do not meet the campus key objectives.

Develop Onsite Renewable Electricity Generation Options

- Develop onsite electricity generation options within the specific context and considerations of the OSU-C campus.

Evaluate Onsite Renewable Electricity Generation Options & Recommended the Best Option

- Evaluate and screen different onsite electricity generation options based on the key objectives, criteria, and constraints described in previous sections.

Develop Implementation Strategy for the Recommended Thermal and Electrical Options

- Develop the campus thermal energy and electricity generation systems to suit the campus phasing plan. Identify the preferred location of the key system components.

2.1 Thermal Energy System Considerations

As previously noted, developing an optimal thermal energy system option for the OSU-C campus is a complex endeavour that requires analyzing a multitude of elements while carefully considering their interrelationships. In broad terms, the configuration of the thermal energy system can follow one of these approaches:

- Centralized or Distributed Configuration
- High-Exergy or Low-Exergy System Type

Centralized vs. Distributed Configuration

A centralized configuration typically consists of a single large-capacity central energy plant and thermal energy distribution network extending outwards to serve individual buildings within the campus. The centralized configuration is best suited for expansions of the existing thermal energy distribution network or for a new network serving large and relatively dense academic campuses, where the network is a relatively small component of the large system and energy loads it serves.

The key advantage of a centralized configuration is that the output capacity of the central plant can be optimized with peak load diversity between the buildings, thus allowing the central plant capacity to be smaller than the sum of the individual building peak loads. Another key advantage of a centralized configuration is that it provides better opportunity for energy recovery when there is simultaneous heating and cooing demands between buildings.

The downside of the centralized energy supply strategy is that, in order to achieve all of its advantages described above, it needs to be carefully planned well ahead, and it typically requires a large deployment of capital at the early stages of the development it is intended to serve, typically long before the buildout of the development is completed.

The distributed configuration is best suited for new or sparse developments with relatively low load densities, where the cost of constructing a new thermal energy network outweighs the other benefits of a centralized configuration. It typically includes individual building-level or nodal thermal energy plants that operate independently to meet the heating and cooling demands of the buildings they serve. In some configurations, when based on heat pump (HP) technologies, the distributed thermal plants can be interconnected on the low-grade energy source side of the system. This allows the plants to benefit from the load diversity and improves the overall energy performance efficiency. This configuration is well suited for new developments or academic campuses with well designed and highly energy efficient buildings that require only a relatively small external energy input.

A key advantage of the distributed configuration is that, for new highly energy efficient buildings, the required building-level or nodal thermal energy plant capacity is relatively small, simple and cost effective to install and operate. Another advantage of this configuration in the context of new buildings is that it requires relatively small amount of capital to install a plant capacity sized to meet only the concurrent demand. This provides significant economic advantage for applications where buildout progress tends to be relatively slow and extending over a long period of time, with capital deployment matching the concurrent plant capacity and building thermal demand.

High Exergy vs. Low Exergy System Type

In order to identify the optimal thermal energy system configuration for the OSU-C campus, it is also important to understand the qualitative aspects of energy defined as exergy.

In practical terms, the term exergy describes the quality or usability of energy in any given form. In the context of thermal energy systems, the High-Exergy category encompasses all heating systems that distribute high-grade forms of thermal energy, such as steam or high-temperature heating water (HW), while the Low-Exergy category is limited to low-temperature heating water (LTHW) only. Consistent with the 2nd law of thermodynamics, all high exergy forms of primary energy can be downgraded and utilized with any low exergy end-use technologies and systems, but not the other way around.

Given all forms of energy eventually end up as thermal energy at various temperature levels, a simplified visualization of the distinction between the high and low exergy energy sources and end use energy forms can be illustrated as a temperature scale as shown in Figure 2.1.1 below.

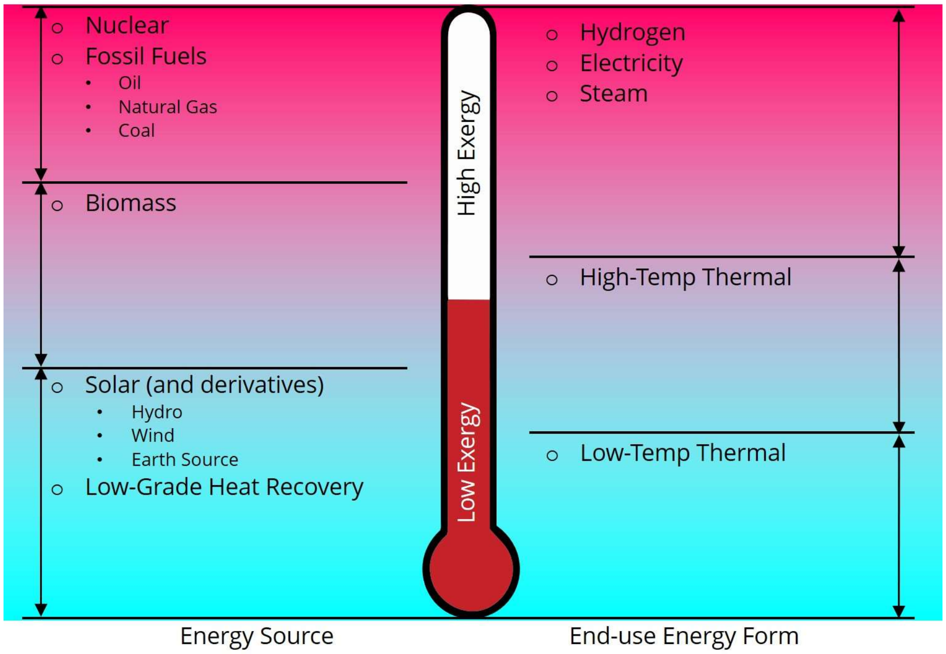


Figure 2.1.1 - High Exergy vs. Low Exergy

High exergy, or high-grade forms of energy, can only be derived from high-grade primary energy sources in combination with specific types of compatible energy conversion technologies; examples of this are fossil fuels with combustion technology, nuclear fission and solar PV systems.

Low exergy, or low-grade forms of energy, are typically derived from lower energy density and more diffused primary energy sources, and in practical terms represent low-temperature thermal energy. Most common examples of low exergy energy sources and energy conversion technologies include low-temperature solar thermal collectors, recovered low-temperature waste heat from cooling systems heat rejection, thermal energy extracted from the ambient temperature, geo-exchange (GHX) using HPs, etc.

In a high-exergy thermal energy system, the heating portion of the system operates with temperatures higher than 140ºF. Generating heating capacity at these temperatures typically requires combustion-based heating technologies and some form of combustible fuel as the primary energy input (i.e. fossil fuels such as natural gas, or biofuels such as biomass). In this category, the possibilities for integrating recovery of various forms of low-grade (low- exergy) “free waste” thermal energy or low-grade renewable energy are essentially eliminated.

The low-exergy category includes all versions of thermal energy systems that distribute LTHW at temperatures up to 140°F. Using low-temperature water does not require combustion-based technologies and opens the possibilities for integrating recovery of various forms of free low-grade waste thermal energy or low-grade renewable energy.

Many large-scale developments, including academic campuses such as the OSU-C campus, have a significant amount of heating and cooling demand simultaneously. Low-exergy systems are ideally suited for these applications as they effectively provide both heating and cooling services with a single technology: heat-recovery chillers or HPs capable of utilizing available low-grade thermal energy sources or sinks (i.e. recovered waste heat from cooling, or from the surrounding environment: ambient air, GHX, sewer, or solar thermal).

It is important to emphasize that low-exergy thermal systems should not be combined with high-temperature (high exergy) in-building heating systems. Considering that most of the new buildings on the OSU-C campus are yet to be designed and built, it is imperative that these buildings be designed with low-temperature building heating systems. These will not only be compatible with both low-exergy and high-exergy type of the new campus thermal energy system, but also offer the best building energy performance efficiency.

3. BACKGROUND

3.1 Previous Studies & Recommendations

Prior to the completion of the campus Long Range Development Plan (LRDP), OSU-C commissioned two studies in 2017: an analysis of potential paths to achieving a net-zero energy campus by PAE Engineers and a preliminary analysis into the feasibility of using biomass as an energy source at the OSU-C campus by Wisewood Energy. The relevant findings from both studies are summarized and discussed below.

Analysis of Potential Paths to Achieving a Net-Zero Energy Campus

A technical memo was issued in February 2017 detailing a three-part approach to achieve the net-zero energy campus goal. This approach, as summarized below, was subsequently incorporated into the LRDP:

- Reduce individual building and campus annual energy use through energy efficient buildings,
- Install high efficiency mechanical systems to further reduce campus energy use, and
- Install renewable energy generation systems, such as PV, to offset campus energy use.

As a starting point, the analysis outlined individual building level energy use intensity (EUI) targets. The targets were selected to achieve a 66% reduction in annual energy use compared to a typical university campus in the region (EUI of 101) while considering the existing buildings that do not meet the targets. The resulting aggregated campus maximum EUI target of 32.8 kBTU / ft^2 yr.

In addition to the EUI targets, the study proposed a central biomass boiler plant with a horizontal closed loop geo-exchange (GHX) field. Both boiler plant and GHX field will be connected to individual buildings via a campus-wide low-temperature condenser loop operating between 60 to 90°F. Individual building level water source heat pumps (WSHP) will connect to the condenser loop to generate the final HW, chilled water (CHW) and domestic hot water (DHW) to meet the building’s thermal energy demands. The report did not provide additional details for the integration of the central biomass plant and the geo-exchange system.

Lastly, to offset the campus's annual energy use, the study recommended implementing a combination of rooftop and ground-mounted solar PV systems to generate renewable electricity.

Biomass Energy for the OSU-Cascades Campus - Preliminary Analysis

In May 2017, Wisewood Energy completed a preliminary analysis of the viability for a central biomass plant at OSU-C. This analysis included energy modeling, plant sizing, an availability assessment of the local forestry wood-waste biomass feedstock and conceptual layouts of the biomass equipment on site. This analysis was subsequently updated in April 2018, along with the issuance of the LRDP. The analysis recommended a biomass plant that utilizes processed wood chips sourced from local forestry management activities as the least expensive form of biomass fuel. The analysis also found that the volume of biomass fuel required was relatively small compared to the available biomass fuel production capacity in the Central Oregon region. Both 2017 analysis and 2018 update recommended a biomass plant to be installed in conjunction with natural gas boilers, sized to meet peak loads to provide redundancy to the system. The 2018 update stated that the biomass plant will be able to meet 59% of the campus's annual heating demand, with the GHX system meeting 30% and the natural gas boilers meeting the remaining 11%.

The analyses conducted and presented in these reports, along with the recommendations outlined in the LRDP, formed the starting point for Integral Group's OSU-C Campus Energy Feasibility Study. Integral's initial review of these previous analyses raised a concern with the proposed systems and their abilities to achieve the campus's net-zero energy goal. The May 2017 analysis recommended a PV system of approximately 400,000 ft^2. The memo noted that this PV system area was sized to only offset the campus's annual electrical demand, but not the thermal energy demand of the campus. The analysis assumed that the fuel consumed by the biomass plant is considered a 'free' source of energy and as such, will not require offsetting since it will be generated by forestry management actives and that the biomass will be burnt anyway if not purchased by the campus as a fuel.

Integral Group Review Comments

After reviewing both the net-zero energy campus analysis and the preliminary biomass analysis, it is unclear how the biomass fuel was accounted for in the overall OSU-C annual energy use balance. This assumption has a major impact on whether the campus can achieve its net-zero energy goal. While the biomass is a by-product of forestry activities and could be considered a net-zero carbon fuel, the consumption of biomass should be factored into the overall energy use balance, like natural gas and electricity. As such, the energy from the biomass consumption will need to be offset in order the for the campus to be considered a net-zero energy campus.

In addition, both biomass and natural gas boilers have energy conversion efficiencies of less than 1; these systems will always generate less thermal energy than the input fuel consumed. As such, if the biomass consumption was included in the annual energy use accounting, the campus will require a significantly larger PV system and area to offset the associated annual energy use to achieve net-zero energy.

3.2 Campus Development and Phasing

The LRDP outlined the forecasted space needs of the OSU-C campus at full buildout including academic buildings (classrooms, teaching labs, office & support etc.), campus life spaces (assembly, dining, retail, etc.) and residential buildings. It also identified the timeline for the development of these buildings and the associated campus infrastructure over the next 20 years.

While understanding that the phasing of the campus and infrastructure development is a key consideration for the design of the campus energy systems, it is also important to note that the LRDP has been evolving and responding to the needs of the campus as they arise. Since the issuance of the LRDP, there have been several rounds of refinement and changes to the expected campus gross square footage (GSF), campus layout and phasing plan. Figures 3.2.1 through 3.2.3 illustrate the evolution of the campus phasing plan throughout this study.

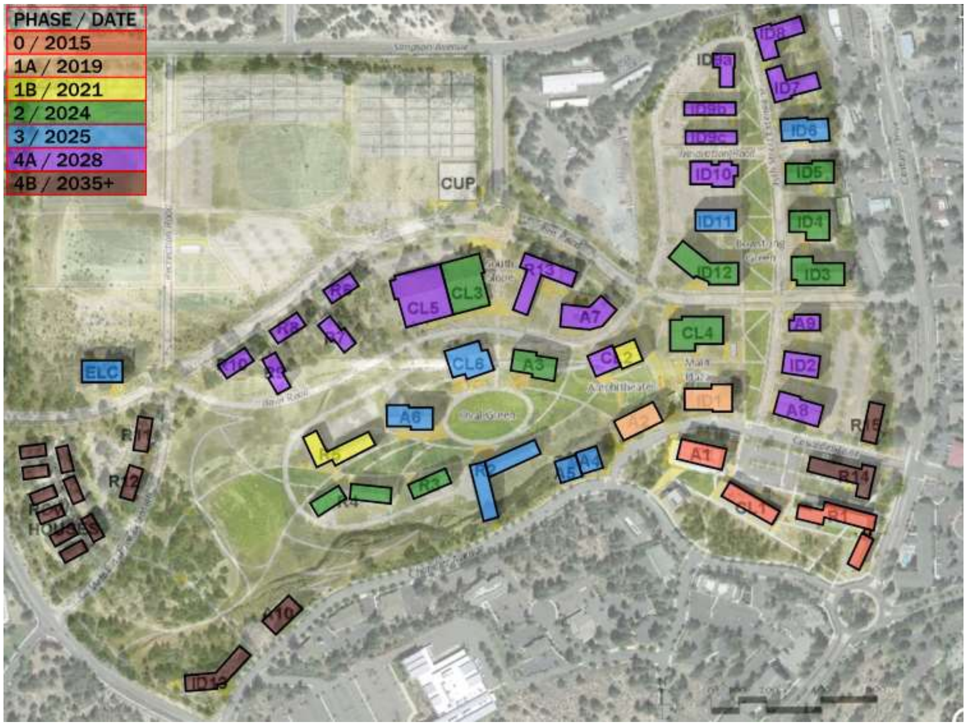


Figure 3.2.1 - Campus Phasing Plan (August 2019)

Figure 3.2.2 - Campus Phasing Plan (November 2019)

The analyses and energy modeling completed for this feasibility study have been in lockstep with these campus layout and phasing changes. Some key changes throughout the study include:

- Addition of an Early Learning Centre,
- Inclusion of the Innovation District (approximately 600,000 ft^2 of office and residential spaces),
- Revision of the location and timing of large residential buildings, and
- Acceleration of several academic buildings.

Table 3.2.1 below outlines the campus GSF used in Integral Group's most recent thermal energy demand and load modeling and Figure 3.2.3 illustrates the campus phasing plan as of March 2020.

Campus Building Space Type	Total GSF (ft^2)
Academic	374,843
Assembly	55,000
Campus Life	75,413
Daycare	53,800
Dining	18,000
Indoor Recreation	75,850
Office	344,988
Residential	752,988
Total	**1,750,882**

Table 3.2.1 - Campus Building Program Gross Square Footage

Another key element of the campus development plan that has been established since the LRDP was issued, is the extent of mechanical cooling on campus. While all academic and campus life buildings will require mechanical cooling, the campus intends to only provide mechanical cooling to short-term residential buildings. Figure 3.2.4 identifies the campus buildings without mechanical cooling: residential buildings RB4, RB6, RB 9 and RB 13.

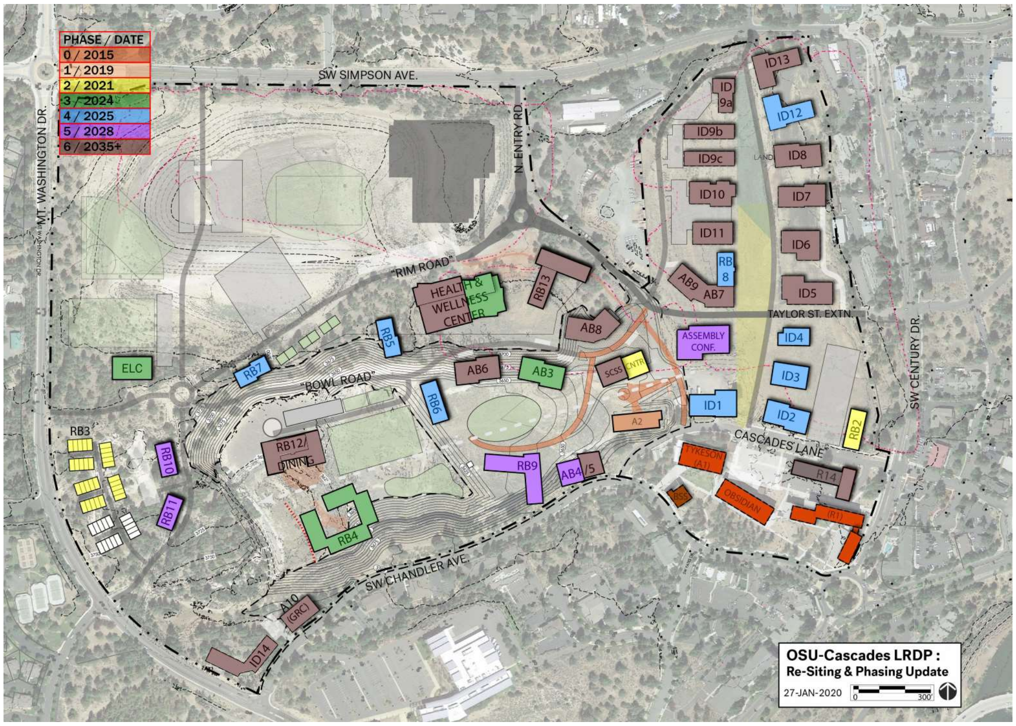


Figure 3.2.3 - Campus Phasing Plan (March 2020)

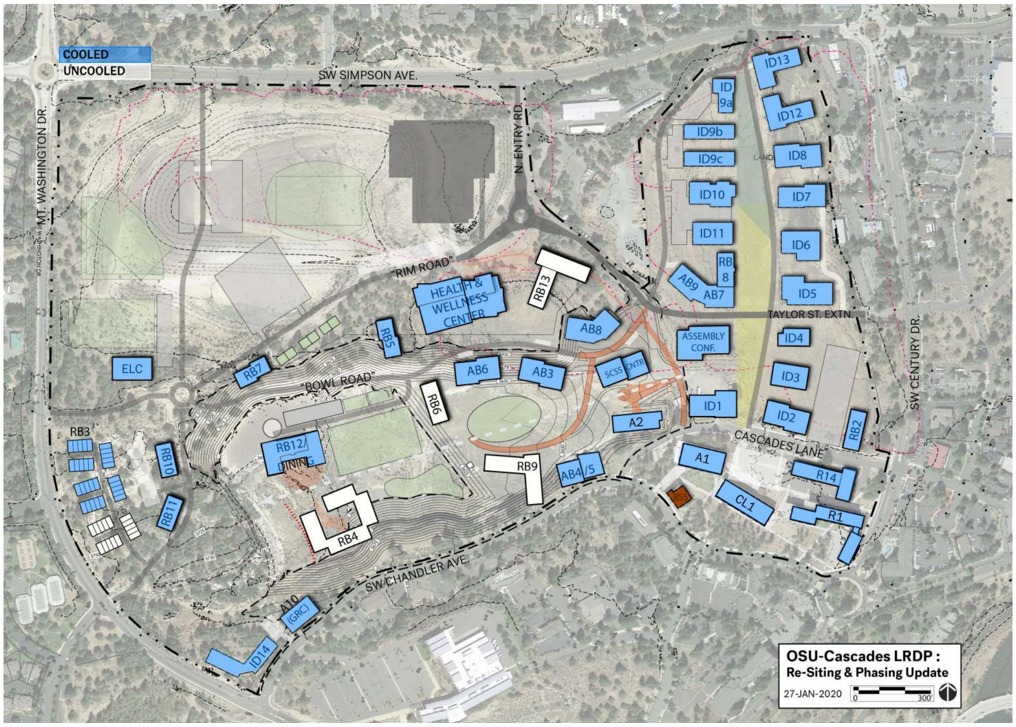


Figure 3.2.4 – Campus Buildings with Mechanical Cooling

3.3 Building Energy Performance Targets

The campus energy infrastructure and building energy performance targets proposed in the LRDP were developed to minimize the primary energy use in order for OSU-C to achieve the goal of a net-zero energy campus.

The LRDP established total Energy Use Intensity (EUI) targets for each building type. An EUI is the total annual energy use by a building per unit gross floor area, in kBTU / ft^2-yr. The EUI targets have only recently been introduced into the building industry to quantify the energy efficiency performance of a building in clear, measurable terms. This metric totals all different forms of energy use of the building, such as electricity and natural gas, which are used to satisfy all energy demands of the building; both thermal and non-thermal energy demands.

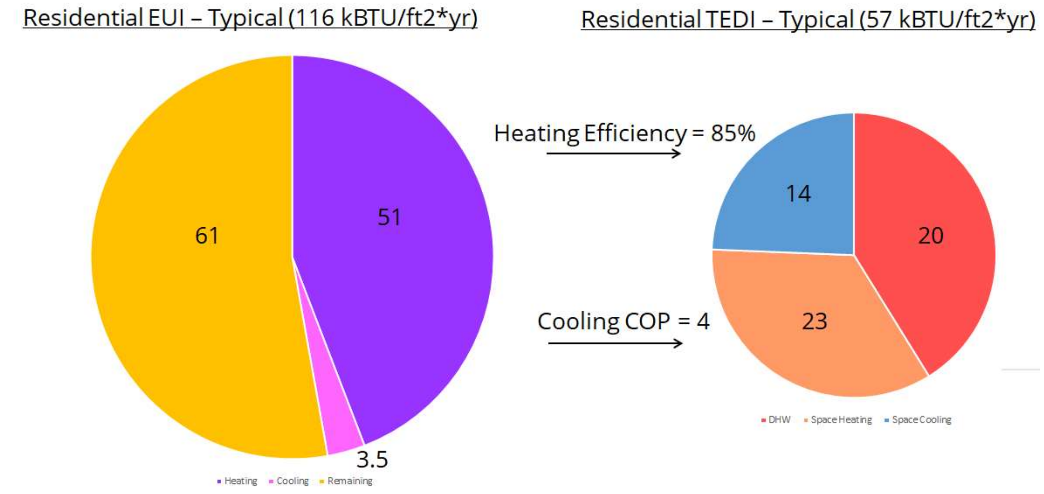
EUI metric does not distinguish between different forms of energy with different greenhouse gas (GHG) emission factors. It also lacks delineation between thermal and non-thermal building energy demands which is a crucial parameter for optimizing the building's passive architectural performance independently from the building systems and non-thermal loads (i.e. lighting, plug loads, etc.).

To provide clear energy performance targets for the new buildings at the proposed OSU-C campus, Integral Group recommends breaking down the total EUI targets to their components, namely the following thermal demand energy targets:

- Space Heating Thermal Energy Demand Intensity (TEDI)
  Annual thermal energy demand for space and ventilation heating per unit gross floor area in kBTU / ft^2·yr
- Domestic Hot Water Thermal Energy Demand Intensity (DHW TEDI)
  Annual thermal energy demand for domestic hot water heating per unit gross floor area, in kBTU / ft^2·yr
- Cooling Energy Demand Intensity (CEDI)
  Annual thermal energy demand for space cooling & ventilation per unit gross floor area, in kBTU / ft^2·yr

To develop thermal energy demand intensities targets for OSU-C campus Integral Group reviewed a number of past energy models and reports for similar projects (both published and internal) to estimate the end use breakdown of EUIs of the different building types in typical (designed to minimum code requirements) and high performance buildings (refer to Appendix A for a list of the energy analysis reports reviewed). The heating and cooling portion of the EUI was then multiplied by the estimated average annual efficiency of the assumed building heating and cooling system to derive the corresponding TEDI, CEDI and DHW TEDI values.

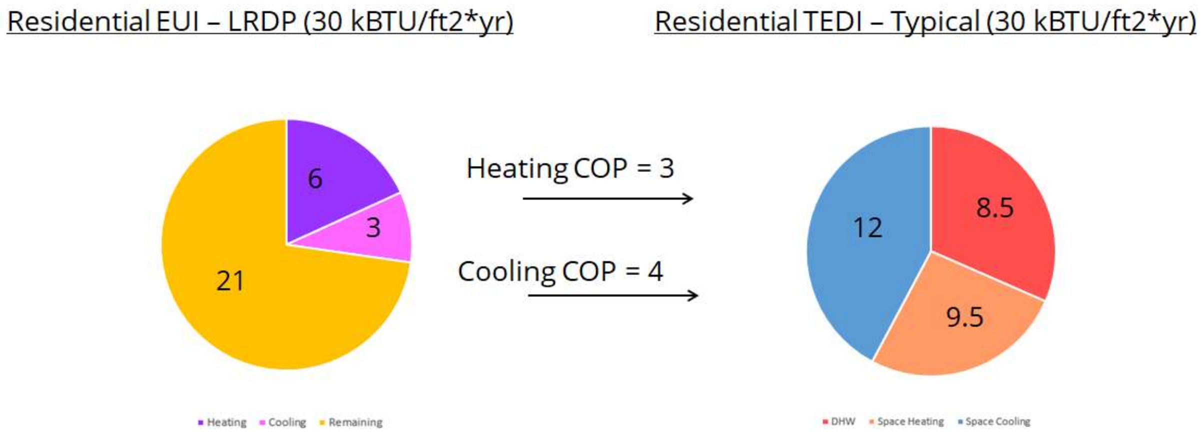
For example, Figure 3.3.1 shows the combined heating portion of the EUI of a typical student residential building is 51 kBTU / ft^2·yr. Assuming the building has a typical natural gas fired boiler plant (the equipment referenced in this study), this EUI was multiplied by a typical annual efficiency of 85% for a standard boiler plant and the resulting combined space heating and DHW TEDI is 43 kBTU / ft^2·yr. Integral Group then separated the combined heating energy demand intensity into a TEDI and DHW TEDI based on the results of previous energy studies (86% and 14% respectively for a typical student residential system).



Remaining includes plug loads, lights & mech equipment elec consumption

Figure 3.3.1 – Energy Demand Intensity Development (Typical Residential Building)

Figure 3.3.2 shows that a high-performance residential building starts with a much lower EUI of 30 kBTU / ft²·yr overall, and a heating EUI of 6 kBTU / ft²·yr. This level of performance can only be achieved with a highly energy efficient HVAC plant, such as high-performance HP system with a coefficient of performance (COP) of 3 (300% energy conversion efficiency). Assuming this annual efficiency of the HVAC plant, the resulting combined TEDI and DHW TEDI is 18 kBTU / ft²·yr.



Remaining includes plug loads, lights & mech equipment elec consumption

Figure 3.3.2 – Energy Demand Intensity Development (High Performance Residential Building)

Using this methodology, we developed the TEDI, CEDI and DHW TEDI targets for each building type at the OSU-C campus. These EUI and energy demand intensity targets are summarized in Table 3.3.2. The same targets were also used in our energy modelling to develop the thermal demand profile of the OSU-C campus. Buildings with multiple space types, Academic and Campus Life, were assigned an area-weighted average of the subspaces GSF, EUI and energy demand intensity targets.

It should be noted that the teaching and research lab TEDI, DHW TEDI and CEDI listed in Table 3.3.1 were developed based on the AB2 energy modelling results, which were provided by the AB2 energy modelling team (Affiliated Engineers). The results of the energy model revealed that process ventilation requirements at the academic buildings could not be reduced, nor could the heating and cooling demands for conditioning the ventilation air. The respective inputs for envelope performance, mechanical, and electrical systems implied a high-performance building. Initial estimates for the teaching and research lab EDIs, presented in Table 3.3.1, were considered too low to accommodate the ventilation air tempering requirements with available technology.

Based on the AB2 energy model results, it was assumed that the energy demand intensities of academic buildings with teaching and research labs would remain relatively high even with high-performance building envelope design.

	Original, August 2019, Teaching Lab Energy Demand Intensity (kBTU/ft^2)	**Original, August 2019, Research Lab Energy Demand Intensity (kBTU/ft^2)**
TEDI	8	9
DHW TEDI	1	1
CEDI	7	8

Table 3.3.1 – Preliminary Teaching Lab and Research Lab Energy Demand Intensity Targets

It was determined that these targets would be to difficult to achieve while providing the high ventilation air flow required for healthy and safe operation of the Labs. Refer to Appendix D for a detailed description of the AB2 energy model review.

Campus Building Space Type	**Typical EUI (kBTU / ft²·yr)**	**Proposed Design EUI (kBTU / ft²·yr)**	**TEDI (kBTU / ft²·yr)**	**DHW TEDI (kBTU / ft²·yr)**	**CEDI (kBTU / ft²·yr)**
Academic Weighted Average	106	32	36	28	8
Classroom	71	23	10	8	1
Teaching Labs	120	36	83	62	30
Research Labs	265	80	183	138	30
Office and Support	70	21	6	6	1
Library and Study	104	32	6	6	1
Flexible Workspace	71	22	6	6	1
Media	104	32	6	6	1

Assembly	31	10	6	6	0
Campus Life - Weighted Average	45	17	7	7	1
Exhibition	31	10	6	6	0
Lounge and Social Space	31	10	6	6	1
Retail	74	23	9	10	0
Meeting	31	10	6	6	1
Support	50	16	8	7	1
Healthcare	73	24	9	10	1
Daycare	73	24	6	6	4
Dining	224	78	6	7	10
Indoor Recreation	43	34	6	6	1
Office	70	21	6	6	1
Student Residential	116	30	11	6	9

Table 3.3.1 - Proposed Building Space Type Thermal Energy Demand Intensity Targets

3.4 Building Energy Performance Benchmarking

In addition to developing energy demand intensity targets, Integral Group also undertook a benchmarking exercise to understand how these targets and the LRDP EUI targets compare against similar industry and national standards. While most building codes and building energy efficiency standards include general energy efficiency criteria, few take the next step to mandate EUI targets, and fewer still to include EDI targets. Refer to Appendix A for a list of the energy codes, green building standards and net-zero ready building analysis that were included in our review.

Construction Type	TEDI (kBTU/ ft^2·yr)	CEDI (kBTU/ ft^2·yr)	EUI (kBTU/ ft^2·yr)
Passive House	5	5	-
NZE – Ready Buildings	4 - 12	1 - 6	10 – 25
High Performance Buildings	5 - 10	6 - 10	28 – 38
Midrange Average	10 - 16	6 - 10	38 - 48
Base Code Construction	25 - 32	-	74

Table 3.4.1 EUI, TEDI and CEDI Benchmarking

Table 3.4.1 summarizes the findings of the review and illustrates that both the LRDP campus-wide EUI targets and Integral Group's proposed TEDI and CEDI targets are inline with the most progressive North American industry standards for high performance buildings. This is a level of building efficiency that is well above base code compliance level, but not as stringent as Net-Zero Energy or Passive House performance targets.

3.5 Energy Performance of the Existing OSU-C Buildings

At the time this energy study was conducted, there were three occupied buildings at the OSU-C campus; Tykeson Hall (A1), Obsidian Hall (C1) and Residential Hall (R1). Figure 3.5.1 below illustrates the average electricity and natural gas EUIs for these buildings between 2017 and 2019 and compares them to the LRDP targets. While Residential Hall and Tkyeson Hall are relatively close to the LRDP targets, Obsidian Hall's EUI is significantly higher than the building's LRDP EUI target (based on an average of the academic, campus life and dining hall LRDP EUI targets).

Further information and analysis are required in order to understand the breakdown of energy use within Obsidian Hall and the difference between the actual EUI and the LRDP targeted EUIs. Nonetheless, Figure 3.5.1 highlights the need for EUI targets to be a key focus point for all future building design teams, if the OSU-C is to meet its campus wide EUI target and subsequently the net-zero energy campus goal.

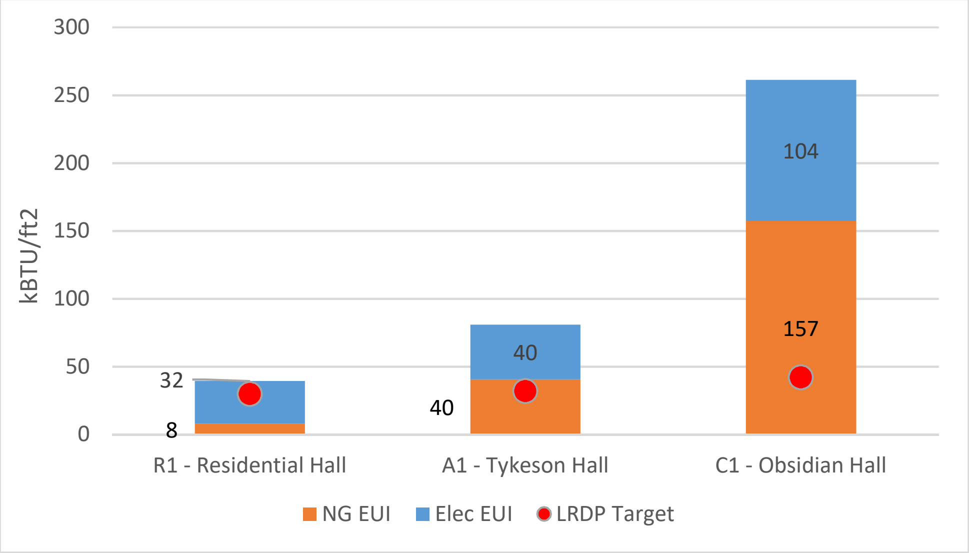


Figure 3.5.1 – Energy Performance of the Existing OSU-C Buildings

3.6 Construction Implications – AB2 Example

While there are many paths available to design and construct a high-performance building, it is important that expectations of the level of design rigor, innovation and capital cost involved are appropriately set before a campus of OSU-C scale embarks on this process. A balance must be struck between allowing future design teams the freedom to address the individual needs of each building, while ensuring that the construction budgets and design methodology used will enable to campus to achieve its net-zero energy goals.

While this energy study was conducted, the second academic building on campus, AB2, was also in design. AB2 will be a model for future buildings on campus, and therefore targets both an overall building EUI inline with LRDP targets (26.2 kBTU / ft^2·year based on an area-weighted average of its building space uses) and an aspirational goal of being net-zero energy by generating more energy with an on-site PV system that it consumes.

The AB2 design process provided valuable feedback to the OSU-C campus energy study, on opportunities and challenges that arise when designing to achieve a high performance EUI target.

This section provides a discussion on the type of mechanical and electrical systems incorporated into the AB2 design that allowed it to meet its EUI target. This is not intended to be a prescriptive design solution for future buildings; rather an example of the level of innovation and construction required to achieve the campus net-zero energy goal. Refer to Appendix D for a full review of the AB2 energy demand intensities and their implications on the final campus thermal demand.

High Performance Mechanical Systems

AB2 has been designed with a Dedicated Outdoor Air System (DOAS) and zone level hydronic heating and cooling fan powered boxes for space conditioning. Decoupling the building ventilation air system from space conditioning reduces the building's annual fan energy and the need for zone level reheat. All of the fan powered boxes and fan coil units utilize high-efficiency variable-speed fans. The DOAS also included an air to air energy recovery device with a 50% total energy recovery effectiveness.

Additionally, the following mechanical system control measures were implemented to reduce the thermal energy demand of the building:

- Unoccupied Temperature Setbacks to 60 / 80ºF during unoccupied hours, in most spaces.
- Expanded Temperature Range from 68 / 75 ºF to 65 / 78 ºF in spaces where an expanded comfort range is appropriate including flex lobby, maker space and machine shop, and flex labs.
- Laboratory Unoccupied Ventilation Setbacks during unoccupied hours, 6 to 4 ACH in research labs and 6 to 2 ACH in flex labs.

High Performance Envelope

Building envelope components which contribute to the energy performance of the building include:

- A portion of south façade is built into the ground to harness the more stable temperatures of the ground as well as minimize solar exposure on the south façade,
- Optimized window and shading placement with an overall gross wall area of 36%, respectively low for current standard design for office or academic applications,
- Opaque envelope performance exceeding prescriptive energy code requirements by 20% to 40%, with continuous insulation at both walls and roofs,
- High performance fibreglass punched windows in place of conventional metal frame curtain wall, and
- Ventilation air will be preheated with a solar collector on the south façade to passive heat ventilation air before it enters the building mechanical system.

High Performance Lighting & Plug Load Systems

Lighting systems will be designed for energy efficiency with the following key elements:

- LED fixtures for low power consumption,
- Conscientious layouts to optimize the use of artificial lighting,
- Daylight sensor controls in perimeter spaces adjacent to windows,
- Continuous dimming control and occupancy sensors to provide lighting only when and where it is needed, and

– Exterior building lighting will be kept at a minimum.

Plug and process electrical load reductions are under evaluation for this building, and strategies such as efficient equipment selection, automatically controlled receptacles, and operational management procedures. Heat gains from zone equipment will be considered in the layout with consideration for any opportunity to recover heat to temper ventilation air.

4. CAMPUS THERMAL DEMAND

Space heating, space cooling and domestic hot water heating energy demand profiles were developed for the OSU-C Campus based on the building space types, areas and phasing established in the LRDP and updated with recent coordination with the campus infrastructure team. These energy demand profiles were used to estimate the required capacities of plant equipment, equipment electrical energy use, fuel energy use, and the amount of heat rejection or heat recovery that would potentially be available.

4.1 Thermal Energy Demand Modeling Methodology

Annual thermal energy demands were estimated for each building using annual energy intensity metrics, TEDI, CEDI and DHW-TEDI that have been proposed as performance targets for the University campus.

Annual demands were converted to hourly load profiles for each building using hourly outdoor dry-bulb temperatures from the Typical Meteorological Year 3 (TMY3) weather file for Redmond Oregon Municipal Airport (Roberts Field).

Phase by phase and site total thermal demand profiles were aggregated by combining load profiles for the respective buildings.

Options for the mechanical plant equipment and configuration were modelled using spreadsheets and, where closed-loop geo-exchange is considered, using the Earth Energy Designer (EED) software. Refrigerant based HP and chiller plant equipment was modelled using the Carnot equation for HPs with system temperatures, ground loop temperatures, and isentropic efficiency appropriate for the type of equipment to calculate the hourly COP, heat of extraction or rejection, and electrical energy use. Plant analysis was conducted for a single central plant, nodal campus plants, and individual buildings.

The plant models were used to review the performance of the considered plant options. The results were used to estimate the required output capacity of respective pieces of equipment, the resulting electrical and fuel energy demands, and to estimate the GHG emissions and energy cost.

4.2 Annual Thermal Energy Demands and Hourly Load Profiles

The energy demand intensities defined in the previous section were applied to each building floor area and the resulting projection for annual energy demands at the campus, including the innovation district, are shown in Table 4.2.1 below.

End Use	Total Annual Energy Demand [MWh]	Total Annual Energy Demand [MBTU]
Space Heating	7,295	24,890
Space Cooling	5,126	17,489
Domestic Hot Water	3,000	10,237

Table 4.2.1 - OSU-C Annual Energy Demands

The annual thermal energy demands were then apportioned over the year to derive hourly loads with a calculation methodology based on the outdoor air temperature and the building neutral temperatures. The building neutral temperature in heating is the outdoor air temperature above which there will be no demand for heating, and in cooling is the outdoor air temperature below which there will be no demand for cooling. The neutral temperatures for heating and cooling have been derived in an iterative manner. The hourly load is calculated with a non-linear relationship to the temperature difference between the neutral and peak OAT for both heating and cooling demand, amplifying the result when the temperature difference is greatest, closely correlating with expected peak load while maintaining the target total annual energy demand.

To apportion the annual energy demands for domestic hot water heating, standardized fractional hourly schedules in representative energy models were used, in a non-temperature-based manner.

The hourly profiles were generated accounting for reduced occupancy at the campus during holidays: two weeks at the end of the year with 0% occupancy, one week in February at 50%, and over the summer at 20%.

The hourly space heating, space cooling and domestic hot water heating energy demands were summed to generate the hourly energy demand profiles for the entire OSU-C Campus as shown in Figure 4.2.1 below.

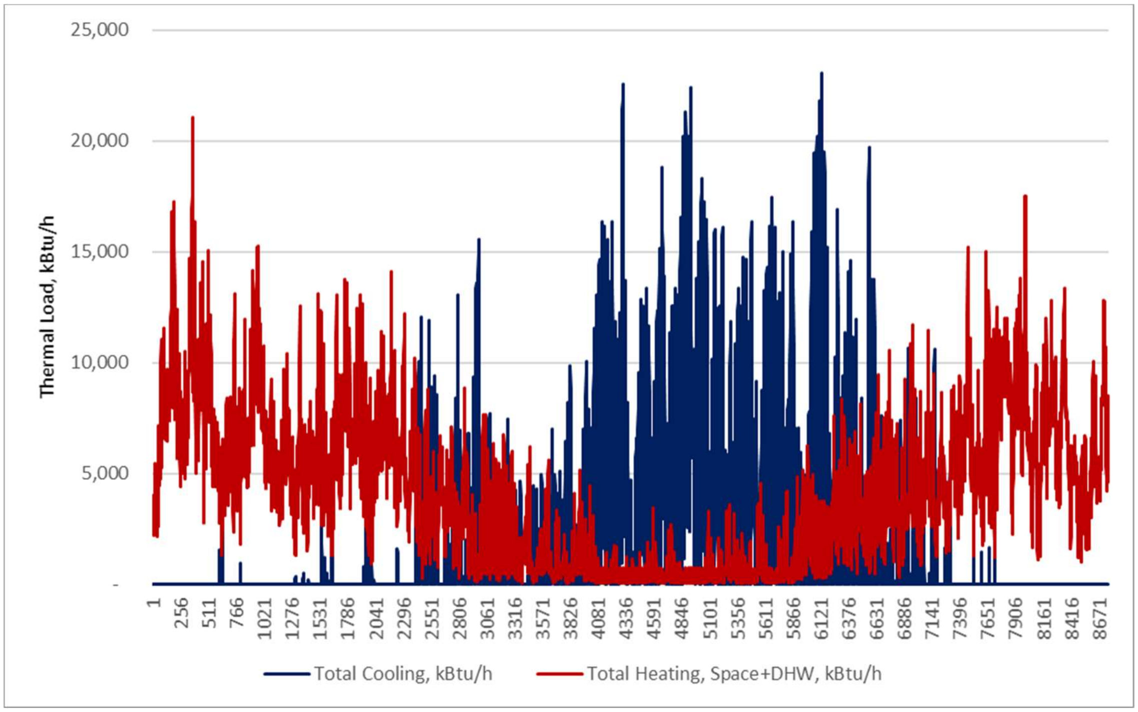


Figure 4.2.1 – OSU-C Campus Hourly Heating (Space + DHW) & Cooling Load Profiles

These hourly load profiles have been used in the analysis to evaluate the energy performance of the mechanical plant options considered for the campus, for a single central plant, nodal plants, and distributed building by building plants.

4.3 Peak Thermal Loads

The hourly load profiles for space heating, space cooling and domestic hot water heating include the peak conditions, and those peak loads are also required for the purposes of sizing the required capacities of each plant energy conversion equipment and other system components.

The peak space heating, space cooling and domestic hot water heating loads for the OSU-C campus, including the innovation district, are summarized in Table 4.3.1 below.

End Use	Peak Load [MW]	Peak Load [MMBTU/h]
Space Heating	5.1	17.5
Space Cooling	6.8	23.1
Domestic Hot Water	1.1	3.7

Table 4.3.1 – OSU-C Campus Peak Heating (Space + DHW) & Cooling Loads

Thermal analysis was conducted on each individual building and the hourly load profiles can be combined as per the project development phasing or as required in the mechanical plant energy analysis for the proposed options.

4.4 Campus Phasing and Implications

In addition to understanding the peak and annual demand of the campus at full build out, incremental peak loads and corresponding annual demands were developed for each of the campus build out phases. These incremental demands for each phase were used to size the plant equipment and estimate the capital costs deployment at each phase of the campus development. The results are summarized in Table 4.4.1 and Figure 4.4.1 below.

Thermal Demands by Phase	Peak Heating Load [MBH]	Annual Heating Energy [MBTU]	Peak Cooling Load [Tons]	Annual Cooling Energy [MBTU]	Peak DHW Heating Load [MBH]	Annual DHW Heating Energy [MBTU]
Existing	2,057	2,380	199	1,808	290	756
Phase 1A	1,325	1,972	169	1,541	234	451
Phase 1B	1,067	1,235	100	910	340	699
Phase 2	2,389	3,576	235	2,138	644	1,627
Phase 3	2,458	2,843	215	1,955	710	1,577
Phase 4A	1,602	2,259	152	1,383	394	989
Phase 4B	6,977	10,625	851	7,753	1,550	4,138

Table 4.4.1 – Campus Annual Thermal Energy Demand and Peak Loads by Phase

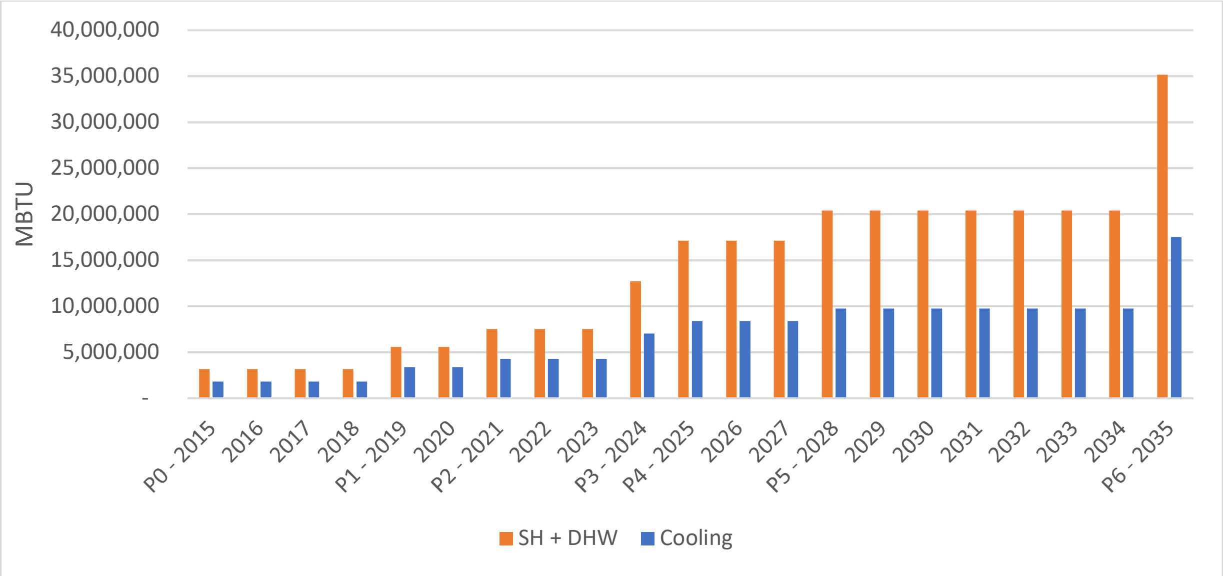


Figure 4.4.1 – Campus Annual Thermal Energy Demand by Phase (Cumulative)

Figure 4.4.1 illustrates the campus's cumulative annual thermal energy demand from Phase 0 to Phase 6. It shows that a significant portion of the campus's development, and the corresponding annual energy demand, will be installed in the final phase 6 in 2035. The campus's energy infrastructure would therefore ideally be configured in a manner that would enable phased installation, to allow the required capital cost to be deployed accordingly. This would reduce the risk of over capitalizing and installing oversized campus energy system capacity early in the campus's development.

5. ENERGY SOURCES AND TECHNOLOGIES

5.1 Introduction

For each energy system option considered for the OSU-C campus, there are several combinations of complementary energy sources and technologies that would be able to meet the campus overall energy demand (i.e. heating, cooling or electrical demand). This section provides a review of the three main campus energy system options considered in this study (biomass, closed loop GHX and open loop GHX), including their benefits and limitations, and their overall capability of achieving the key net zero energy objectives of the OSU-C campus.

5.2 Biomass Cogeneration and Trigeneration

Description

The Biomass system version considered for the OSU-C campus would utilize waste wood products from the regional forestry industries to generate high-grade or high exergy forms of end use energy, such as high-temperature HW and electricity, and as such would be considered a high exergy system. Biomass systems can be designed using several different technologies. While some new technologies (such as gasification) can be used with biomass, conventional boilers capable of achieving complete combustion of the solid biomass fuel represent the most robust solid fuel energy conversion technology that can also work with a wide quality range of solid biomass fuels.

The most prevalent technology that is traditionally used in cogeneration and trigeneration systems relies on complete combustion of the primary fuel. In a cogeneration system, the heat generated by burning biomass is used to generate steam to drive a turbine generating electricity and high-grade thermal energy usable for heating.

If a biomass cogeneration system operates year-round to generate electricity, the waste heat that cannot be utilized for heating during the summer months must be rejected or used for other purposes such as tri-generation. Tri-generation systems start with the same steps as cogeneration (combusting fuel and converting the fuel energy to electricity and useful heat) but adds on an additional cooling generating step. Instead of rejecting the surplus heat, it is redirected to power an absorption chiller to produce chilled water that can be used for cooling. This is the distinct advantage of tri-generation: it maximizes the energy output from fuel combustion year-round.

Carbon and Energy Use Impact of Biomass

Biomass fuels are generally, though not unanimously, considered carbon neutral if the biomass fuel is 100% derived from a variety of waste streams of organic materials from construction, forestry, agriculture and food industries that would have otherwise been disposed of and ended up in landfills, or burnt for forestry management. Crop based biofuels derived from purposely grown crops (i.e. corn for manufacturing of ethanol, or fast-growing trees grown for firewood, or wood pellets) are generally not considered as carbon neutral.

Another key aspect directly related to the carbon neutrality of biomass fuels consideration is the energy use and carbon emissions related to their sourcing, processing and transportation. Using forestry wood waste biomass at OSU-C campus would require transporting large amounts of biomass to the campus, as there are no readily available sources onsite. This may require transporting the biomass over long distances which would diminish the carbon reduction potential of the fuel as well as make it difficult to procure fuel on short notice.

As noted in Section 3.1, while certain types of biomass fuel could be considered as carbon neutral, it is still an energy source that needs to be procured and should be accounted for in the OSU-C annual energy use intensity and energy cost analysis. It also needs to be ultimately offset by a corresponding amount of renewable energy generation if it is to be properly considered towards achieving the OSU-C's net-zero energy campus goal.

High Level Biomass EUI Analysis

Biomass boilers are a form of combustion technology and therefore, as noted in Section 3.1, will therefore always have an efficiency of less than 1. To analyze the impact this level of efficiency will have on the campus's annual energy use intensity, Integral Group did a high level EUI comparison between a conventional 'base case' mechanical system, a biomass plant system and a GHX system. The results are illustrated in Figure 5.2.1 below.

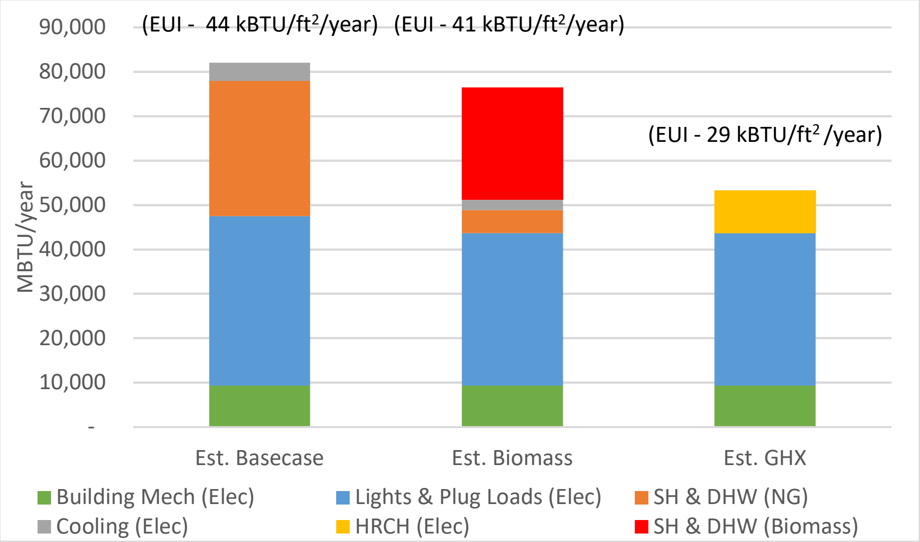


Figure 5.2.1 – High Level EUI Estimates for Selected Technologies

In the base case mechanical system space heating and DHW is provided by condensing natural gas boilers and cooling is provided by conventional chilled water plants (water cooled chillers and cooling towers). In the biomass system space heating and DHW are provided by biomass and natural gas boilers, while cooling is provided by a combination of conventional chilled water plant and absorption chillers. For the GHX system, space heating, DHW and cooling are provided by heat recovery chillers (HRCH).

This initial high level analysis shows that due to the lower energy conversion efficiency of either a conventional mechanical system or a biomass plant, these system options would not be able to meet the LRDP's campus wide EUI target of 32.9 kBTU / ft^2·yr and therefore, would not be able to meet the OSU-C's key objective of achieving net-zero energy campus.

Biomass Option Review Summary

The key objective of this study to recommend and develop a campus energy system that would support OSU-C's goal of achieving a net-zero energy campus. Based on the results of this high level EUI analysis, and after consultation with OSU, Integral Group concluded that a biomass plant would not be a suitable energy option for the OSU-C campus because it would not be able to meet the OSU-C's key objective of achieving net-zero energy campus. While biomass systems offer several benefits, such as reducing the campus dependence on fossil fuels, generating electricity and high-temperature HW, its limitations (the need for peaking heat source, inability to recovery heat within the campus, onerous fuel transportation, handling and storage requirements) prevent it from achieving the OSU-C's key objective. For these reasons, Integral Group concluded the biomass analysis after this initial, high level review stage. The biomass option was eliminated and did not proceed into detailed concept design stage that would include equipment selections, capital cost estimates or financial analysis for this system.

5.3 GHX Systems

Continuing with the system concepts included in the LRDP, GHX represents another renewable energy system option being considered for the OSU-C campus.

Description

GHX systems use the natural ambient temperature of the ground which is essentially solar radiation stored as a low-grade heat within the upper crust of the earth, which can be tapped wherever there is adequate access to the earth, ground water (GW), a lake, or the ocean. The relatively low temperature of the ground, which is normally equal to the annual average outdoor air temperature of the region, means that it can be used as either a low-grade heat source or heat sink in combination with HP technologies.

A GHX system includes three primary components– a ground heat exchanger providing the "source-side" of the system, a HP serving as the energy conversion technology, and a thermal (heating and cooling) distribution system (building, or campus scale) providing the "load side" of system.

The most common versions of ground heat exchangers are either "open-loop" wells using GW in a non-consumptive manner as a heat source or sink, or a "closed-loop" vertical or horizontal system of buried plastic piping network. The most prevalent version of the closed-loop GHX system is vertical ground heat exchangers with boreholes typically drilled to 300-600 ft depth. This is primarily due to its higher capacity per unit of installation site area when compared to a horizontal version of the closed loop. Open-loop groundwater systems are less common since their viability is largely dependent on adequate groundwater yield and quality available at the specific project site. The most typical configuration of an open-loop groundwater system consists of a set of groundwater "production" wells and the matching number of groundwater "injection" wells. The groundwater is pumped out from the production wells, passes through heat exchangers (HX) that extract or reject heat from/to the groundwater before it is re-injected back into the same aquifer via the injection wells. Even though the groundwater is used in a non-consumptive manner installation and operation of the open loop systems is subject to all applicable federal and state groundwater protection and environmental regulations.

Considered GHX Options

Even though the LRDP considered horizontal "slinky" version of the closed-loop GHX complementing the central biomass heating plant, this version of the GHX system would not be able to provide adequate capacity on its own due to the limited site area for the OSU-C Campus thermal demand. For this reason, this version of the GHX system was eliminated early on in this study.

As noted above, the vertical closed-loop version of the GHX can provide much larger thermal capacity per installation site area. This is because the array of relatively deep vertical boreholes more effectively interacts thermally with a larger volume of the earth than the relatively shallow horizontal loop version. Based on our initial analysis, we confirmed that the OSU-C campus has enough site area for installation of a vertical closed loop version of the GHX to support the thermal demand of the campus.

Finally based on Integral Group's initial desktop review of the regional hydrogeology, and assuming reasonable groundwater yield and quality, an open-loop GHX system on the OSU-C campus has the potential for even greater thermal capacity per unit of installation site area than a closed-loop system. In a campus scale system, this high thermal capacity would also result in lower initial capital costs than a comparable closed-loop vertical GHX systems.

It is important to note that, even though the open-loop groundwater-based versions of the system are less common, the regional deep geology of Oregon East of Cascades offers one of the best opportunities on the North American continent for successful applications of open-loop groundwater-based systems. This is due to the presence of underlying volcanic bedrock geology with relatively small amounts of dissolved minerals and productive groundwater aquifers in this region. Most of the successfully installed open-loop systems in North America are in this region. In fact, there is a similar open-loop system only several miles west of Bend, at the Seventh Mountain Resort, that has been in operation for a number of years without any reported system performance issues.

Groundwater Yield and Quality Test

The first step in evaluating both options included a custom-designed in-situ test that included drilling and installation of a 500 ft deep test well and conducting a set of tests to confirm the groundwater yield and quality, and if the groundwater test results would end up being not favorable, the well would be converted into a vertical closed-loop borehole and additional formation thermal conductivity (FTC) test would be completed.

To facilitate Integral Group's assessment of the viability of an open-loop groundwater system, OSU-C procured the installation of a 12" diameter, 500 ft deep groundwater production 'test' well on the campus.

The groundwater yield of the well confirmed by the test was higher than anticipated, with the pump drawdown test originally targeting 1,000 GPM but achieving 1,200 GPM of sustained yield. The results of the water chemistry analysis were also positive. With almost no dissolved minerals, there is minimal risk of scaling, and with limited amounts of iron and manganese and their oxides, the overall groundwater quality is close to drinking water quality. The only concern noted from the test results is the highly corrosive nature of the water that would tend to oxidize any iron containing parts of the system. However, this risk can be effectively mitigated by avoiding the use of any ferrous components of the system in contact with the groundwater.

Even though the bacteria concentrations detected in the groundwater test were low, effective complimentary mitigation strategy to first avoiding the use of ferrous components in the system (which eliminates the potential source of oxidized iron and manganese for iron and manganese bacteria), and to limit the leaving groundwater temperature downstream the HX during heat rejection mode to 65° F. Additional safety provision can be provide by including UV filters downstream the HXs to disinfect and inactivate any potential bacteria in the leaving groundwater prior to it being returned to an injection well.

While the chemical analysis did confirm presence of Total Dissolved Solids (TDS) in the groundwater sample, which is the amount of minerals and other compounds dissolved in the water, it did not specifically report on the quantity of non-dissolve particles such as sediment, mud or sand present in the groundwater. The report observed that the GW was clear but did contain some suspended black particles. We could infer that the system will require some level of filtration to remove suspended particles (dirt, sand, etc.) to assure its proper operation. To confirm the optimal level of required suspended solid particles filtration, Integral Group will be requesting some additional groundwater sample testing as part of the upcoming test injection well installation.

Refer to Appendix E for the production well flow rate and chemical analysis test results.

GHX Summary

Both the closed-loop vertical and open-loop GHX systems have the capacity to meet the OSU-C campus demand, and therefore achieve OSU-C's objective of being a net-zero energy campus. However, upon further evaluation, the open-loop system is able to achieve this objective while meeting this study's three key analysis criteria; it offers the lowest initial capital cost, can be delivered in stages to match the campus phasing plan and still offers the potential for third-party ownership. Based on this evaluation, and in consultation with OSU-C, Integral Group recommended that the following systems be analyzed and designed in detail:

- Central, open-loop GHX system,
- Nodal, open-loop GHX system, and
- Distributed, closed-loop GHX system.

The central and nodal open-loop GHX systems were selected because they represent the best options for meeting study's analysis criteria of capital cost effectiveness and potential for third-party investment. A distributed closed-loop GHX system does not offer the potential for third-party investment, and therefore is not considered to be an appropriate solution for the campus. It has been included, however, to provide a base case for the detailed analysis, since it is also able to achieve the OSU-C's goal of being a net zero energy campus.

6. THERMAL ENERGY SYSTEM OPTIONS

6.1 Introduction

As noted in Section 5, following our review of potential thermal energy system approaches and technologies, Integral Group developed three potential GHX thermal energy system options most viable to achieve the OSU-C goal of being a net-zero energy campus:

- Central Open-Loop
- Nodal Open-Loop
- Distributed Closed-Loop

6.2 Plant Analysis Methodology

The thermal demand profiles derived as per the previous sections were input to the mechanical plant analysis, which consists of calculation spreadsheets and EED software where closed-loop vertical borehole heat exchangers were assessed.

The hourly plant analysis spreadsheet processes the hourly thermal demands to model the HRCH, which provides simultaneous heating and cooling and preheats the domestic hot water, as well as a second stage HP to boost temperatures for domestic hot water heating. The electrical energy use, COP, heat of extraction, and heat of rejection at the HPs were modelled using the Carnot equation for HPs with the hourly variations in system design temperatures. For the earth source energy, ground loop fluid temperatures were as determined by the EED simulation or measured site-specific GW temperature, for the closed-loop and open-loop options respectively.

The Carnot equation uses conservative isentropic efficiencies derived from equipment selections for similar applications, with 60% efficiency applied to the central HRCH and 40% applied to the 2nd stage HPs. Heat recovery between simultaneous loads is calculated with heat rejection offsetting simultaneous heating loads, or heat extraction offsetting simultaneous cooling loads. The net heat extraction and rejection load profile is input to the EED simulation for the closed-loop GHX calculation. The ground loop simulation with several system performance variables is iterated until convergence is achieved.

If the area available for boreholes is limited and the GHX field cannot meet the entire thermal demand, the plant analysis adds supplementary heating with high efficiency boilers 85% seasonal efficiency or supplementary heat rejection with cooling towers as needed.

The resulting model provides the electrical and fuel energy demands at the chiller, HP, distribution pumps and supplementary boiler and cooling towers, as needed.

6.3 Option 1: Central Open-Loop GHX

System Description

Option 1 of the analyzed thermal energy systems has the most similarities to the campus thermal system outlined in the LRDP: a centralized open-loop system with a single HRCH plant that provides HW & CHW to all the buildings on campus. A key difference between Option 1 and the LRDP system, however, is Option 1 draws and rejects heat from a series of interconnected open-loop GW wells, thereby utilizing the aquifer beneath the campus as a heat source/sink instead of the ground.

In Option 1 the central HRCH plant would be located in a central utility building (CUB) to the west of the Rim Road roundabout. This HRCH plant would generate LTHW (HWS of 118°F) and CHW, then distribute it to each building on campus. The central plant and the building level mechanical systems hydraulically separated by plate and frame HXs. In addition to this, the central plant would include condensing natural gas boilers sized to provide back-up to meet peak campus heating demand, and to provide redundancy from both a fuel supply and equipment standpoint. A backup heat rejection plant, sized to meet the campus's peak heat rejection demand of 2,200 tons, would also be included. Back-up cooling towers have been included in system components list, capital costing and schematic, because they are the most cost-effective technology to implement on a campus scale. However, other heat rejection technologies, such as evaporative coolers and hybrid adiabatic coolers, would also be appropriate.

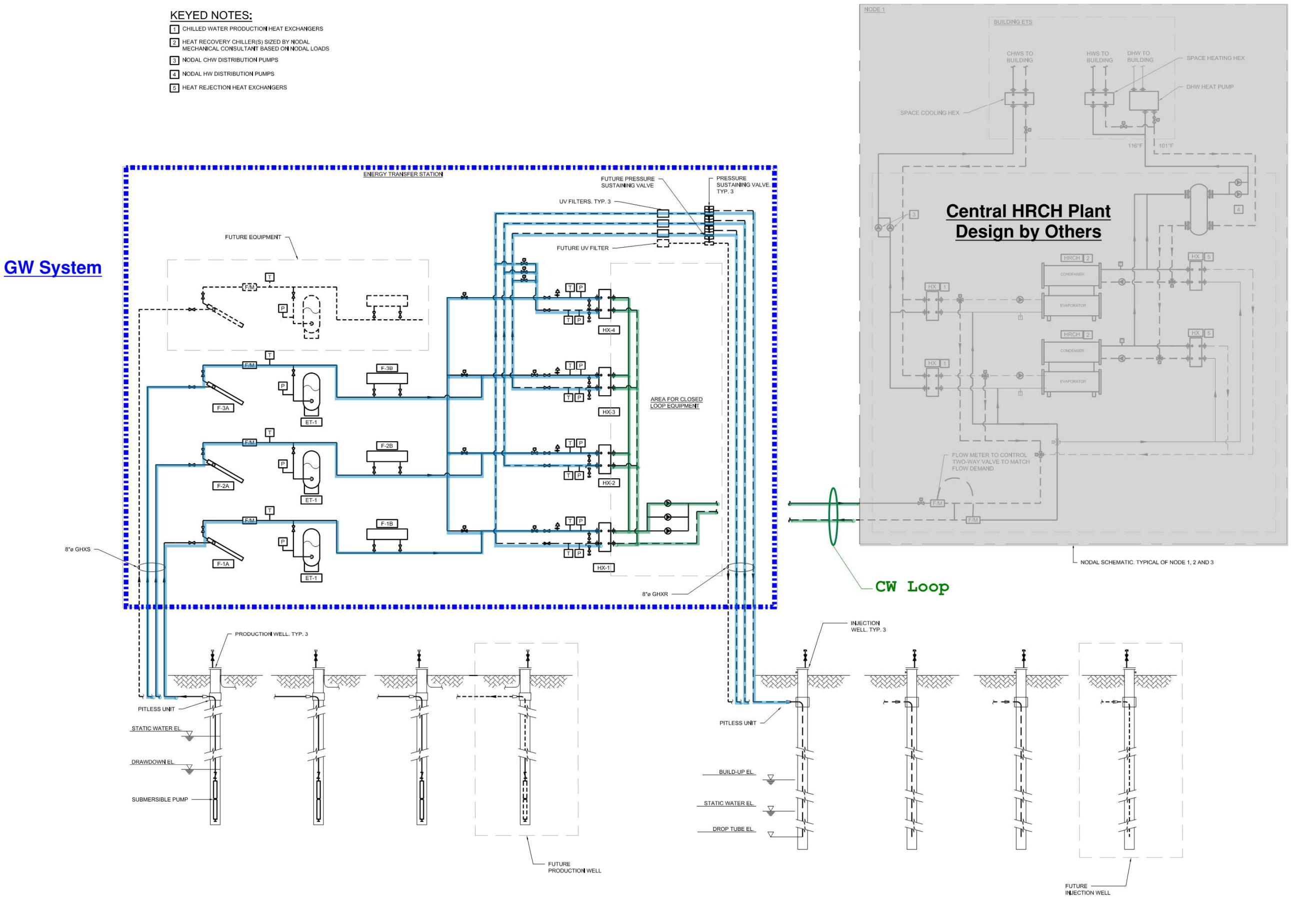


Figure 6.3.1 Central Open-Loop System Schematic

There are two general strategies for utilizing a centralized mechanical plant to meet the campus's DHW demand while still delivering LTHW to buildings for space heating; either the central plant can include dedicated 2nd stage HRCHs that generate 140°F DHW and distribute it throughout the campus, or the central plant can generate and distribute LTHW (120°F) throughout the campus and each individual building mechanical plant lifts the LTHW to 140°F as required. This final lift could be achieved with either dedicated DHW HPs or natural gas boilers.

Each strategy for generating DHW has it's benefits and its challenges. Utilizing a central plant to generate 140°F DHW, for example, simplifies the design, capital costs, space requirements and maintenance costs associated with the individua buildings. It is also a simpler strategy to implement on campus's with existing buildings that already require high-temperature HW for space heating and DHW. Alternatively, utilising building level equipment to generate DHW offers the campus greater flexibility to tailor the DHW systems to each individual building's needs. In the context of the OSU-C campus, the 2nd stage lift could be achieved by HPs, boilers or electric DHW tanks (for spaces with minimal DHW demand) depending on how close the building was to achieving it's EUI target.

Based on OSU-C's focus on developing a campus of new, high-performance buildings and Integral Group's recommendation that these buildings utilize low-temperature, low-exergy building level heating systems, Integral Group also recommends that each individual building mechanical plant include 2nd stage DHW HPs to lift the LTHW to the DHW setpoint. This strategy offers OSU-C flexibility in designing their individual building systems and ensures that conventional, standard lift water source chillers can be utilized in the central plant.

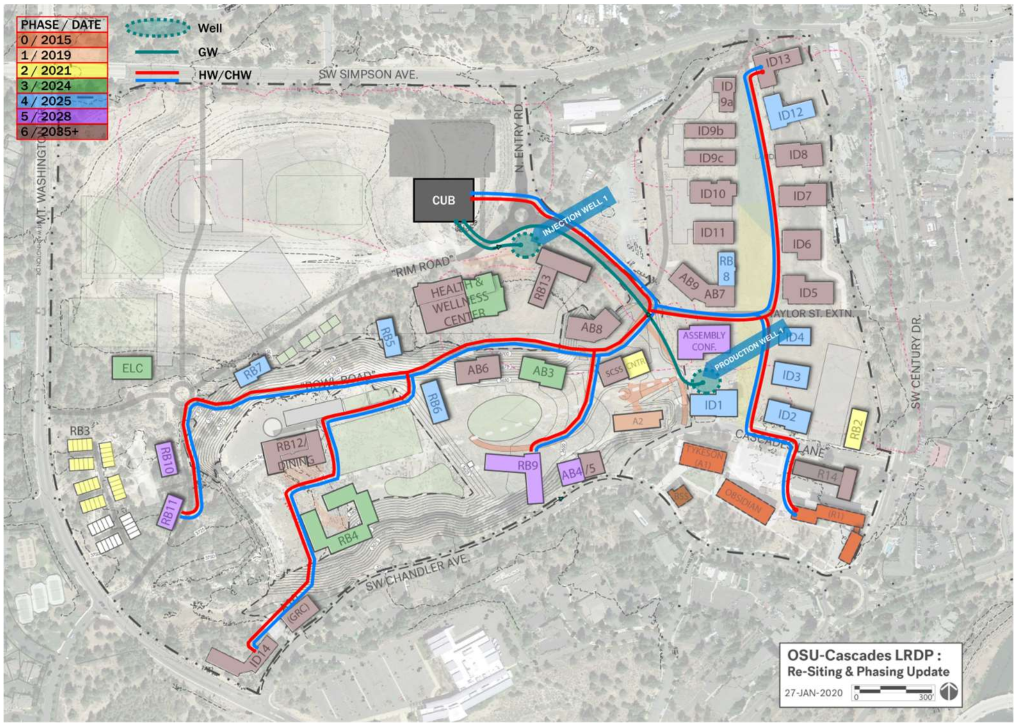


Figure 6.3.2 - Central Open-Loop Network

The open-loop groundwater system, at full buildout, would consist of 3 production/injection well pairs providing a 'source side' heat sink/source to the central plant HRCHs. The corrosive nature of the campus groundwater would require the groundwater system to be hydraulically separated from the HRCHs, to minimize the need for corrosion resistant components.

In order to determine an appropriate capacity for the GW system, that balances both the system's capital cost and meets the campus's heat source/sink requirements, Integral Group reviewed the following:

- The campus's annual heating and cooling demand profiles at full buildout,
- The campus's associated source side heat rejection and heat extraction demands (assuming heating and cooing COPs of 4.44 and 5 respectively) taking into account heat recovery between buildings, and
- The GW system flowrate that would be required to meet it (assuming dT's of 14°F for heat rejection and 7°F for heat extraction).

Figure 6.3.3 illustrates the annual GW flowrates profiles required to meet the campus's heat rejection and heat extraction demand. It shows that although the Campus's peak GW flowrate is 4,500 GPM in heat rejection mode and approximately 3,700 GPM in heat extraction mode, these peaks occur very infrequently. The campus would require a GW flowrate of 3,000 GPM or greater, in either heat rejection or heat extraction mode, for only 0.3% of the year. Based on this analysis, Integral Group recommends that the GW system be sized with a maximum GW flowrate of 3,000 GPM which would allow it to meet a diversified peak heating demand of 12,000 MBH (3.5 MW) and a diversified peak cooing demand of 1,900 Tons (6.6 MW).

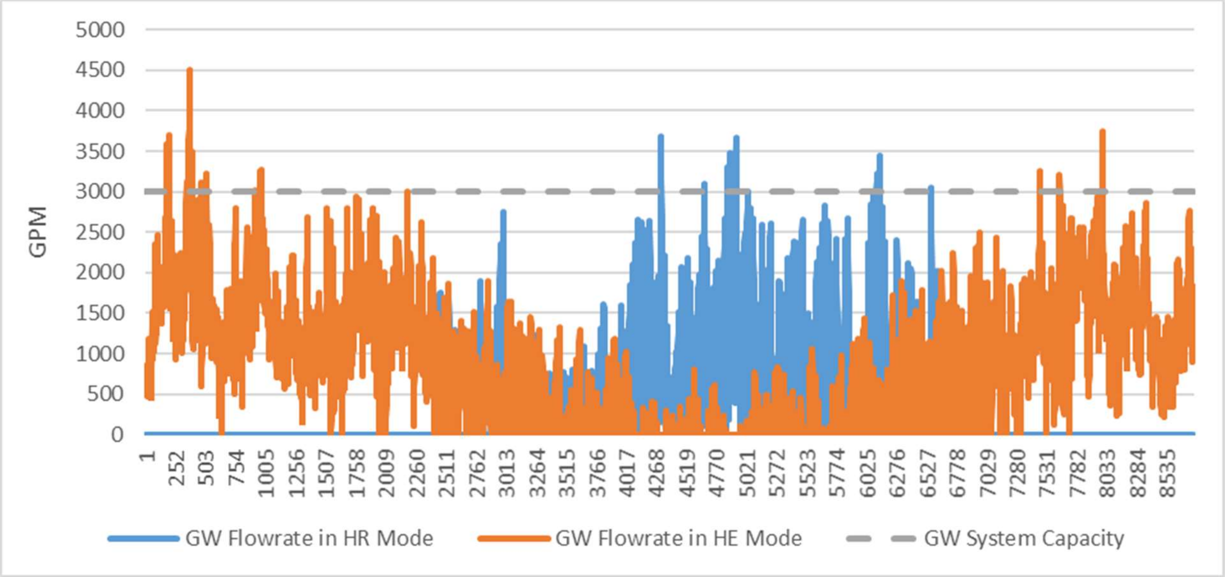


Figure 6.3.3 – Campus Annual GW Flowrate (Heat Extraction & Heat Rejection)

The first GW test well, installed in December 2019, that has recently been converted into production well, is expected to produce 850 GPM. The remaining GW capacity would be split between well pairs 2 & 3. While only three well pairs will be required in order to meet the campus's full build out heating and cooling demand, space in the plantroom has been allocated for a potential future 4th well pair as redundancy. Potential locations for the future GW well pairs are shown on Figure 6.3.4.

	GW Well Pair #1	GW Well Pairs #2, #3
Production Well Diameter (inch)	10”	12”
Injection Well Diameter (inch)	12”	14”
Targeted GW Flowrate (GPM)	850 GPM	1,075 GPM
GW Pipework Diameter (in)	8”	8”

Table 6.3.1 – Open-Loop GW Well Design

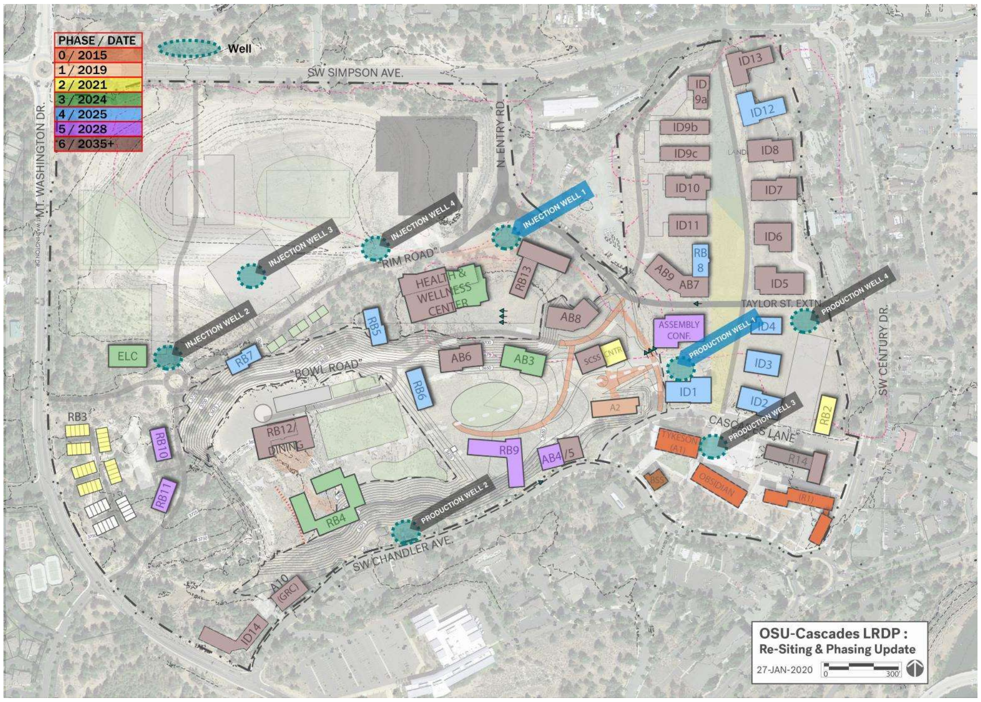


Figure 6.2.4 – Considered Future Open-Loop Well Pair Locations

System Components

Based on the campus peak heating and cooling demands outlined in Section 4, Integral Group developed preliminary equipment selections and quantities for thermal energy system Option 1 (outlined Table 6.3.2 below).

HRCH	3 @ 650 Tons Peak Cooling Capacity
Peaking & Backup Natural Gas Boilers	2 @ 5,800 MBH Peak Heating Capacity 2 @ 4,800 MBH Peak Heating Capacity
Backup Cooling Towers	3 @ 740 Tons Heat Rejection
Open-Loop GW Pumps	1 @ 850 GPM, 150 HP 2 @ 1,075 GPM, 200 HP
Condenser Water HXs	3 @ 3300 MBH Heat Extraction (6,200 MBH Heat Rejection)
Closed-Loop Condenser Water Pumps	2 @ 50HP, 1,000 GPM

Table 6.3.2 - Option 1 Central Open-Loop System Components and Capacities

Central Plant CHW Temperature	41ºF / 51º F
Central Plant HW Temperature	125ºF / 105ºF
Building Level CHW Temperature	46ºF / 56º F
Building Level HW Temperature	120ºF / 100ºF

Table 6.3.3 - Option 1 Central Open-Loop System Temperatures

Annual Thermal Energy Capacity and Fuel Consumptions

Table 6.3.4 and Table 6.3.5 outline the annual energy performance and fuel consumption of the Option 1 system.

Annual Campus Heating Demand (MBTU)	35,127
Heating Demand met by HRCH (MBTU) (% of campus annual heating demand)	35,127 (100%)
Heating Demand met by Natural Gas Boiler (MBTU) (% of campus annual heating demand)	0 (0%)
Annual Campus Cooling Demand (MBTU)	17,490
Cooling Demand met by WSHP & GHX Field (MBTU) (% of campus annual cooling demand)	17,490 (100%)
Cooling Demand met by WSHP & Cooling Towers (MBTU) (% of campus annual cooling demand)	0 (0%)

Table 6.3.4 – Option 1 Central Open-Loop Annual Energy Performance

Natural Gas (MBTU)	0
Electricity (MWh)(Peak Mechanical Plant Electrical Demand)	4,517 (2.1 MW)

Table 6.3.5 – Option 1 Central Open-Loop Fuel Consumption

6.4 Option 2: Nodal Open-Loop GHX

System Description

The second thermal energy system Option relies on the same open-loop GW system as a heat source/sink, however instead of a single central plant the campus is subdivided into three sub-areas, each served by its own nodal HRCH plant. Each nodal HRCH plant effectively operates as its own district energy system; each generating and distributing CHW and LTHW to each building within that node. Each building mechanical plant would include 2nd stage DHW HPs to lift the LTHW to its final DHW setpoint of 140°F. The nodal HRCH plants are interconnected on the source side via a closed-loop CW network, which is interconnected with the open-loop GW system via a Central Energy Transfer Station (CETS).

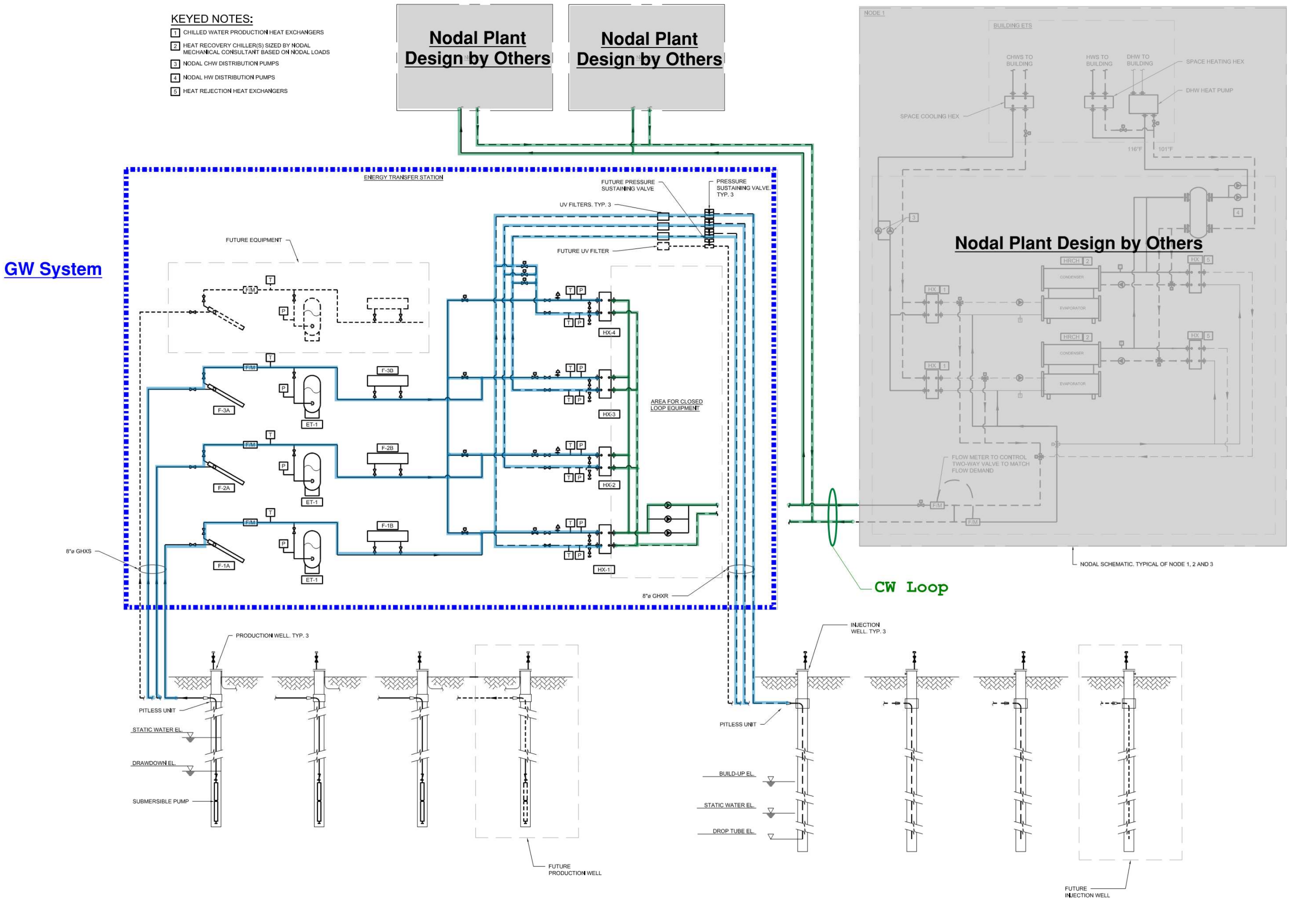


Figure 6.4.1 - Nodal Open-Loop System Schematic

Based on the current campus layout, the three nodal HRCH plants would be located within the following buildings:

- Nodal Plant #1 – in ID1,
- Nodal Plant #2 – in Student Success Centre
- Nodal Plant #3 – in RB4

Similar to Option 1, the LTHW and CHW distribution and source side temperatures of the HRCHs were selected to ensure that conventional, standard lift water source chillers can be utilized in the central plant. Each nodal plant would also include condensing natural gas boilers sized to meet its peak heating demand, to provide redundancy from both a fuel supply and equipment standpoint. A backup nodal heat rejection plant, utilizing conventional cooling towers, would also be included. As in Option 1, back-up cooling towers were included in the Option 2 design and capital cost estimate because they are a cost effective heat rejection technology. Other technologies, however, such as evaporative coolers or hybrid adiabatic coolers would also be appropriate.

The equipment associated with the CW network and open GW system (CW pumps, heat exchanges, GW pump VFDs and filtration) would be housed together in a Central Energy Transfer Station (CETS) located on the site of the future AB8.

The open-loop groundwater system would be sized to meet the same capacity as in Option 1, with 3 production/injection well pairs and a total GW flow rate of 3,000 meeting 99.7% of the campus's annual source side heat extraction and heat rejection demand, as well as diversified heating and cooling demands of 12,000 MBH (3.5 MW) and 1,900 Tons (6.6 MW) respectively.

System Components

Table 6.4.1 below outlines the peak heating & cooing demand of each node. Based on these thermal demands, Integral Group developed preliminary equipment selections and quantities for thermal energy system Option 2 which are outlined in Table 6.4.2.

	Units	**Node 1**	**Node 2**	**Node 3**
Peak Heating Demand	MBH	4,900	11,300	4,900
Peak Cooling Demand	Tons	455	1,181	284

Table 6.4.1 - Option 2 Nodal Peak Heating and Cooling Demand

HRCHs	Node 1: 2 @ 230 Tons Peak Cooling Capacity Node 2: 2 @ 600 Tons Peak Cooling Capacity Node 3: 2 @ 140 Tons Peak Cooling Capacity
Peaking and Backup Natural Gas Boilers	Node 1: 3 @ 1,700 MBH Peak Heating Capacity Node 2: 3 @ 3,800 MBH Peak Heating Capacity Node 3: 3 @ 1,700 MBH Peak Heating Capacity
Backup Cooling Towers	Node 1: 2 @ 280 Tons Peak Heat Rejection Capacity Node 2: 2 @ 740 Tons Peak Heat Rejection Capacity Node 3: 2 @ 170 Tons Peak Heat Rejection capacity
GW Pumps	1 @ 850 GPM, 150 HP 2 @ 1,075 GPM, 200 HP
Condenser Water HXs	3 @ 3.3 MBTU/**h** Heat Extraction (6.2 MBTU/**h** Heat Rejection)
Closed-Loop Condenser Water Pumps	2 @ 50HP, 1,000 GPM

Table 6.4.2 - Option 2 Nodal Open-Loop System Components and Capacities

Nodal Plant CHW Temperature	40ºF / 50º F
Nodal Plant HW Temperature	116ºF / 101ºF
Building Level CHW Temperature	46ºF / 56º F
Building Level HW Temperature	113ºF / 98ºF

Table 6.4.3 - Option 2 Nodal Open-Loop System Temperatures

Annual Thermal Energy Capacity and Fuel Consumptions

Table 6.4.4 and Table 6.4.5 outline the annual energy performance and fuel consumption of the Option 2 system.

Annual Campus Heating Demand (MBTU)	35,127
Heating Demand met by WSHP (MBTU) (% of campus annual heating demand)	35,127 (100%)
Heating Demand met by Natural Gas Boiler (MWh) (% of campus annual heating demand)	0 (0%)
Annual Campus Cooling Demand (MBTU)	17,490
Cooling Demand met by WSHP & GHX Field (MBTU) (% of campus annual cooling demand)	17,490 (100%)
Cooling Demand met by WSHP & Cooling Towers (MBTU) (% of campus annual cooling demand)	0 (0%)

Table 6.4.4 – Option 1 Nodal Open-Loop Annual Energy Performance

Natural Gas (MBTU)	**0**
Electricity (MWh) (Peak Mechanical Plant Electrical Demand)	4,528 (2.2 MW)

Table 6.4.5 – Option 1 Nodal Open-Loop Fuel Consumption

6.5 Option 3: Distributed Closed-Loop GHX

System Description

The third thermal energy system that Integral Group analyzed differs from the first two options in both its energy plant configuration and its GHX system type. Option 3 is a Distributed Closed-Loop GHX system, in which LTHW (HWS of 113°F) and CHW for each building is generated by building level WSHP systems, with 2nd stage DHW HPs used to lift the LTHW to the DHW setpoint of 140°F. Each WSHP system will utilize its own, individual closed-loop GHX field ideally located within its building footprint. As a distributed system, and in contrast to the previous options, in this particular configuration each building will operate independently; there would not be any interconnection between individual building mechanical systems. As a side note, it is also possible to interconnect the individual building level GHX system in a "daisy chain" configuration to gain some additional improvements in the overall system efficiency. However, this variation was not included or costed as part of Option 3.

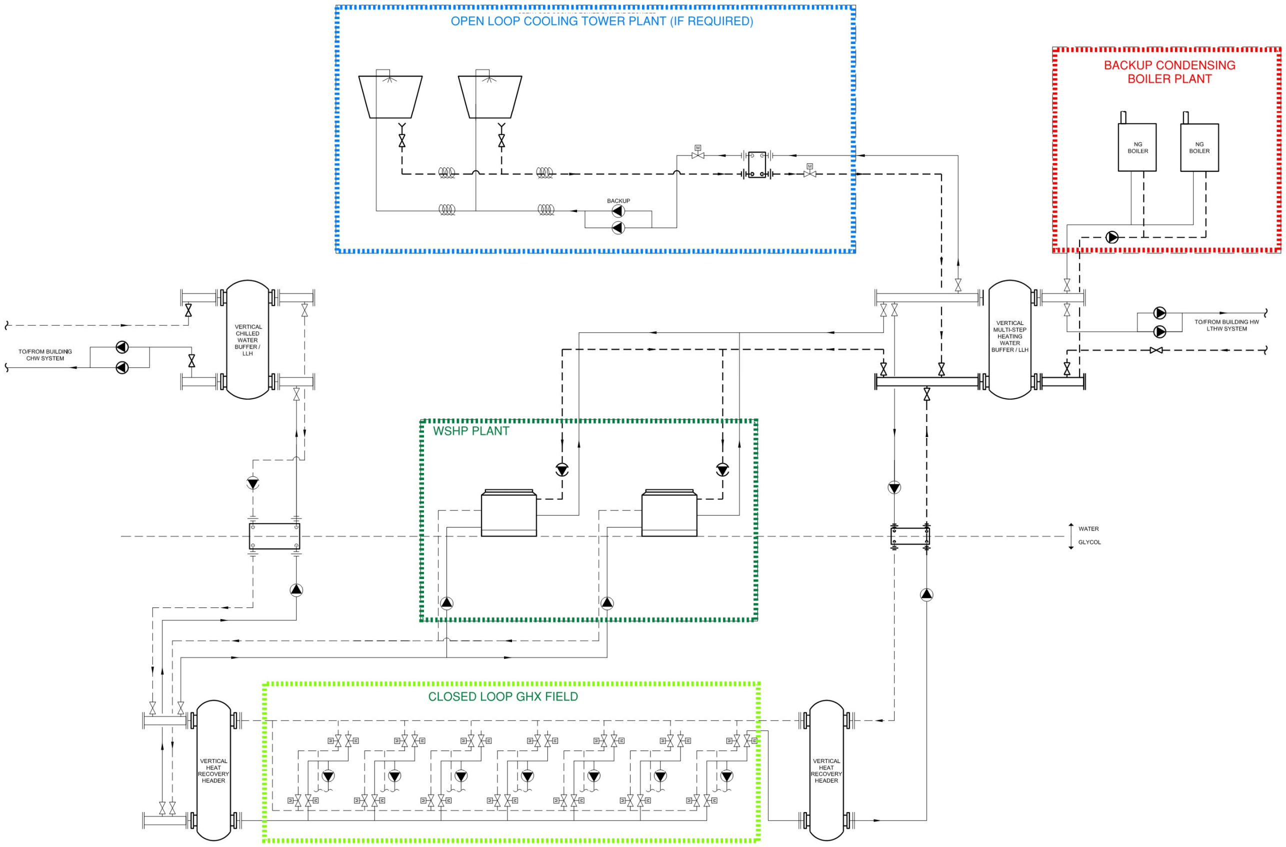


Figure 6.5.1 – Distributed Closed-Loop System Schematic (Typical)

Based on Integral Group's thermal energy demand models, extended range modular WSHPs can be utilized in the building level plants. To provide both equipment & fuel supply redundancy, back up condensing natural gas boilers were included in each building and open loop cooling towers were included as required. As in Option 1 and Option 2, open loop cooling towers were included in the Option 3 system design and capital cost estimates because they are a cost effective for of heat rejection technology. Hybrid adiabatic coolers and evaporative coolers, however, could also be utilized.

The equipment associated with each closed-loop GHX system would include a GHX field (located either within the building footprint or nearby) and main GHX pipework runs connecting the field to the building's WSHP plant, GHX field circulation pumps and headers.

No. Boreholes @ 590 ft	942
BH diameter	6 inches Grout k=0.87 Btu/h-ft-ºF
BH Spacing	16 feet
Pipe	Single U-tube at 1 ¼" Pipe k=0.24 Btu/h-ft-ºF

Table 6.5.1 – Distributed Closed-Loop Field Design Parameters

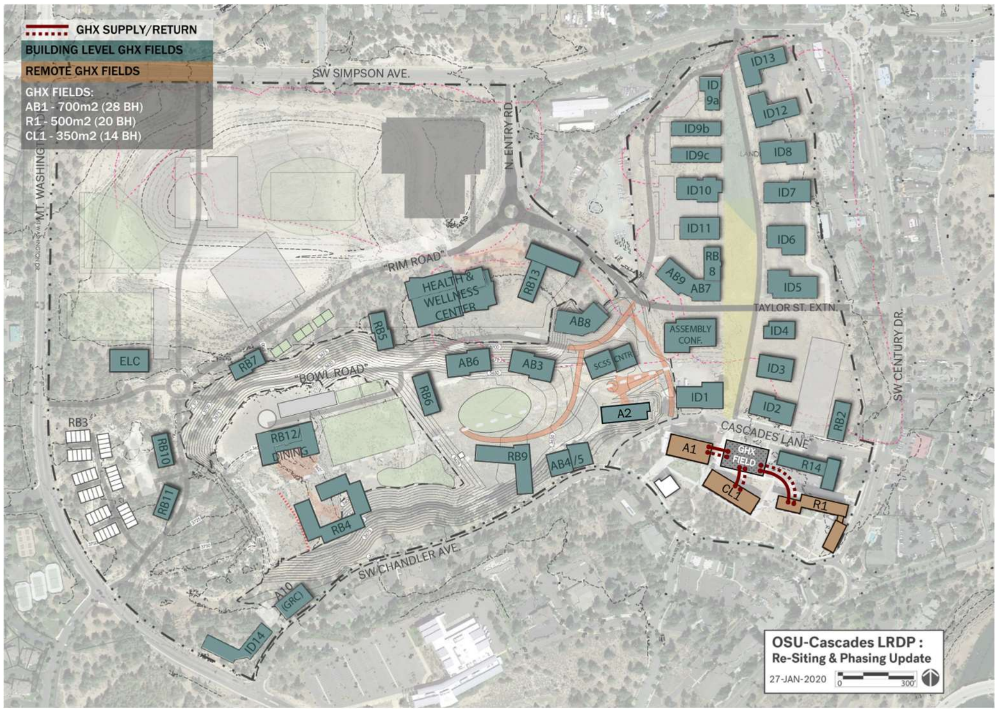


Figure 6.5.2 – Distributed Closed-Loop Map

System Components

In Option 3, each building mechanical plant would include 2 extended range WSHPs sized to meet 50% of the individua building's peak cooling capacity and able to meet the majority of the building's annual heating energy demand. The system would include 2 condensing natural gas boilers each sized for 50% of the building's peak heating demand to provide redundancy from both a heating system fuel supply and equipment standpoint. For buildings that require supplementary heat rejection equipment 2 cooling towers, each sized for 50% of peak building heat rejection, would be included.

Each building would also include dedicated GHX field circulation pumps, GHX field supply and return headers and second stage HPs to generate DHW.

WSHPs	92 @ between 10 Tons – 50 Tons
Natural Gas Boilers	92 @ between 26 MBH and 840 MBH
Backup Cooling Towers	76 @ between 28 Tons and 114 Tons

Table 6.5.2 - Option 3 Distributed Closed-Loop System Components and Capacities

Building Level CHW Temperature	46ºF / 56º F
Building Level HW Temperature	113ºF / 98ºF

Table 6.5.3 - Option 3 Distributed Closed-Loop System Temperatures

Annual Thermal Energy Capacity and Fuel Consumptions

In Options 1 & 2, the capacity of the Open-Loop systems was designed to meet a specific percentage of the campus's annual heating and cooling demand. In Option 3, the capacity of the Closed-Loop system is limited by the area available to install the vertical Closed-Loop boreholes; the available footprint of each individual building. The percentage of annual heating and cooling demand met by the GHX system of each individual building will therefore vary, between 21% and 100% of annual heating and 83% - 100% of annual cooling. Overall, this results in a higher use of natural gas boilers across the campus, as indicated by Table 6.5.5.

Annual Campus Heating Demand (MBTU)	35,127
Heating Demand met by WSHP (MBTU) (% of campus annual heating demand)	24,614 (70%)
Heating Demand met by Natural Gas Boiler (MBTU) (% of campus annual heating demand)	10,512 (30%)
Annual Campus Cooling Demand (MBTU)	17,490
Cooling Demand met by WSHP & GHX Field (MBTU) (% of campus annual cooling demand)	15,703 (90%)
Cooling Demand met by WSHP & Cooling Towers (MBTU) (% of campus annual cooling demand)	1,786 (10%)

Table 6.5.4 – Option 3 Distributed Closed-Loop Annual Energy Performance

Natural Gas (MBTU)	12,365
Electricity (MWh) (Peak Mechanical Plant Electrical Demand)	3,318 (2.2 MW)

Table 6.5.5 – Option 3 Distributed Closed-Loop Fuel Consumption

6.6 Annual Energy Use Analysis

The key study objective, by which each thermal energy system is primarily evaluated, is to achieve the net-zero energy performance target for the OSU-C campus. Based on the previous LRDP analysis, in order for the campus to generate enough renewable energy to meet this goal the campus must not exceed the campus wide EUI of 32.8 kBTU/ft2. All three of the campus thermal energy system options were developed and sized to perform up to the limits of this LRDP campus wide EUI target. The Central Open-Loop system (Option 1) had the lowest EUI at 26 kBTU/ft^2, though at 27 kBTU/ft^2 the Nodal Open-Loop system (Option 2) achieves a similar level of performance. The building level closed-loop system (Option 3), with its restricted site area for geo-exchange field and no opportunity for heat recovery between buildings requires larger natural gas boiler use which in turns results in the highest EUI at 30 BTU/ft^2.

In order to analyze the campus's overall annual energy use intensity (EUI), Integral Group estimated the electricity use from non-thermal systems such as lighting, plug loads and building level mechanical systems (such as ventilation fans) for each of the building types on OSU-C campus. These estimates were later verified in Section 7 during the detailed electrical analysis. The EUI analysis also included an estimate of the non-thermal natural gas consumption of the existing Obsidian Building.

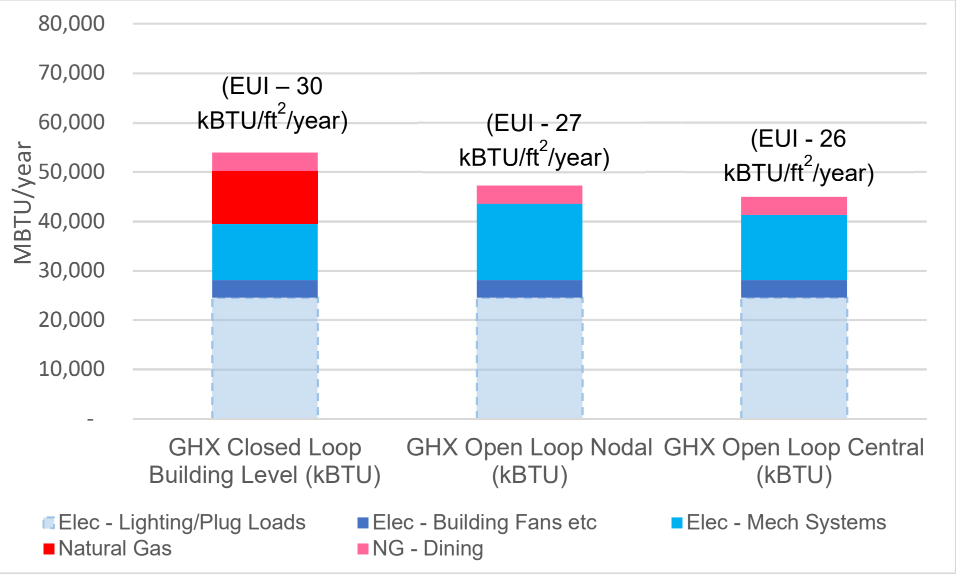


Figure 6.6.1 – Thermal Energy System EUI Analysis

6.7 Financial Analysis

The following section presents the financial analysis conducted to compare and assist in the selection of a recommended thermal energy system for the OSU-C campus.

Capital Cost & Ongoing Maintenance Costs

In cooperation with JMB Consulting Group, using the concept level equipment sizing, quantities and system configurations outlined in this section, Integral Group developed Class D cost estimates for all thermal energy system options. A breakdown of the results is summarized in Table 6.6.1 below.

'Plant' costs refer to all equipment located within either the central, nodal or distributed mechanical plantrooms and includes (as required) HRCHs, boilers, open loop cooling towers, distribution pumps, pipework within the plantrooms, HXs, buffer tanks, valves and hydronic specialties (expansion tanks, chemical treatment, strainers etc.).

'Building ETS' costs include all equipment needed to connect an individual building to a central LTHW and CHW network including HXs, DHW HPs and a portion of the individual building LTHW and CHW pipework.

'Project Burden' refers to all costs not directly related to the purchasing or installation of the mechanical system, such as contingencies, design fees, contractor's mark-up, etc.

System	**Central Open-Loop ($M)**	**Nodal Open-Loop ($M)**	**Distributed Closed-Loop ($M)**
Plant	$6.3	$8.3	$23.1
Building ETS	$2.4	$2.2	-
CW Network	-	$0.5	-
HW/CHW Network	$9.2	$6.4	-
GW/GHX System	$4.0	$4.0	$16.7
Project Burden	$6.4	$6.4	$11.9
Total	**$28.3**	**$27.8**	**$51.7**

Table 6.6.1 - Capital Costs Breakdown

The distribution of capital costs within each thermal energy system costing varies widely between the different options. The Central and Nodal Open-Loop options have significant capital costs associated with the campus distribution network (piping) and comparatively lower costs associated with the GHX components. On the other end of the spectrum, the Distributed Closed-Loop has no campus wide distribution network costs, but significant costs associated with building level plants and GHX system components, and increased construction scope.

Ongoing Maintenance Costs

Table 6.6.2 below summarizes the expected operations and maintenance costs associated with each of the campus thermal energy system options. Higher O&M costs are associated with "active" mechanical equipment such as HPs, boilers, chillers; the increasing quantity of active mechanical equipment required for the Nodal Open-Loop and Distributed Closed-Loop options lead to progressively increasing O&M costs.

Annual ongoing operations and maintenance costs were calculated as a % multiplier of the estimated the capital cost (refer to Appendix F for a list of maintenance cost multipliers) based on similar project experience. The salaries of the operation and maintenance staff (i.e. power engineers) were not included in the annual O&M cost estimates of each LCES Option.

Equipment	Central Open-Loop ($M)	Nodal Open-Loop ($M)	Distributed Closed-Loop ($M)
HPs	$14,400	$16,300	$49,200
Boilers	$4,800	$11,100	$13,600
Chillers	$10,200	$46,100	$86,200
Pumps	$300	$5,800	$31,300
HXs	$5,600	$10,300	$6,300
Cooling Towers	$4,000	$4,700	$3,900
Total	$41,200	$94,200	$161,400

Table 6.6.2 - Annual Operations & Maintenance Costs Breakdown

Ongoing Input Energy Cost

The annual input energy costs of each thermal energy system refer to the cost of the primary energy inputs needed to operate the systems; this is the cost of electricity and natural gas consumed by the mechanical plant in each option.

The present day, average cost of electricity and natural gas (including both demand and consumption charges) used in the analysis was $0.09/kWh and $0.03/kWh respectively. A utility cost escalation rate of 2% was used for both electricity and natural gas cost forecasting. The results outlined in Table 6.6.3 summarise the total input energy cost of each thermal energy system over the 30 year lifespan of the project. The costs listed in Table 6.6.3 below are in 'today's dollars'; the impact of inflation was included in the Lifecycle Cost Analysis (Section 6.7.5) but not in the values below.

System	Central Open-Loop ($M)	Nodal Open-Loop ($M)	Distributed Closed-Loop ($M)
Electricity	$9.0	$8.6	$9.5
Natural Gas	$0	$0	$3.5
Total	$9.0	$8.6	$13.0

Table 6.6.3 – 30 Year Lifecycle Input Energy Cost Breakdown

Replacement Costs

Integral Group also estimated the cost, over the 30-year lifecycle of the project, of replacing key equipment within each thermal energy system option. The results are summarised in Table 6.6.4. The replacement cost estimate took into account the phased construction timeline of the three thermal energy system options (as per the February 2020 campus phasing plan) and assumes that equipment installed toward the end of the study's 30-year timeframe will not need to be replaced for another 20 years.

The Central Open-Loop option has the highest replacement costs because a larger portion of the mechanical plant is installed earlier in the campus phasing plan, and therefore needs to be replaced during the 30-year timeframe. The Distributed Closed-Loop option has the lowest replacement costs, because its construction of its mechanical plants is the most distributed.

The costs listed in Table 6.6.4 below are in 'today's dollars'; the impact of inflation was included in the Lifecycle Cost Analysis (Section 6.7.5) but not in the values below.

System	Central Open-Loop ($M)	Nodal Open-Loop ($M)	Distributed Closed-Loop ($M)
Total 30 Year Replacement Cost	$2.2	$2.0	$1.5

Table 6.6.4 – 30 Year Lifecycle Replacement Costs

Lifecycle Cost Analysis

To compare the total cost of owning and operating each thermal energy system the Total Cost of Ownership (TCOO) and Levelized Cost of Delivered Thermal Energy (LCOE) over a 30-year time frame was calculated.

The TCOO is the net present value (NPV) of the phased system capital costs and ongoing costs (input energy cost, O&M cost & replacement cost) summed together. To calculate the LCOE, the TCOO was divided by the NPV of the total thermal energy delivered by the system over its 30-year life span. Phasing for the capital costs and ongoing costs is as per the current OSU-C phasing plan (February 2020). A discount rate of 3% was used for both the TCOO and LCOE analysis and the results are listed in Table 6.6.5 below.

Because each system delivers the same quantity of energy, the LCOE results are largely driven by the different TCOO's of each thermal energy system. The Central and Nodal Open-Loop options have similar TCOO's and LCOE's, while the Distributed Closed-Loop option has a higher TCOO, and therefore a higher LCOE.

	Central Open-Loop	Nodal Open-Loop	Distributed Closed-Loop
TCOO ($M)	$27.7	$27.4	$46.4
LCOE ($/kWh)	$0.139	$0.138	$0.233

Table 6.6.5 – TCOO and LCOE Analysis Results

6.8 Recommendation

In addition to achieving the LRDP EUI target, and therefore enabling the OSU-C campus to achieve its goal of net-zero energy performance, Integral Group evaluated the thermal energy systems against three key criteria: capital and lifecycle cost efficiency, ability to be phased inline with the campus development phasing plan and compatibility with third-party investment. Table 6.6.6 compares the results of this analysis.

	EUI Target	**Capital Cost**	**LCOE**	**Phasing**	**3rd Party Investment**
Central Open-Loop System	🟡	🟢	🟢	🟡	🟢
Nodal Open-Loop System	🟡	🟢	🟢	🟡	🟡
Distributed Closed-Loop System	🟡	🔴	🔴	🟢	🔴

Table 6.6.6 – Thermal Energy System Evaluation Matrix

Table 6.6.6 highlights the difficulties in balancing different analysis criteria when selecting a thermal energy system. The system that offers the most flexibility and is the easiest to design around the campus phasing plan, the Distributed Closed-Loop System, is also the most expensive and is not a viable option for 3rd party investment. In contrast, the Central Open-Loop System offers the greatest potential for third-party investment and is notably more efficient from a capital cost and LCOE perspective. However, the Central Open-Loop System is also the most difficult to install inline with the campus phasing plan and will ultimately involve an element of overcapitalization and risk (installing larger capacity equipment network piping and using it at a lower capacity while the campus development catches up).

Based on the objective of this study and the key analysis criteria identified in Section 1, and through ongoing consultation with OSU-C Integral Group recommends the campus proceeds with an implementation of the Nodal Open-Loop System. This system offers a balance between the lower capital cost of the Central Open-Loop system but maintains some of the flexibility of the Distributed Closed-Loop System and can be installed in smaller distinct phases.

7. ELECTRICAL SYSTEMS OPTIONS

7.1 Introduction

As outlined in Section 2, as a part of this study Integral Group evaluated a number of renewable electricity generation technologies, developed onsite generation options and reviewed their performance against this study's analysis criteria and objective of being a net-zero energy campus.

7.2 Forecasted Campus Electrical Demand

In order to develop onsite renewable electricity generations options for OSU-C, Integral Group first developed annual electrical demand profiles for the campus based forecasted lighting and process end uses and taking into consideration the forecasted electrical demand of the recommended Nodal Open-Loop thermal energy system. These electrical demand profiles were used to determine the required capacities of the PV system.

Lighting and unregulated process end use (receptacles, elevators, etc.) electrical demand profiles were developed for the campus based on the building space types, areas, and phasing established in the LRDP and updated with recent coordination with the campus infrastructure team.

Electrical Energy Demand Modeling Methodology

Installed lighting power densities (W/sf) were assumed for each building type, based on targeted reductions from code maximum values. Installed process load power densities (W/sf) were assumed for each building type, based on typical building usage from standard energy modeling guidelines.

Hourly demand schedules were converted to annual demands for each building. Schedules for the various buildings account for weekday, weekend, and holiday variations.

Phase by phase and site total electrical demand profiles were aggregated by combining load profiles of the respective buildings.

Peak Electrical Loads

The peak lighting and process end use loads for the OSU-C campus, including the innovation district, are summarized in Table 7.2.1 below.

End Use	Peak Load (MW)	Annual Load (MWh)
Lighting	1.2	1,788
Process	2.5	5,556

Table 7.2.1 OSU-C Peak and Annual Lighting, Process and Mechanical System Loads

Campus Phasing and Implications

In additional understanding the peak and annual electrical demand of the campus at full build out, in order to efficiently size plant equipment and understand how capital costs will need to be deployed over time Integral Group also reviewed the peak and annual electrical demand of the campus at each phase of development. The results are summarized in Table 7.2.1 and Figure 7.2.1 below.

Electrical Demands by Phase	Peak Lighting Demand (kW)	Annual Lighting Energy (kWh)	Peak Process Demand (kW)	Annual Process Energy (kWh)	Peak Mechanical System Demand (kW)	Annual Mechanical System Energy (kWh)	Peak Campus Demand (kW)	Annual Campus System Energy (kWh)
Existing	55	129,753	118	331,398	208	429,221	323	890,542
Phase 1A	39	79,815	31	64,778	167	344,144	338	734,036
Phase 1B	42	147,361	147	458,208	120	246, 929	159	479,186
Phase 2	79	190,240	235	685,199	265	620,509	973	2,762,629
Phase 3	136	298,457	512	1,350,215	251	548,613	557	1,486,890
Phase 4A	66	215,261	178	542,225	181	397,217	921	2,574,609
Phase 4B	294	727,412	769	2,123,665	906	1,941,495	1,030	2,794,248

Table 7.2.1 OSU-C Peak and Annual Electrical Demand by End-Use and Campus Development Phase

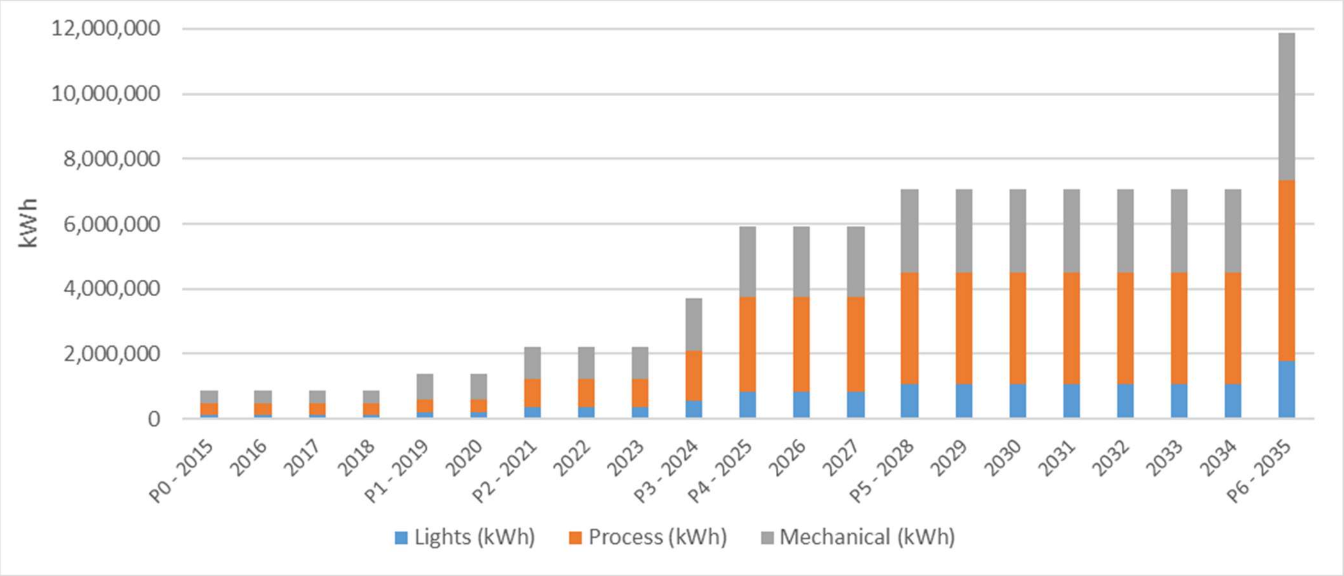


Figure 7.2.1 OSU-C Annual Electrical Demand by End-Use and Campus Development Phase

Figure 7.2.1. illustrates the campus's cumulative annual energy demand from Phase 0 to Phase 6. It shows that a significant portion of the campus's annual electrical demand will be installed in the final phases 5 in 2028 and 6 in 2035. The campus's electrical infrastructure would therefore ideally be designed to be installed in phases, to allow the capital cost to be spread out accordingly. This would reduce the risk of over capitalizing and installing oversized equipment early in the campus's development.

7.3 Solar Photovoltaic (PV)

Bottom-Line: Solar PV can make OSU-C a net zero energy campus

By the campus expansion completion, Integral recommends that OSU-C deploy roughly 13 MW of solar PV capacity, generating as much as 16M kWh of renewable electricity per year. This would be one of the largest behind-the-meter solar PV installations in the Pacific Northwest (likely the largest), and, critically, it would complement the highly energy efficient campus thermal energy system — and provide energy generation for the OSU-C campus to achieve net zero energy performance. This solar PV generation capacity will generate more energy than used by the campus.

Figure 7.3.1 Initial design for solar PV on rooftops of existing buildings

Technology Background

Solar PV panels work by absorbing sunlight into PV cells, which then generate direct current (DC) energy that is converted into useful alternating current (AC) energy by inverter technology. This electricity can be used directly by concurrent loads, or it can be fed into the electric grid. Solar PV installations use modular panels, allowing systems to be sized for specific locations, power generation capacity and applications.

Solar PV systems naturally generate electricity intermittently at varying generation capacity, depending on the solar radiation availability as a function of time of day, season, and weather variation. While specific generation profiles are determined by location and weather patterns, solar PV panels generally produce power as one might expect greatest generation in summer months and during midday hours. Another challenge with solar PV, stemming from the fact that it converts low-exergy source to a high-exergy form of energy, is relatively poor conversion of solar radiation into useful electricity, with average solar PV cell efficiency ranging from 12% to 25%. As such, solar PV requires significant area (relative to, say, a typical power plant) in order to generate substantial amounts of electricity.

Despite these challenges, renewable electricity generation from solar PV is an essential part of achieving OSU-C campus net-zero energy goal. Solar PV is among the most reliable, mature means of renewable electricity generation without carbon emissions. Ideal locations for on-campus solar PV installations include building rooftops, canopies over parking lots ("carports"), and open space for ground-mounted solar PV panel arrays.

System Financing & Third-Party Investment

Electricity systems can be purchased in two ways: (i) traditional capital purchase; (ii) Power Purchase Agreement (PPA). A PPA is a legal contract between an electricity generator ("solar developer") and a power purchaser. The relatively turn-key solution requires no upfront capital. The power purchaser (i.e. OSU-Cascades) only pays a set price for the electricity generated from the on-site solar PV installation(s) The solar PV developer finances, installs, owns, and maintains the system(s). It is analogous to a new utility selling you power via new power plants on your rooftop, parking lot, or open space.

PPAs also offer OSU-C de facto access to federal incentives not available with direct purchase and ownership. Because OSU-C does not have a tax appetite, it cannot receive federal tax credits or utilize available accelerated depreciation. These benefits can offset 25%+ of a solar PV installation's cost.

Integral advises that the optimal solar PV procurement vehicle for OSU-C's Cascade campus would be a PPA.

Financial Benefits

Solar deployments often reduce utility costs, as solar electric energy production eliminates the need to buy the equivalent power from the grid. This often results in two basic benefits: (i) avoided energy charges; (ii) avoided demand charges.

- Avoided energy charges from the utility or retail electricity provider. (Each kWh of solar power produced onsite means one less kWh of power needed from a utility power plant.)
  - Taking into account the likely phasing of the installations, over the first 30 years, the recommended solar systems would save OSU-C $8.1 million (nominally). This results in a project NPV of $5 million.
- Avoided demand charges (sometimes referred to as delivery charges). Because an electric grid needs sufficient capacity to meet the grid's demand at all times, utilities typically charge customers for the highest amount of power drawn during a given period. Many entities typically use peak power in afternoon hours — the hours when solar panels generate the most electricity. When paired with battery storage, an entity can further target the reduction of its peak demand (more below).

For the financial analysis, Integral assumed that the PPA contract terms would be 20 years, which is industry standard. While the system lifetimes are estimated to be 30-35 years, the only contracted rates would be for the first 20 years; the extension of the PPA would be done at Fair Market Value (FMV). To be conservative, Integral assumed that the extended PPA rated would be roughly equivalent to the alternative of rates for power purchased from the grid.

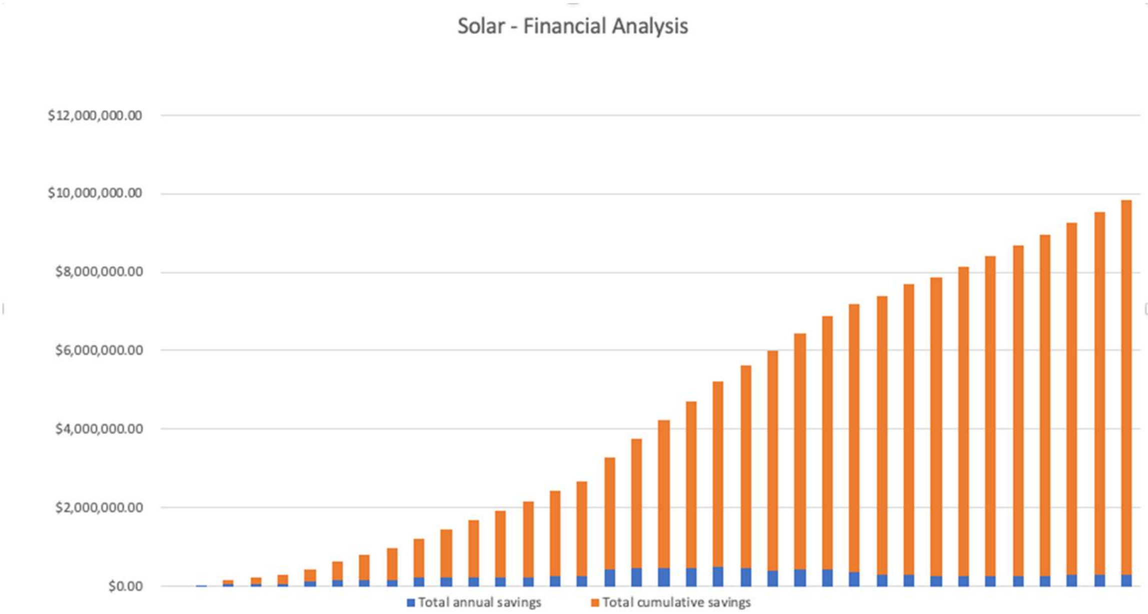


Figure 7.3.2 Financial analysis of Solar PPA vs Traditional Grid Power

Locations

After extensive review, Integral has conceptually designed and phased a solar deployment that would utilize building rooftops, canopies over parking lots ("carports"), and open space for ground-mounted solar. In its end state, the distribution of solar:

- Rooftops. Using 435,000 square feet of roof space, OUSE could deploy 6,773 kW (6.8 MW) of solar capacity on campus rooftops — generating 8,167,249 kWh annually.
- Carports. Across 230,000 square feet of parking lots, OSU-C could deploy 1,755 kW (1.8MW) of solar capacity, generating 2,308,789 kWh annually.
- Ground-mount. Using 300,000 square feet of open space, OSU-C could deploy 4,500 kW (4.5 MW) of solar capacity, generating 5,919,108 kWh
- Total estimated capital cost: $29M.

7.4 Battery Storage

Overview

Battery Energy Storage Systems (BESS) store electric energy that can be used to provide power on demand. Most often using lithium-ion chemistry, a BESS can provide both physical and financial benefits:

- Resilience. This benefit is plain: batteries can provide power for buildings during a grid outage.
- Energy savings. Through so-called "rate arbitrage" and demand charge reductions, a BESS can reduce utility costs.

If OSU-C decides to pursue storage, Integral recommends that pair with the prospective solar deployments. This pairing creates a microgrid.

The BESS and a microgrid, in this instance, provide the same functional benefits. See Section 7.5 below for information on their impacts.

7.5 Microgrids

Overview

An interconnected system of on-site power generation, battery storage, and electric loads — distinguished by its ability to connect and disconnect (“island”) from the grid — is often called a microgrid. Microgrids can include all forms of power generation, but often rely on on-site solar power as the prime generation source. If the physical and financial benefits ultimately outweigh the costs, Integral would recommend a solar-centred microgrid for OSU.

Physical Impact

Given its prospective energy systems and building consumption, Integral counsels that a logistically feasible microgrid could provide useful power during grid outages.

The impact of this backup power ultimately depends on two factors: (i) size; (ii) load served.

- Size. A microgrid’s ability to provide backup power naturally depends on the size of the solar system and associated BESS. For OSU, the potentially massive solar installation presents the opportunity for relatively significant battery storage.
- Load served. A critical and often-overlooked variable in a microgrid’s ability to provide backup power is the specific load served by the microgrid. Integral counsels that OSU-C could expect a reasonably-sized BESS to power for 12+ hours. If the critical loads were defined and targeted narrowly, the microgrid could provide islanded power for 24+ hours.

Another key feature of a microgrid is its ability to keep solar systems operating during grid outage. This is not the case with traditional solar installations — as utilities require solar system shutdowns to ensure the safety of workers who come in contact with power lines. If the solar system is capable of islanding from the grid, however, it can continue to operate unabated.

Financial Impact

Microgrids offer several compelling financial benefits:

- Energy Savings via “Rate Arbitrage”. Though OSU-C currently pays a flat rate for electricity, utilities are increasingly moving to time-of-use (TOU) energy rates. With TOU, the price of power is determined by when its used. In this framework, a BESS can be utilized for so-called “rate arbitrage.” The BESS is charged when electricity rates are low — when tied with solar, the solar power first goes to the BESS, before serving building load — and discharged when rates are high. This thus displaces the high rates with the low-priced electricity that has been stored.
- Demand Charge Savings. As noted in the Solar section above (7.3), OSU-C’s peak draw from the electric grid determines its demand charges. Similar to the its ability to shift load for rate arbitrage, the BESS and microgrid can shift load to mitigate peak demand charges.
- Business Continuity. A power outage disruption to the OSU-C campus and innovation center operations would have clear financial implications. The economic benefits of islanding — that is, the opportunity costs of continued vs ceased operations — are not always easy to quantify. Only an advanced operational analysis can accurately specify the impact. Nevertheless, it is vital recognize the unmistakable financial benefits of maintaining power and continuing some or all operations during a grid blackout.

Microgrid Controller: Balancing Interests

While often imagined that they can do so, microgrids cannot generate all the possible benefits all of the time. This is where the microgrid controller and intelligent software becomes central.

A basic example of possible tension between benefits: the microgrid's BESS is discharged to reduce demand charges that are expected at 2pm. If the grid goes down at 3pm, the microgrid's ability to serve load will be limited. Even if some of the BESS is reserved for resilience, every kWh discharged to reduce peak demand could be a kWh not available for backup power.

With the microgrid controller, OSU-C can forecast — and prioritize the importance of — these various events. For instance, if grid outages are deemed less likely during winter months, the BESS could be deployed more aggressively for energy savings. During summer months, the top priority might change to standby backup power.

The quality of the microgrid controllers has improved considerably as the industry has matured. Now capable of processing detailed hour-by-hour (and even minute-by-minute) data about weather, power prices, and electric infrastructure stress, intelligent software can leverage AI to optimize the prioritization and dispatch of microgrid resources.

7.6 Summary of Recommendation

Integral Group recommends OSU-C pursue PPAs for solar deployments across the campus: rooftops, parking lots (carports), and ground mount on open space. In total, by the completion of the campus expansion, Integral estimates that the campus could deploy 13 MW of solar. These installations would generate roughly 16,000 MWh/year, once fully deployed.

End Result:

- Nearly $10M in total in estimated savings (solar vs traditional grid power)
- Net zero energy for the OSU-C campus

8. ADDITIONAL CONSIDERATIONS

Bringing together all the objectives and analysis criteria to develop the recommended thermal and electrical energy system option, the following additional points should be considered:

8.1 Nodal Open-Loop GHX System – Potential Impact on Individual Building Areas

Over the course of this study, and through discussions with OSU, Integral Group came to understand that a Central, Nodal and Distributed version of the considered system options would impact OSU-C's planned development financing in different ways. Funding for new buildings and new infrastructure projects on the campus often comes from different sources. One benefit of a Central system version is that it shifts the costs of the mechanical plant out of each individual building and into a single infrastructure project. These cost savings could then be used to either fund additional building area, or simply reduce the building's overall construction cost. In contrast a Distributed system version does not offer any capital cost efficiency and 100% of it's mechanical plant costs would need to come out of individual building construction budgets.

The recommended Nodal version of the Open-Loop GHX system offers the benefits of the Central version of the system for the majority of buildings on campus but does place additional capital cost requirements on the three buildings containing 'nodal plants'. To better understand this Integral Group undertook additional high-level cost analysis to estimate the additional capital costs, cost savings and potential additional GSF available to OSU-C. The results are summarized in Table 8.1.1 and Table 8.1.2 below.

Refer to Appendix G for a detailed list of the analysis assumptions.

	Building Area GSF (ft^2)	**Mech Plant Costs of a 'Connected' Building (\$/ft^2)**	**Mech Plant Costs of Distributed GHX System (\$/ft^2)**	**Cost Savings (\$)**	**Potential Additional GSF (ft^2)**
Academic Buildings	401,150	\$2/ft^2	\$23/ft^2	\$8,425,000	17,500
Campus Life Buildings	317,500	\$2/ft^2	\$18/ft^2	\$5,080,000	11,600
Innovation District Buildings	650,200	\$2/ft^2	\$11/ft^2	\$5,789,000	25,600
Residential Buildings	666,000	\$2/ft^2	\$11/ft^2	\$5,994,000	21,400

Table 8.1.1 – High Level Mechanical Plant Capital Cost Analysis

	Building Area GSF (ft^2)	Mech Plantroom Costs of a 'Individual' Building ($/$ft^2$)	Mech Plant Costs of Nodal Plant ($/$ft^2$)	Cost Savings ($)	Potential Additional GSF (ft^2)
Academic Buildings	56,000	$41/$ft^2$	$11/$ft^2$	-$1,680,000	-6,100
Campus Life Buildings	27,500	$41/$ft^2$	$23/$ft^2$	-$495,000	-1,700
Innovation District Buildings	58,500	$41/$ft^2$	$11/$ft^2$	-$1,755,000	-6,700

Table 8.1.2 – High Level Nodal Plant Capital Cost Analysis

The high-level analysis found that OSU-C would save approximately $25.3 million from the sum of overall construction budgets of individual buildings by installing the proposed 'nodal' plants and distribution networks. Based on the current construction cost estimates for each building, this cost saving could potentially fund additional 63,000 ft^2 of building area amongst the connected buildings. OSU-C would, however, need to invest an additional $3.9 million in the proposed nodal buildings (ID1, the Student Success Center and R4) to establish the nodal plants.

It's important to note that this analysis is intended to give OSU-C a high-level understanding of the impact a Nodal Open-Loop GHX system will have on it's funding plans; it should not be used for detailed budgeting or construction cost estimates. There are a number of factors and additional considerations which could impact the analysis results:

- Updated construction costs
  A key assumption in calculating the potential additional GSF available to the campus under a Nodal Open-Loop system is the $/ft cost of construction the proposed campus buildings. The estimates for the majority of buildings on the campus are in the early stages of development and are likely to change as the building design progresses.

- Updated campus planning and building footprint
  The high-level analysis assumes the campus build-out GSF and building space use breakdown outlined in the March 2020 campus development map. This map covers campus development over the next 20 years and is likely to be subject to change and the OSU-C's needs evolve.

- Cost of installing additional GSF
  The high-level analysis accounts for the different estimated construction costs of the proposed OSU-C campus buildings. These costs range from $200/ft2 to $690/ft2 depending on the building space use type. However, each additional square foot of conditioned building space will in turn increase the thermal and electrical demand of the associated buildings. If OSU-C installed an additional 60,000ft2 in GSF across the campus, the required capacity and cost of installing of the 'nodal plants' would also increase.

8.2 COVID-19 – Impact on Campus Thermal Energy Systems

The world around us changed dramatically during the course of this project, which began in 2019. At the time of this report, the COVID-19 public health emergency is ongoing and has introduced significant risks into short- and, potentially, long-term planning for the college. While a full accounting of the impact of COVID-19 is currently impossible, several risks deserve discussion:

Occupancy Patterns

OSU-C transitioned to delivering almost all of it educational activities remotely in the Spring 2020 term. Since then the campus has begun planning the gradual and phased resumption of its onsite educational activities (with the first phase expected to start in mid-June), though a full return to onsite operations is expected to take between 12 to 18 months. Even as this process continues, the need for ongoing social distancing will change levels of occupancy in buildings, hours of operation, levels of research and other energy-intensive activities and could also result in seasonal occupancy shifts. These factors will all change the energy demands of the campus in the short-term. Some remote work/study options explored in this emergency may be found to be beneficial and may continue longer term. The models used in this study do not account for these changes.

Enrollment

Many colleges and universities are seeing reduced yield rates for new student acceptances and are anticipating a temporary dip in enrollment. How long this will continue is unknown. While most indicators for the short-term point to fewer students, a long-term increase in enrollment is also possible, depending on the degree of remote study and the fortunes of peer institutions. The models for this study all assume continued enrollment at recent historical levels, demand data, and do not account for these changes.

Financial Uncertainty

The economic impacts from the ongoing public health emergency have negatively affected investments, endowments, and other resources. In light of uncertainties about university enrollments, resources, and future operations, college projects may face higher interest rates for borrowing. The option to outsource most energy systems to a third-party, under a long-term contract, may be more challenging in the near-term, with investors wary about the aforementioned risks. The financial analysis for this study uses prevailing recent borrowing costs, prior to the pandemic, and does not adjust for these financial uncertainties.

8.3 Third-Party Investment – RFI Feedback & COVID-19 Impact

Integral Group explored a wide range of options for third-party investment for the new campus energy systems envisioned by this project.

With respect to solar PV, as explained above in Section 7.3.3, there is a mature market for third-party investments with solar PPAs that could serve OSU-C well. This could be seen as a separate transaction or, potentially, combined with broader thermal energy system financing.

With respect to the broader thermal energy systems and GHX, Integral put together an informal RFI process to gather information about the interest and capabilities of potential project owners; these third parties would finance, install, own, and operate the systems (similar to the manner in which solar PPAs work).

Two major challenges became apparent:

- The size of the system was on the low end of the minimum size investment sought by this community.

- Perhaps most importantly, the COVID-19 pandemic caused material concerns by investors about future enrollment. Without future enrollment, energy use would go down – and the system would not serve the load anticipated. If the transaction was structured wherein OSU-C would pay on a $-per-BTU basis, a limited demand for BTUs could cause fundamental risks to the project.

9. CONCLUSION & RECOMMENDED NEXT STEPS

OSU-C has set itself an ambitious and inspiring objective of becoming a net-zero energy campus. As part of this feasibility study Integral Group developed and analyzed three technical solutions available to the campus that will allow it to achieve this objective while still meeting other key performance criteria; most importantly a cost effective system that can be implemented in phased manner and that has the potential for third-party utility ownership.

Based on the overall results of Integral Group's technical and financial analysis, the nodal-plant configuration with three nodal plants coupled with an open-loop geo-exchange system has been recommended as the campus energy system option best meeting the OSU-C's objectives. This option is now being developed into a detailed design and progressing into implementation phase.

Adding to this recommendation is implementing 13 MW solar PV system across the campus, to be installed on selected building rooftops, canopies over outdoor parking lots and ground-mounts, to meet the OSU-C's goal of achieving a net-zero energy campus. The solar PV system can be complemented with battery storage and a campus microgrid if resilience and independence from the local power grid is a priority, or if the utility has limited capacity to accept excess electricity generated by the solar PV system. At full buildout, OSU-C's solar PV infrastructure would be one of the most notable, and likely the one of the largest, behind-the-meter solar PV installations in the Pacific Northwest.

In addition, Integral Group recommends the following next steps for the OSU-C campus:

- Develop detailed design and construction documents for the recommended campus thermal energy system with three nodal plants coupled with an open-loop geo-exchange system and proceed with the initial phase of its implementation,
- Review the current OSU-C campus infrastructure design package to identify synergies between the proposed thermal energy system and the campus infrastructure construction scope, and
- Proceed with detailed design of a solar PV system on the roof of the selected existing campus buildings and AB2 and seek opportunities for third-party investment for the system,
- Update campus LRDP and develop technical guidelines for future building design to ensure compatibility with the recommended campus nodal open-loop geo-exchange system.

APPENDIX A – REFERENCES – REVIEWED ENERGY ANALYSIS REPORTS

The following list of energy codes and energy analysis reports were reviewed and used as a basis for developing OSU-C building space type energy demand intensities:

- City of Vancouver Step Code,
- Toronto Green Standard Tier 3,
- BC Energy Step Code Development for Public Sector Buildings by Morrison Hershfield (2019),
- University of British Columbia Energy Density Performance Targets by Cobalt Engineering (2011), and
- Low-Exergy Climate Adapted Buildings and Technologies Study by Cobalt Engineering (2013).

The following list of energy codes, green building standards and net-zero ready building analysis were also reviewed and used to validate the building space type energy demand intensities developed in this study:

- Massachusetts Energy Stretch Code,
- New York Stretch Energy Code,
- Zero Energy Buildings in Massachusetts: Saving Money from the Start (Led by Integral Group for USGBC),
- New Building Institute Municipal Building Analysis Final Report Summary (by Integral Group),
- British Columbia Step Code, Levels 3 - 4, and
- Passive House Institute Building Certification Requirements.

APPENDIX B – CLOSED-LOOP AND OPEN-LOOP GHX ANALYIS ASSUMPTIONS

1. Closed-Loop Modelling Assumptions

Vertical closed-loop boreholes were modelled for all scenarios with the following input assumptions:

Ground Properties:

Without specific thermal response testing onsite with a test borehole, the ground properties and borehole geometry were estimated.

Ground properties were estimated for the site using information from the Oregon Department of Geology and Mineral Industries online Geologic Map of Oregon. For the site location this source indicates volcanic formations with basalt the primary material. Ground thermal properties were selected from the recommended values for basalt in the EED database.

- Ground thermal conductivity = 0.98 Btu/h-ft-°F
- Ground volumetric heat capacity = 35.8 Btu/ft^3-°F

The undisturbed ground temperature was estimated by calculating the annual average outdoor air dry bulb temperature of the weather file used in this analysis. (USA_OR_Redmond.Muni.AP-Roberts.Field.726920_TMY3)

- Undisturbed ground temperature = 47.8 °F

Boreholes:

Borehole field assumptions were based on typical parameters from previous projects. With the borehole array varying in quantity the aspect ratio of a rectangle was maintained at all fields for consistency.

- Arrangement = Rectangular grids with 16 foot spacing and 590 foot depth
- Geometry = Boreholes are 6” diameter with single 1 ¼” U-tubes with
- Thermal properties = Pipe conductivity 0.24 Btu/h-ft-°F and grout conductivity = 0.87 Btu/h-ft-°F

Building footprint areas were used to estimate the number of boreholes that could feasibly be installed below each building assuming 30% of the footprint area would not be accessible due to foundation coordination limitations.

2. Open-Loop Modelling Assumptions

The open-loop heat exchange was calculated with the hourly heat extraction and heat rejection load profiles and assumptions based on site-specific open well test results. Each well was assumed to be able support a flow rate of 1,000 GPM and a temperature difference of 7°F in heat extraction and 14°F in heat rejection. With the constant flow assumption for open wells this capacity was assumed available all year long.

The required flow rate was determined from the heat extraction and rejection profile and hourly load. The hourly flow rates were reviewed to determine the number of wells that would be required to serve each plant that was assessed.

APPENDIX C – ADDITIONAL ANALYSIS – IMPACT OF INNOVATION DISTRICT

The Innovation District was included in the campus thermal demand profile for the purposes of planning. The load profiles for the campus are compared both with and without the Innovation District floor areas in this Appendix.

The following Table C.1 A1 presents the floor areas assumed for the analysis with the areas allocated to Innovation District noted.

Campus Building Space Type	**Total GSF** (ft²)
Academic	374,843
Assembly	55,000
Campus Life	75,413
Daycare	53,800
Dining	18,000
Indoor Recreation	75,850
Office	344,988
Innovation	344,988
Residential	752,988
Campus	569,186
Innovation	183,802
Total	**1,750,882**

Table C.1 A1 GSF per building type with Innovation District areas

The Innovation District buildings account for 100% of the assumed office building floor area and 24% of the assumed residential building floor area.

The resulting thermal demand profiles are compared in the following Figures C-1 through C-4 below.

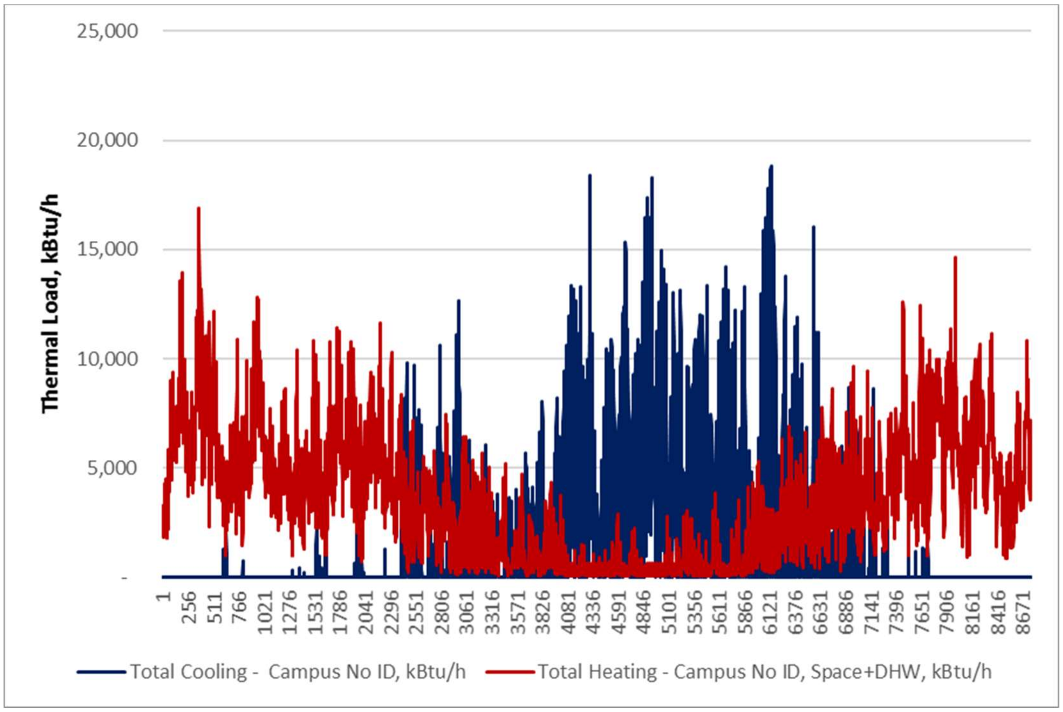


Figure C-1 - A1 Hourly heating (Space+DHW) and cooling load profiles for the Campus without Innovation District

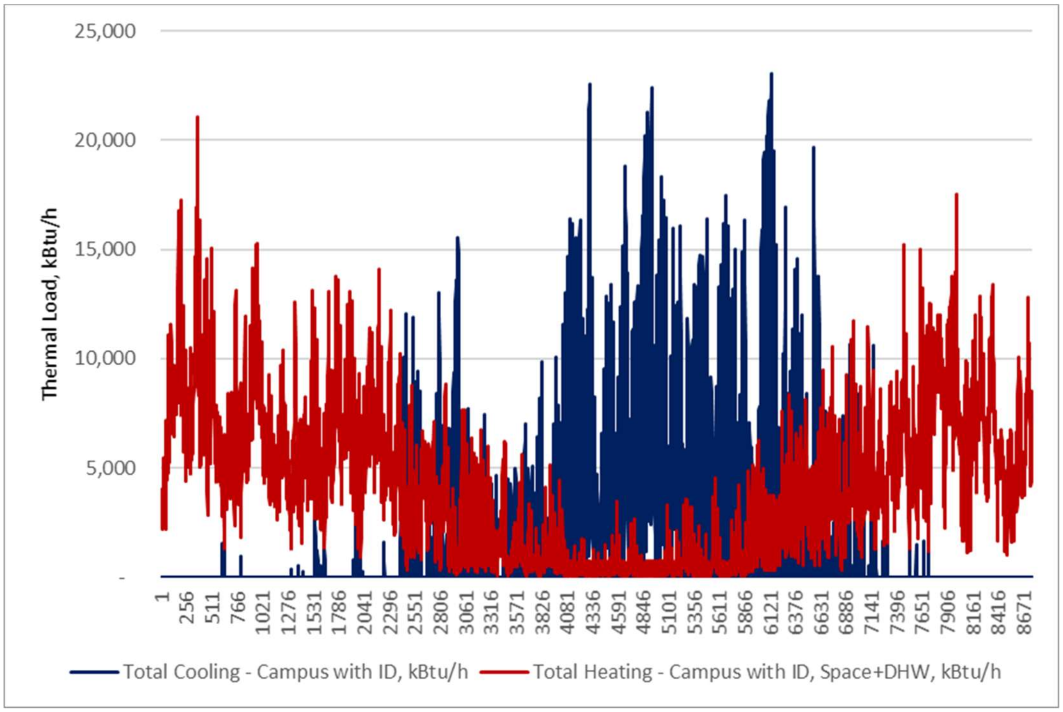


Figure C-2 - A1 Hourly heating (Space+DHW) and cooling load profiles for the Campus including the Innovation District

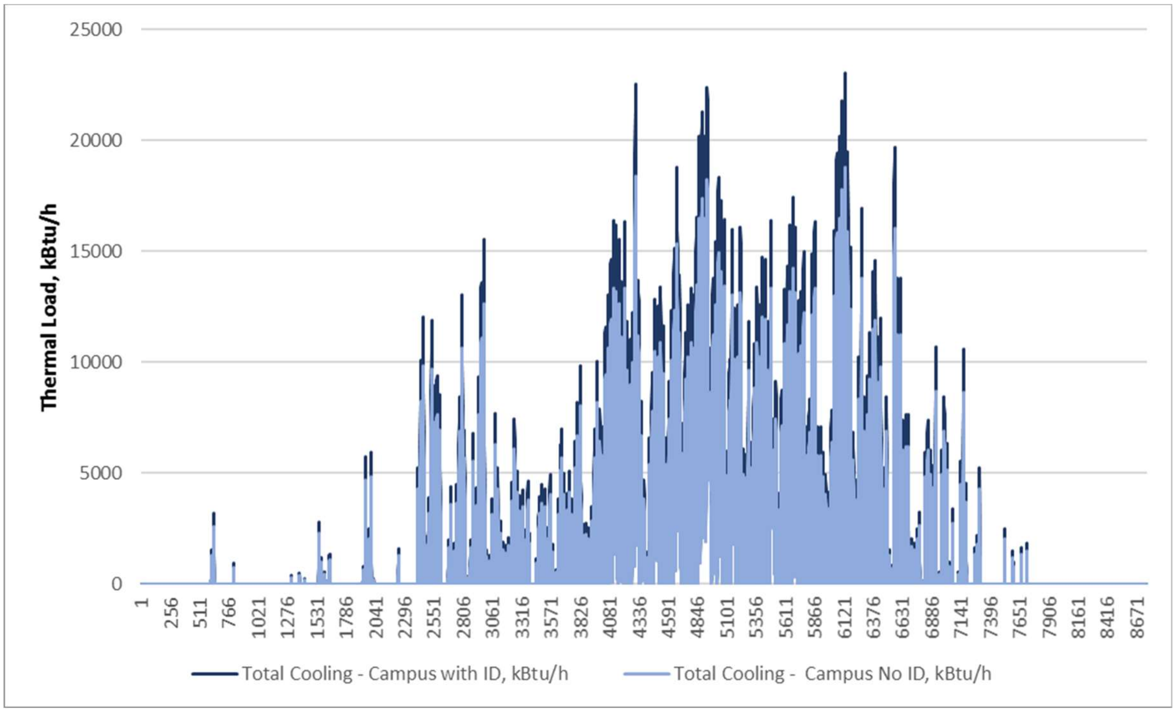


Figure C-3 - A1 Hourly cooling load profile with and without Innovation District

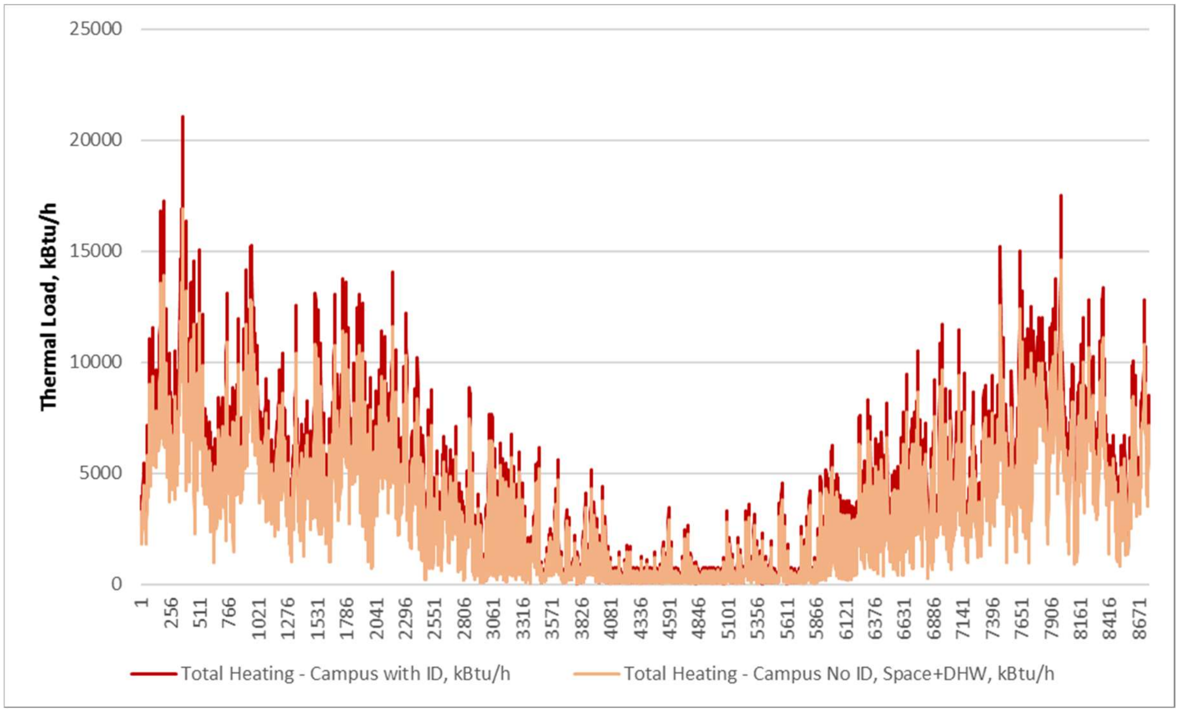


Figure C-4 - A1 Hourly heating (Space+DHW) load profile with and without Innovation District

The annual totals and peak demands for the campus profiles are compared in the following Table C.2 A2 for the Innovation District, the remaining Campus without Innovation District, and the Campus total used in the plant analysis.

	Innovation District	% of Campus Total	Campus Without Innovation District	% of Campus Total	Campus Total
Annual Space Heating Energy, MBTU	4,000	16%	20,890	84%	24,890
Peak Space Heating Load, MBH	3,457	20%	14,055	80%	17,512
Annual DHW Heating Energy, MBTU	1,907	19%	8,330	81%	10,237
Peak DHW Heating Load, MBH	631	17%	3,115	83%	3,746
Annual Cooling Energy, MBTU	3,228	18%	14,261	82%	17,489
Peak Cooling Load, Tons	354	18%	1,566	82%	1,920
Total Thermal Energy, MBTU	9,135	17%	43,482	83%	52,617

Table C.2 A2 Annual heating, DHW heating, and cooling energy demands and peak loads with Innovation District

The total thermal energy use of the Innovation district is 17% of the total campus thermal energy use that modelled for the plant analysis used in this study.

The Innovation District forms the vast majority of Node 1 buildings, is not included in Node 2, and has just one residential building in Node 3.

The Innovation District buildings are included in only Phases 3 and 4B.

APPENDIX D – ADDITIONAL ANALYSIS – AB2 THERMAL DEMAND INTENSITY FEEDBACK

Thermal demand intensities for the laboratory floor areas were established in this analysis based on review of building energy modelling results which were provided by the AB2 energy modelling team (Affiliated Engineers).

Initial estimates for the thermal demand intensities were derived for the laboratory space uses as a function of the target EUIs in the LRDP, as was done for the other space uses and described in Section 3 of this report, assuming reductions in the EUI would result from reductions in the thermal demands for space heating and space cooling.

The energy model results were reviewed in terms of the heating TEDI, DHW heating TEDI, and cooling CEDI and showed respectively high demand intensities when compared with other benchmark data for high performance buildings. The energy model inputs were reviewed and considering the proposed envelope, passive and active mechanical systems, and electrical systems, the proposed design as represented in the model should achieve high energy performance.

The high demand intensities of the energy model results were attributed to the mandatory ventilation requirements for the laboratory spaces, based on the ventilation flow rates and schedules cited in the energy modelling report. The ventilation requirements cannot be avoided and present limited opportunity for heat recovery, or other measures for thermal demand reduction. To accommodate this process load in the projected energy demand for the campus, the thermal demand intensities for laboratory spaces were increased from the initial estimates. To achieve the proposed reductions in total energy use requires technical solutions to reduce utility demands while meeting respectively high thermal loads.

Original Laboratory Thermal Demand Intensity Estimates

	Teaching Labs	**Research Labs**
Typical EUI, kBTU/ft^2-year	120	265
Proposed EUI, kBTU/ft^2-year	36	80
TEDI , kBTU/ft^2-year	8	9
DHW TEDI, kBTU/ft^2-year	1	1
CEDI, kBTU/ft^2-year	7	8

AB2 Laboratory Thermal Demand Intensity Feedback

The thermal demand results for the Schematic Design stage model were divided by the model floor area and the resulting energy demand intensities were as follows:

TEDI 45 kBTU/ft^2-year, DHW TEDI 5 kBTU/ft^2-year, and CEDI 23 kBTU/ft^2-year

The whole building energy demand intensities results represent a mixture of space uses, including offices, conference rooms, support, and circulation. Specific energy demand intensities for the laboratory floor area were not available from the model results.

Updated Laboratory Thermal Demand Intensity Estimates

Resulting from this review of the AB2 model, the thermal demands applied the laboratory floor areas were increased and portioned to values closer to the typical energy demand intensities, as follows:

	Teaching Labs	Research Labs
Typical EUI, kBTU/ft^2-year	120	265
Proposed EUI, kBTU/ft^2-year	36	80
TEDI , kBTU/ft^2-year	83	183
DHW TEDI, kBTU/ft^2-year	62	138
CEDI, kBTU/ft^2-year	30	30

Updated Campus Thermal Energy Model Results

This adjustment affected only the academic buildings, of which only a portion of the floor area is laboratory, however the overall impact resulted in a significant increase in heating and cooling thermal demands. The resulting impact on the proposed campus thermal demand profile is shown below.

Campus Building Space Type	Initial Input Assumptions	Nov 28, 2019/Nov 12 2019 Adjusted inputs with AB2 feedback	Final Inputs with AB2 Feedback, Massing, and floor area adjustments
Total Heating Energy Demand, MBTU/year	24,355	36,726	35,127
Peak Total Heating Load, MBH	16,296	21,643	21,061
Total Cooling Energy Demand, MBTU/year	12,172	20,053	17,490
Peak Cooling Load, Tons	1,336	2,202	1,920

APPENDIX E – PRODUCTION WELL FLOW RATE AND CHEMICAL ANALYSIS TEST RESULTS

Water Systems Engineering, Inc.

Date: January 15, 2020

Lab Report No. 21717

Shane Cochran
Wallace Group, Inc.
62915 NE 18th Street, Suite 1
Bend, OR 97701

Project Description: OSU Test Well 0920 and 1320; samples dated 12/19/19
Complete Well Profile (1)

Test Description:

The Complete Well Profile analysis is designed for comparative analysis of two samples, typically one static and one pumping sample. The Complete Well Profile utilizes a series of inorganic chemical and microbiological tests to identify fouling and corrosion issues with potential impacts on the operation of the sampled well. The tests include a number of inorganic chemical parameters such as pH, total dissolved solids/conductivity, hardness, alkalinity, oxidation reduction potential (ORP), bicarbonate, carbonates, silica, sodium, potassium, chloride, iron, manganese, phosphate, nitrate, sulfate, and total organic carbon (TOC). Biological assessment is designed to quantify the total bacterial population, identify two dominant populations of bacteria, assess anaerobic conditions, and identify the presence of iron related bacteria and sulfate reducing organisms. Also included are tests for Adenosine triphosphate (ATP), heterotrophic plate count (HPC), total coliform and E. coli coliform, and a microscopic evaluation.

Testing Procedures:

All laboratory testing procedures are performed according to the guidelines set forth in *Standard Methods for the Examination of Water and Wastewater* as established by the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF). Corrosion analyses are performed in accordance with the guidelines as set forth by the National Association of Corrosion Engineers (NACE). In general, these methods are approved by both the Environmental Protection Agency (EPA) and AWWA for the reporting of water and/or wastewater data.

Sample collection and shipment is the responsibility of the customer, performed according to protocol and procedures defined by the laboratory in advance of the sampling event with regards to the specific project and nature of the problem.

Disclaimer:

The data and interpretations presented are based on an evaluation of the samples and submitted data. Conclusions reached in this report are based upon the data available at the time of submittal and the accuracy of the report depends upon the validity of information submitted. Any recommendations presented are based on laboratory and field evaluations of similar fouling occurrences within potable water systems. Further investigative efforts, such as efficiency testing, site inspection, video survey, or other evaluation methods may offer additional insight into the system's condition and the degree of fouling present.

Client: Wallace Group, Inc.
Date: January 15, 2020
Lab Report No. 21717

Re: OSU Test Well 0920 and 1320; samples dated 12/19/19
Complete Well Profile (1)

ND - Not Detected NA - Not Applicable * as $CaCO_3$	**OSU Test Well 0920**	**OSU Test Well 1320**	**Detection Limits**
pH Value	7.76	7.66	NA
Phenolphthalein Alkalinity*	ND	ND	4 mg/l
Total Alkalinity*	40	44	4 mg/l
Hydroxide Alkalinity	ND	ND	4 mg/l
Carbonate Alkalinity	ND	ND	4 mg/l
Bicarbonate Alkalinity	40	44	4 mg/l
Total Dissolved Solids	82	76	1.0 mg/l
Conductivity (µm or µS/cm)	114	105	NA
ORP (mV)	343.6	339.1	NA
Langelier Saturation Index (at 16°C)	- 1.49	- 1.54	NA
Total Hardness*	40	32	4 mg/l
Carbonate Hardness	40	32	4 mg/l
Non Carbonate Hardness	ND	ND	4 mg/l
Calcium*	16	16	4 mg/l
Magnesium*	24	16	4 mg/l
Sodium (as Na)	7.66	7.04	0.02 mg/l
Potassium (as K)	1.40	1.40	0.1 mg/l
Phosphate (as PO_4)	0.34	0.35	0.06 mg/l
Chlorides (as Cl)	8.4	8.8	2 mg/l
Nitrate (Nitrogen)	ND	ND	0.3 mg/l
Chlorine (as Cl)	ND	ND	0.02 mg/l
Dissolved Iron (as Fe^{2+})	ND	ND	0.02 mg/l
Suspended Iron (as Fe^{3+})	0.05	0.05	0.02 mg/l
Iron Total (as Fe)	0.05	0.05	0.02 mg/l
Iron (resuspended)	0.08	0.06	0.02 mg/l
Copper (as Cu)	ND	ND	0.04 mg/l
Manganese (as Mn)	ND	ND	0.1 mg/l
Sulfate (as SO_4)	ND	ND	2 mg/l
Silica (as SiO_2)	36.8	35.4	1.0 mg/l
Tannin/Lignin	ND	ND	0.1 mg/l
Total Organic Carbon (C)	0.0	0.0	0.0 mg/l

Biological Analysis:

	OSU Test Well 0920	OSU Test Well 1320	Detection Limit
Plate Count (colonies/ml)	150	139	NA
Anaerobic Growth (%)	<10	15	NA
Sulfate Reducing Bacteria	Negative	Negative	NA
Fe/Mn Oxidizing Bacteria	Negative	Negative	NA
ATP (cells per ml) Initial	30,000	20,000	NA
ATP (cells per ml) 24 Hour	45,000	89,000	NA
Bacterial Identification	*Acinetobacter johnsonii*	*Pseudomonas stutzeri*	NA
Bacterial Identification	*Pseudomonas fluorescens*	*Pseudomonas fluorescens*	NA

Microscopic Evaluation:

0920:	Very low visible bacterial activity, low crystalline debris with moderate iron oxide.
1320:	Very low visible bacterial activity, very low crystalline debris with low iron oxide.

Observations:

When received in the lab, the samples from the OSU test well were clear of visual turbidity with minor accumulations of black particulate present. The samples each exhibited a neutral pH and relatively low levels of total dissolved solids and conductivity.

High oxidation-reduction potentials (ORP) were recorded for both samples. Elevated ORPs generally reflect oxidative conditions which can serve to oxidize available metals such as iron and manganese.

The Langelier Saturation Index (LSI) is a calculation used to identify the saturation of a water chemistry with respect to calcium carbonate. The LSI is useful in indicating the potential for chemical corrosion as well as the likelihood of calcium carbonate-based scale. Positive LSI values typically indicate a chemical environment which is saturated with respect to calcium carbonate with an elevated potential for the development of calcium scale. Negative LSI values reflect an undersaturated geochemical environment which typically favors corrosion within the system. Calculation of the LSI yielded strongly negative values for the two samples indicative of an elevated potential for corrosion to occur. The negative LSI values within the samples are a result of the neutral pH and low calcium presence.

Calcium levels within both samples were low. Magnesium, elevated by comparison in the casing sample, remained equal to the calcium level in the second sample. Elevated levels of magnesium in relation to calcium and a high ORP can indicate a potential for the development of magnesium hydroxide in areas were aeration occurs within the well.

Dissolved iron was not present in either sample. Suspended iron and total iron values were in general, low, yet reflect mobilization of iron within the well casing. Resuspended iron, a total iron test that accounts for both chemically oxidized and biologically mobilized iron, was also low in both samples despite observable iron noted during microscopic evaluation. Manganese, a mineral which is often viewed similarly to iron in its function as a fouling mechanism, was not detected.

Total organic carbon (TOC) and tannin and lignin are evaluated as a reflection of the presence or concentration of organic material and humic substances. Neither of these parameters were identified in either sample.

Heterotrophic plate growth in the two samples was limited, coinciding with reported low levels of visible microbial activity. Adenosine triphosphate (ATP) testing, a means of quantifying the bacterial population that is not agar dependent, reported minor levels in each of the samples. Growth in ATP levels over a twenty-four hour period under ideal environmental conditions is expected and was considered typical in both samples. As a point of reference, ATP values typically fall within the range of 10,000 to 70,000 cells per milliliter (cpm) for active, potable well systems.

Testing for iron and manganese oxidizing bacteria was negative in both samples.

Anaerobic bacterial growth, reported as a function of the total population, was less than ten percent in the first sample and increased to fifteen percent in the second sample. Anaerobic growth is used as a measure of population maturity as well as flow disruption. Testing for sulfate reducing bacteria (SRB’s), a group of anaerobic bacteria known for hydrogen sulfide (H_2S) gas production, was negative.

Microscopic evaluation of the samples noted very low levels of visible microbial activity present. Crystalline debris and iron oxide were identified n each sample with higher levels of accumulation present in the first sample. No accumulations of biomass, larger microorganisms, or stalked bacteria were reported.

The dominant species identified within the samples included multiple soil related organisms. A brief description of the dominant species is presented below.

Acinetobacter johnsonii is a nonmotile, gram negative coccobacillus. It grows under aerobic conditions, is catalase positive and oxidase negative. They are important soil organisms and widely dispersed in nature. *Acinetobacter* species are commonly identified in environmental sites with hydrocarbon contamination, as well as being isolated from both humans and animals. Most *Acinetobacter* are considered opportunistic pathogens, being involved in nosocomial infections, including bacteremia, urinary tract infections and wound infections.

Pseudomonas fluorescens is a common gram-negative, rod-shaped, aerobic bacterium. Pseudomonas fluorescens inhabit soil, plants, and water surfaces. It is an obligate aerobe but certain strains are capable of using nitrate instead of oxygen as a final electron acceptor during cellular respiration. *Pseudomonas fluoresc*ens are considered non-pathogenic.

Pseudomonas stutzeri is a gram-negative, rod-shaped soil bacterium that is highly motile. As a member of the genus *Pseudomonas*, it is a prolific slime former; however, it’s known to produce a particularly dense, almost leathery form of biomass. It is also considered a denitrifying bacterium.

Interpretations:

It was requested that the generated data be evaluated with regards to the potential for mineral scale development, biofouling occurrence, and the impacts on both on the well, conveyance lines, and industrial systems.

The main concern identified within the testing was the corrosion potential of the water. As a reflection of the level of aggressiveness, the use of less reactive materials such as PVC or stainless steel should be considered. The use of low carbon steel, high-strength-low-alloy steel, galvanized metal, or other less noble metals would result in the mobilization of iron and subsequent development of iron oxide scale and iron oxide entrained biomass. Similarly, associated components including column pipe, pump, monitoring equipment and conveyance lines should utilize similar metallurgy to reduce the potential for dissimilar metals corrosion.

The oxidative nature of the water will aid in the development of metallic oxides and aerobic microbial populations. Based on the current test data, iron oxide and magnesium hydroxide are the most likely mineral assemblages expected. The development of biomass (biofilm) within the well will encourage the accumulation of mineral scale as well as the entrainment of mobilized sediment and other particulate.

As with all well systems, regular operation is encouraged. Wells that sit out of service or idle, or that become stagnant generally have higher rates of fouling. If the well sits off-line for an extended time period either prior to employment as a water supply or during its operational life cycle, it should be operated and pumped to waste prior to supplying the system. This is designed to flush any detritus or biomass from the well and limit introduction into the system.

Within industrial systems, it is likely that the water will require buffering and corrosion control. As industrial systems generally have specific requirements for water and make-up water, each component should be individually evaluated.

If you have questions regarding the analysis and the interpretations, please contact our office.

Michael Schnieders, PG, PH-GW
Hydrogeologist

APPENDIX F – ECONOMIC ANALYSIS ASSUMPTIONS

System Component	% of Initial Capital Cost
Maintenance - HPs	2.00%
Maintenance - HXs	0.50%
Maintenance - Boilers	1.00%
Maintenance - Cooling Towers	0.50%
Maintenance - ORC Engine	2.00%
Maintenance - Chillers	2.00%
Maintenance - Pumps	0.50%
Lifecycle	30

Annual O&M Cost Multiplier

APPENDIX G – NODAL OPEN-LOOP/INDIVIDUAL BUIDLING AREA ANALYSIS ASSUMPTIONS

‘Connected Building’ Capital Cost Estimate and Assumptions

The goal of the ‘connected building’ capital cost estimate was to estimate the typical cost of connecting a building to a nodal HW & CHW network. It is intended to capture all the mechanical plant equipment required to make the connect and the cost of installing them.

Equipment and system capacity/sizing were based on the estimated thermal demand of ID1. The building area used to calculate the $/ft2 value of the ‘connected building’ plantroom cost was the predicted ID1 building area.

The equipment and systems included in the Connected Building capital cost estimate are:

- HW & CHW distribution pumps,
- 2nd Stage DHW HP,
- Building Level HW and CHW HX,
- A portion of the plantroom HW and CHW pipework (insulated),
- A provision for electrical and other construction costs, and
- A provision for ‘project burdens’ or non construction related project costs.

It does not include the following:

- The value of the plantroom square footage within the building,
- The cost of the building level systems and equipment required to condition the building itself, and
- The cost of designing the individual building connection (i.e. consultant costs).

‘Nodal Plant’ Capital Cost Estimate and Assumptions

The goal of the ‘nodal plant’ capital cost estimate was to estimate the typical cost of installing a nodal plant within a future OSU-C campus building. It is intended to capture all the mechanical plant equipment required to operate and distribute CHW & HW within the node.

It does not include the following:

- The value of the plantroom square footage within the building,
- The cost of installing a CHW and HW network from the nodal plant to the connected buildings,
- The cost of building level systems and equipment required to condition the nodal buildings itself,
- The cost of designing the nodal plant (i.e. consultant costs).

Equipment and system capacity/sizing were based on the estimated thermal demand of Node 1. The building area used to calculate the $/ft2 value of the ‘nodal plant’ plantroom cost was the predicted ID1 building area.

The equipment and systems included in the Nodal Plant capital cost estimate are:

- Boiler system
  (HW pipework including boilers, flues, HW pipework within the plantroom and boiler circulation pumps),
- HRCH system
  (Including HRCHs, CHW and HW pipework within the plantroom, HW and CHW circulation pumps),
- Cooling Tower System
  (Including cooling towers, CW pipework within the plantroom, CW pipework outside the plantroom, circulation pumps between the HR/HE headers, CT HX, CT header, circulation pumps between the header and the CTs),
- GHX System
  (Including GHX field, GHX piping connecting the field to the plant, GHX field headers, GHX pipework within the plantroom and GHX circulation pumps),
- 2nd Stage DHW HP (for ID1),
- Building Level HW and CHW HX,
- System Auxiliaries
  (Including HW & CHW buffer tanks, HR and HE header, HW & CHW distribution pumps, HR/HE HXs)
- A provision for electrical and other construction costs, and
- A provision for 'project burdens' or non construction related project costs.

It does not include the following:

- The value of the plantroom square footage within the building or the cost of installing a CHW and HW network to the connected buildings,
- The cost of building level systems and equipment required to condition the nodal buildings itself, and
- The cost of designing the nodal plant (i.e. consultant costs).

Individual Building Capital Cost Estimate and Assumptions

The goal of the 'individual building' capital cost estimate is to estimate the cost of installing a stand-alone closed loop GHX system in a future campus building.

Capital cost estimates and $/ft2 costs were analyzed for 4 building types: academic buildings (AB2), innovation district buildings (ID1), residential buildings (RB4) and campus life buildings (CL3).

Equipment and system capacity/sizing were based on the estimated thermal demand of ID1. The building area used to calculate the $/ft2 value of the 'connected building' plantroom cost was the predicted ID1 building area.

The equipment and systems included in the Nodal Plant capital cost estimate are:

- Boiler system
  (HW pipework including boilers, flues, HW pipework within the plantroom and boiler circulation pumps),

- WSHP system
  (Including WSHPs, CHW and HW pipework within the plantroom, HW and CHW circulation pumps),

- Cooling Tower System (if required)
  (Including cooling towers, CW pipework within the plantroom, CW pipework outside the plantroom, circulation pumps between the HR/HE headers, CT HX, CT header, circulation pumps between the header and the CTs),

- GHX System
  (Including GHX field, GHX piping connecting the field to the plant, GHX field headers, GHX pipework within the plantroom and GHX circulation pumps),

- 2nd Stage DHW HP,

- Building Level HW and CHW HX,

- System Auxiliaries
  (Including HW & CHW buffer tanks, HR and HE header, HW & CHW distribution pumps, HR/HE HXs)

- A provision for electrical and other construction costs, and

- A provision for ‘project burdens’ or non construction related project costs.

It does not include the following:

- The value of the plantroom square footage within the building,

- The cost of building level systems and equipment required to condition the building itself, and

- The cost of designing the nodal plant (i.e. consultant costs).