THERMAL SYSTEMS TRANSITION STUDY

University of Oregon
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1.0 Executive Summary

1.1 Objectives

The commissioning of this study is a direct result of an update to the University's Climate Action Plan (CAP 2.0). A key component of CAP 2.0 is development of a long term plan to transition to more sustainable methods of generating heat for the campus district heating system. The objective of this study is to identify and analyze options that can be considered for development of a Thermal Utility Systems Transition Plan (the Plan) that best serves the University's goals to reduce greenhouse gas (GHG) emissions, reduce reliance on carbon emitting sources and transition to more sustainable and economical energy sources for thermal utility production and distribution.

The University has identified three GHG reduction targets for consideration in the study:

- 50% campus heating emissions reduction by 2050
- 80% campus heating emissions reduction by 2050
- 100% campus heating emissions reduction by 2050

Affiliated Engineers Inc. (AEI) was commissioned by the University of Oregon Campus Planning and Facilities Management (CPFM) to perform this study in support of consideration for and development of a Transition Plan to meet the University's needs. Taking an approach of "putting everything on the table", numerous options to achieve the University's GHG reduction targets were developed and evaluated. All options were screened based on advantages and disadvantages for implementation, expected energy performance, ability to meet GHG reduction targets, commercial availability of the technology and fuel required, availability and capacity of thermal sources to support campus demands, and estimated cost impacts for implementation and operations. A series of workshops were conducted with primary stakeholders to discuss the options and application of the evaluation criteria to develop a short list of the most viable options which were then subjected to a more detailed analysis.

Viable options were compared on a life cycle cost basis. As part of the workshops conducted with University staff, inputs to a life cycle cost analysis (LCCA) and analysis of GHG emissions (i.e. utility rates, emissions factor, escalation rates, operations and maintenance costs, equipment replacement periods, etc.) were reviewed and agreed upon. A LCCA and GHG emissions analysis was performed for the options listed below.

1. Business as Usual (BAU). This is the base case for which other options are compared against. The operation of the central plant and thermal distribution system continues as-is, including any scheduled maintenance, repairs and improvement projects.

2. Business as Usual with the existing heating plant operating an electrode steam boiler as the primary source of heating steam instead of operating a natural gas fired steam boiler.

3. A campus conversion from a steam heating system to a heating hot water system using heat recovery chillers (HRCs) to simultaneously generate chilled water and heating hot water.

4. A campus conversion to a heating hot water system using heat recovery chillers. Operation of the HRCs is to be supplemented with the utilization of the Millrace as an alternate thermal source.
5. Decentralizing the campus heating system, creating utility zones throughout campus which are served by nodal heat recovery plants utilizing heat recovery chillers as the primary source of heating and cooling. This option also includes a campus conversion from steam to a heating hot water system.

The most viable options analyzed focused on the ability to significantly reduce or eliminate the consumption of natural gas as this is the predominant source of scope 1 GHG emissions. However, none of the options are able to fully achieve a 100% emissions reduction due to the fact that there is always some level of Scope 2 emissions associated with utility electricity production and Scope 1 emissions associated with the continued use of fossil fueled boilers during a phased transition.

Three of the options described above are estimated to surpass the 80% emissions reduction target. Estimated emissions over the 30 year period of analysis are listed below:

Option	Estimated 30 year GHG Emissions (MTCDe/yr)	Approximate Reduction
1. Business as Usual	668,000	N/A
2. BAU with electrode boiler	87,000	87%
3. Heating hot water conversion with heat recovery chillers	293,000	56%
4. Heating hot water conversion with heat recovery chillers and Millrace as supplemental thermal source	104,000	84%
5. Campus decentralization with nodal heat recovery plant	105,000	84%

Net present costs for each option are listed below. Note that the cost figures in the table below include a conversion to a heating hot water system only for those buildings on campus that are currently utilizing steam as the heating source. As none of the options achieved a 100% reduction in GHGs, the additional costs of purchasing carbon offsets to reach that target is also stated.

While an electrode steam boiler option yielded the greatest reduction in GHG emissions and lowest net present cost, there are other considerations of this option that would have impacts to the operating costs that should factor into a decision process for implementing this option.

Installation of an electrode boiler does not eliminate the need for the existing natural gas fired boilers or combustion turbine cogeneration system. These existing assets must be maintained to meet peak demand periods and provide resiliency for heating and electrical power. Achieving the emissions reductions estimated for the electrode boiler results in a large increase in the campus electrical demand, adding an 18 MW load. This would require a load study to be performed by the electric utility. The results of a load study may be accompanied by a requirement for additional delivery charges and/or an increase in energy and demands costs. As these costs are unknown until the utility performs a load study they are not accounted for in the net present cost of the electrode boiler option. Additional capital costs that would impact this option may include increased backup power generating capacity and implementation of a revised load shed scheme.

Option	30 Year Net Present Cost w/o Carbon Offsets	Estimated Purchase of Carbon Offsets	30 Year Net Present Cost w/ Carbon Offsets
1. Business as Usual	$104,100,000	$16,400,000	$120,500,000
2. BAU with electrode boiler	$210,500,000	$2,400,000	$212,900,000
3. Heating hot water conversion with heat recovery chillers	$258,100,000	$7,200,000	$265,300,000
4. Heating hot water conversion with HRCs and Millrace as supplemental thermal source	$307,300,000	$2,500,000	$309,800,000
5. Campus decentralization with nodal heat recovery plants	$370,900,000	$2,400,000	$373,300,000

Notes:

1. Net present cost for the BAU case includes planned O&M and existing debt service.
2. Carbon offsets include the cost to purchase a sufficient quantity of offsets to increase the GHG reduction of an option from it's estimated performance capability to a 100% reduction target.

2.0 Existing Utility Infrastructure

2.1 Central Heating and Chiller Plants

2.1.1 Central Power Station

The Central Power Station (CPS) generates steam to provide heating and process steam for the campus. Steam generation equipment consists of two watertube boilers and one combustion turbine generator with a heat recovery steam generator (HRSG). All are dual fueled units utilizing either natural gas or No. 2 oil, with natural gas as the primary fuel. Rated capacities are listed below.

- Boiler 1: 60,000 lb/hr
- Boiler 2: 65,000 lb/hr
- Combustion Turbine Generator: 7.5 MW
- Heat Recovery Steam Generator: 65,000 lb/hr

In addition to the Combustion Turbine Generator the plant also includes a 2.5 MW back pressure steam turbine generator. The combustion turbine generator, HRSG and steam turbine generator are operated as a cogeneration system to provide backup electric power and heating steam. It is maintained for standby operation in the event utility grid power is unreliable or unavailable, thus providing resiliency for campus operations.

Main heating steam, which is generated at 135 psig, is supplied to a skid mounted Clean Steam Generator (AB-1). The Clean Steam Generator has a rated capacity of 1,200 lb/hr and provides process steam to several autoclaves on campus. This unit is scheduled for decommissioning.

The majority of main steam produced is routed through a pressure reducing station, reducing pressure from 135 psig to 60 psig for distribution to the campus through a network of utility tunnels. The steam distribution network is an aged system but piping and the tunnels were observed to be well maintained. The University has an on-going maintenance program to repair or replace steam piping and insulation as necessary.

While the tunnels are observed to be in good condition, many spaces throughout the tunnels are very cramped due to the quantity and sizes of the various piping and cables routed through the tunnels. Some sections of the tunnel were difficult to access due to the crossing of piping. Small and crowded spaces in the tunnels makes the addition of new utility piping difficult and expensive or infeasible.

Figure 1 **- Existing Utility Tunnels**

2.1.2 Central Chilled Water

Campus chilled water is generated at the Central Chilled Water Plant and is distributed through underground piping to buildings on the main campus. The existing 7,500-ton capacity chilled water plant that finished commissioning in 2012 consists of five 1,500-ton variable speed centrifugal chillers, twelve (12) induced-draft cooling towers and a waterside economizer heat exchanger. Chillers are equipped with variable speed compressors and rated to operate efficiently at 0.385 kW/ton NPLV. Annual chilled water plant efficiency is approximately 0.75 kW/ton. The plant has a primary-secondary piping configuration - each chiller has a constant speed 50 HP primary pump and secondary distribution pressures are maintained by staging four 400 HP and three 100 HP variable speed distribution pumps. Each chiller operates with a constant speed 125 HP condenser pump.

The chilled water plant operates continuously and primarily operates to produce 42 deg F chilled water by staging chillers and cooling towers during normal operation. The plant produces 48 deg F chilled water during the winter when operating in a free cooling mode using a waterside economizer. Peak chilled water load during a 2019 trend study evaluated for this report is 5,000 tons, with a minimum winter load of 300 to 400 tons.

Campus chilled water distribution is routed in utility tunnels throughout the campus via an east and west distribution network. Much of the chilled water distribution was installed in 1965. Low return water temperature is observed and stems largely from the various ways chilled water is connected to each building (i.e. heat exchangers, series pumping, decoupled bridge) and effectively causes chillers to operate with limited capacity. The chiller plant is currently operating with four chillers in operation because of these temperature limitations and has reached maximum capacity with the desired N+1 operating capacity. The plant is designed to accommodate three additional 1,500-ton chillers for a total capacity of 12,000-tons. The construction of a chilled water storage tank is underway and is scheduled for completion in mid-2022. The chilled water storage tank is intended to increase functional capacity for peak operation without adding new chiller equipment.

2.2 Existing Electrical Infrastructure

The University receives electrical service from two independent Eugene Water and Electric Board (EWEB) feeders. Feeders route from EWEB substations and terminate at utility owned transformation located within a dedicated equipment yard north of the Central Power Station. The installed utility equipment arrangement allows fully redundant operation on the utility side of distribution. Equipment ratings allow doubling of current campus load while maintaining redundant configuration.

Utility transformation provides two primary metered services and each service is direct coupled to University owned switchgear. These service entrance switchgear line-ups are interconnected by tie breakers and a medium voltage bus duct allowing operation and utilization of utility power in redundant system configuration. Switchgear installations are located in the Switchhouse, a building dedicated to providing space for medium voltage distribution switchgear.

The University maintains capability for alternate power generation independent of utility service. Three diesel engine generators provide standby power; a single gas turbine generator and a single steam turbine generator provide co-generation capability. Total installed generating capacity from these sources approximately equals the capacity from one utility source. Campus generating equipment can be paralleled with the utility or disconnected to operate in “island” mode as required. Alternate power generation is delivered at utilization voltages matching utility primary service using two switchgear line-ups located in the Switchhouse. Similar to the utility service entrance switchgear, an arrangement of tie breakers and bus duct allow alternate power sources to interconnect with service entrance switchgear. Overall topology and interconnection of switchgear using tie breakers provides a “ring-bus” configuration.

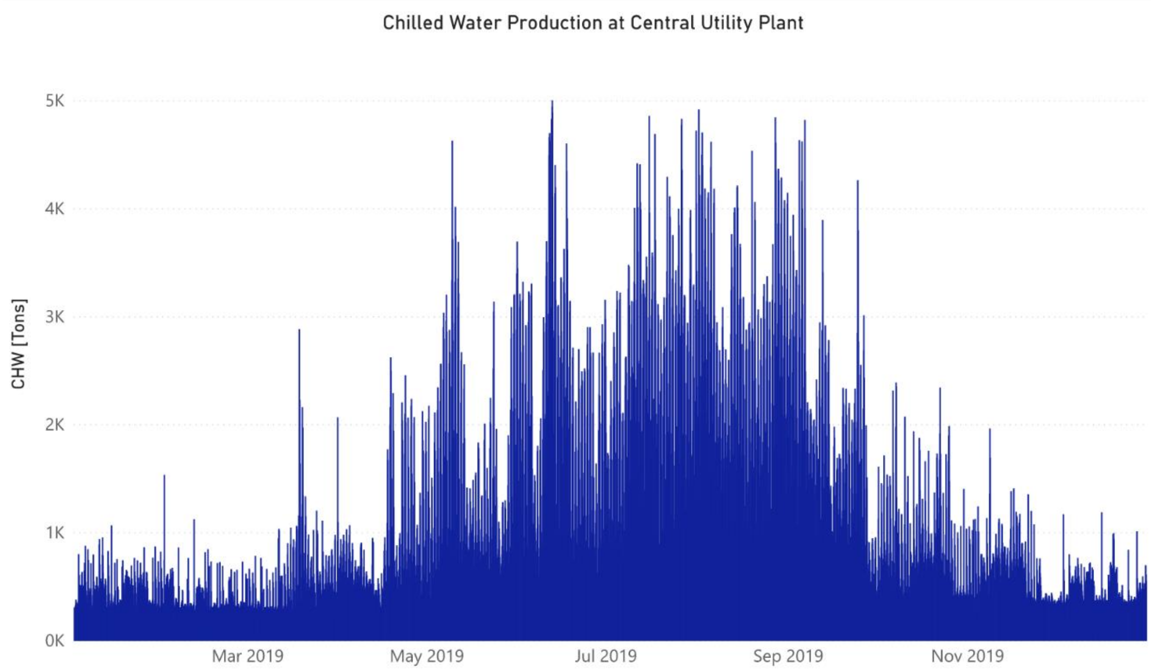
Campus medium voltage feeders and large loads are fed from the ring-bus topology using radial distribution from the Switchhouse. After leaving the Switchhouse, all feeders have only one service path.

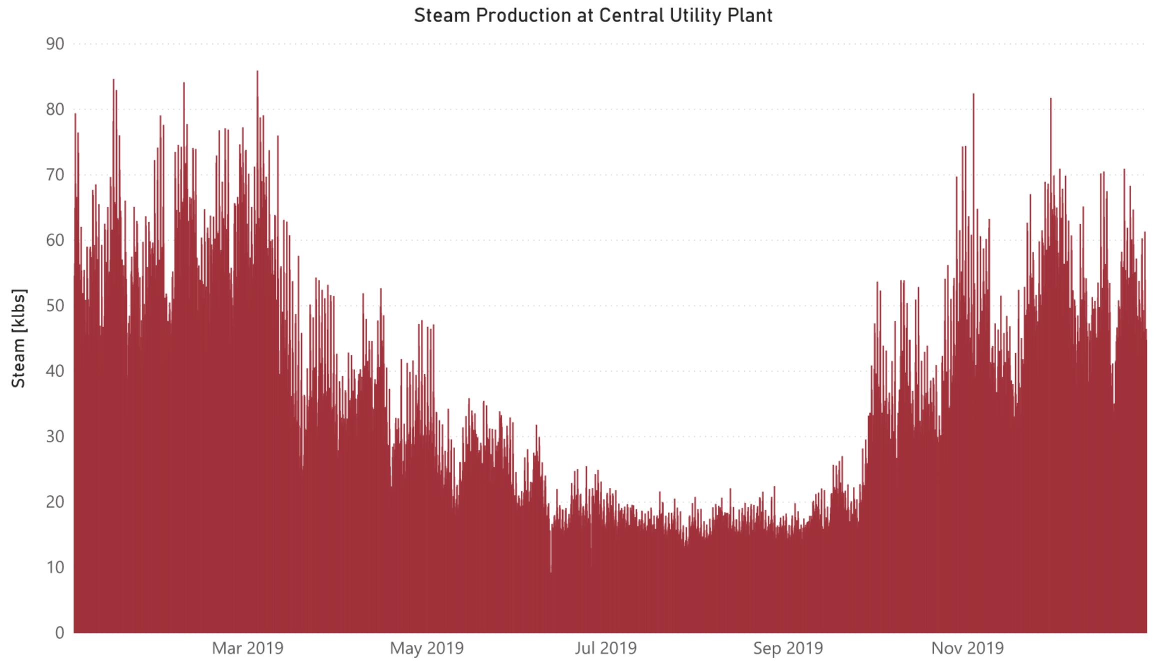
3.0 Thermal Load Data and Growth

3.1 Campus Thermal Demand and Analysis

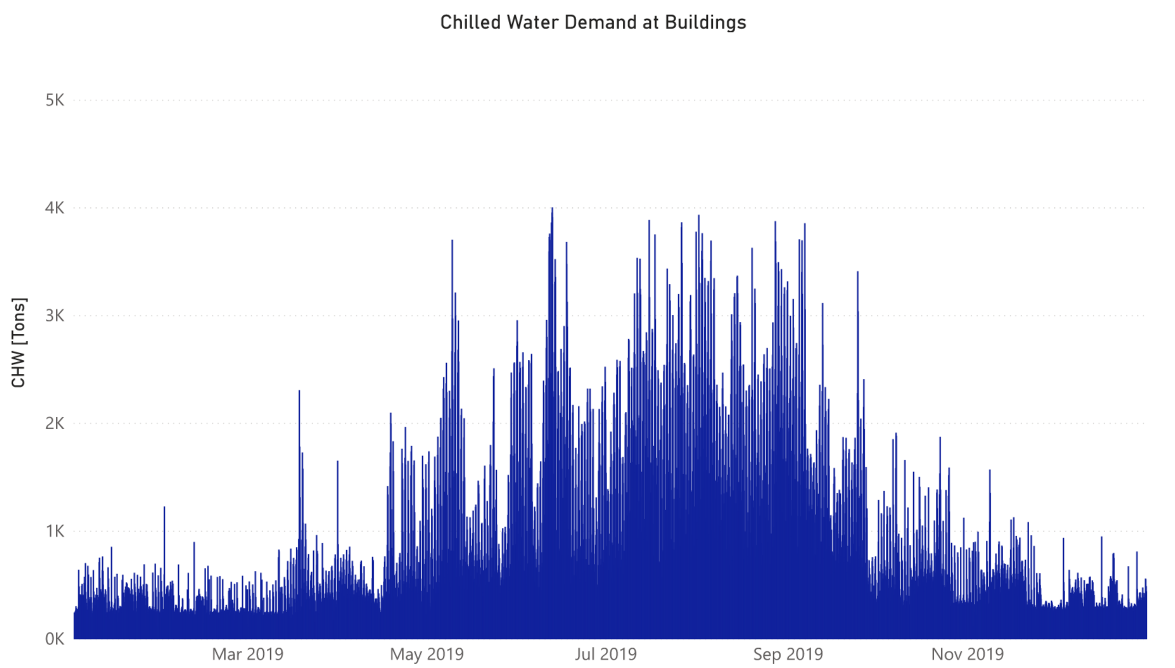
AEI received recent and historical data from UO Campus Planning and Facilities Management regarding utility consumption on campus and central plant operations. Key data sharing included hourly campus steam production, chilled water production, and outdoor air dry-bulb temperatures for the full year of 2019. This data will be used as the basis for establishing the campus heating and cooling demands. Additional pertinent data that will be utilized for the Business As Usual (BAU) baseline case includes estimated distribution losses for steam and chilled water distribution, monthly steam consumption per building for 2019, and annual average efficiencies for the chilled water plant and steam boilers.

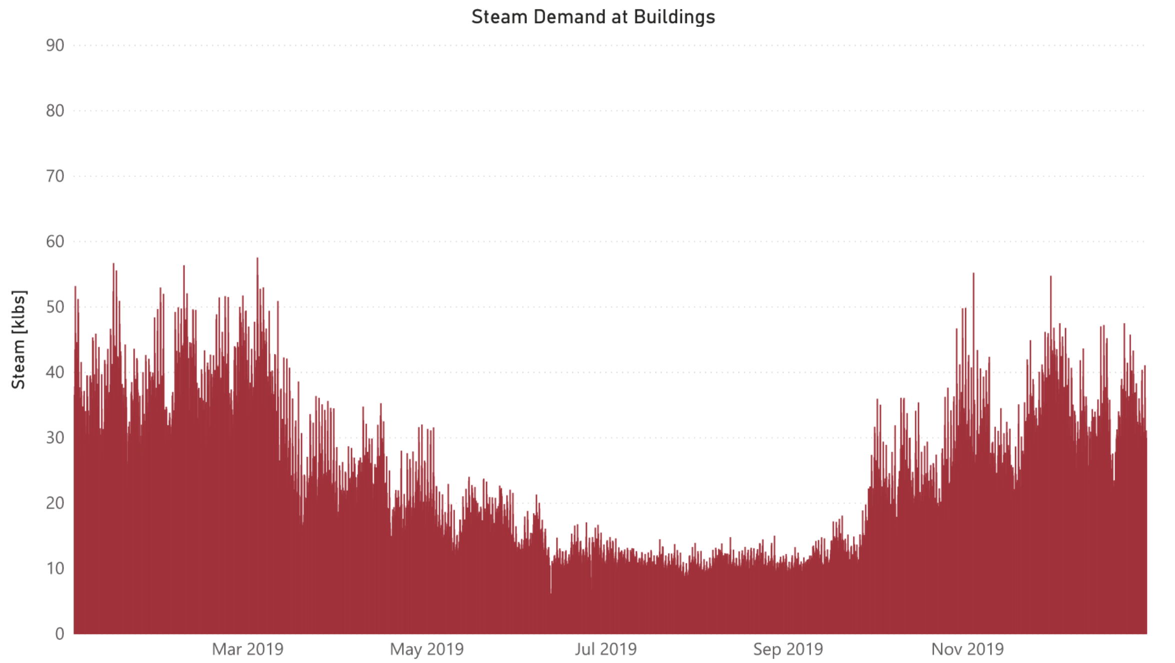
The 2019 hourly steam production and chilled water production from the central plant is shown below.



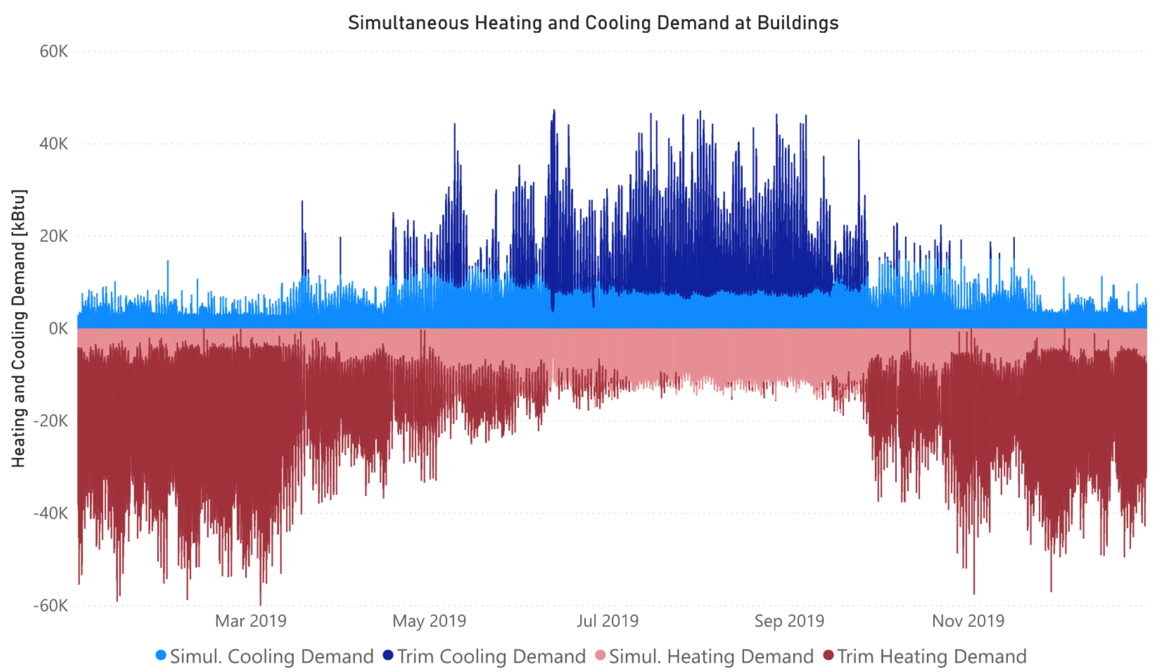


From the data provided, the annual average distribution losses are assumed to be 33% for steam distribution and 20% for chilled water distribution, derived from discussion with UO Facilities Management and by comparing the steam consumption at each building to the steam production leaving the central utility plant. By removing these losses from the distribution system, the building level heating and cooling demands are estimated as shown below.





The chart below illustrates the simultaneous heating and cooling demands on campus. The instantaneous and short term overlap of heating and cooling demands will inform the analysis of central heat recovery and thermal energy storage options.



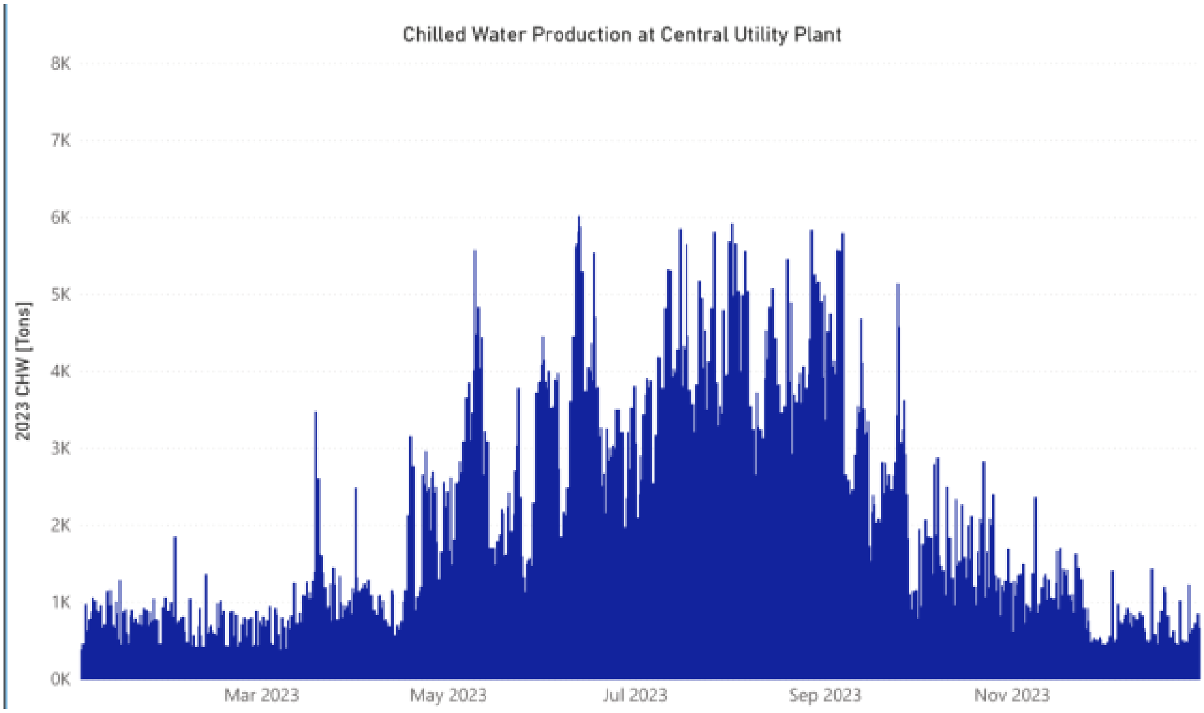
3.2 Thermal Load Growth

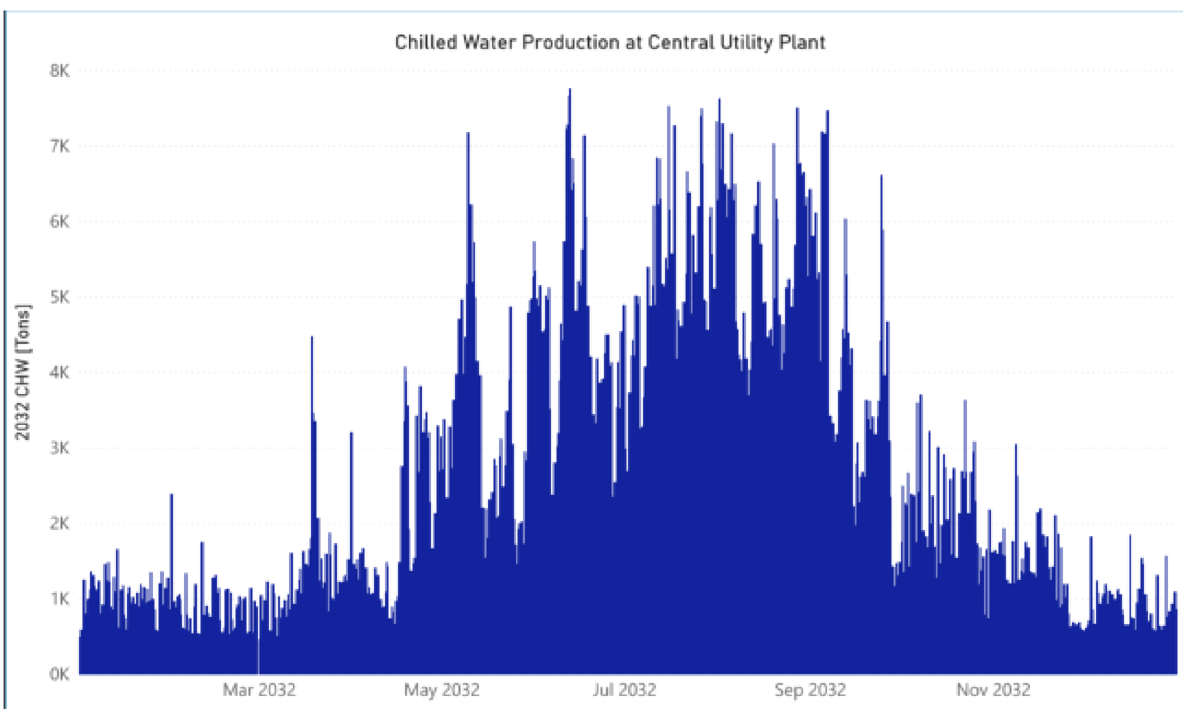
The analysis period for this study is 30 years, from 2023 to 2052, with the assumption that 2023 would be the earliest that any thermal systems transition work could feasibly begin. The following load growth rates will be applied to the campus heating and cooling demands. The growth rates for the analysis period 2020-2025 are taken from the UO Strategic Energy Management Plan (FY20-21 Edition). These growth rates were applied to the 2019 measured data to generate the campus heating and cooling demands for the first year of the study period (2023) and beyond for each year in the study period.

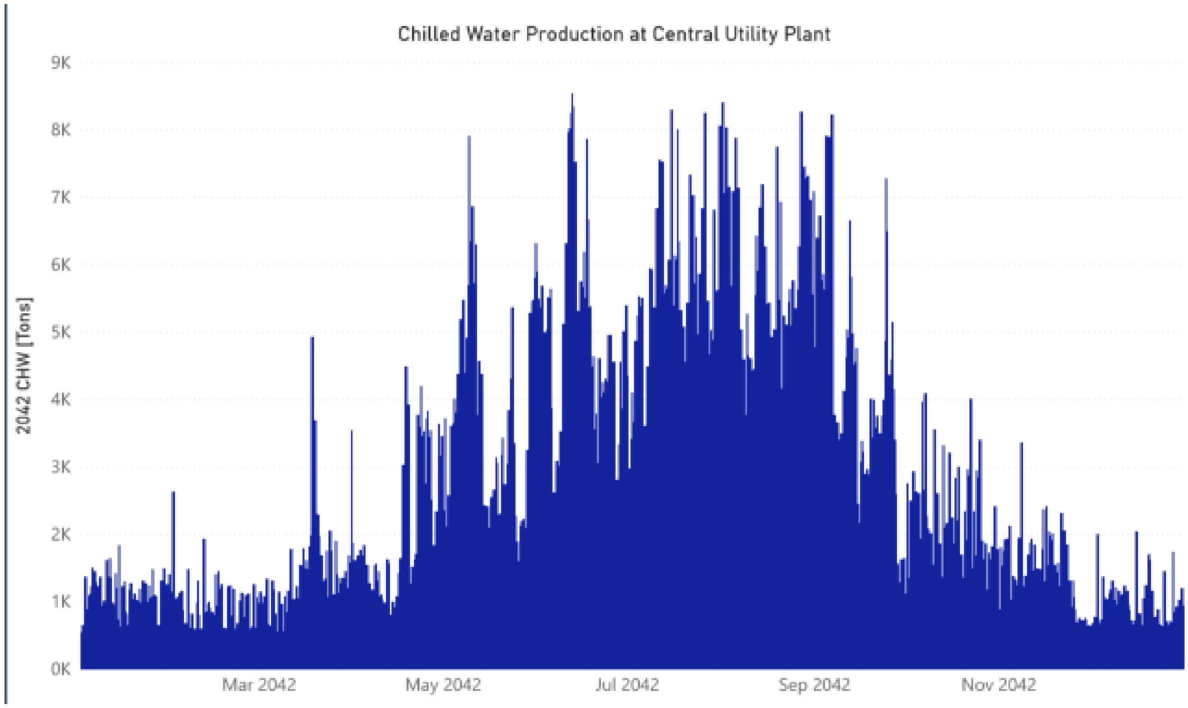
Analysis Period	Heating Demand Growth Rate	Cooling Demand Growth Rate
2020-2025	0.08%	6.34%
2026-2030	1%	2.25%
2031-2052	0.75%	0.97%

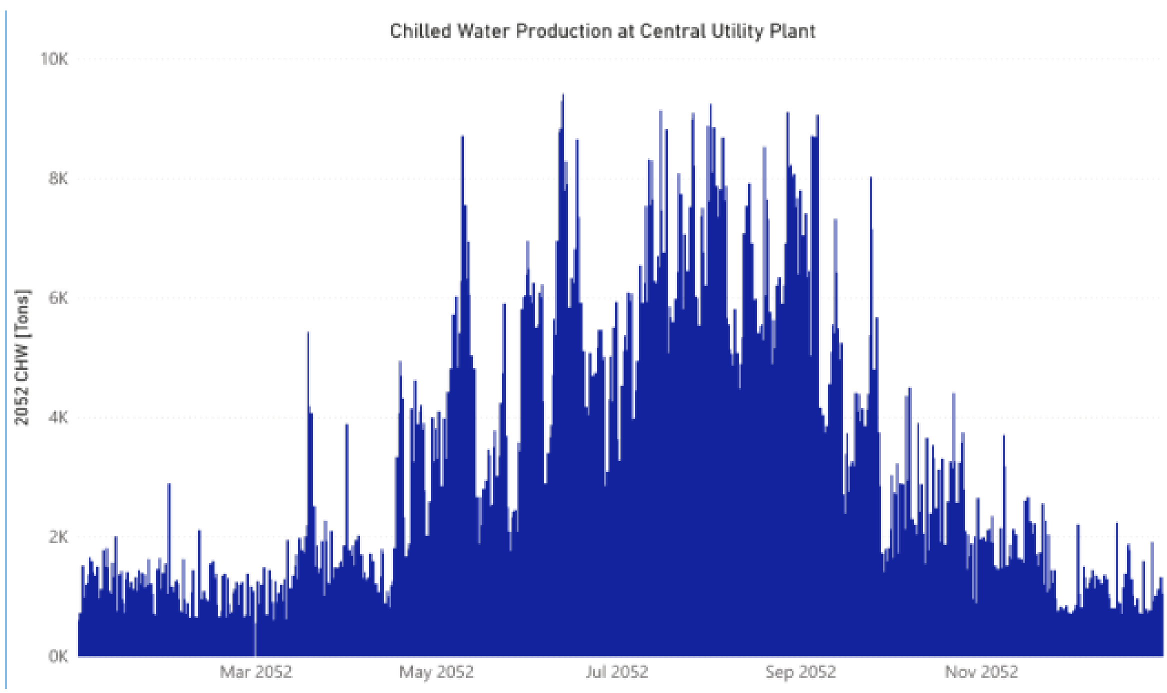
Chilled water and steam distribution losses are assumed to remain constant throughout the entire study period. Some of the options that were analyzed include heating hot water distribution in lieu of steam distribution (with a 2 phase steam to heating hot water transition) with an assumed heating hot water distribution loss of 10% for a newly constructed heating hot water distribution system.

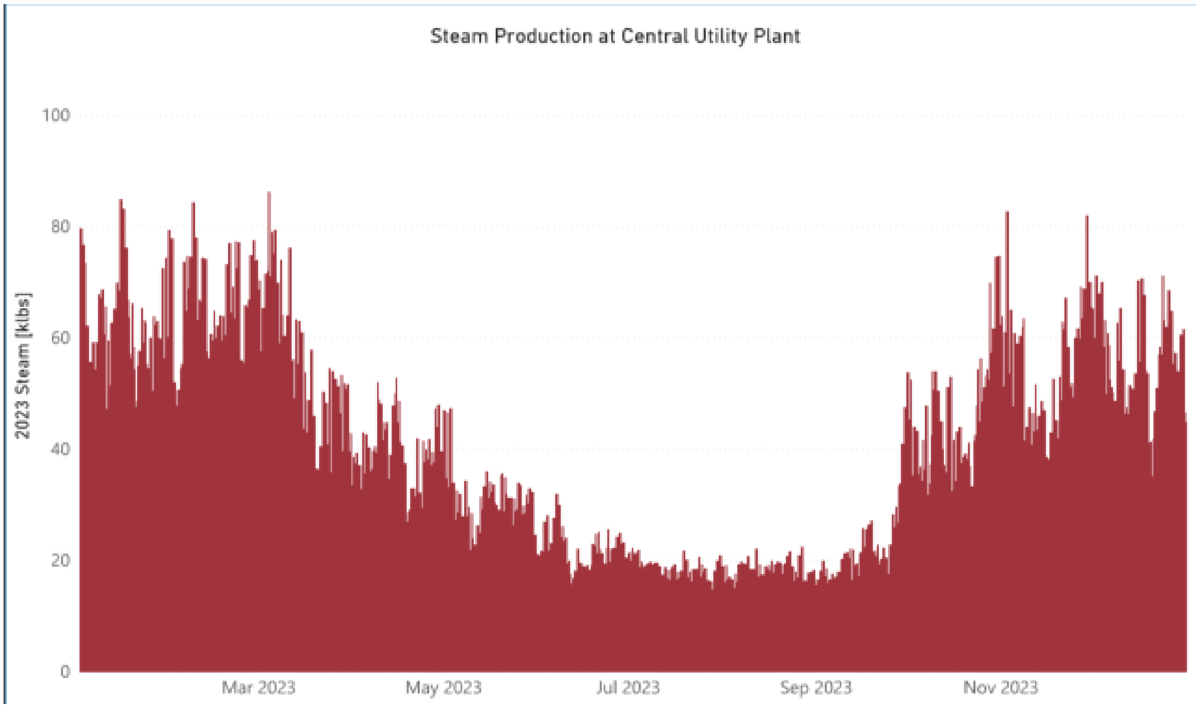
For the purposes of comparing to the current central utility plant heating and cooling production, the future campus production for chilled water and steam distribution are shown below, representative of year 1, 10, 20 and 30 of the analysis period with the heating and cooling demand growth rates applied.


Chilled Water Production at Central Utility Plant
2023 CHW [Tons]
8K
7K
6K
5K
4K
3K
2K
1K
0K
Mar 2023
May 2023
Jul 2023
Sep 2023
Nov 2023

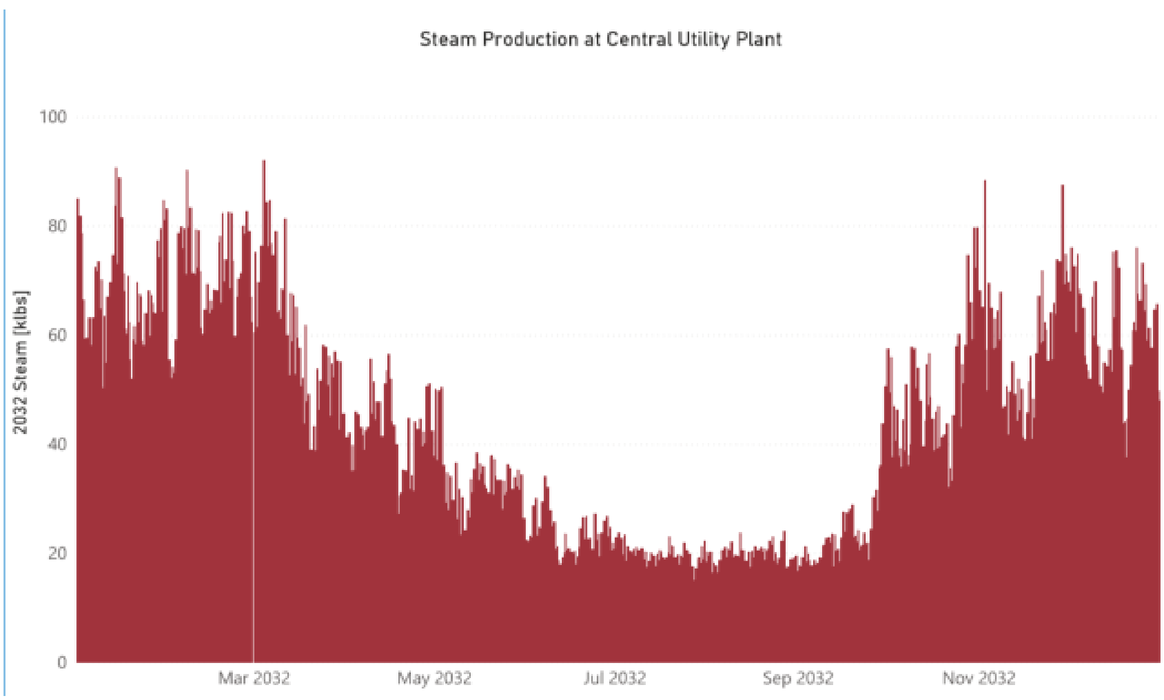

Chilled Water Production at Central Utility Plant
2032 CHW [Tons]
8K
7K
6K
5K
4K
3K
2K
1K
0K
Mar 2032
May 2032
Jul 2032
Sep 2032
Nov 2032


Chilled Water Production at Central Utility Plant
2042 CHW [Tons]
9K
8K
7K
6K
5K
4K
3K
2K
1K
0K
Mar 2042
May 2042
Jul 2042
Sep 2042
Nov 2042

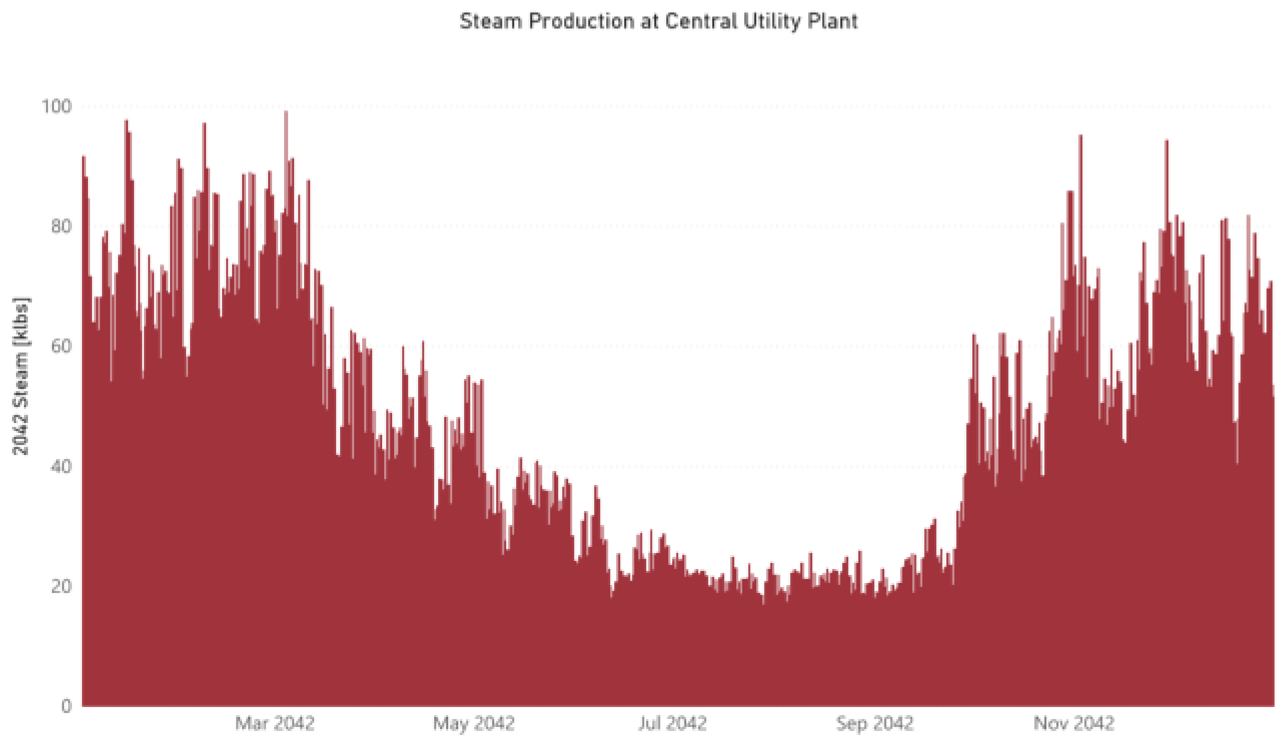

Chilled Water Production at Central Utility Plant
2052 CHW [Tons]
10K
8K
6K
4K
2K
0K
Mar 2052
May 2052
Jul 2052
Sep 2052
Nov 2052

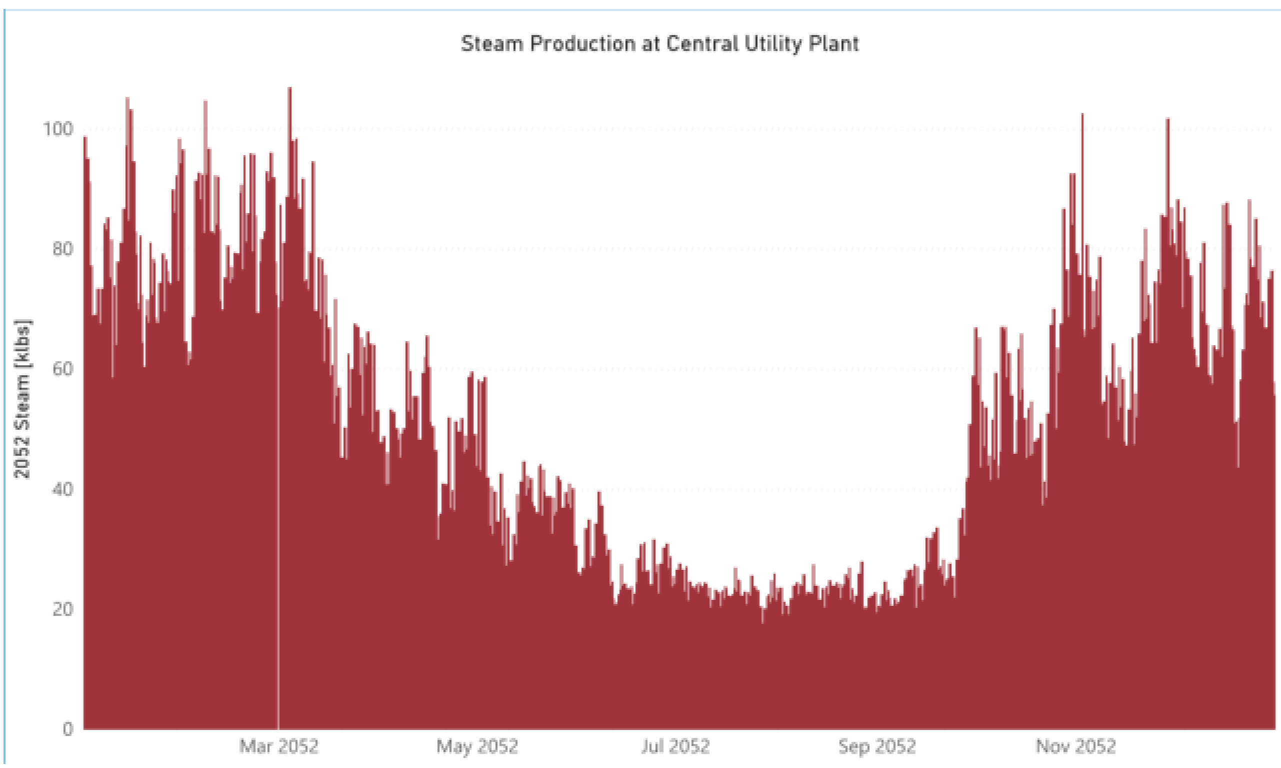


Steam Production at Central Utility Plant
2023 Steam [klbs]
100
80
60
40
20
0
Mar 2023
May 2023
Jul 2023
Sep 2023
Nov 2023



Steam Production at Central Utility Plant
2032 Steam [klbs]
100
80
60
40
20
0
Mar 2032
May 2032
Jul 2032
Sep 2032
Nov 2032


Steam Production at Central Utility Plant
2042 Steam [klbs]
0
20
40
60
80
100
Mar 2042
May 2042
Jul 2042
Sep 2042
Nov 2042


Steam Production at Central Utility Plant
2052 Steam [klbs]
0
20
40
60
80
100
Mar 2052
May 2052
Jul 2052
Sep 2052
Nov 2052

4.0 Cases for Infrastructure Development

A number of different options were evaluated for this study. An approach of "putting everything on the table" was taken in developing options for consideration. All options were then screened based on pros and cons for implementation, expected performance, availability of the technology and fuels required, availability of thermal sources, and estimated costs. A series of workshops were conducted with primary stakeholders to discuss the options and application of evaluation criteria. A listing of all options considered is listed below. A simplified diagram of each option, integrated with existing systems, is provided in the Appendix.

Business as Usual Options

These options are based on the Business as Usual (BAU) case. BAU consists of the existing steam heating and chilled water systems and infrastructure continued to be operated as-is.

Option 1: Business as Usual. This is the base case to which all other options will be evaluated against.

Option 1a: BAU with the addition of a second cogeneration unit. As mentioned earlier the plant makes use of an existing cogeneration system (CTG-1) consisting of a dual fuel combustion turbine generator, heat recovery steam generator and back pressure steam turbine to supply both electric power and heating steam to the campus. The design of the central plant station provides space for addition of a second cogeneration system.

Option 1b: BAU, utilizing existing boilers fueled with renewable natural gas (RNG). This option would consist of supplying RNG to the CPS and converting the existing boilers from firing natural gas to RNG. RNG is a zero-carbon resource produced from the decomposition of organic wastes such as food, forestry and agricultural industries, and landfills. The gas is processed for use in natural gas systems and either piped directly to a plant for use as the primary fuel or injected into existing natural gas systems to supplement natural gas consumption.

Option 1c: BAU, utilizing purchased offsets, renewable energy credits (RECs) and/or regional investments. In place of modifying existing CPS systems and steam and chilled water distribution, this option consists of the annual purchase of carbon offsets, RECs, or investments in regional sustainable power projects to be used as credit towards the University's GHG inventory.

Option 1d: BAU with the addition of an electric boiler. Existing natural gas boilers remain in place on standby with this option. Operation of an electric steam boiler would be used in place of operating a natural gas fired boiler to generate heating steam. Electric boilers convert electric energy to heat energy with a conversion efficiency near 100 percent.

Option 1e: BAU, with energy conservation measures (ECMs) implemented in campus buildings. The implementation of ECMs in all buildings throughout campus would reduce the heating and cooling demand, thus reducing the quantity of natural gas and electric power consumed by the CPS. On-going and planned ECMs, such as system optimization and retro-commissioning activities, are assumed to continue. However, the determination and analysis of potential ECMs for campus buildings is beyond the scope of this study.

Option 1f: BAU, with removal of the existing clean steam generator and a reduction of operating steam pressure. Existing boilers are operated at a steam pressure of 165 psig to support proper operation of the central clean steam generator. However, heating steam is distributed to the campus at a much lower pressure of 60 psig. Decommissioning the clean steam generator will allow boilers to be operated at a lower pressure, thus reducing natural gas consumption. Decommissioning the central clean steam generator would reduce, and possibly omit, the need for operating the boilers during the summer. Process steam loads supplied by the existing clean steam generator would then be supplied by several smaller, electric powered, clean steam generators located at individual buildings. It should be noted that maintenance activities at individual buildings will need to address the new clean steam generators.

Figure 2 - Cleaver Brooks 18 CEJS Electrode Boiler

<u>**Heating Hot Water Conversion with Existing Boilers**</u>

Option 2a1: Hot water conversion with steam to hot water converters and a reduced steam operating pressure. This option assumes the central clean steam generator is decommissioned and replaced with local electric powered clean steam generators at individual buildings. The steam plant would generate steam at a reduced pressure (100 psig), routed to heat exchangers in the CPS to produce heating hot water for distribution to the campus. The efficiencies associated with a hot water heating system (lower production losses and lower distribution system losses) result in a reduction in fuel usage. Heating hot water systems also have the advantage of lower operation and maintenance costs than steam heating systems. All heating hot water options require that new hot water distribution piping is routed throughout campus and that buildings that currently utilize steam heating are converted to utilize heating hot water.

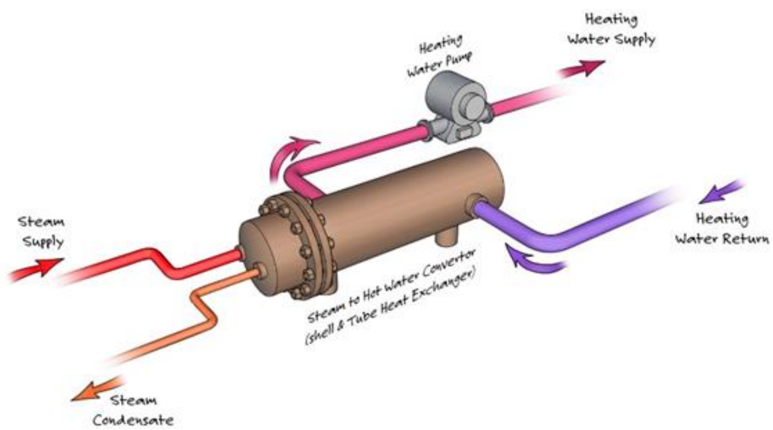


Figure 3 - Steam to Hot Water Converter

Option 2a2: Hot water conversion utilizing existing steam boilers fueled by RNG. This option is similar to Option 2a1 above, with the exception of utilizing RNG to supplement natural gas consumption of the existing boilers.

Option 2b: Hot water conversion utilizing steam to hot water converters and existing steam boilers. Hot water boilers replace existing steam boilers over time. This option is also similar to Option 2a1 above. However, as the existing steam boilers reach their end of life they are replaced with more efficient hot water boilers.

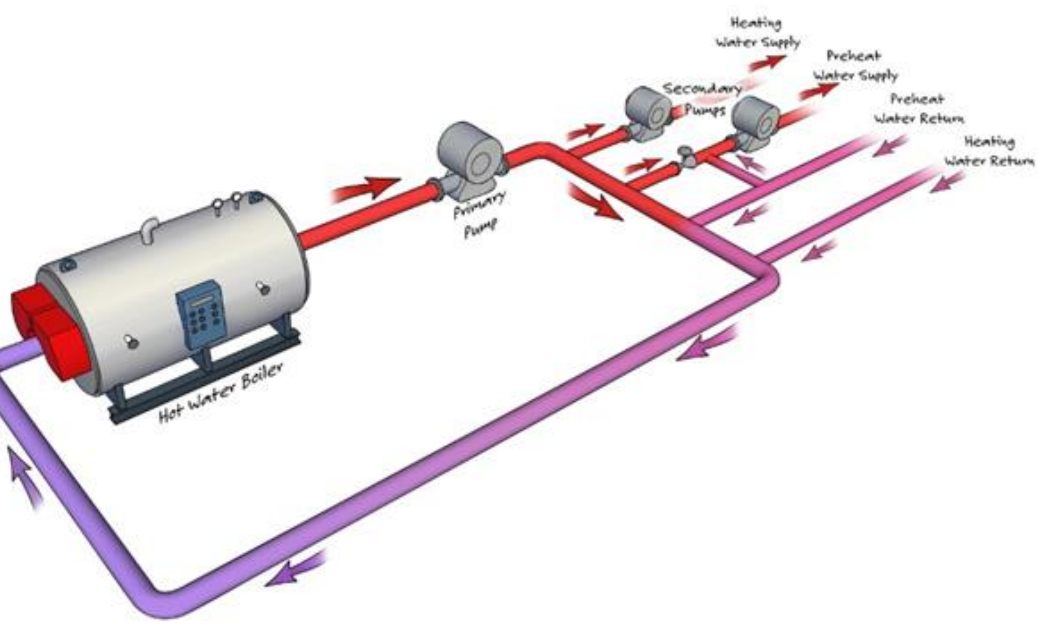


Figure 4 - Hot Water conversion with Hot Water Boiler

Option 2c1: Hot water conversion, replacing existing steam boilers with hot water boilers. This option considers that existing steam boilers are immediately replaced with new hot water boilers.

Option 2c2: Hot water conversion with hot water boilers fueled by RNG. This option is similar to Option 2c1 above, however new hot water boilers are fueled with RNG.

Option 2c3: Hot water conversion utilizing hot water boilers fueled with biomass instead of natural gas. This option requires the use of hot water boilers configured to utilize a biomass feedstock such as wood chips, pellets or sawdust. Storage silos, conveyors, and particulate emissions control equipment make up major components of the system to operate the boilers. Biomass boilers will require a secondary fuel for startup and for maintaining boilers in a standby condition. Typically, a natural gas or fuel oil fired boiler is maintained to provide redundancy and support peak heating demands.

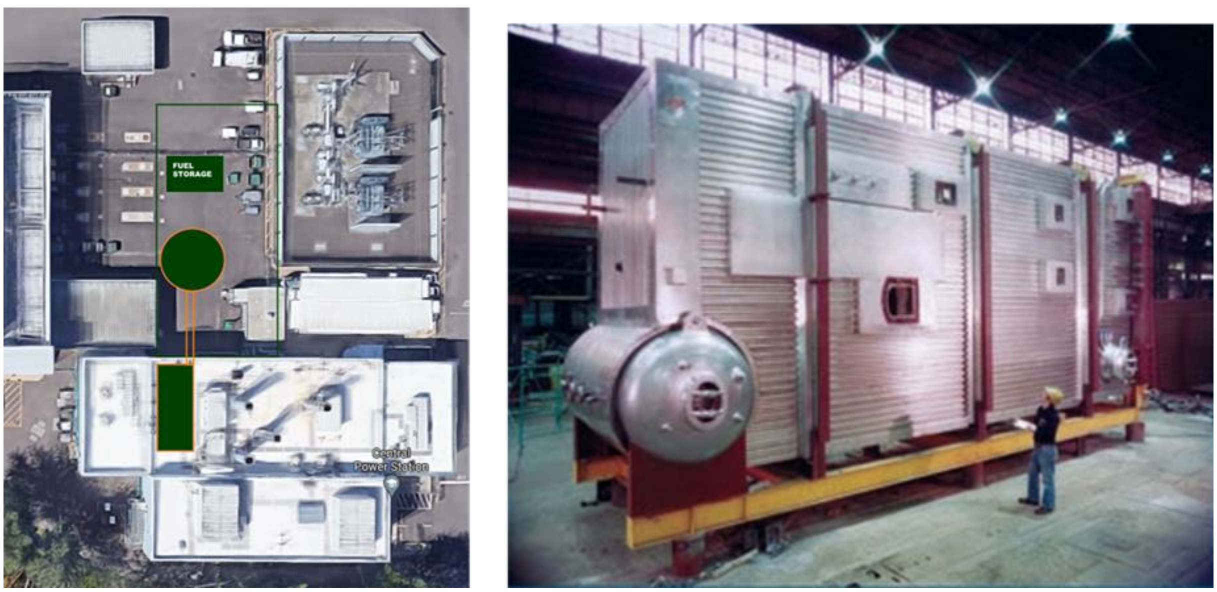


Figure 5 - Typical Biomass Boiler and Potential Location with Storage at CPS

<u>**Heating Hot Water Conversion with Electric Boilers**</u>

Option 3: Hot water conversion, replacing all existing natural gas fired boilers with electric boilers. This option immediately replaces the existing steam boilers with electric hot water boilers and implements a conversion of the existing steam distribution system (and steam heating in campus buildings) to a heating hot water system.

<u>**Heating Hot Water Conversion with Heat Recovery Chillers**</u>

Option 4: Hot water conversion utilizing heat recovery chillers. As with Options 2 and 3, a conversion throughout campus to a heating hot water system is implemented. Heat recovery chillers (HRCs) can be installed parallel to the existing conventional chillers and connected to a new heating hot water distribution system. HRCs can produce chilled water and heating hot water simultaneously. HRCs

operate similar to conventional chillers on the evaporator side, but on the condenser side they are connected to the hot water system rather than an evaporative cooling tower loop. The amount of heat produced by HRCs is dependent on the concurrent cooling and heating loads of the campus. Heating demands that exceed the capacity of the HRCs can be met with hot water boilers.

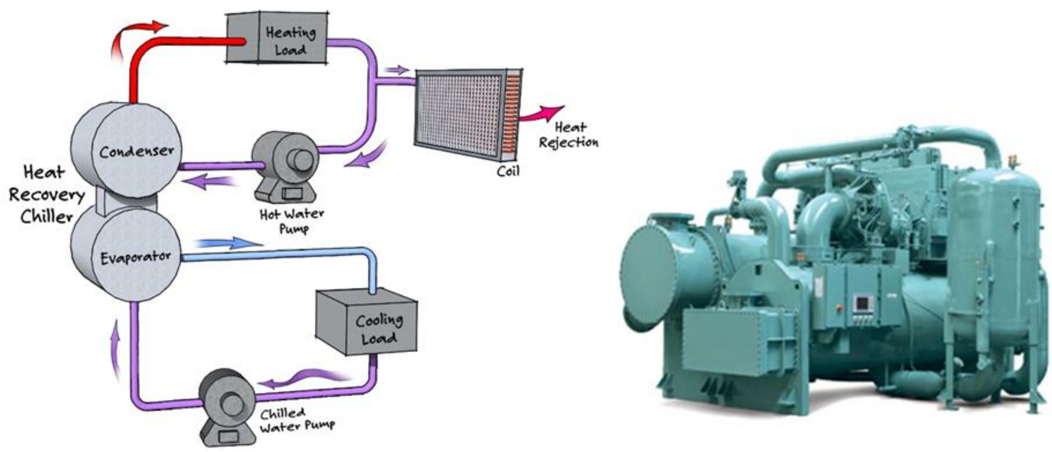


Figure 6 - Heat Recovery Chiller Operation

Option 4a: Hot water conversion with hot water thermal energy storage (TES). In addition to converting the campus steam heating system to a heating hot water system, a thermal energy storage (TES) tank is constructed at the CPS to provide peak load capacity and increased operating efficiency. TES tanks function as a thermal battery and allow plant equipment to operate at their most efficient levels.

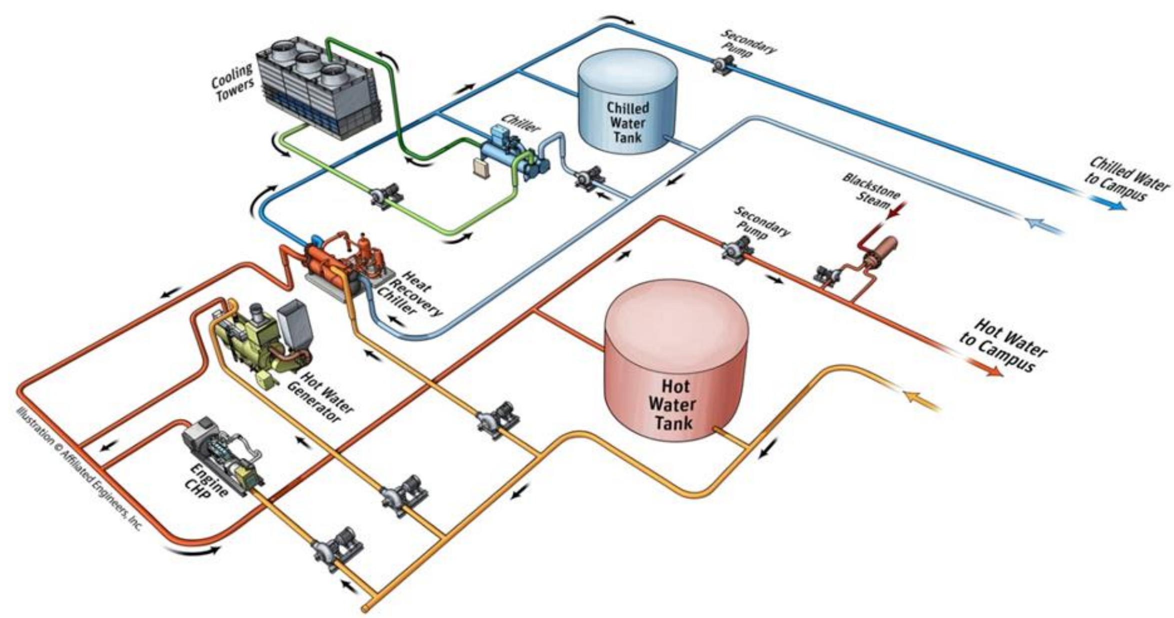


Figure 7 - Hot Water System with TES

Option 4b: Hot water conversion using alternative thermal sources such as the millrace, waste water, building exhaust, solar thermal, air source, and/or geothermal exchange. This option is similar to the options described above that convert the campus steam heating system to a hot water heating system. However multiple sources of low grade heat sources are utilized to capture thermal energy and transfer it to the campus heating system. Many of these potential thermal energy sources require multiple connections in order to aggregate a sufficiently large capacity for campus heating.

Decentralization

Option 5: Decentralization of the steam and chilled water system with nodal heat recovery plants located throughout campus. This option considers dividing the campus into several zones and the construction of a heat recovery plant in each zone to provide heating hot water. This would replace the operation of the existing centralized steam boilers with several smaller heating plants consisting of heat recovery chillers and a heating hot water distribution system. Each heat recovery plant would be sized to support the loads of it's associated zone.

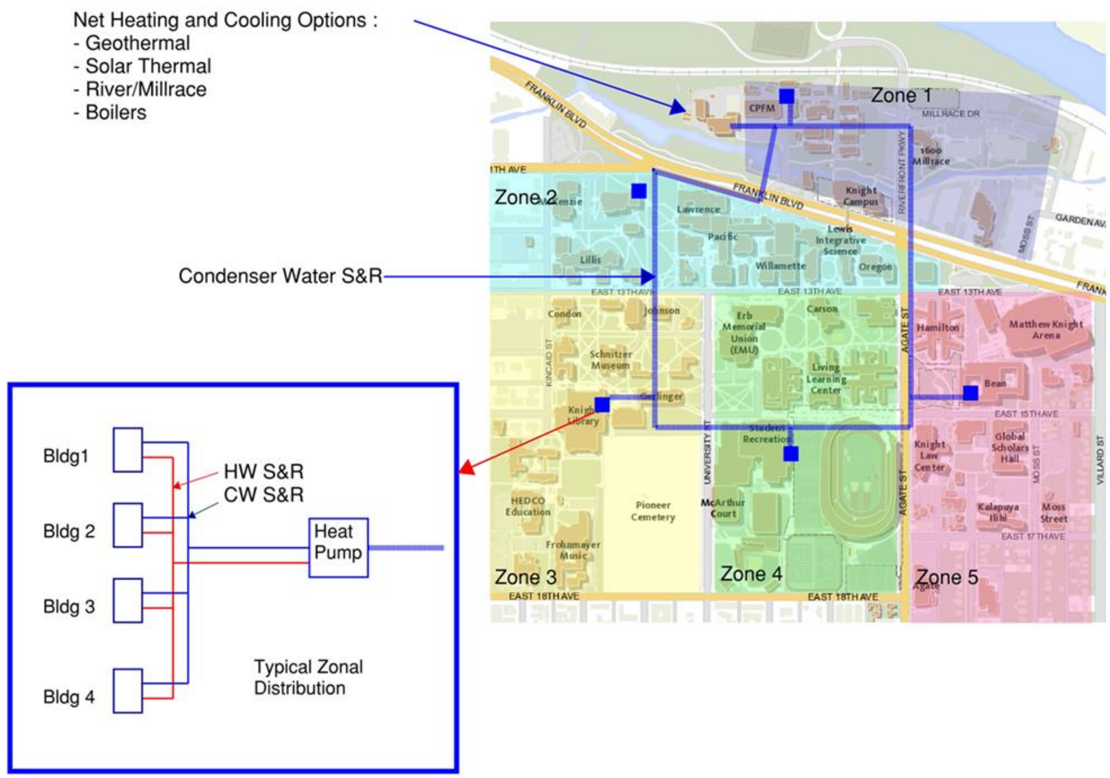


Figure 8 – Example of Potential Nodal Zones and Distribution Loop

Option 5a: Decentralization of the steam and chilled water system utilizing heat recovery plants located in each building on campus. This option replaces the central heating system by constructing a heat recovery plant in each building throughout campus to serve only the demands of the building in which they are located in.

Renewable Energy Technologies

Option 6a: Solar photovoltaic (PV) arrays. The construction and operation of solar PV arrays can be used to offset a portion of the electric power purchased from the utility grid. As the Eugene campus does not have large open spaces available for construction of solar PV arrays this option considers roof mounted PV systems on existing campus buildings.

Option 6b: Solar photovoltaic arrays with battery storage. The addition of battery storage allows renewable energy from the solar PV array(s) to be utilized when the array is not producing power, increase resiliency of the campus and to offset electric utility demand charges during periods of high electric usage.

Option 6c1: Fuel cells fueled by natural gas. Industrial fuel cells, such as those manufactured by Bloom Energy or FuelCell Energy, convert the chemical energy from natural gas to electric power through an electrochemical reaction, not combustion. A fuel cell consists of layers of an anode and cathode combined with an electrolyte. Numerous fuel cells are then grouped together into stacks. Stacks are then grouped together, with the quantity of stacks combined determining the capacity of the fuel cell. Since combustion does not take place within a fuel cell, there are no sulfur dioxide (SOx) or particulate emissions. Carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions are very low as compared to conventional combustion technologies. As with the solar PV option, fuel cells can be operated to offset the amount of electric power purchased from the utility grid.

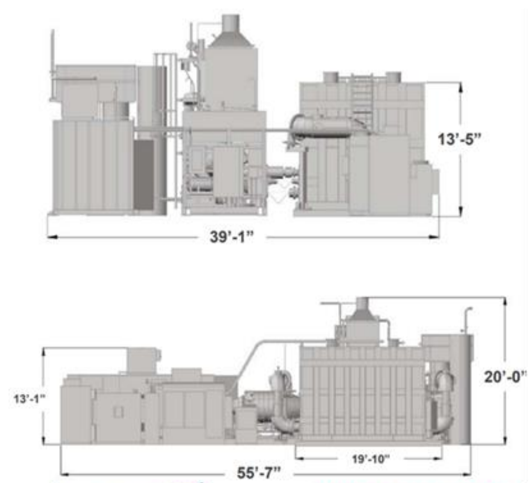


Figure 9 - Fuel Cells

Option 6c2: Fuel cells fueled by renewable hydrogen. This is the same technology as described above in Option 6c1. However, the fuel cells can be designed to utilize renewable hydrogen for the electrochemical reaction instead of natural gas.

Option 6d: Implementation of a microgrid. A microgrid is a localized electric grid that can operate independently from the central utility power grid to generate, control and distribute power. A campus microgrid would consists of an advanced control system to manage distributed renewable generation assets combined with the existing combined heat and power generation system to control operation of each asset, improve efficiency, and resiliency of utility systems on campus.

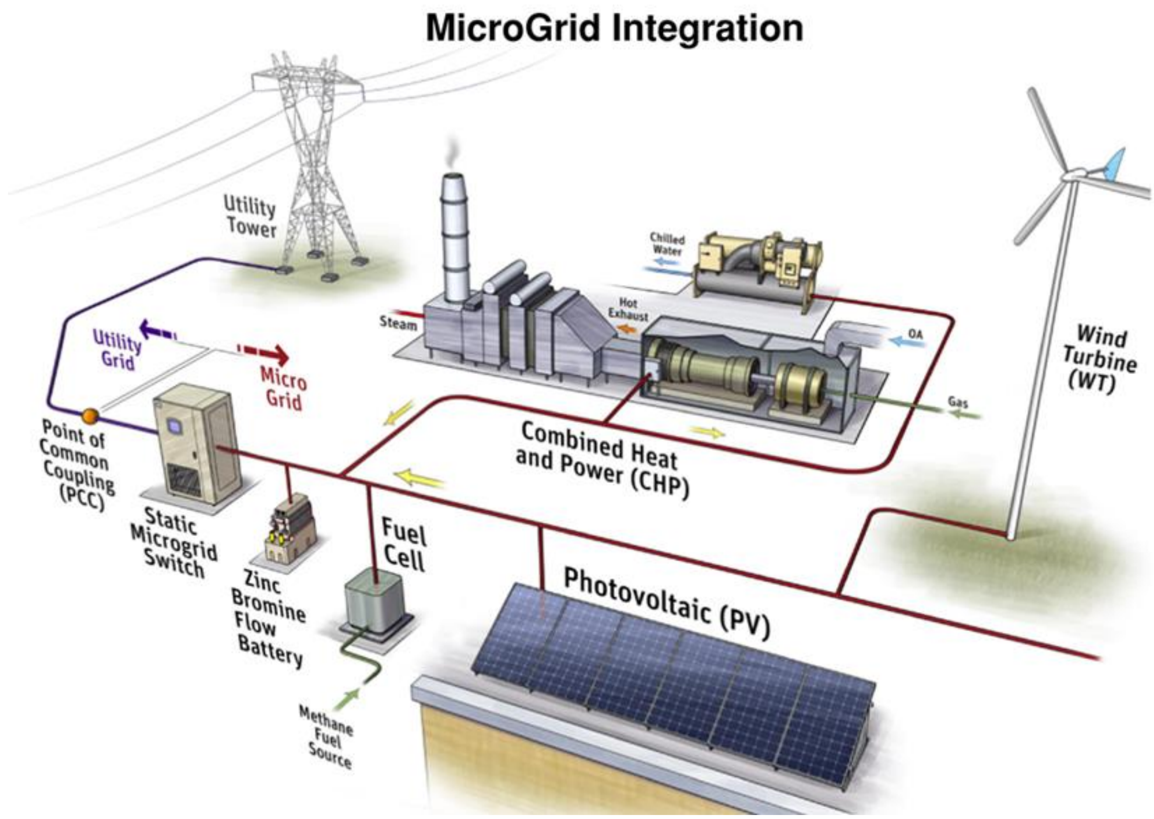


Figure 10 - Microgrid Example

Option 6e: Supplementing renewable power options with carbon offsets and renewable energy credits. As with Option 1c described earlier, the purchase of carbon offsets and renewable energy credits (RECs) can be combined with the implementation of renewable power options to attain GHG reduction targets that cannot be practically reached with on-site renewable energy systems alone. The annual purchase of carbon offsets and/or RECs can be used as credit towards the University's GHG inventory.

Option 6f: Renewable hydrogen supplementing natural gas consumption. When the production of hydrogen is generated from renewable energy sources such as solar PV and wind energy, the resulting hydrogen is considered renewable. This source of renewable hydrogen can then be used to fuel boilers. As the quantity of fuel necessary to operate boilers would exceed the quantity of renewable hydrogen practically available, this option considers renewable hydrogen as a supplement to natural gas.

4.1 Steam Generation

Several options have been considered that would utilize the existing steam generation equipment and distribution. These options are considered with the intent of exploring the potential to minimize capital costs while maximizing realization of investment in existing assets. The Business as Usual (BAU) case consists of existing equipment maintained and operated as-is. This is the base line case for which other options will be compared to.

The existing plant includes one Solar Taurus 70 Combustion Turbine Generator (CTG) with a HRSG equipped with a bypass duct. The bypass duct allows the combustion turbine to operate in a simple cycle mode, thus bypassing exhaust gases from the CTG directly to an exhaust stack instead of through the HRSG. The CPS was designed with space available for a second CTG and HRSG.

Option 1b considers the BAU case with existing boilers firing renewable natural gas (RNG) in place of, or supplementing, the use of natural gas. As RNG is a developing market this option serves only as a potential long term strategy due to reliance on a third party for project development, a high cost of the fuel and limited production capability. While the use of RNG would result in a reduction of scope 1 GHG emissions from the existing boilers, the high costs of designing, constructing and operating a local and dedicated source to generate and distribute RNG to the CPS, in the quantity required for operation of the existing boilers, currently renders this option impractical.

Oregon Senate Bill 98 set voluntary targets for adding RNG into the natural gas utility distribution in the state. Targets for implementation increase gradually up to thirty (30) percent RNG by the year 2050. As of the writing of this report NW Natural Gas has agreements to procure RNG and is pursuing the development of RNG production projects to supplement their current natural gas distribution. However, the procurement and production projects are not intended for direct supply to the University but rather will interconnect with NW Natural's distribution network for supply throughout the state. The limited mix of RNG (30% by 2050) and the lack of a dedicated supply to the University restricts the ability of this option to attain the University's GHG reduction targets.

Option 1c considers the purchase of allowances or offsets or regional investments. This option does not reduce Scope 1 GHG emissions. However, while there is currently no Cap and Trade legislation in effect in Oregon, it is expected that this may become law at some point in the future. This option is considered to evaluate the potential for utilizing it as transitional strategy to provide financial flexibility for the University and demonstrate the University's commitment to sustainability while on-campus GHG reduction strategies are in planning and/or construction. As there is no cap and trade program in Oregon, the cost of carbon allowances in the State of California is used as a proxy for the financial analysis of this option.

Option 1d proposes the replacement of an existing fossil fueled boiler with an electrode steam boiler. Either one or both existing boilers may be replaced. Electrode boilers can provide the required steam capacity and pressure necessary to meet current and future heating demands at a much higher thermal efficiency and would eliminate the majority of scope 1 GHG emissions. An electrode steam boiler with the same capacity as one of the existing boilers also has a much smaller footprint that the existing boiler. However, the use of an electrode boiler would significantly increase the electric power demand (and resulting utility costs) of the CPS. The operating cost of electric power versus natural gas, costs of necessary electrical upgrades to support the significant increase in electrical load, and continued maintenance of fossil fueled boilers as a backup will factor into the difference of long term operating costs for electric versus gas fired boilers.

Based on a Cleaver Brooks electrode boiler, model CEJS 1800, operating at 60,000 lb/hr at 125 psig, the electrical power requirement of a single boiler is approximately 18 MW. The campus electrical distribution system has sufficient capacity to support a single electrode boiler of this capacity. Additional campus standby power capacity and a load shedding scheme would need to be evaluated with this option to maintain resiliency in the event of an electric power outage. Additional onsite power generation and/or maintaining the natural gas fired boilers is recommended to provide resiliency if an electrode boiler is utilized as a primary source of heating. Significant and costly upgrades will be necessary for the public utility and the campus electrical distribution systems to support the addition of two electrode boilers of this size.

Option 1e addresses Energy Conservation Measures (ECMs) at individual buildings throughout campus. The objective of ECMs is to reduce the heating and cooling demands of buildings, thus reducing Scope 1 and 2 emissions. The University has commissioned an on-going assessment of campus buildings to determine existing conditions and recommended improvements. The University's Capital Plan also notes several projects currently in progress or planned to improve heating and cooling systems in various buildings. A survey and analysis of individual buildings is beyond the scope of this study. Thus this study does not propose specific ECMs to be implemented in campus buildings. The projected increase in efficiency due to building improvements is factored into the analysis of load profiles and growth factors for heating and cooling demands.

Option 1f proposes that the existing Clean Steam Generator in the CPS be decommissioned, thus allowing boiler steam generating pressure to be reduced from 135 psig to 100 psig. Reducing the boiler steam generating pressure would reduce boiler fuel consumption, boiler radiation and convection losses, and boiler blowdown and steam distribution losses. Based on discussions with the boiler vendor it is estimated the lowest pressure the existing boilers can be operated without adverse effects, such as carryover and poor circulation, is 100 psig. Clean steam demands that are supplied by the existing Clean Steam Generator will then be supplied by new and smaller clean steam generators located at the individual buildings. These new, smaller clean steam generators can be electric powered instead of natural gas fired.

4.2 Hot Water Conversion

The options for hot water conversion are grouped according to the plant level technology employed for hot water generation. Under the Option 2 group, the options range from retention of the steam boilers coupled with conversion of steam to hot water via heat exchangers, to replacement of the existing steam boilers with hot water boilers. Reduced operating pressure (and associated savings) at the steam boilers is also possible once the existing central clean steam generator in the heating plant and associated centralized clean steam distribution is decommissioned. The Option 2 group assumes the central clean steam generator is decommissioned and replaced with local electric powered clean steam generators at individual buildings. The Option 2 group could be further augmented in terms of carbon performance by the use of renewable natural gas (for either the steam or hot water boilers). However, as noted above in the discussion of Option 1B, the availability of RNG is limited.

Option 3 converts fossil fueled steam generation to electric, replacing all steam boilers with electric hot water boilers. The Eugene Electric and Water Board (EWEB) sources it's electric power generation largely from hydroelectric power stations. Almost eighty percent of power sourced by EWEB is from hydroelectric power, with the remaining coming from a mixture of conventional and other renewable energy sources (wind, solar, biomass). EWEB states that approximately ninety percent of their power is generated from carbon-free resources. Thus the use of electrode boilers takes advantage of the very low carbon content of the EWEB energy mix.

The Option 4 group also switches the base heating loads to an electric generation source, but does so with much more efficient heat recovery chillers. The base option focuses the use of heat recovery chillers on simultaneous heating and cooling loads, while the other options expand the use of heat recovery chillers via thermal storage and alternate thermal sources (refer to section 4.3 of this report for an expanded discussion of alternate sources).

The distribution system conversion is the same for all heating hot water options. Costs and operating assumptions are based on conversion of the entire campus distribution system to hot water and assume a direct-buried network of hot water supply and return piping routed throughout campus. Routing of new hot water supply and return piping will largely mimic the existing steam distribution system, including similar features, such as the dual feeds under Franklin Boulevard. The existing 60 psig steam distribution would be phased out (with remaining steam needs met locally). Hot water supply temperature will be optimized based on future building temperature sensitivity. Based on observations of the existing utility tunnels and discussion with University staff, direct-buried piping is considered the only practical option due to the congestion and pinch points in the existing tunnel system.

The conversion of steam to hot water distribution will require a concerted planning effort to phase construction activities and reduce disruptions to campus activities. Construction activities are expected to include partial closing of streets, re-routing of traffic, and short term service interruptions.

Building conversions to connect to a new hot water heating distribution network assume direct connection of the building space heating hot water systems to the campus hot water distribution system. Exceptions to this are where glycol is currently used in a building heating system. Double-wall plate-and-frame type heat exchangers are assumed for domestic hot water system connections to the campus hot water distribution system. Building conversions also include allowances for replacement of any steam heating coils with hot water coils and elimination of sources of bypass in existing building systems. Heating hot water systems require a high delta-T to operate efficiently and cost-effectively. This study accounts for conversions only for those buildings that are currently served by steam heating.

Figure 11 - Distribution System Conversion Example

Figure 12 - Distribution System Conversion Example

4.3 Alternate Thermal Sources

The list of potential alternate sources of thermal energy is potentially long and includes building relief and exhaust air, open water sources (well or river), closed loop geothermal sources, city water mains, sewer mains, solar thermal systems, and ambient air.

Geothermal systems take advantage of a sustainable and potentially significant source of energy. However, the high construction costs and significant land use requirement for a geothermal system eliminates it from further consideration on the Eugene campus.

The other potential alternate thermal energy sources require multiple connections in order to aggregate a sufficiently large capacity to support campus heating. For this reason, the focus of our review of alternate thermal sources has been on the existing Millrace water right, which earmarks 6,000 GPM for industrial use. This water right was established since it was originally intended as condenser water for the chiller plant. The water right represents a potential 2,500 ton supplemental heat source (or sink), assuming a 10 degree delta-T is achievable. The design and construction of new infrastructure (i.e. piping, pumps, heat exchanger) will be required to utilize the Millrace as a thermal source. Property ownership and rights of way must be considered and will factor into the determination of routing of new piping. Additionally, implementation of this option may also require the rehabilitation of the Millrace, thus greatly increasing the scope and capital costs of such a project.

Another alternative thermal energy source that often proves most practical for use is building relief, or building exhaust. This can be augmented when appropriate by forcing buildings into full or expanded economizer mode during the heating season. AEI recommends these sources be incorporated into a set of guidelines for future building designs and retrofit of existing buildings as the campus moves toward realization of its GHG reduction goals.

4.4 Decentralization

Decentralized heating/cooling plants may present an efficient way to transition away from using existing infrastructure in phases and may be scalable for campus growth. Opportunities for distributed heat and cooling generation have been explored through the analysis of the existing building inventory and campus distribution. Any strategies for decentralization are also informed by campus planning and are dependent on the real estate required for remote utilities.

Decentralized heating and cooling plants offer the advantage of a simpler method of recovering waste heat from building resources, such as exhaust air. Equipment sizing is also smaller and the effect of an equipment failure is limited to the building, or few buildings, served by that plant. The option of constructing a heating/cooling plant in each building throughout campus also has the advantage of eliminating the need for constructing a new distribution piping network throughout the campus.

The disadvantage of a decentralized option is that capital and maintenance costs are significantly higher than a centralized plant system due to the multiple plants that must be constructed and the greater quantity of major equipment that must be operated and maintained. Limitations on available real estate in which to locate new heating/cooling plants is another disadvantage. Considering the much greater quantity of major equipment and lack of available real estate in existing buildings, a decentralized option that consists of a plant in each building was omitted from further consideration as impractical and cost prohibitive.

4.5 Renewable Technologies

A list of renewable technology options was developed with the intent of being combined with other options to enhance or expand their impact on reducing GHG emissions and achieving the University's goals.

Solar Photovoltaics (PV), possibly combined with battery storage, would provide 100% carbon-free electricity generation. Implementation of a solar PV plus storage project could be accomplished through direct UO ownership, community or third party partnerships, or power purchase agreements. As noted earlier in the option descriptions, solar PV and battery storage technologies would offset electric power purchased from the utility grid, thus reducing the University's scope 2 GHG emissions.

Advantages of a solar PV and/or battery storage system include:

- Low operation and maintenance costs (as compared to conventional power generation systems)
- Relatively short design and construction durations
- Hedge against rising electric power rates

However, there are a number of considerations that make solar PV and battery storage systems impractical to make a significant contribution to meeting the University's targets for this study. The Eugene campus does not have large open spaces available for construction of solar PV arrays, this limits consideration to roof mounted PV systems on existing campus buildings. Existing roof mounted equipment, safety considerations, structural loading, and aesthetic concerns would further limit available real estate for solar PV arrays. From a financial perspective, solar PV and battery storage projects perform well when electric utility tariffs are high. The relatively low cost of power purchased by the University challenges the financial performance of renewable technologies. This is especially notable when considering the current high costs of battery storage systems. Battery systems serve to increase resiliency by providing power during periods when generation systems are inoperable and to reduce utility costs by discharging during periods of high electric power demand, thus offsetting utility demand charges. Given the current cost of battery systems, investment in energy storage systems is typically rationalized when demand charges are approximately $15/kW or higher. The University's current electric tariff includes a demand charge of $2.87/kW. With this large disparity, it is likely that a battery storage system may experience a significant reduction in capacity and useful life before the University can realize a payback on the investment.

Fuel cells are another electric power generation technology that would result in the reduction of the University's scope 2 GHG inventory. Fuel cells use an electrochemical reaction to generate electricity from natural gas or renewable natural gas as a fuel source. Fuel cells are a reliable and proven technology that benefits from very low emissions. But fuel cells remain a very expensive technology option with installed costs ranging from approximately $7,000/kW to $9,000/kW. Thus a 1 MW installation can have a capital cost from $7,000,000 to as high as $9,000,000. With a current campus electric peak load of nearly 13 MW[1] and a relatively low cost of utility power that is generated from predominantly renewable energy resources, the purchase of fuel cells is cost prohibitive and only results in a low impact to the University's GHG emissions inventory.

A campus microgrid could combine distributed renewable generation assets with the existing combined heat and power generation system to control operation of each asset, improve efficiency, and resiliency of utility systems on campus. The advanced control system of a microgrid can only be realized with the installation and operation of multiple generation sources on campus.

As with the renewable technologies noted above, another option under consideration would be to supplement primary power generation options with carbon offsets, renewable energy credits (RECs), or other allowances. As the purchase of carbon offsets or RECs does not modify or construct any new systems on campus, it does not result in the reduction of GHG emissions resulting from campus operations. However, this could be used as a transitional strategy, prior full implementation of other options, to help manage near term capital costs while demonstrating the University's commitment to reducing GHG emissions.

5.0 Preliminary Screening

5.1 Qualitative Evaluation Criteria

Net present value (NPV) is the best single economic indicator of overall performance for infrastructure upgrades. NPV has been determined for viable options as part the life cycle cost analysis (LCCA) for this study. However, NPV does not assess some of the subjective aspects of each option, which are also important in the decision making process and must be considered. While there are many options that can contribute to reduce GHG emissions, not all options are practical or feasible for implementation to support achieving the University's targets.

As part of the preliminary screening process qualitative evaluation criteria were developed and applied to each option to determine initial feasibility. The qualitative evaluation criteria consists of several questions, requiring either a 'Yes' or 'No' response. Options that received a Yes response for all evaluation criteria were considered for further investigation. Options that cannot meet all criteria with a Yes response either do not meet minimum requirements for consideration as being feasible or do not have the ability to be a major contributor to meeting the GHG reduction targets. Table 1 lists all the options that were considered and the qualitative evaluation criteria.

[1] University of Oregon Strategic Energy Management Plan, FY20-21 Edition

Based on the results of the qualitative evaluation criteria and discussions with University staff during a Preliminary Screening workshop, only the options listed below were determined to be suitable for further consideration.

- **Option 1b.** Business as usual with existing boilers firing RNG
- **Option 1d.** BAU with electric steam boilers
- **Option 2a1.** Hot water conversion with steam to hot water converters and reducing steam operating pressure
- **Option 2a2.** Hot water conversion with steam boilers firing RNG
- **Option 2b.** Hot water conversion with converters initially and hot water boilers replacement over time
- **Option 3.** Hot water conversion with electric boilers
- **Option 4.** Hot water conversion with heat recovery chillers
- **Option 4a.** Hot water conversion with hot thermal energy storage
- **Option 4b.** Hot water conversion with use of Millrace, waste water, building exhaust or geothermal as a thermal source.
- **Option 5.** Decentralize and locate nodal heat recovery plants across campus
- **Option 5a.** Decentralize with heat recovery plants in campus buildings

Table 1 - Options and Qualitative Evaluation

Option	Maintain Critical Loads	Phased Impplementation	Fuel/Thermal Source Available	Fuel/Thermal Source Reliability & Quantity	No 3rd Party Developer Project	Meets Environmental Restrictions	Reduce Scope 1 Emissions
1. BAU - Central steam and electric chilled water generation and distribution, CHP as backup power. Future chilled water TES							
1a. BAU w/ addition of CTG-2	Y	N	Y	Y	Y	Y	N
1b. BAU, existing boilers firing RNG	Y	Y	N	N	N	Y	Y
1c. BAU w/ purchased offsets, RECs or regional investments	Y	Y	Y	Y	Y	Y	N
1d. BAU w/ electric steam boilers	Y	Y	Y	Y	Y	Y	Y
1e. BAU w/ ECMs at buildings	Y	Y	Y	Y	Y	Y	Y
1f. BAU w/ reduced steam pressure and remove CSG	Y	Y	Y	Y	Y	Y	Y
2a1. HW conversion w/ S2HWC and reduced operating pressure	Y	Y	Y	Y	Y	Y	Y
2a2. HW conversion w/ steam boilers fired by RNG	Y	Y	N	N	N	Y	Y
2b. HW conversion w/ converters initially, HWB replacement over time	Y	Y	Y	Y	Y	Y	Y
2c1. HW conversion w/ HWBs on day 1	Y	N	Y	Y	Y	Y	Y
2c2. HW cnversion w/ HWBs firing RNG	Y	Y	N	N	Y	Y	Y
2c3. HW conversion w/ HW biomass boilers	Y	Y	N	N	Y	Y	Y
3. HW conversion w/ electric boilers	Y	Y	Y	Y	Y	Y	Y
4. HW conversion w/ heat recovery chillers	Y	Y	Y	Y	Y	Y	Y
4a. HW conversionw/ hot TES	Y	Y	Y	Y	Y	Y	Y
4b. HW conversion w/ alternate sources (Millrace, waste water, building exhaust, solar thermal, air source, geoexchange)	N	Y	Y	Y	Y	Y	Y
5. Decentralize and locate nodal heat recovery plants across campus	Y	Y	Y	Y	Y	Y	Y
5a. Decentralize w/ heat recovery plant in buildings	Y	Y	Y	Y	Y	Y	Y
6a. Solar PV	N	Y	Y	Y	Y	Y	N
6b. Solar PV with battery storage	N	Y	Y	Y	Y	Y	N
6c1. Fuel cells w/ natural gas	N	Y	Y	Y	Y	Y	N
6c2. Fuel cells w/ renewable hydrogen	N	Y	N	N	N	Y	Y
6d. Microgrid	Y	Y	Y	Y	Y	Y	N
6e. Supplement other renewable options with offsets and RECs	Y	Y	Y	Y	Y	Y	N
6f. Renewable hydrogen supplementing natural gas consumption	Y	Y	N	N	N	Y	Y

While the use of RNG would result in a reduction of scope 1 GHG emissions from the existing boilers, the high costs of designing, constructing and operating a local source to generate and distribute RNG to the CPS renders this option financially impractical. Additionally, a limited production capacity from an RNG project is further expected to restrict the ability of this option to attain the University's GHG reduction targets. For these reasons, Option 1b. BAU with existing boilers firing RNG, and Option 2a2. Hot water conversion with steam boilers firing RNG, were removed from consideration of a detailed analysis.

Option 1c. Business as usual with purchased offsets, RECs, or regional investments did not receive a 'Yes' response for all evaluation criteria. However, this option may be an important and viable strategy to demonstrate the University's commitment for reducing GHG emissions during a transitional period. Given this, the cost of purchasing offsets are considered further in the study.

Option 1e. Business as usual with energy conservation measures (ECMs) at buildings meets all qualitative evaluation criteria with a Yes response. This option requires a continuous effort to evaluate, design and implement modifications to existing buildings to increase operating efficiency and reduce heating and cooling demands. The University already has an on-going effort to improve existing heating and cooling systems in existing buildings. A detailed survey of buildings on campus to determine viable ECMs for each building is beyond the scope of this study. This study does not propose specific ECMs to be implemented in campus buildings but rather the projected increase in efficiency due to building improvements is factored into the analysis of load profiles and heating system capacities.

The group 2 options retain the operation of the existing natural gas fired steam boilers and convert steam to hot water via heat exchangers. Option 2b plans for the replacement of the steam boilers, when they reach end of life, with hot water boilers. The group 2 options benefit from the reduced losses of a hot water distribution system versus steam distribution. These options incur the cost of converting the distribution system (and associated building conversions), which comprises more than eighty percent of costs for implementing these options. However, only a relatively small increase in efficiency and GHG reduction is realized due to the operation of the gas fired steam boilers. These options cannot achieve the GHG reduction targets. In view of the costs incurred with limited reduction in GHG emissions the group 2 options were omitted from further examination.

Option 3 replaces existing natural gas fired boilers with electrode boilers and implements a conversion of the existing steam distribution system (and steam heating in campus buildings) to a heating hot water system. As noted earlier, significant and costly upgrades will be necessary for the public utility and campus electrical distribution systems to support the operation of two electrode boilers. The addition of campus standby power systems and a load shedding scheme would also need to be re-engineered with this option to maintain resiliency in the event of an electric power outage. Additional onsite power generation or maintaining natural gas fired boilers is recommended to provide resiliency when electrode boilers are utilized as the primary source of heating. These concerns, combined with the significant increase in electric utility costs and costs of converting the campus to a heating hot water distribution system render Option 3 cost prohibitive.

Option 4a is similar to Option 4, consisting of a heating hot water conversion and heat recovery chillers but adds the construction of hot thermal energy storage. Thermal energy storage tanks demonstrate their value in managing time of use utility rates, acting as a thermal battery that is charged during periods of low utility costs and discharged during periods of higher utility costs. The University is not subject to a time of use electric tariff and this study assumes the rate structure remains consistent throughout the period of analysis. The University is planning on the construction of a chilled water TES to allow the existing chilled water system to operate more efficiently during the cooler night time hours and to supplement peak chilled water capacity. These needs would not apply to a new heating hot water system. A hot TES tank may be operated in conjunction with a cold TES to increase simultaneous production, however increases in operating efficiency are expected to be marginal. A disadvantage of TES tanks is the physical space required for storing several hundred thousand gallons of water or more. Limited real estate is available near the CPS to accommodate such a large footprint in addition to the already planned chilled water TES. The marginal efficiency increase with limited or insufficient real estate eliminated a hot TES from further consideration in this study.

Option 4b. Hot water conversion with alternate sources did not meet all qualitative evaluation criteria required as these alternate thermal sources cannot provide sufficient thermal capacity to meet critical loads. The high construction costs and significant land use requirement for a geothermal system eliminates it from further consideration on the Eugene campus. The other potential alternate thermal energy sources require multiple connections in order to aggregate a sufficiently large capacity to support campus heating. Due to this requirement the focus of analysis of alternate thermal sources is on the existing Millrace water right.

As noted earlier, the disadvantage of a decentralized option is that capital and maintenance costs are significantly higher than a centralized plant system due to the multiple plants that must be constructed and the greater quantity of major equipment that must be operated and maintained. Considering the much greater quantity of major equipment and lack of available real estate in existing buildings, a decentralized option that consists of a plant in each building was omitted from further consideration as impractical and cost prohibitive.

6.0 Detailed Option Development

Options that have been selected for detailed analysis are described below. A diagram of each option integrated with existing systems is provided in the Appendix. The following table lists the options identified for further study during the November 04, 2020 workshop. The short list of options deemed viable and subjected to detailed analysis were renumbered for the remainder of this report for simplicity.

Option #	Option Description
1	Business As Usual
2	Business As Usual with Electric Steam Boilers
3	Heating Hot Water Conversion with Heat Recovery Chillers

Option #	Option Description
4	Heating Hot Water Conversion with Heat Recovery Chillers and Alternate Heat Source/Sink (Millrace)
5	Decentralized with Nodal Heat Recovery Plants Across Campus

6.1 Business As Usual

Under business as usual, all equipment is replaced in kind as it reaches the end of its useful life. This includes steam boilers, chillers, cooling towers and ancillary equipment. The one exception is the cogeneration system, consisting of the gas turbine, heat recovery steam generator (HRSG) and backpressure steam turbine. Due to their limited operating hours, the life of this equipment will extend beyond the term of the net present value analysis (30 years). Maintenance costs for cogeneration system equipment will be based on recommended service for cumulative hours of operation, assuming 100 hours of operation per year. All other ancillary maintenance costs will be carried as O&M costs in the study per the UO Repair & Replacement Fund FY21 data provided by the University.

The University has commissioned an on-going assessment of campus buildings to determine existing conditions and recommended improvements. The University's Capital Plan also notes several projects currently in progress or planned to improve heating and cooling systems in various buildings. A survey and analysis of individual buildings is beyond the scope of this study. Thus this study does not propose specific ECMs to be implemented in campus buildings. The projected increase in efficiency due to building improvements is factored into the analysis of load profiles and growth factors for heating and cooling demands.

6.2 Business As Usual with Electric Steam Boiler(s)

This option takes advantage of EWEB's low carbon sources of generation and simply switches the fuel source for a large part of the campus heating load from natural gas to electricity. This option was modified as part of discussions during the Preliminary Screening Workshop to include a single, base-loaded electrode style electric boiler, rather than two electrode style boilers, in order to avoid the major electrical system upgrade that the second boiler would require, while still allowing a high percentage of annual campus loads to be met with electric power.

Under this option, a single 18 MW medium voltage electrode boiler will be provided and used to meet base steam heating loads; the boiler will be similar to the Cleaver-Brooks CJES 1800, and will roughly match the 60,000 pph output capacity of one of the existing boilers. The use of medium voltage power eliminates the need for any additional transformation and the associated parasitic energy loss. A additional consideration for the installation of an electrode boiler of this capacity is the effect it may have on the University's electric power rates. A single large electrical load of 18 MW may result in changes to the University's power sales agreement, potentially incurring increases in delivery and/or demand charges. The impact of such changes are not known and thus are not included in the cost analysis of this report. A load impact study performed by EWEB and agreement with EWEB and the

Bonneville Power Administration (BPA) will be required to determine the cost impact of this single large load.

The electrode boiler will be installed on ‘Day One’ in an expansion space within the plant, likely the space allocated for a second combustion turbine and HRSG assembly. It will act as the lead boiler and will carry a very high proportion of the annual load, approximately 85% of the time. This will allow all existing boilers to remain in place as backup devices, to improve campus resilience and to meet peak heating demands.

The oldest remaining boiler (#1) will be replaced in 2032 per the campus utility budget and debt issuance plan. The second oldest gas-fired steam boiler (#2) will remain in service beyond its normally expected service life, in order to maintain backup heating capability (it is assumed that this boiler will have an extended life due to reduced operating hours under this option). The electrode boiler will be replaced in 2043 after 20 years of service per ASHRAE Applications Handbook Table 4 for Service Life Estimates. All five existing chillers will be replaced in 2032 at the end of their useful lives and as their debt is retired. As noted previously under the BAU option, the cogeneration equipment will remain for the life of this study, due to its limited hours of operation and provision for resiliency.

Under this option, the existing steam distribution system remains as is, and no building conversion work to a hot water heating system is necessary, avoiding the cost and disruption of a hot water conversion throughout campus. All other ancillary maintenance costs will be carried as O&M costs in the study per the UO Repair & Replacement Fund FY21 data provided by the University.

6.3 Heating Hot Water Conversion with Heat Recovery Chillers

Under this option, the campus heating system distribution will be converted to a hot water distribution system. The campus conversion will be phased, with the science campus converted in Phase 1 and the remainder in Phase 2. Steam-to-hot water convertors will be used to generate hot water at the central utility plant initially, along with a single 1000 ton heat recovery chiller, located in a chiller expansion bay in the chiller room. A second heat recovery chiller will be added when distribution conversion phase 2 is implemented in 2032, taking the place of one of the (5) 1500 ton conventional chillers as those (5) machines are replaced and new debt service implemented. The initial sizing estimates are (1) 1000 ton cooling heat recovery chiller on Day One, with a second 1000 ton (cooling) chiller in 2032. When boiler 3 reaches the end of its useful life in 2032, it will be replaced by a hot water boiler. Boiler #2 will remain in place as a backup device through the life of this study, providing backup via the steam-to-hot -water convertors.

As with other options, the cogeneration system equipment will be left in place as backup for campus resilience, with a life expectancy exceeding the life of this analysis due to limited equipment use. In addition to the heat recovery chillers, a new campus hot water pumping system will be added to serve the new hot water distribution system. Two pumps will be installed initially, with a third added to serve Phase 2 loads in 2032.

The conversion of the campus heating system to a hot water based distribution system will require installation of a parallel hot water distribution system on 'Day One', serving the Phase 1 area of conversion, along with conversion of all buildings within the Phase 1 zone to use hot water as their heat source. Phase 2 of this implementation follows for the remainder of campus in 2032. This distribution system implementation and building conversions are described further in the Appendix.

All other ancillary maintenance costs will be carried as O&M costs in the study per the UO Repair & Replacement Fund FY21 data provided by the University. With the exception that the steam tunnel piping annual maintenance line item will be avoided and new maintenance costs for the heat recovery chillers and hot water pumps are added.

6.4 Heating Hot Water Conversion with Heat Recovery Chillers and Alternate Heat Source/Sink (Millrace)

The option is very similar to the one above, but this option includes the incorporation of an alternate heat source on Day One. The alternate heat source will be assumed to be the Millrace industrial water right component, a 6000 GPM source (that is in addition to a roughly 18000 GPM aesthetic water use right). This right will be re-developed to bring river water directly to a heat exchanger at the plant. Under this option, the industrial use component of flow will be pumped directly into a pipe at the upstream point of withdrawal from the Willamette, with piping paralleling the Millrace back the CUP, where it will be run through a heat exchanger, then discharged directly to the Millrace. A number of steps are necessary to allow this option to move forward including: 1) verification with Oregon Water Resources Department (OWRD) that this water right has not been compromised due to lack of use or reporting, 2) coordination with the Army Corps of Engineers, 3) negotiation with property owners over routing of the pipe required, and 4) discovery related to obstacles in routing. Implementation of this option may require rehabilitation of the Millrace. The cost to implement this option is estimated to be between $30,000,000 and $50,000,000 and includes soft costs and the potential for hazardous material testing and abatement.

The incorporation of the alternate source/sink allows initial sizing of the heat recovery chiller(s) to be increased to approximately 1500 tons (cooling)/2000 tons (heating) on Day One, this will be in the form of (2) 750 ton heat recovery chillers for redundancy. Two additional 1500 ton (cooling) heat recovery chillers will be added in 2032. In addition to the heat recovery chillers, a new campus hot water pumping system will be added to serve the new hot water distribution system. Three pumps will be installed initially, with two additional pumps installed to serve Phase 2 loads in 2032.

Similar to Option 3, the details of the hot water distribution system and building conversions are described in more detail in the Appendix.

All other ancillary maintenance costs will be carried as O&M costs in the study per UO Repair & Replacement Fund FY21 spreadsheet, with the exception that the steam tunnel piping annual maintenance line item is avoided, and new maintenance costs for the heat recovery chillers and hot water pumps are added.

6.5 Decentralized with Nodal Heat Recovery Plants Across Campus

The nodal plant option is similar in concept to both hot water conversion measures except that central plant heat pump equipment would be distributed into several smaller plants that are sited throughout campus, each serving zones adjacent buildings. As analyzed, approximately 10,000 tons of heat pump chiller equipment installed in six nodal plants will provide heating water and chilled water to all buildings in the campus building conversion inventory. Building heating water conversions are identical to other heat pump options except that nodal plants will have smaller localized heating water distribution piping. Existing campus chilled water distribution would be converted to a source/sink loop by connecting Millrace water system described in option 6.4 into the chilled water system through heat exchangers. Chilled water distribution will require upgrades to support the additional flow required for the nodal plants.

The design and siting of nodal plants will require careful planning and is beyond the scope of this analysis. Where it may be feasible to locate nodal plant equipment in existing or future buildings, conceptual estimating for this study is based on the use of prefabricated modular chiller plant buildings. New nodal plants will house single-story structures between 2,500 and 5,000 sf totaling roughly 20,000 sf. Nodal plants should be sited in close proximity to large bore piping in chilled water distribution and may connect to and reuse existing chilled water to distribute to the buildings. Chilled water to buildings on the north campus and Lokey Science Complex will need to be re-piped.

The nodal plant option was analyzed as a single phase of construction – a phased approach may be possible where the existing plant continues to deliver chilled water during the summer and may changeover to source/sink distribution for heat pump operation in the winter.

Nodal heat recovery plants will have many functional disadvantages compared to central plant options.

- Nodal heat pump plants may not solve chilled water distribution issues on campus because heat pump chillers will require more flow from the source/sink water loop than what is currently delivered by campus chilled water.
- Distribution piping costs are similar or potentially higher than central plant heating water conversions due to unknown constraints related to acceptable siting of nodal plants.
- Nodal plants do not have the advantage of chilled water diversity in the system and will require considerably more capacity than the existing plant or other presented options.
- Heat recovered from load dense areas of campus such as the Lokey Science Complex cannot be shared across campus resulting in lower energy performance than central plant measures.
- O&M costs for distributed plants are considerably higher, resulting from inefficiencies due to the remote location of equipment and added costs for maintenance and repair of a higher quantity of pumps, heat exchangers and chiller equipment.
- Nodal plant siting within the central campus creates negative impacts to campus real estate and aesthetics.

Additional O&M costs related to distributed equipment are included in the O&M cost summary.

7.0 Greenhouse Gas Emissions

The University of Oregon has collected and aggregated all of the University's Greenhouse Gas (GHG) emissions data since 2009 through the Office of Sustainability. The primary focus of this study is to develop strategies to reduce the Scope 1 emissions attributed to building heating demands and provide a long-term transition plan to reduce the use of fossil fuels as the primary fuel used in the district heating system. In 2018, Scope 1 GHG emissions were roughly 20,000 MTCDe and made up approximately 38% of the total GHG emissions for the campus. GHG emissions for this study are determined using the carbon dioxide emissions factor for natural gas of **0.181 MTCO2e/MWh** (117 lbs/MMBtu) per the U.S. Energy Information Administration (EIA).

Scope 2 GHG emissions, specifically the emissions associated with electricity production, are also considered in this study. The options presented will aim to transition away from natural gas toward electricity as the primary fuel used in the district heating system. EWEB sources their electric power primarily from sustainable sources. Roughly 90% of their power generation is from carbon-free resources, a majority of which is hydroelectric power. Per EWEB's 2019 operational data, the carbon dioxide emissions factor for electricity is **0.015 MTCO2e/MWh**.

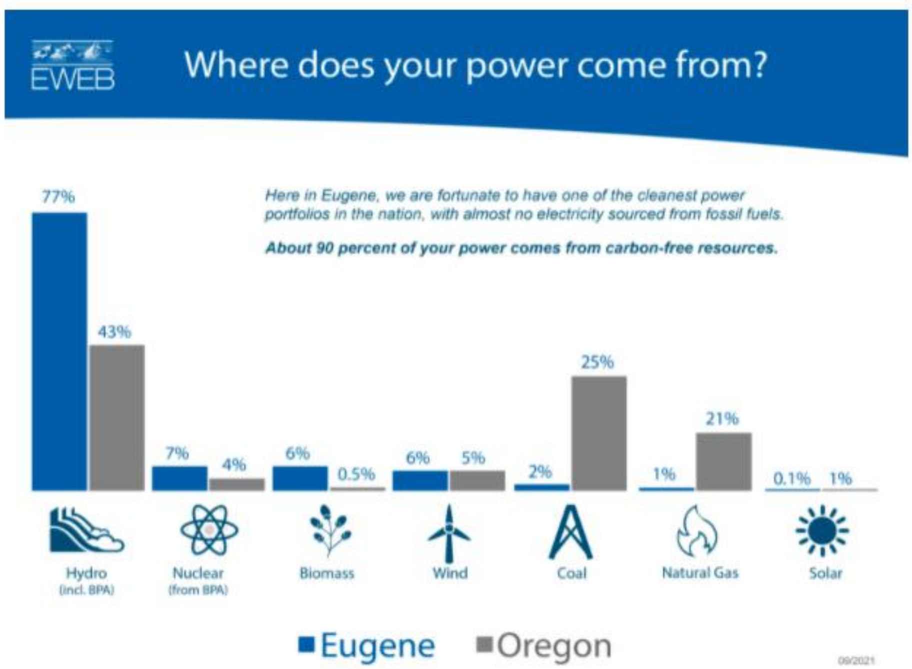


Figure 13 **- EWEB Infographic – sourced from EWEB website**

7.1 GHG Reduction Targets

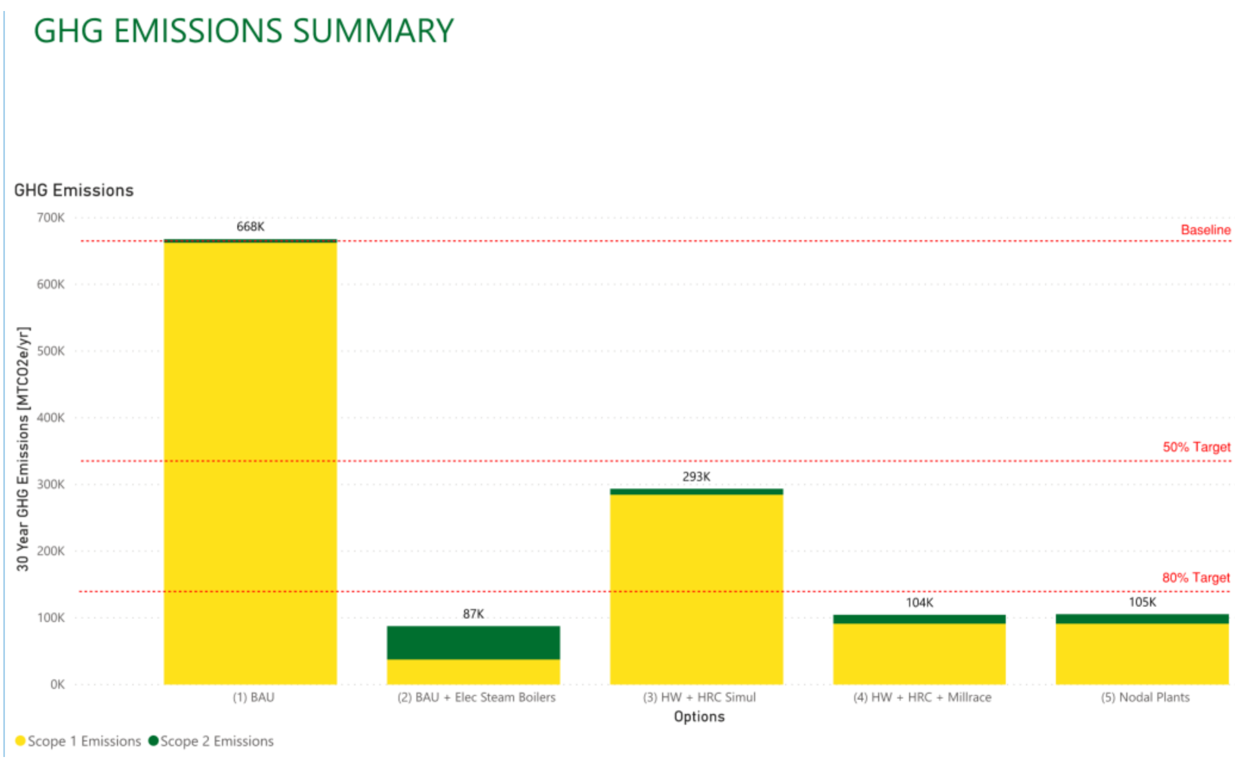
The University has identified three GHG reduction goals for consideration in the study:

- 50% campus heating emissions reduction by 2050
- 80% campus heating emissions reduction by 2050
- 100% campus heating emissions reduction by 2050

The Scope 1 and Scope 2 emissions for each of the detailed options were calculated for the 30 year study period. As discussed with the UO Thermal Systems Transition Study stakeholder group, there are two different ways of looking at the GHG reduction as described below.

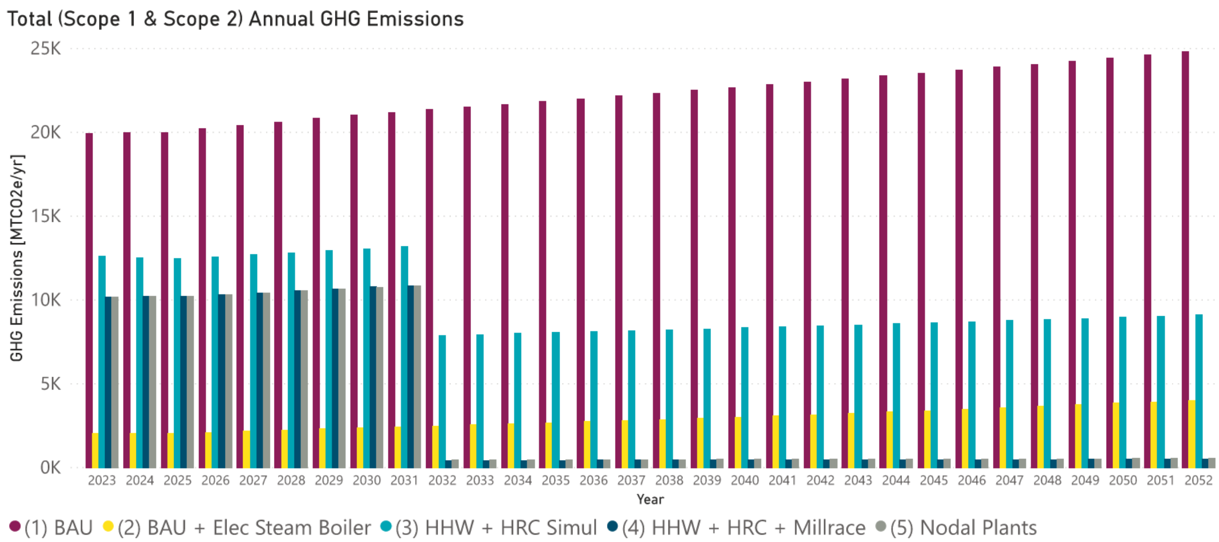
One way to consider GHG emissions reduction is to normalize all of the detailed options in this study by applying the future cost of carbon to each option; thereby including the cost of carbon offsets to bring each option to net zero GHG emissions. The financial analysis and net present costs presented at the end of this report include a scenario where GHG costs are included to capture this.

Another way to consider GHG emissions reduction is to use the BAU option as the base level of GHG emissions and calculate the percentage of GHG emissions reductions from there. This method is used to establish the 50%, 80%, and 100% emissions reduction threshold as shown in the figure below. Detailed Option 3 achieves a GHG emissions reduction of over 50% savings. The remaining Options (2, 4, and 5) achieve a similar emissions reduction to one another of over 80% savings. Using this methodology, no Option is able to fully achieve 100% emissions reduction because there is always some level of Scope 2 emissions associated with utility electricity production, in addition to the Scope 1 emissions associated with the continued use of fossil fuel boilers during the phase 1 of the transition.



The figure below illustrates the annual Scope 1 and Scope 2 GHG emissions for each year in the analysis period.

ANNUAL GHG EMISSIONS



Option 1 (Business as Usual) sees a continued increase of GHG emissions as a result of the natural gas fired steam boilers meeting the increasing heating demand on campus over time. A similar profile is observed for Option 2 (business as usual with electric steam boilers) although the magnitude of GHG emissions is significantly reduced as the fuel source for the steam boilers is now low carbon electricity.

The remaining options see a drop in GHG emissions at year 2032 because this is the assumed time period for when the Phase 2 heating hot water transition would be completed.

Option 3 (heating hot water conversion with heat recovery chillers) realizes a GHG emissions reduction from the heat recovery chillers' ability to meet a portion of the heating hot water demand when simultaneous heating and cooling demands exist on campus, with the remainder of the heating demand being met by natural gas fired hot water boilers.

GHG emissions associated with Option 4 (heating hot water conversion with heat recovery chillers and alternate heat source/sink) are tied primarily to the Phase 1 and 2 steam to heating hot water transition. The campus heating demand in Phase 1 is met by a combination of electric heat recovery chillers serving the Phase 1 heating hot water distribution and natural gas fired boilers serving the Phase 1 steam distribution. When the Phase 2 heating hot water distribution is realized in 2032, the majority of campus is served by electric heat recovery chillers that take advantage of both the simultaneous heating and cooling demands on campus as well as utilizing the alternate heat source/sink (Millrace) to provide electric heat pump based heating to campus.

Option 5 (decentralized with nodal heat recovery plants across campus) is similar in GHG performance to Option 4, however there is a slight reduction in the simultaneous heating and cooling demand across campus from having separate decentralized systems along with a minor reduction in heat pump efficiency, resulting in a slight increase in GHG emissions as compared to Option 4.

8.0 Economic Analysis

8.1 Capital Cost Estimates

Capital cost estimates summarized in this section are presented as first costs for new materials, labor and soft costs for each option. Line item estimates for new equipment were not included in the scoping study due to the complexity of the proposed work. But other metrics were used, based largely on cost data from other University campus installations. The accuracy of the estimates presented in this study may be useful for comparison of relative financial impact of measures, but more detailed scoping and analysis are recommended prior to project funding.

Cost estimates for new equipment were based on following:

- Significant equipment such as chillers and boilers based on vendor quotes with an applied factor for installation cost.
- HW distribution piping based on unit cost data from district heating water projects from AEI projects and others. For the study, heating water piping footage was estimated by using the campus inventory of steam piping and converting to heating water supply and return piping with an equivalent length. Unit costs assumed for direct buried heating water piping is $225 /in ft.
- Distributed central plant buildings and mechanical equipment were based on a vendor quote for pre-manufactured modular central plants building, and scaled up to match the tonnage required for the campus. Assumed factors for engineering, utilities and soft costs represent a roughly 250% markup. University architectural specifications may require distributed plant buildings to match the aesthetics of other existing structures, resulting in higher capital costs than estimated for this study.
- Building conversion costs based on metrics obtained from post-construction cost analysis of the Stanford SESI project, a project that AEI had developed the design for and is very similar in nature to scope analyzed in this study. Average building conversion costs at $8.75/sf.

Capital Cost summary for year zero (2023) costs for each measure presented are summarized as follows:

Option	Estimated Capital Costs
1. Business as Usual	N/A
2. Electrode Steam Boiler	$2,508,000
3. Heat Recovery Chillers – HW Conversion	$101,755,210
4. Heat recovery Chillers – HW Conversion + Alt Source	$157,192,460
5. Distributed Plants	$302,242,020

The major equipment and scope of work included in cost estimates is outlined below.

OPTION 1 Business As Usual – no new equipment except end of life replacement not included.

OPTION 2 Electrode Steam Boiler

- Electrode Steam Boiler –18MW Cleaver Brooks CJES 1800
- Installation, pad, power feeders, steam connections

OPTION 3 Heat Recovery Chiller – Simultaneous

- (2) 1000-ton York CYK Chillers and installation
- Heating water pumps, installation
- Campus Heating water Distribution
- Building Heating water Conversions
- Steam to hot water converter

OPTION 4 – Heat Recovery Chiller – Alternate Source

- (2) 1000-ton York CYK Chillers and installation
- (2) 1500-ton York CKY Chiller and installation
- Heating water pumps, installation
- Campus Heating water Distribution
- Building Heating water Conversions
- Steam to hot water converter

OPTION 5 – Distributed Plant

- TMI MPC Modular Central Plant heat pump chiller plant 900-tons, 10,200-ton capacity
- Modular chiller installation, design, soft costs, utilities
- Campus Heating water Distribution
- Building Heating water Conversions

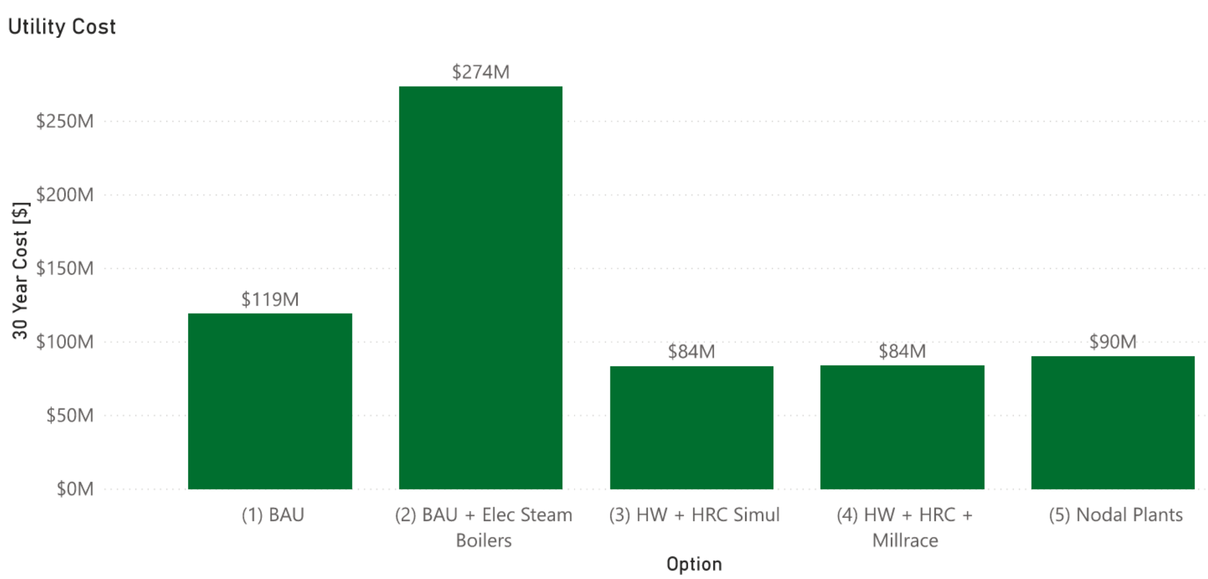
8.2 Purchased Utility Costs

Annual purchased utility costs for each Option were estimated including electricity, natural gas, water, and sewer tariffs. The table below shows the current base utility rate along with the annual escalation rate as applied throughout the analysis period.

Utility Type	Base Rate	Annual Growth Rate
Electricity (energy)	0.0431 [$/kWh]	2.56%
Electricity (demand, monthly)	2.87 [$/kW]	2.56%
Natural Gas	0.475 [$/Therm]	1.2%
Water	3.63 [$/1000gals]	4%
Sewer	6.00 [$/1000gals]	4%

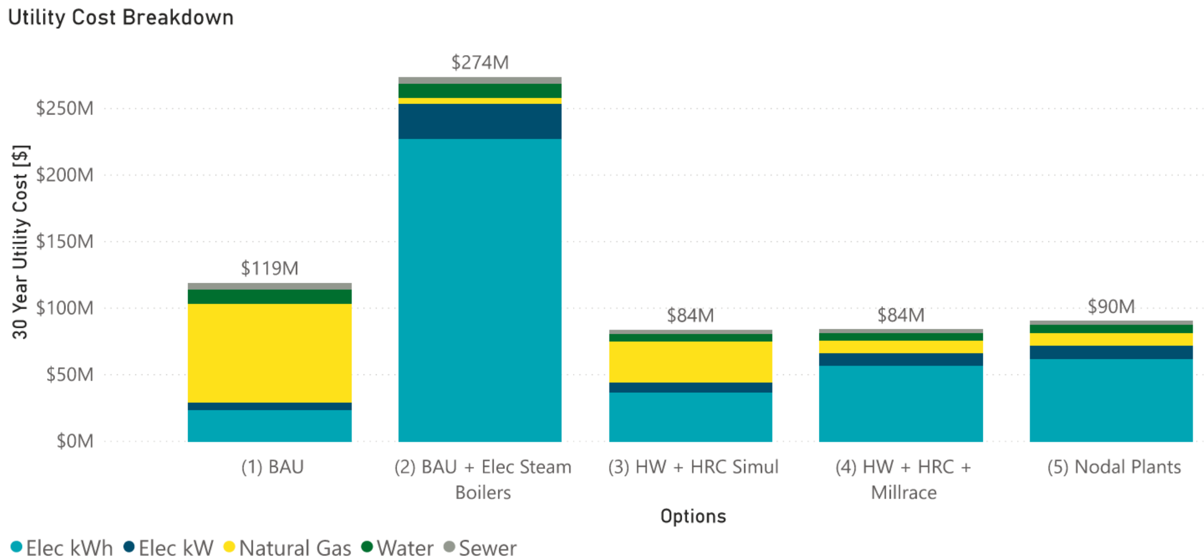
The figure below shows the estimated 30 year utility cost for each Option over the duration of the analysis period. For reference, the utility costs shown in this section have not yet been discounted to present value costs.

UTILITY COST SUMMARY



The figure below shows the estimated 30 year utility cost breakdown by utility type for each Option over the duration of the analysis period.

UTILITY COST BREAKDOWN



Option 1 (business as usual) sees all of the campus heating demand met by natural gas fired steam boilers and the associated natural gas utility cost. The remaining electricity, water, and sewer utility costs are attributed to the production of chilled water utilizing the campus water-cooled chiller plant.

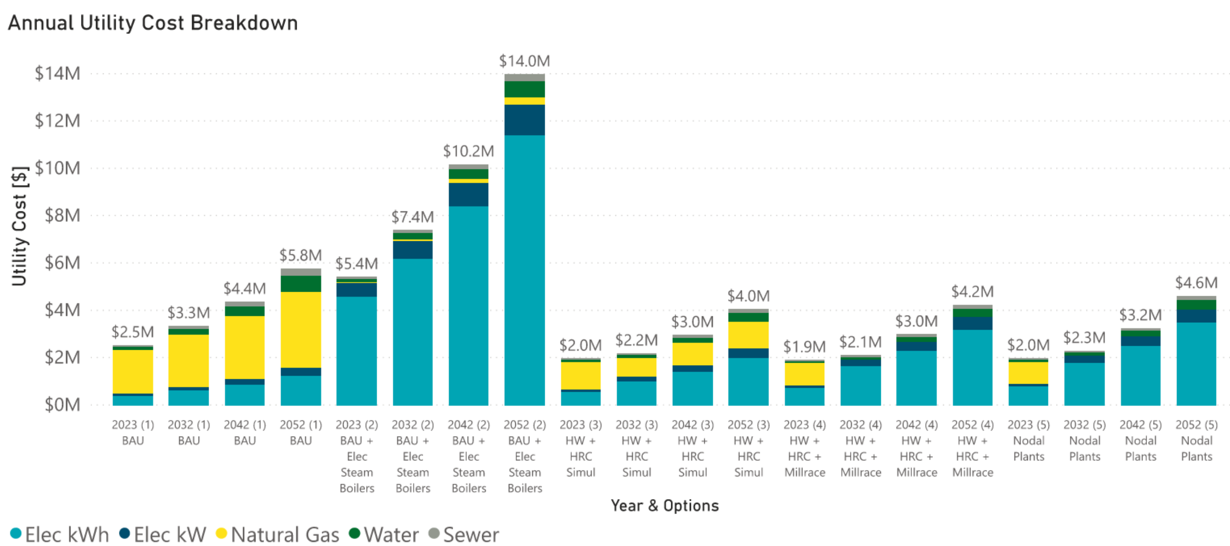
Option 2 (business as usual with electric steam boilers) has, by far, the highest total purchased utility costs due to the price of electricity and the efficiency of the electric steam boilers being close to 1 COP (Coefficient of Performance) which amounts to large energy and demand charges for purchased electricity associated with campus heating.

Option 3 (heating hot water conversion with heat recovery chillers) sees a significant reduction in purchased electricity costs, as compared to Option 2, associated with the use of heat recovery chillers and their ability to provide heating and cooling at a combined COP of 5.5 when simultaneous heating and cooling demands are present on campus. This COP is slightly conservative for the purpose of this study assuming high-lift heat recovery chillers are provided. The natural gas utility costs in this Option are associated with gas fired boilers being utilized to provide the remaining campus heating demand beyond what is met by the heat recovery chillers and simultaneous heating and cooling production.

Option 4 (heating hot water conversion with heat recovery chillers and alternate heat source/sink) and Option 5 (decentralized with nodal heat recovery plants across campus) see a majority of the campus heating demand being met by electric heat pumps and heat recovery chillers, with only a portion of the campus heating demand being provided by natural gas fired boilers in Phase 1 prior to 2032.

The figure below shows the estimated annual utility cost breakdown by utility type for representative years in the analysis period to illustrate how utility rate escalation (combined with load growth) impact the purchased utility costs over time. The years shown below represent year 1, 10, 20 and 30 of the analysis period.

ANNUAL UTILITY COST BREAKDOWN



8.3 GHG Costs

GHG emissions costs (including Scope 1 and Scope 2 emissions) were calculated for each Option and are included in one of the scenarios presented in the net present cost comparative financial performance section later in this report. Applying the future cost of carbon to each Option is a means to normalize all options to achieve net zero GHG emissions and better understand the potential future financial impacts associated with ongoing GHG emissions.

At the time of this report being published, there is no policy or regulation in place for a carbon tax or cap-and-trade program that currently applies to the University of Oregon. However, AEI and the UO Thermal Systems Transition Study stakeholder group agree that future regulation and cost of carbon is likely to emerge within the analysis period of this study (30 years) as a means to drive substantial GHG emission reductions in the State of Oregon and local economies, and therefore it's prudent to consider GHG emissions costs in one of the two net present cost scenarios. This thinking stems from observation of other policies in North America (State of California and British Columbia, for example) as well as the burgeoning movements across the United States to begin eliminating the use of fossil fuels for space heating and realize significant reductions in GHG emissions across the Country. It also manifests from Oregon lawmakers who have proposed a bill that, if passed, would create a carbon market in Oregon with links to the Western Climate Initiative (which includes California, Quebec, and Ontario). In the draft legislation covered entities include sources that meet or exceed 25,000 MTCO2e annually.

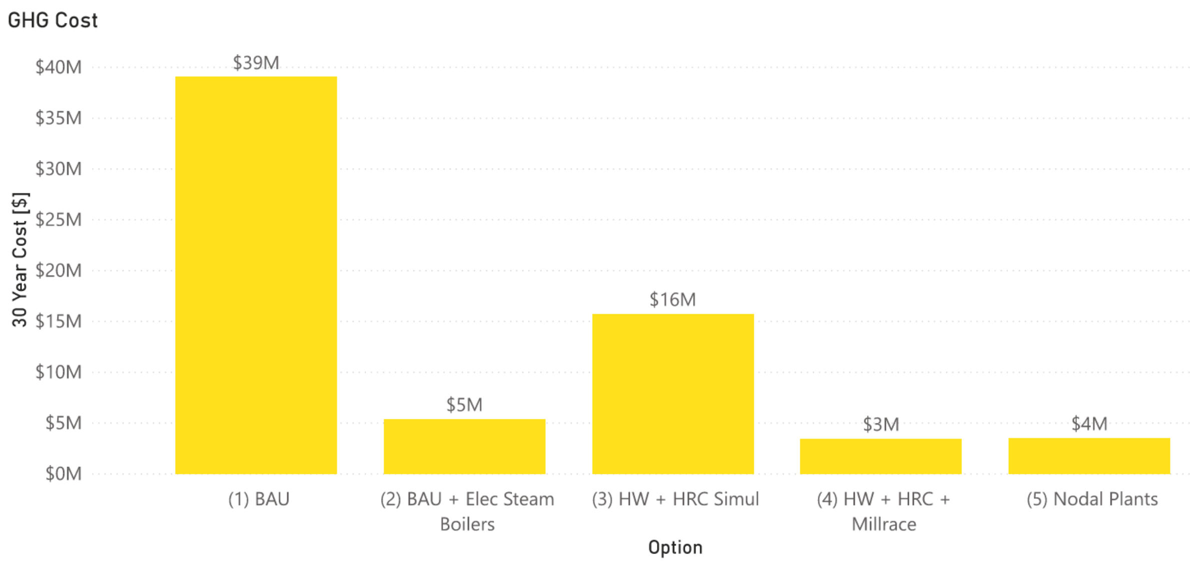
For the purposes of this study, AEI and the UO Thermal Systems Transition Study stakeholder group agreed to use the costs for the California cap-and-trade program as a proxy for the potential future cost of carbon and carbon price growth rate. From data published by the California Air Resources Board (CARB) for 2020 auction prices along with historical and future price projections, the base GHG cost for this study is assumed to be 16.93 $/MTCO2e with an annual escalation rate of 8% until 2030 and 5% until the end of the study period in 2052.

In addition to the regulatory cost of carbon described above, the 'social cost of carbon' was also discussed which considers how the impacts of ongoing GHG emissions and climate change can have cost impacts to society from extreme weather events and property damage, cost of healthcare, impacts to food supply and agriculture, etc. The social cost of carbon is a measure of the economic impacts to society that stem from ongoing GHG emissions.

While AEI and the UO Thermal Systems Transition Study stakeholder group acknowledge that the social cost of carbon is legitimate, determining an appropriate figure to assign to it would require a lengthy study in itself. Thus it was not factored in as part of the GHG cost or comparative financial study within this report. By President Biden's Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle Climate Change, the Federal Government's Interagency Working Group (IWG) was re-established to evaluate the social cost of carbon. The IWG has presented an interim value of the social cost of carbon at $51/MT of CO_2.

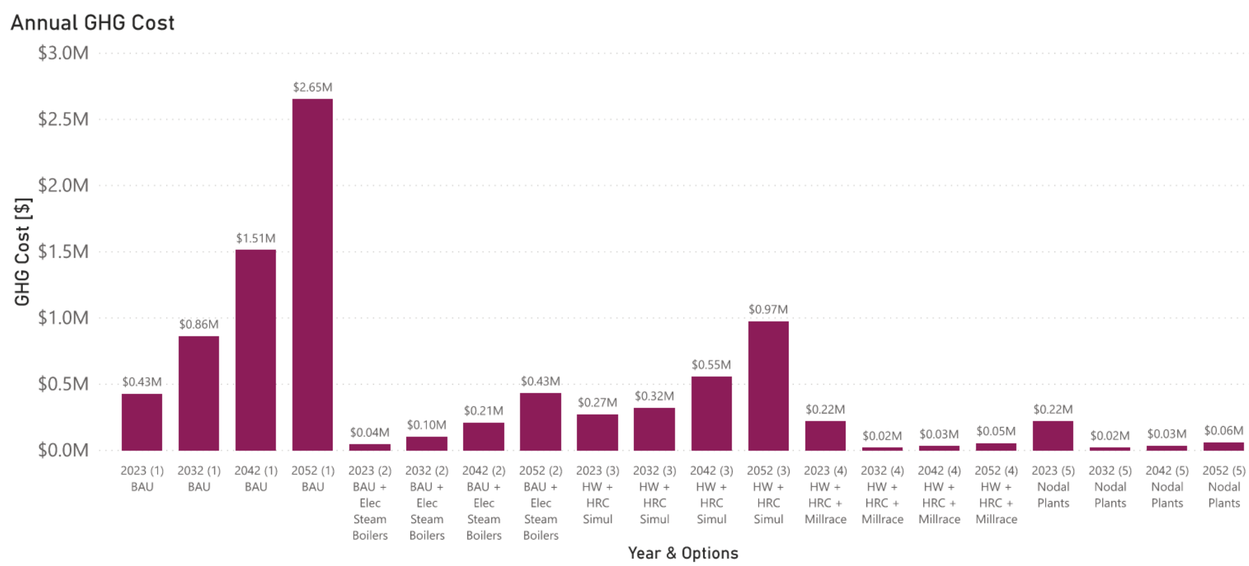
The figure below shows the estimated 30 year GHG cost for each Option over the duration of the analysis period. For reference, the GHG costs shown in this section have not yet been discounted to present value costs.

GHG COST SUMMARY



The figure below shows the estimated annual GHG cost for representative years in the analysis period to illustrate how GHG rate escalation (combined with load growth) impact the GHG costs over time. The years shown below represent year 1, 10, 20 and 30 of the analysis period.

ANNUAL GHG COST



8.4 Operation and Maintenance Costs

Budgets for the replacement and repair of existing central plant equipment were obtained from the UO Office of Finance and Administration but not included for reference in this study. Operations and maintenance costs are categorized as small equipment that is to be paid out of operating cash flow, or large equipment replacement funds that will be financed. Baseline O&M costs with 2% inflation for approximately 30-years for small equipment work are approximately $54,745,000. Financed major equipment replacement including all 5 existing chillers and a steam boiler in 2032 will budget for $15,000,000.

Operations and Maintenance costs for new equipment were included as well as avoided replacement. Options 3, 4 and 5 replace the operation of steam boilers. Thus, this presents the potential for a reduction of labor costs as a continuous operator presence will not be required. Any potential reduction in labor costs was not included in the analysis for these options. The major equipment and scope of work included in cost estimates is outlined below.

OPTION 1. Business as usual (see above for baseline).

OPTION 2 Electrode Steam Boiler

- Major Equipment Replace Electrode Steam Boiler in year 20
- Small equipment - same as baseline

OPTION 3 Heat Recovery Chiller – Simultaneous

- Major Equipment – Replacement of new Heat recovery equipment in year 23, avoided replacement of existing Chiller #5 that is discontinued
- Small Equipment – reduced work on Chiller #5

OPTION 4 – Heat Recovery Chiller – Alternate Source

- Major Equipment – Replacement of new more Heat recovery equipment in year 23, avoided replacement of existing Chiller #5 that is discontinued
- Small Equipment – reduced work on Chiller #5

OPTION 5 – Distributed Plant

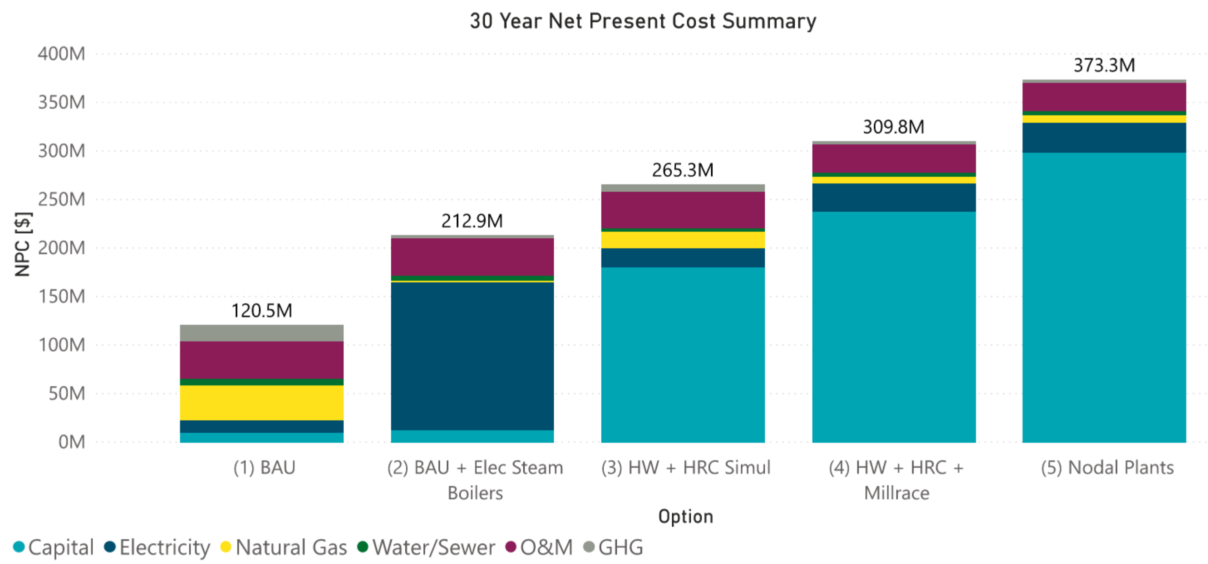
- Major Equipment – Replacement of all new modular plant equipment Heat exchanger, pumps, chillers in year 23
- Small Equipment – reduced work on Chiller #5
- Factors for increased staffing (FTEs) were not included in O&M costs.

8.5 Comparative Financial Performance

Life cycle cost analysis was performed with a 30-year cycle beginning in 2023 for the five options presented. Life cycle cost summary tables are included in the Appendix.

The 30-year net present cost of the options is presented below.

NET PRESENT COST SUMMARY (with GHG cost)



Option 1 – Business as Usual presents the lowest lifecycle cost for the systems analyzed. The existing system is not efficient from a carbon emissions standpoint and does not meet the University's GHG reduction targets. But penalties for potential greenhouse gas emissions charges are modest compared to the total cost of other measures.

- Capital expenses for the replacement of existing chiller and boiler equipment are modest and will occur in the future where the cost discount factor at 3% may outweigh inflation as estimated at 2%.
- Natural gas is relatively inexpensive now and not predicted to rise significantly from \$0.49/therm in year zero to \$0.69 in year 30 at annual escalation rate of only 1.2%. Present value of the gas rate in year 30 is less than current at \$0.29 per therm.
- Greenhouse Gas costs are low initially and as analyzed will escalate from \$21.32/ MTCO2e in year 0 up to \$106.92/MTCO2e in year 30. Present cost calculations diminish the cost of future expenses by a 3% discount rate per year, reducing the calculated impact of potentially high GHG rate escalation.
- The low net present cost may be in part due to the existing debt service on the central plant projects is considered as a baseline cost and is not included in any of the options analyzed.
- Current budgets and utility costs based on historic use are relatively stable and known.
- The Business as Usual case may be used to show a relative cost impact to other options but does present a way for the University to meet its carbon goals.

Option 2 – Electrode Steam Boiler

- Electrode Steam boiler costs are dominated by the high electrical utility cost compared to natural gas. Electric resistance heating is nearly three times the cost of using natural gas even considering the inefficiencies of the boiler system.
- Electric utility costs are estimated to increase at 4.5% per year.
- The costs and impact of installing an electrode steam boiler in the existing plant is modest.
- GHG costs are still present as there is a small amount of natural gas needed for trim heating to meet peak demands and the electric utility supply is not entirely carbon free.

Option 3 – Heat Recovery Chiller – Simultaneous Heating and Cooling

- The capital cost burden is high due to the price of a heating hot water distribution and building conversion and the associated borrowing costs.
- Present value impact is somewhat delayed by the proposed project phasing. Debt service for the 25-year term on the second phase of work starting in 2032 is not fully captured in the 30 year term of the life cycle cost analysis.
- Utility and GHG costs are expected to be reduced from the existing central plant by approximately 30% and 38%, respectively.

Option 4 – Heat Recovery Chiller – Alternate Source

- Utility costs are roughly the same as for Option 3. However the GHG costs for Option 4 is roughly 12% lower than Option 3 and presents a significant reduction in utility and GHG costs over the existing plant.
- Option 4 may exhibit higher net present costs than Option 3 but exceeds the greenhouse gas reductions. These reductions do not represent a cost savings and should be evaluated with GHG reduction performance in mind.

Option 5 – Distributed Nodal Plants

- Distributed Nodal plants represents the highest capital expense of any measure and performs similarly to Options 3 and 4 in reducing utility costs from the Business as Usual case.
- The financial impact of real estate and aesthetics is currently unknown and cannot be represented in the life cycle cost at this time.
- Considering the limited real estate available, final location of nodal plants, and architectural design requirements, the construction costs and impacts to facilities may be highly variable.

Life Cycle Cost Methodology

Life Cycle cost analysis was performed with the following parameters:

- Term – 30 years

- Discount Rate – 5.25%
- Annual inflation – 4.5%
- Interest Rate 5.25%
- Interest Term 25 years
- First year of study period: 2023

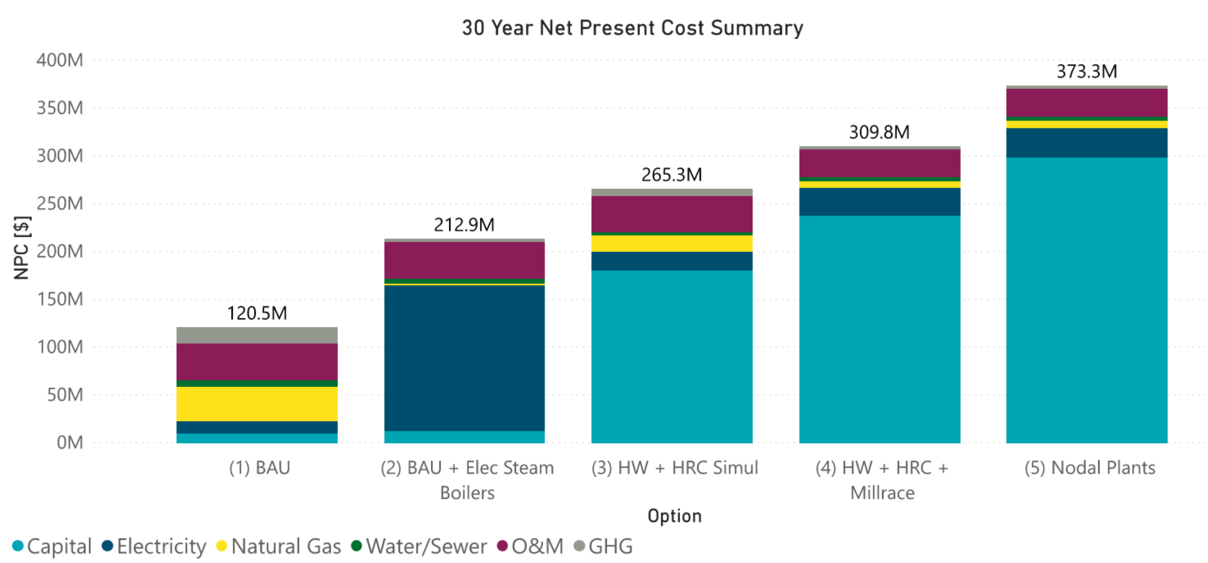
Investment Cost – Capital expenses are entered for a loan term beginning with the first year of the construction loan and amortized for 25 year loan period at 5.25% interest. Capital expenses include the first costs for the installation of any option as well as budgeted major equipment replacements under the O&M cost.

Utility Costs – Electricity, Natural Gas, Water and Sewer costs are entered with expected cost escalation built in. Utility costs are calculated from the results of the energy analysis.

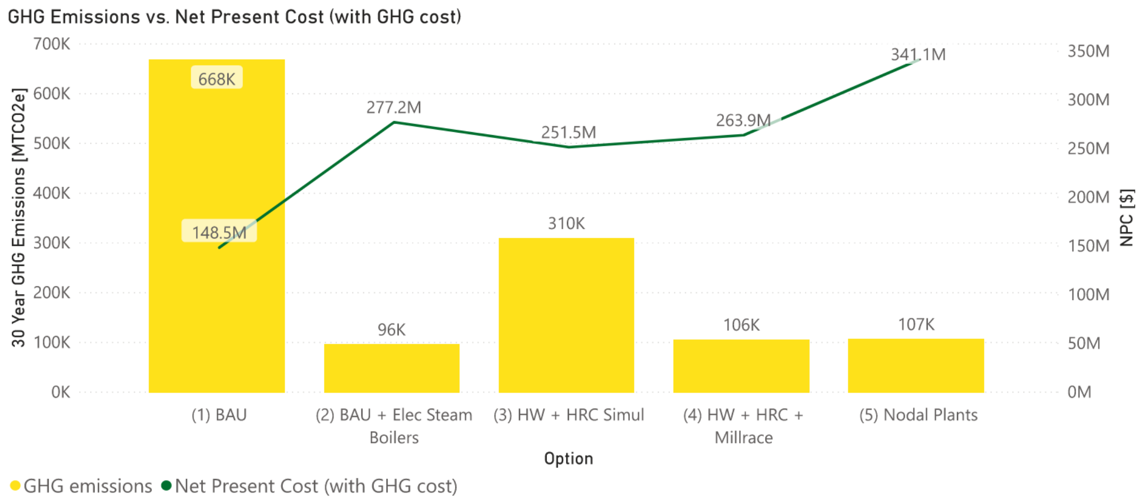
Greenhouse Gas (GHG) Emissions – Costs based on assumptions in the energy analysis including escalation.

Operations and Maintenance costs or other budgets that are not financed are included in O&M costs. The charts below illustrate the net present costs and GHG emissions for each of the options over the 30 year period of analysis. Net present costs are presented with and without the cost of carbon factored in.

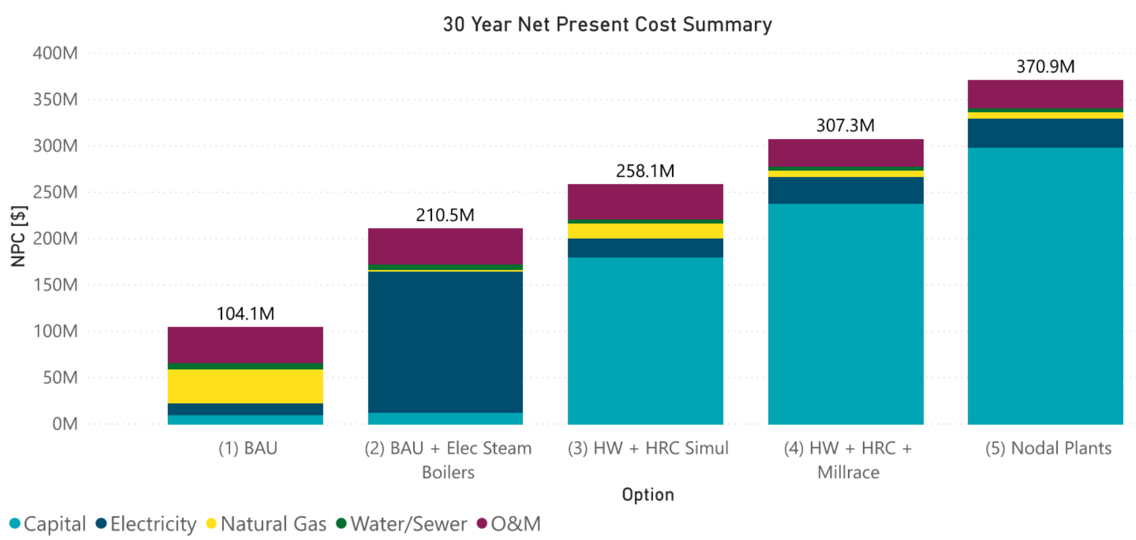
NET PRESENT COST SUMMARY (with GHG cost)



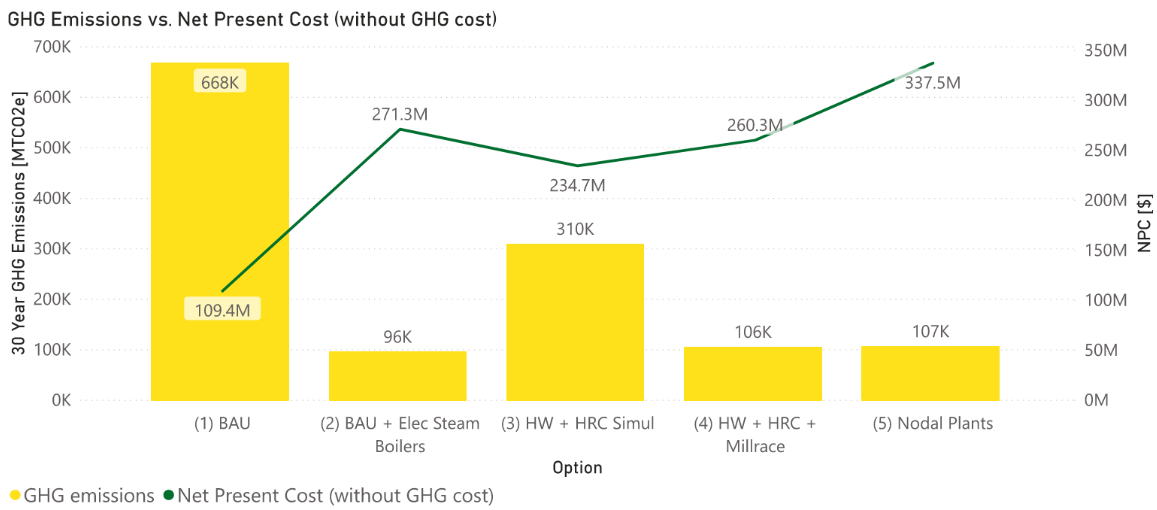
GHG EMISSIONS vs. NET PRESENT COST (with GHG cost)



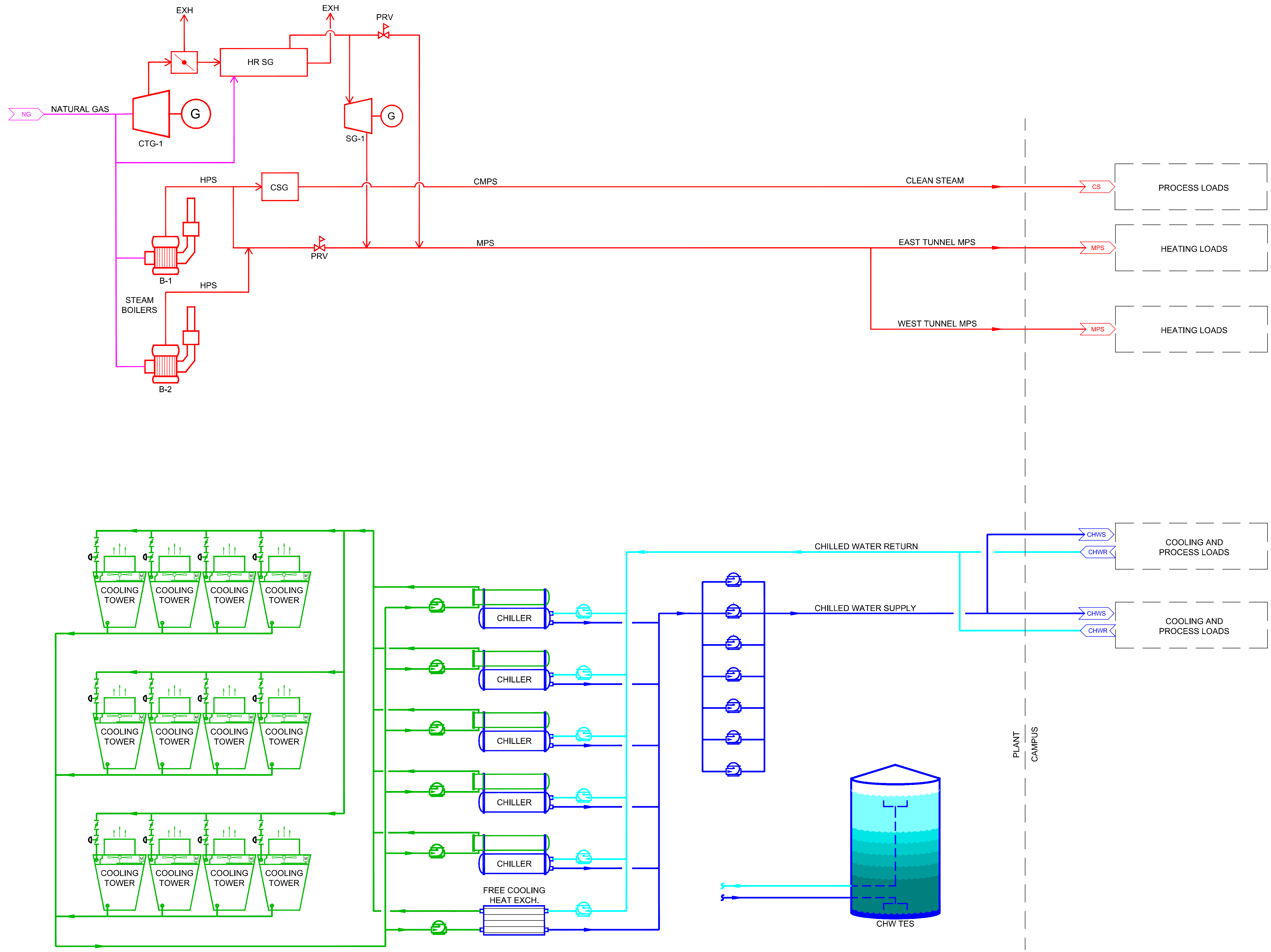
NET PRESENT COST SUMMARY (without GHG cost)



GHG EMISSIONS vs. NET PRESENT COST (without GHG cost)

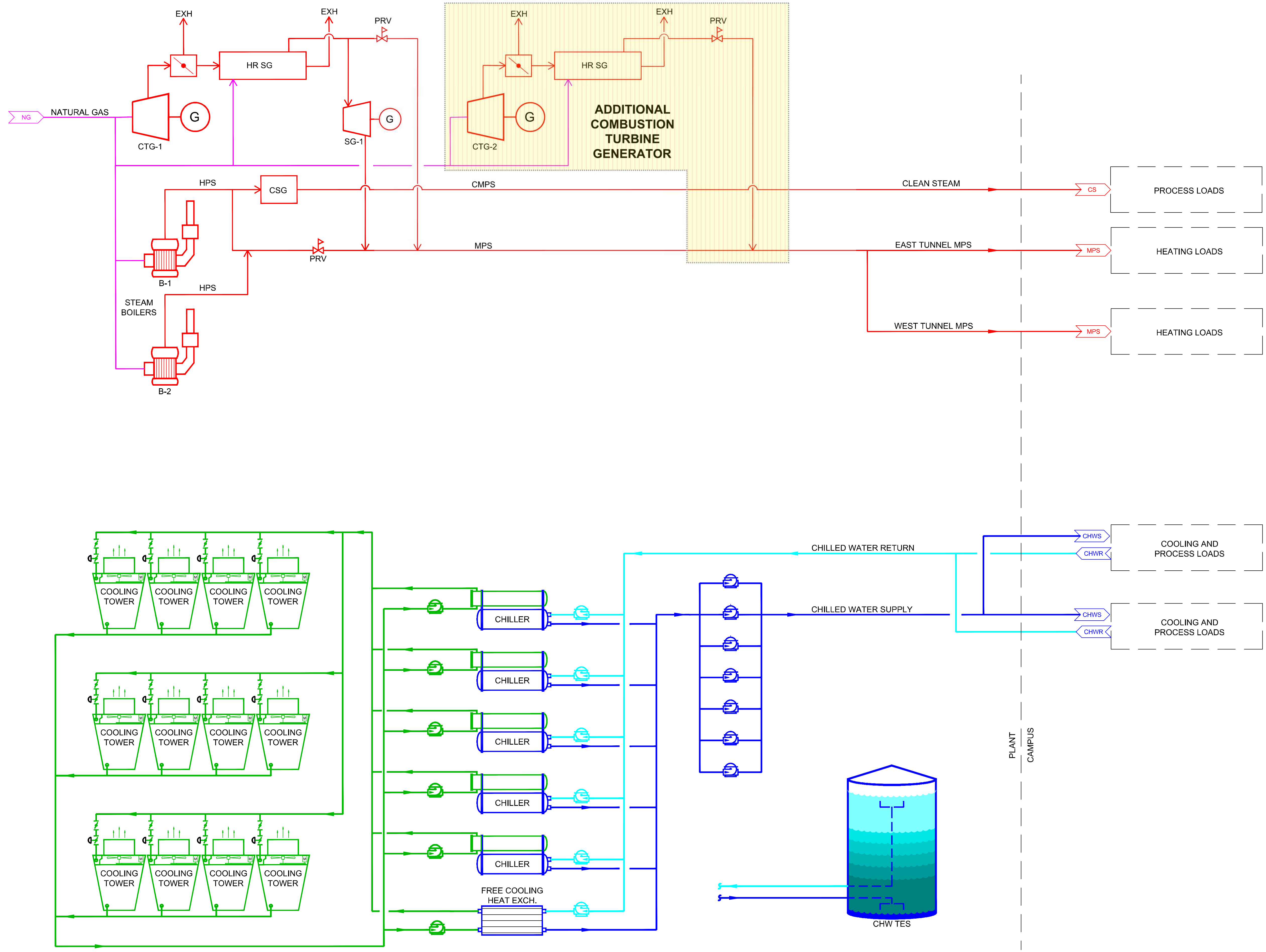


Appendix A: Simplified Diagrams of Options



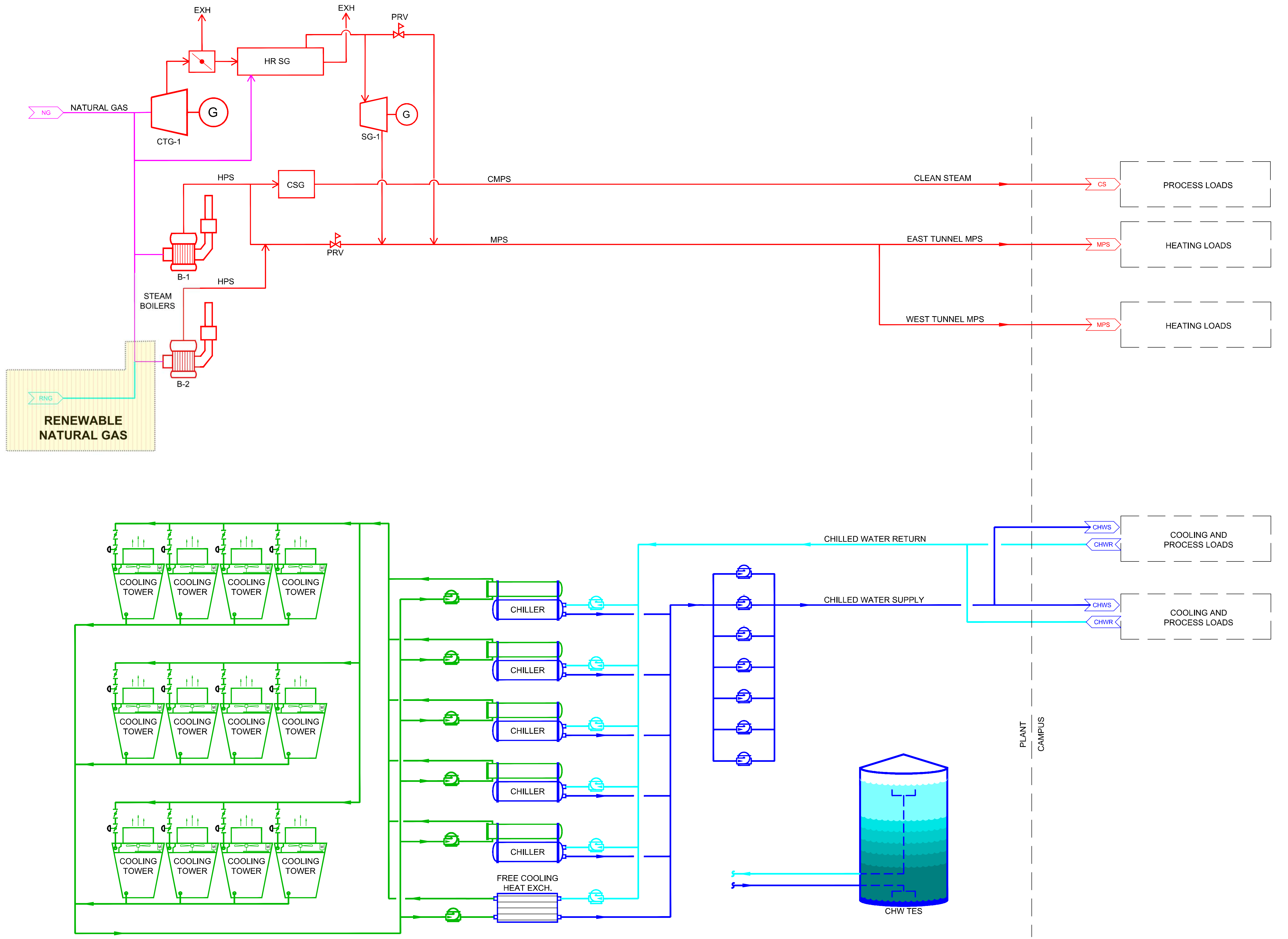
OPTION 1: BUSINESS AS USUAL

Affiliated Engineers



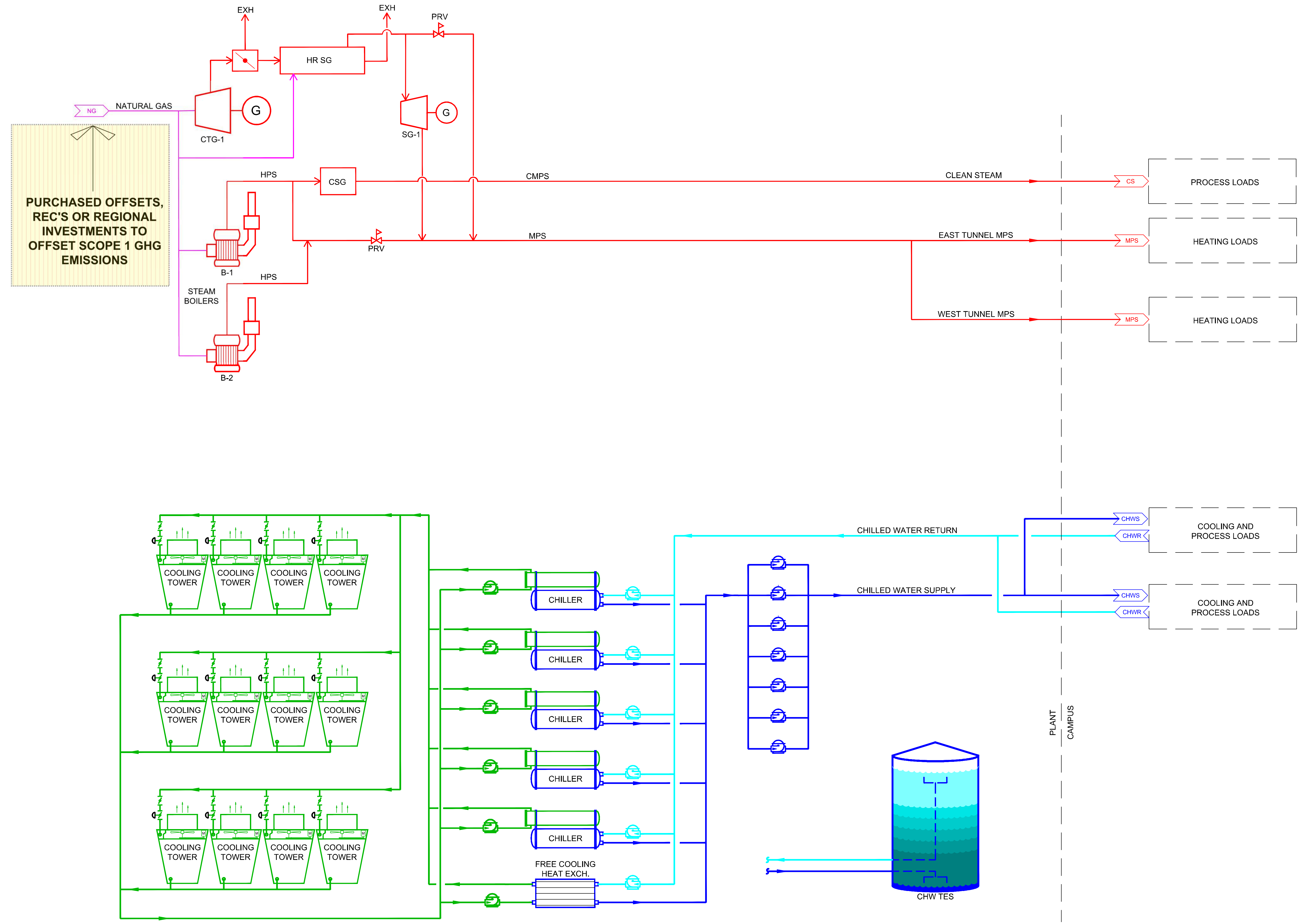
OPTION 1a: BUSINESS AS USUAL W/ ADDITION OF CTG-2

Affiliated Engineers



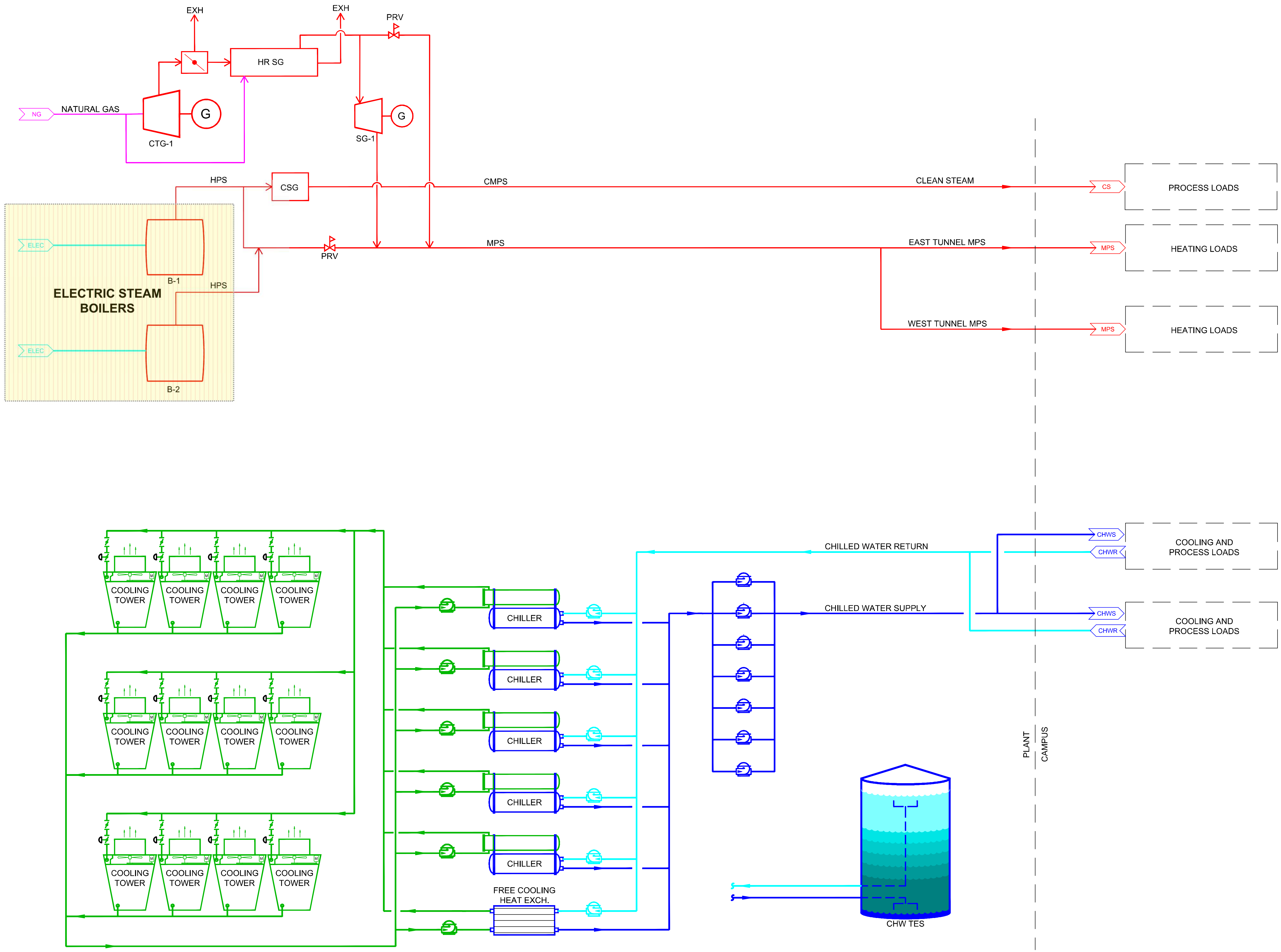
OPTION 1b: BUSINESS AS USUAL W/ BOILERS FIRING RNG

AEI Affiliated Engineers



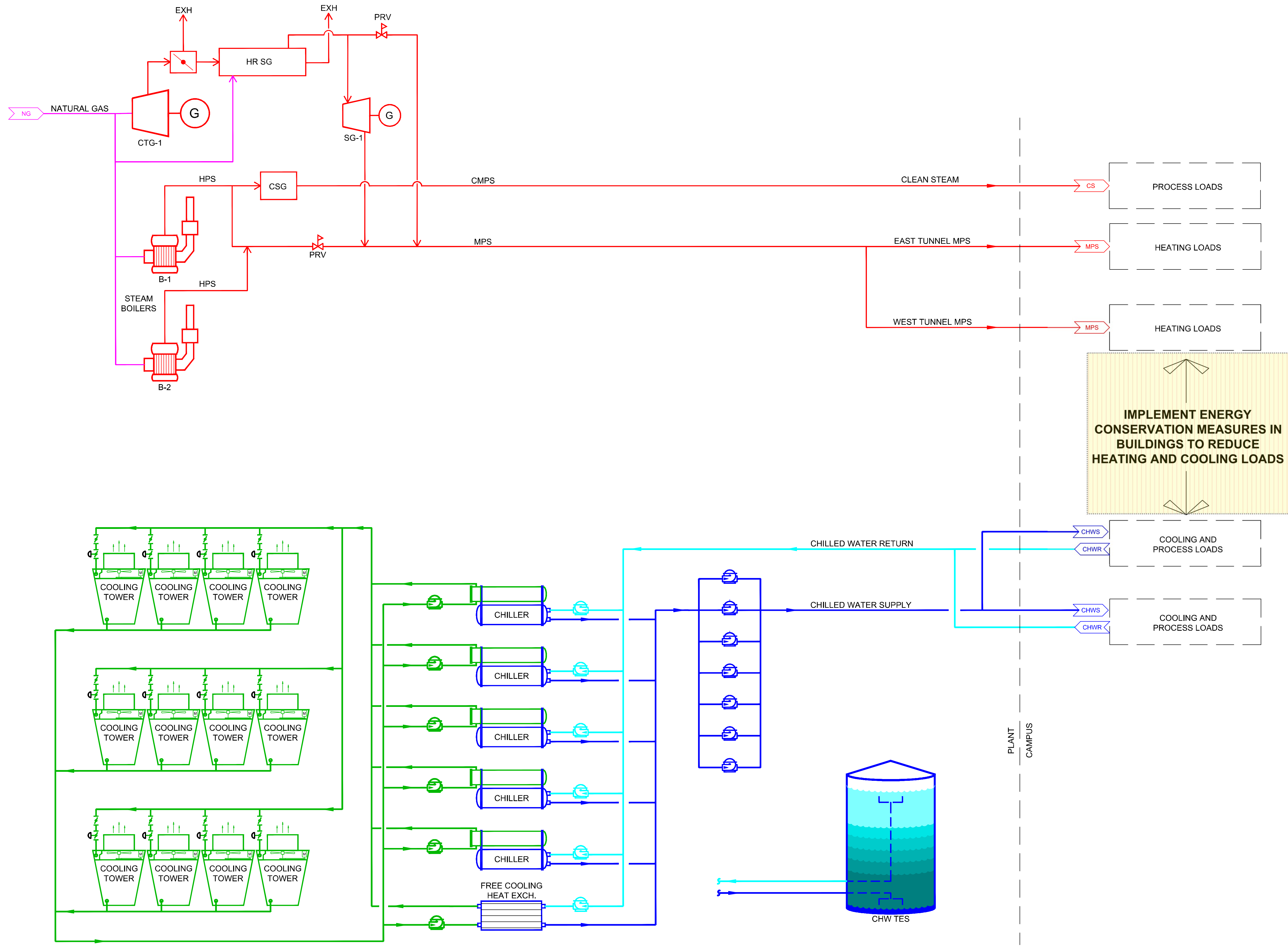
OPTION 1c: BUSINESS AS USUAL W/ PURCHASED OFFSETS, REC'S OR REGIONAL INVESTMENTS

AEI Affiliated Engineers



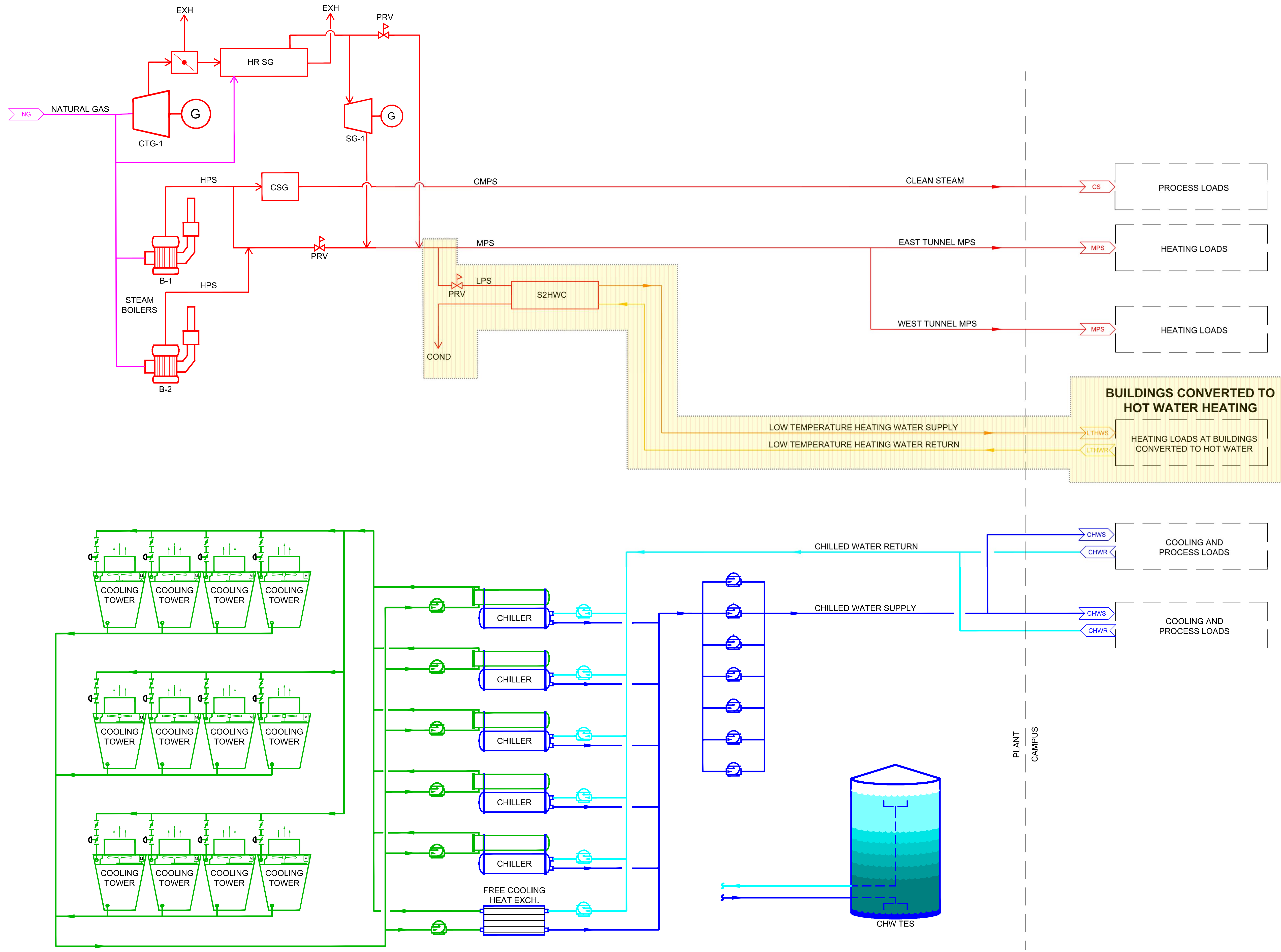
OPTION 1d: BUSINESS AS USUAL W/ ELECTRIC STEAM BOILERS

Affiliated Engineers



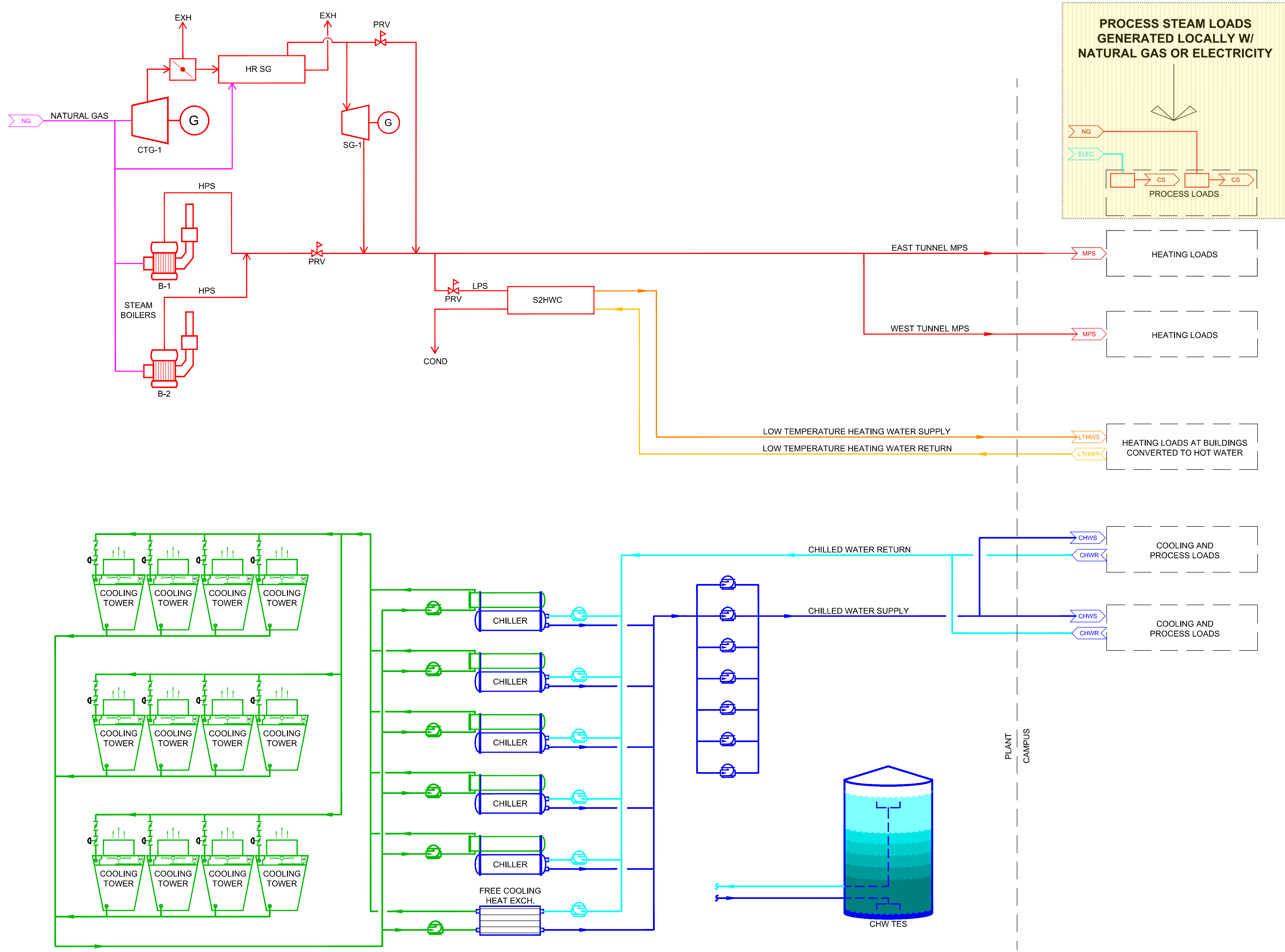
OPTION 1e: BUSINESS AS USUAL W/ ENERGY CONSERVATION AT BUILDINGS

AEI Affiliated Engineers



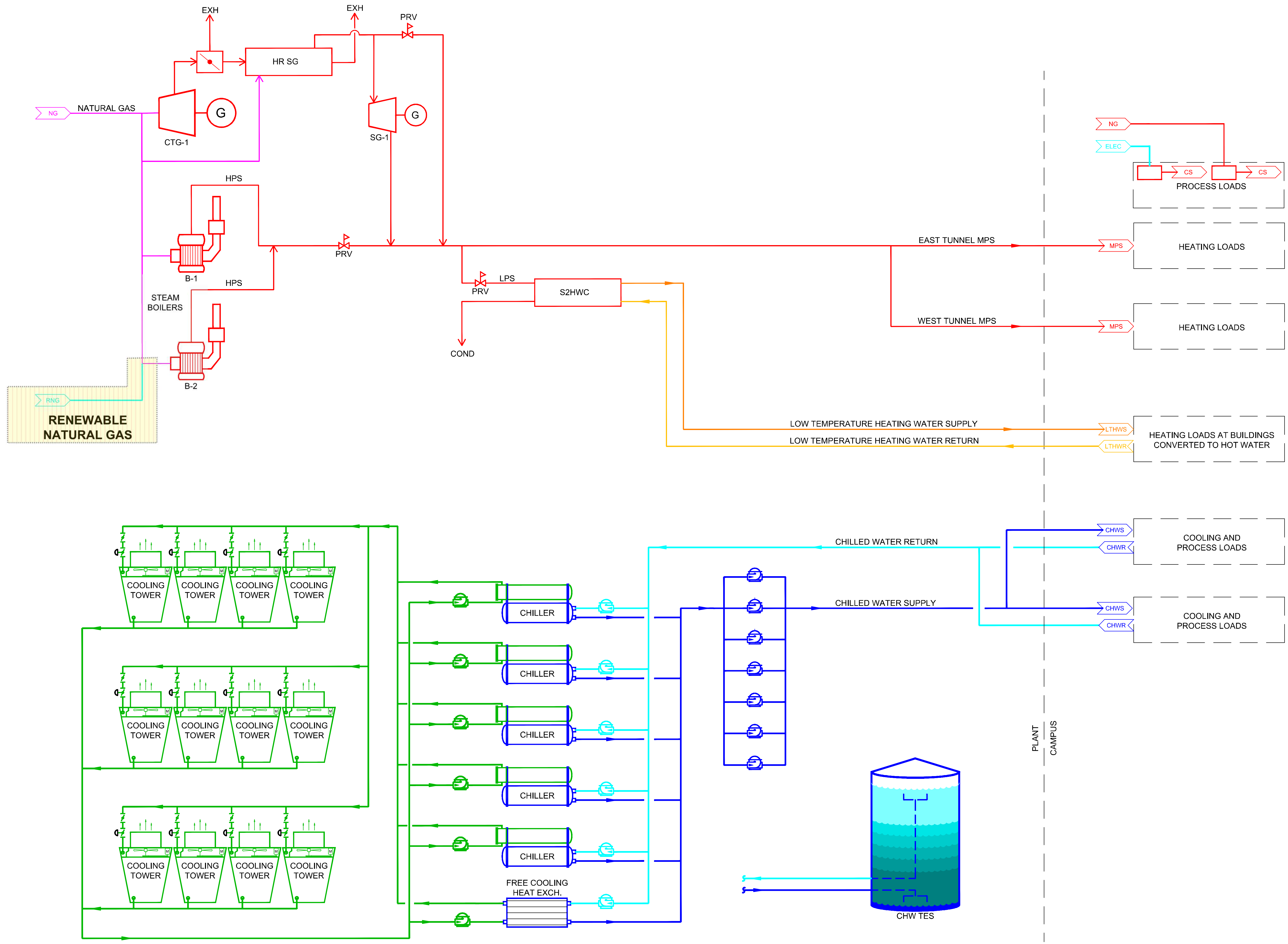
OPTION 2: HW CONVERSION W/ FUEL FIRED SOURCE

Affiliated Engineers



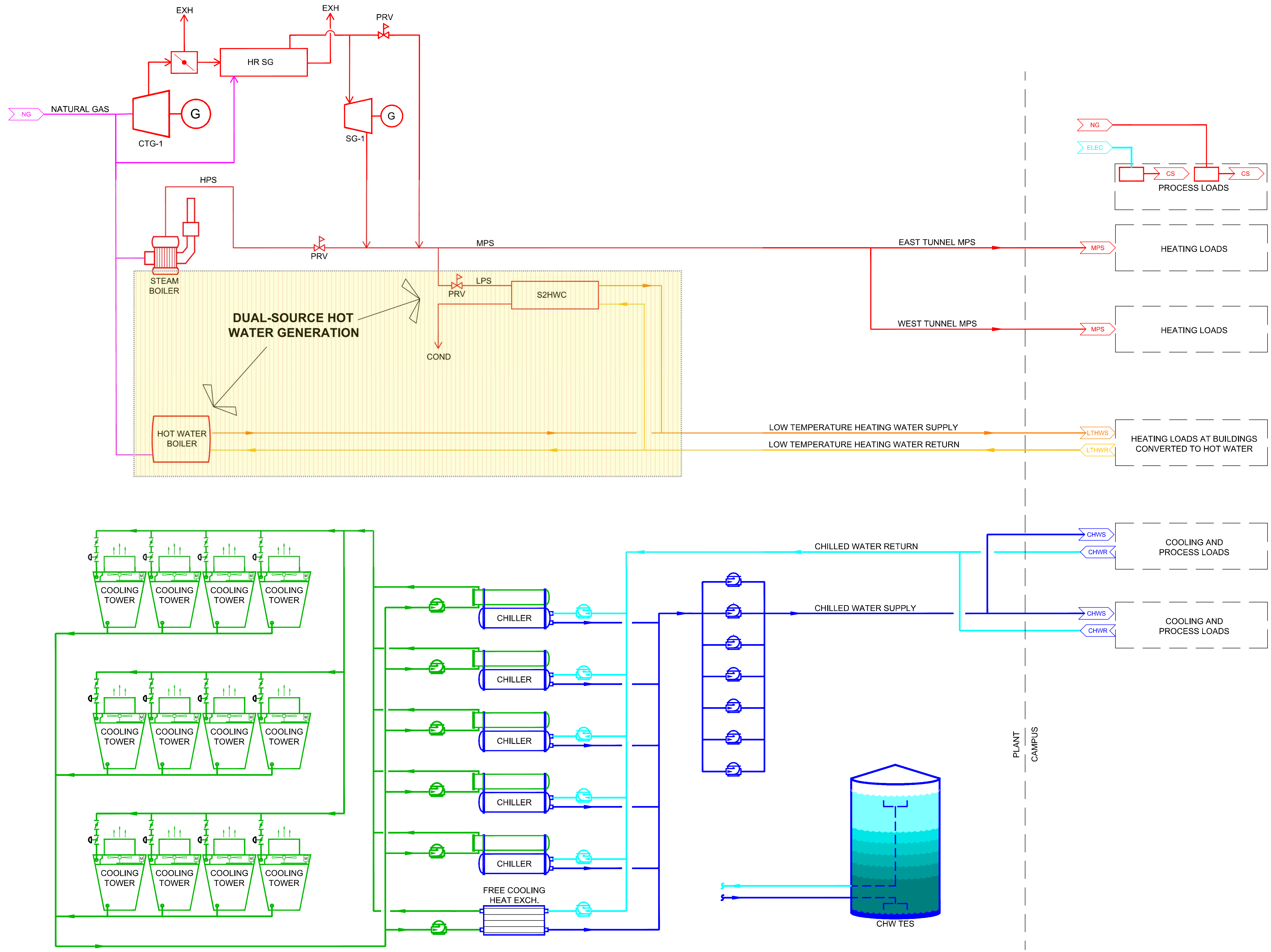
OPTION 2.a.1: HW CONVERSION W/ S2HWC, REDUCED PRESSURE

AEI Affiliated Engineers



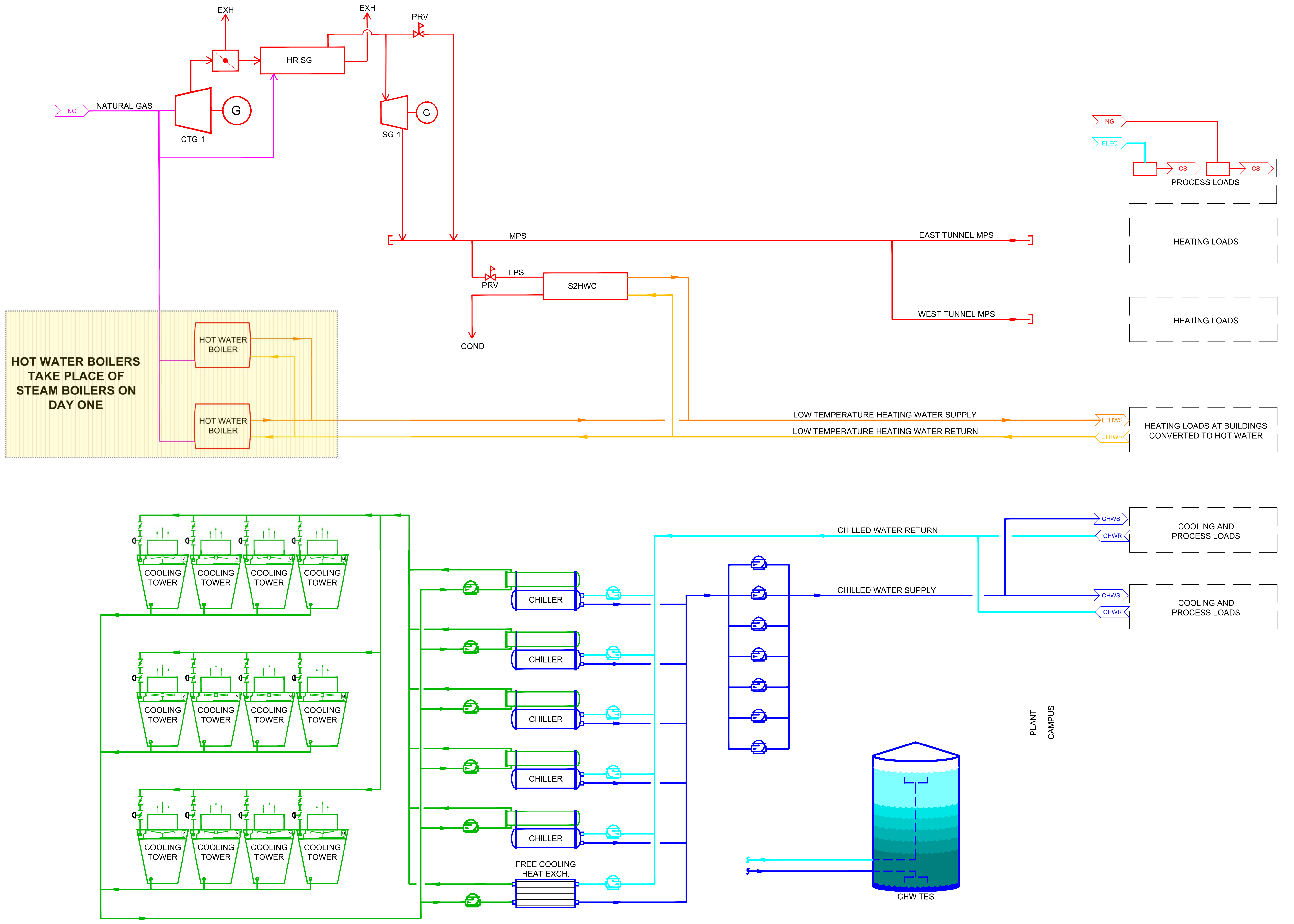
OPTION 2.a.2: HW CONVERSION W/ S2HWC, REDUCED PRESSURE AND RNG

Affiliated Engineers



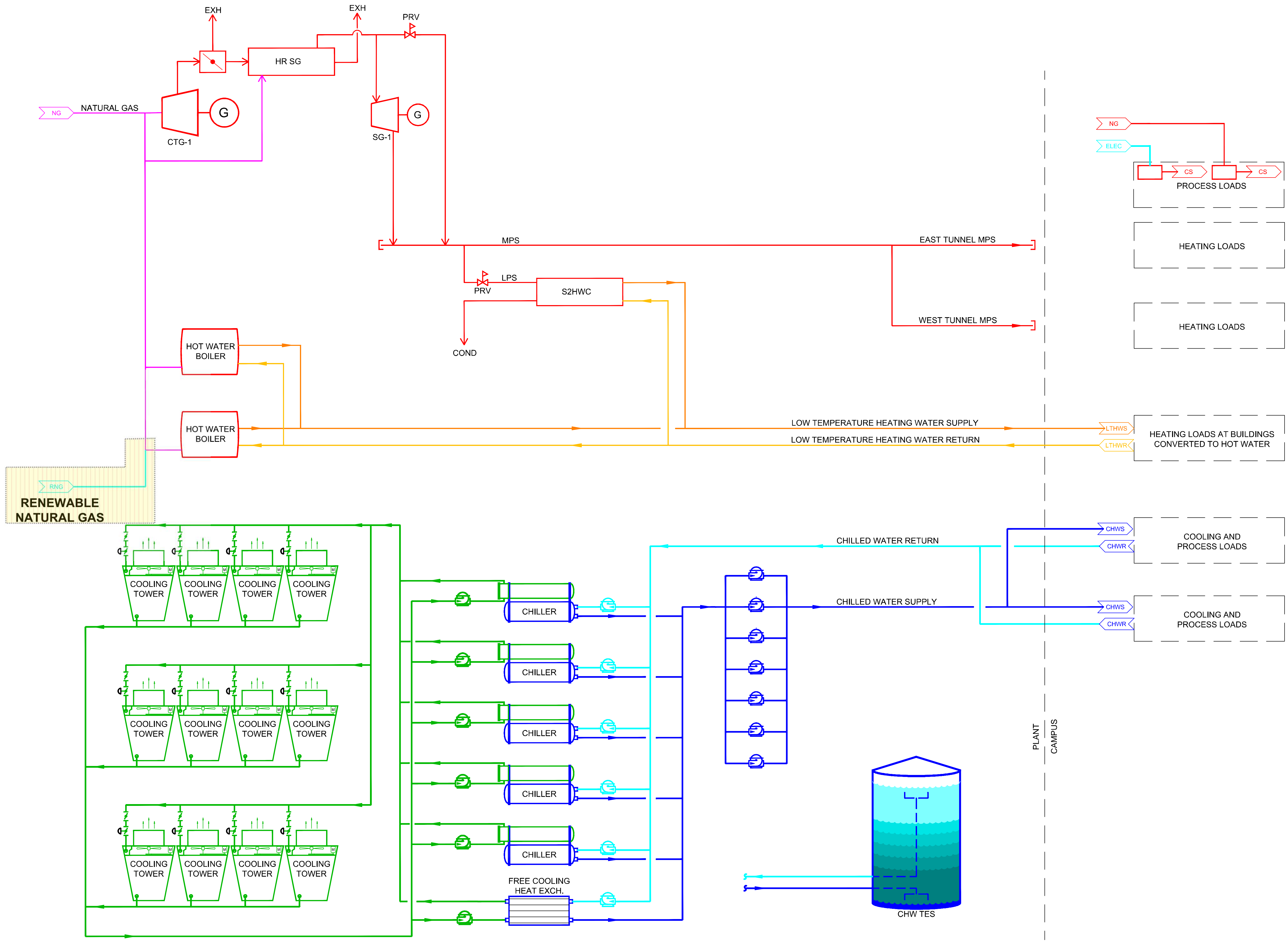
OPTION 2.b: HW CONVERSION W/ S2HWC, HW CONVERSION OVER TIME

Affiliated Engineers



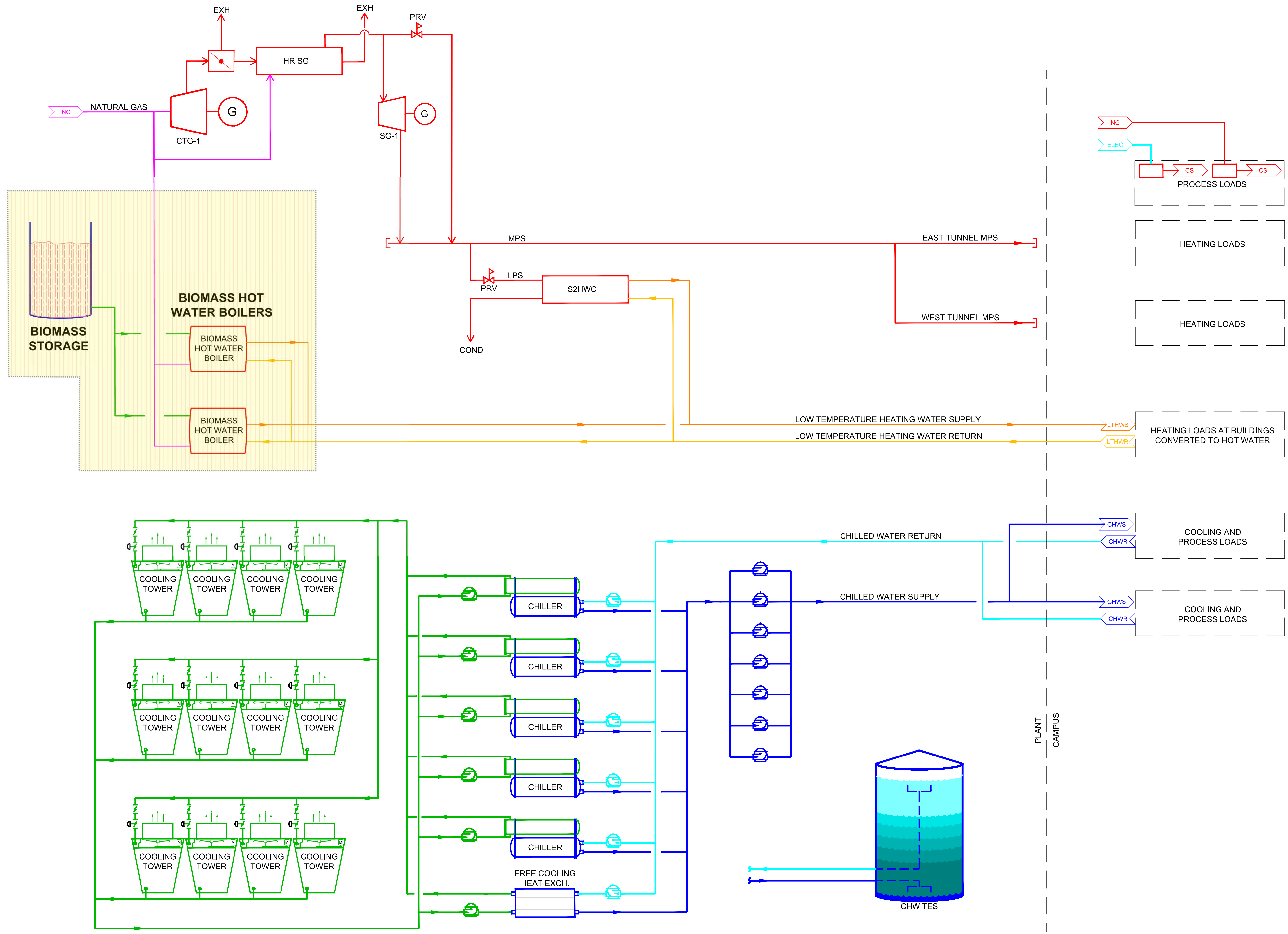
OPTION 2.c.1: HW CONVERSION W/ HW BOILERS, DAY 1

Affiliated Engineers



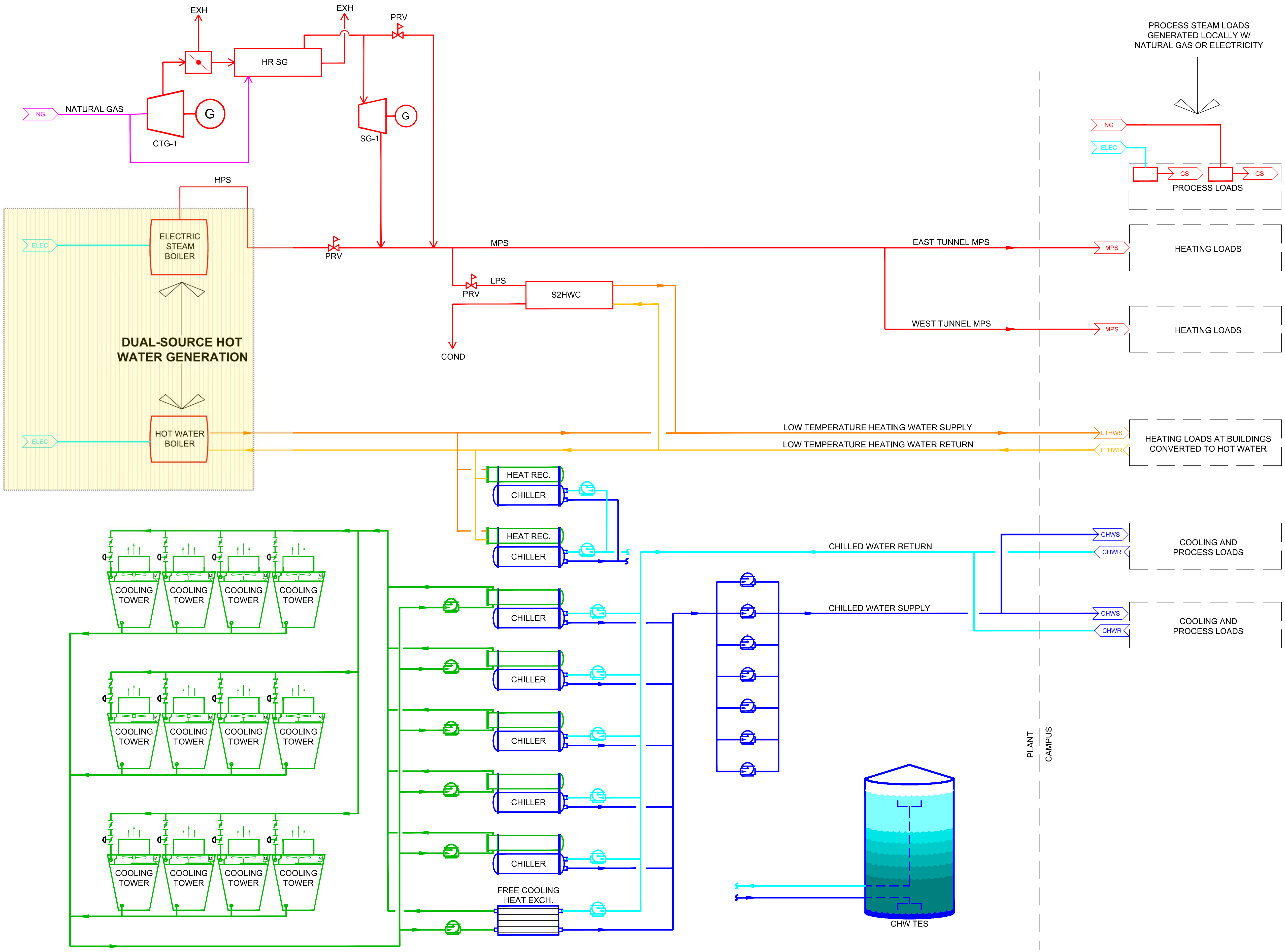
OPTION 2.c.2: HW CONVERSION W/ HW BOILERS, DAY 1, FUELED W/ RNG

Affiliated Engineers



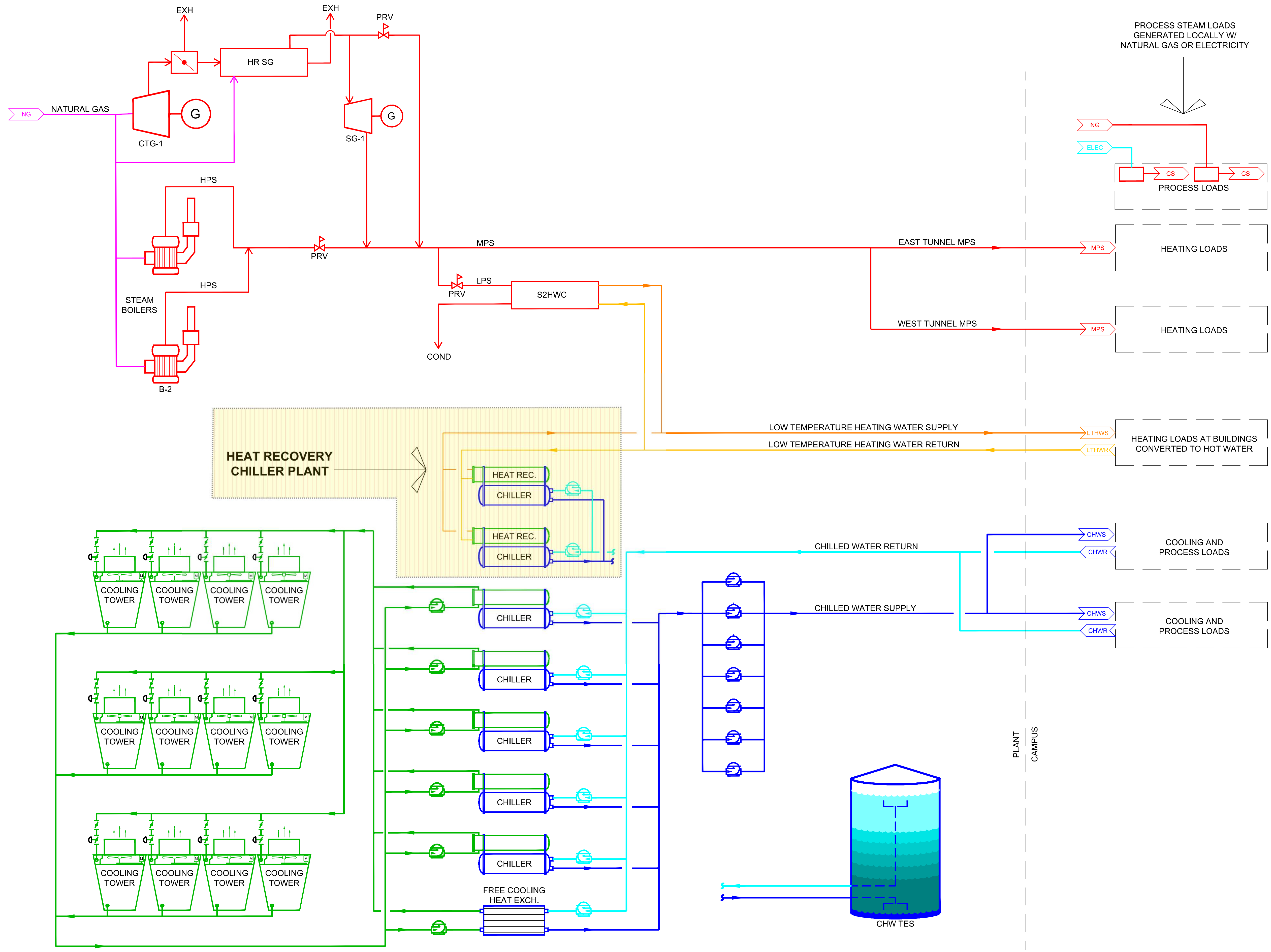
OPTION 2.c.3: HW CONVERSION W/ HW BOILERS DAY 1, FUELED W/ BIOMASS

Affiliated Engineers



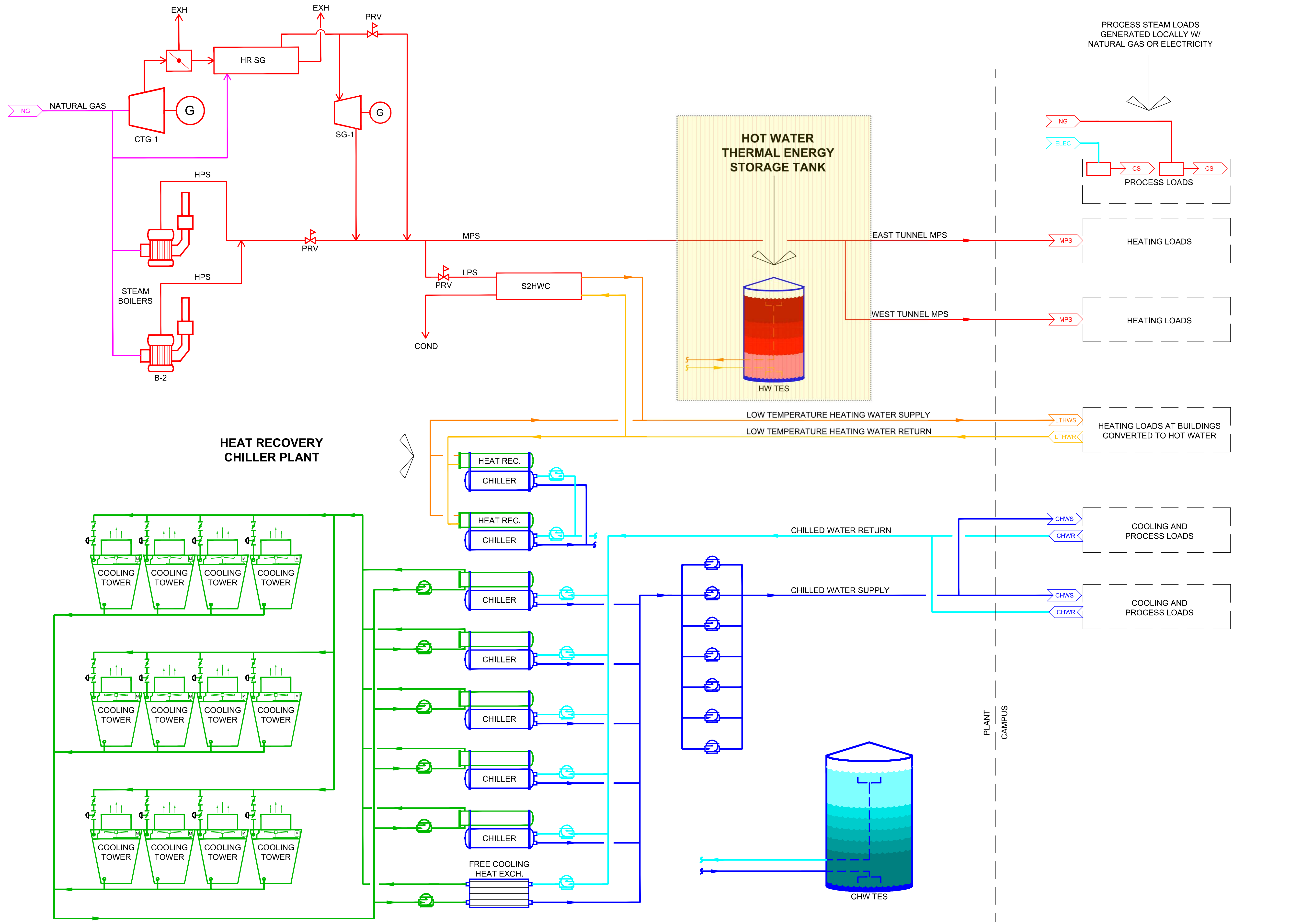
OPTION 3: HW CONVERSION W/ ELECTRIC HW BOILER AND STEAM BOILER

Affiliated Engineers



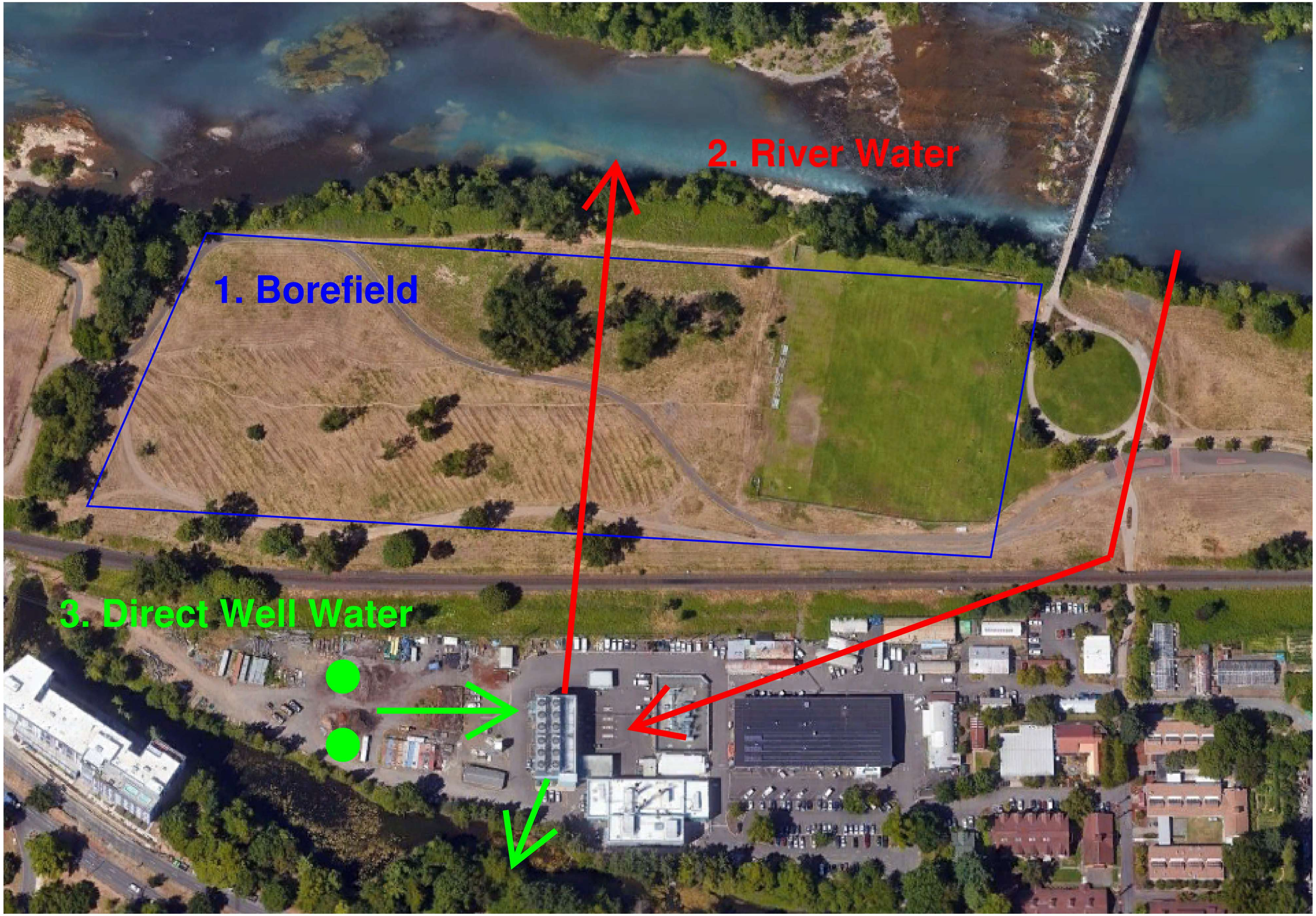
OPTION 4: HW CONVERSION W/ HEAT RECOVERY CHILLERS

Affiliated Engineers



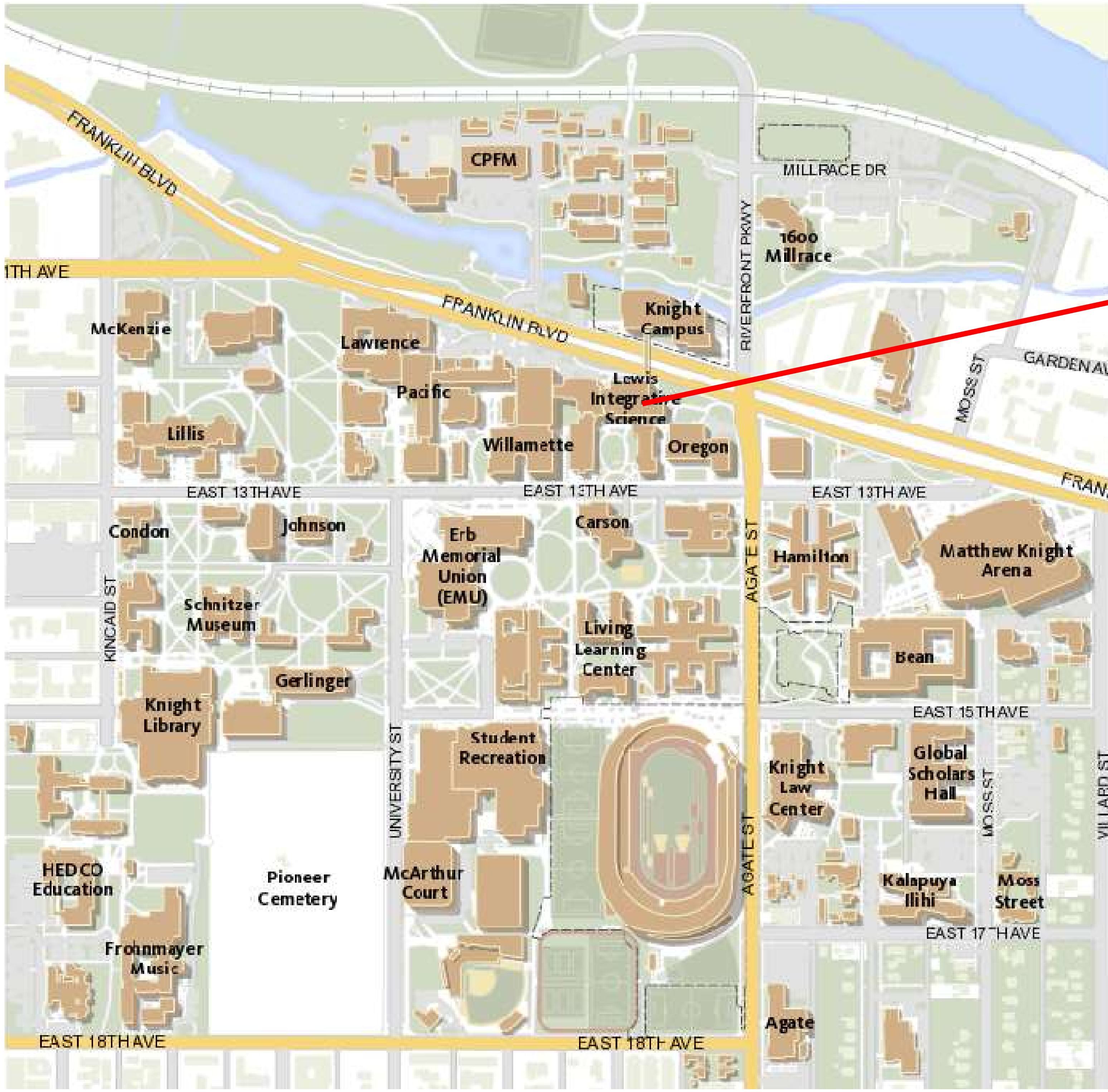
OPTION 4a: HW CONVERSION W/ HEAT RECOVERY CHILLERS AND HW TES

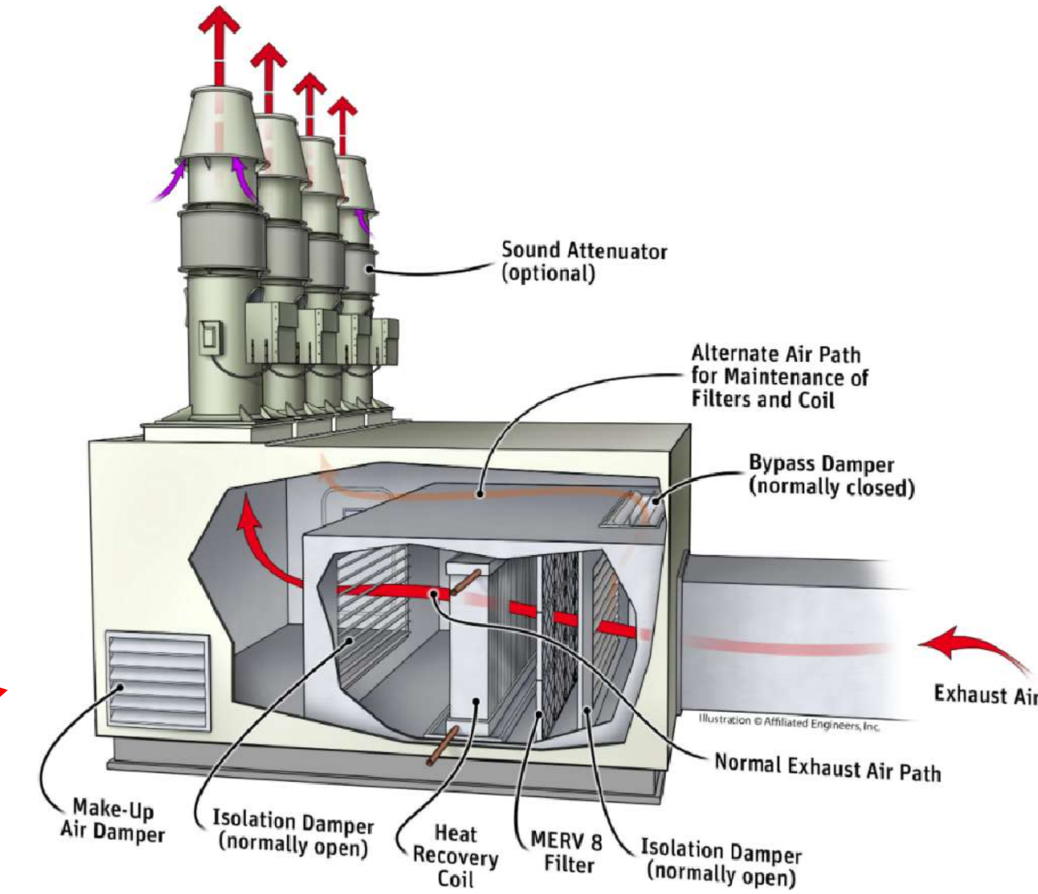
Affiliated Engineers



OPTION 4b: Hot Water Conversion with Alternate Sources (1 of 2)

Affiliated Engineers

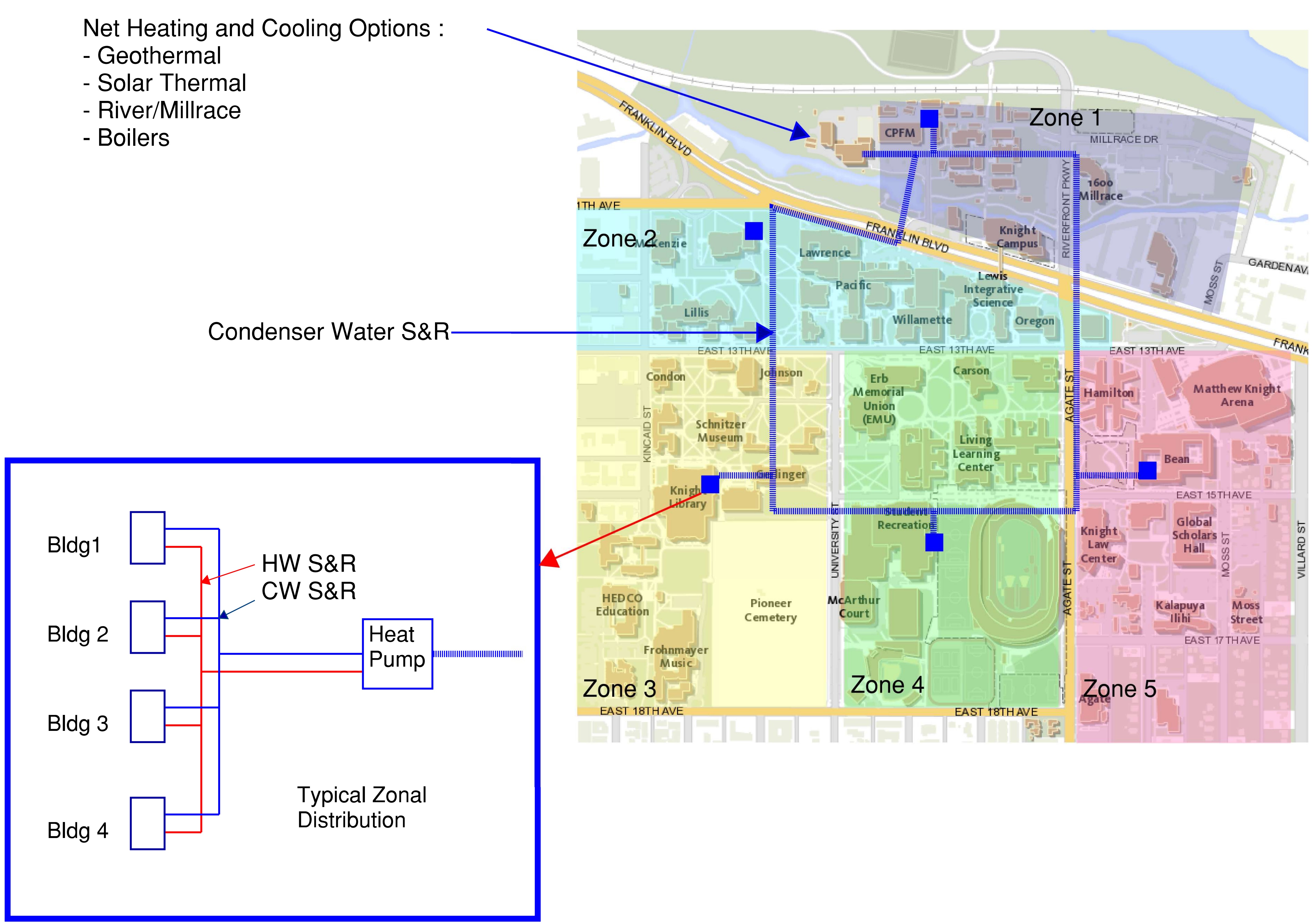




Typical Exhaust Heat Recovery Unit

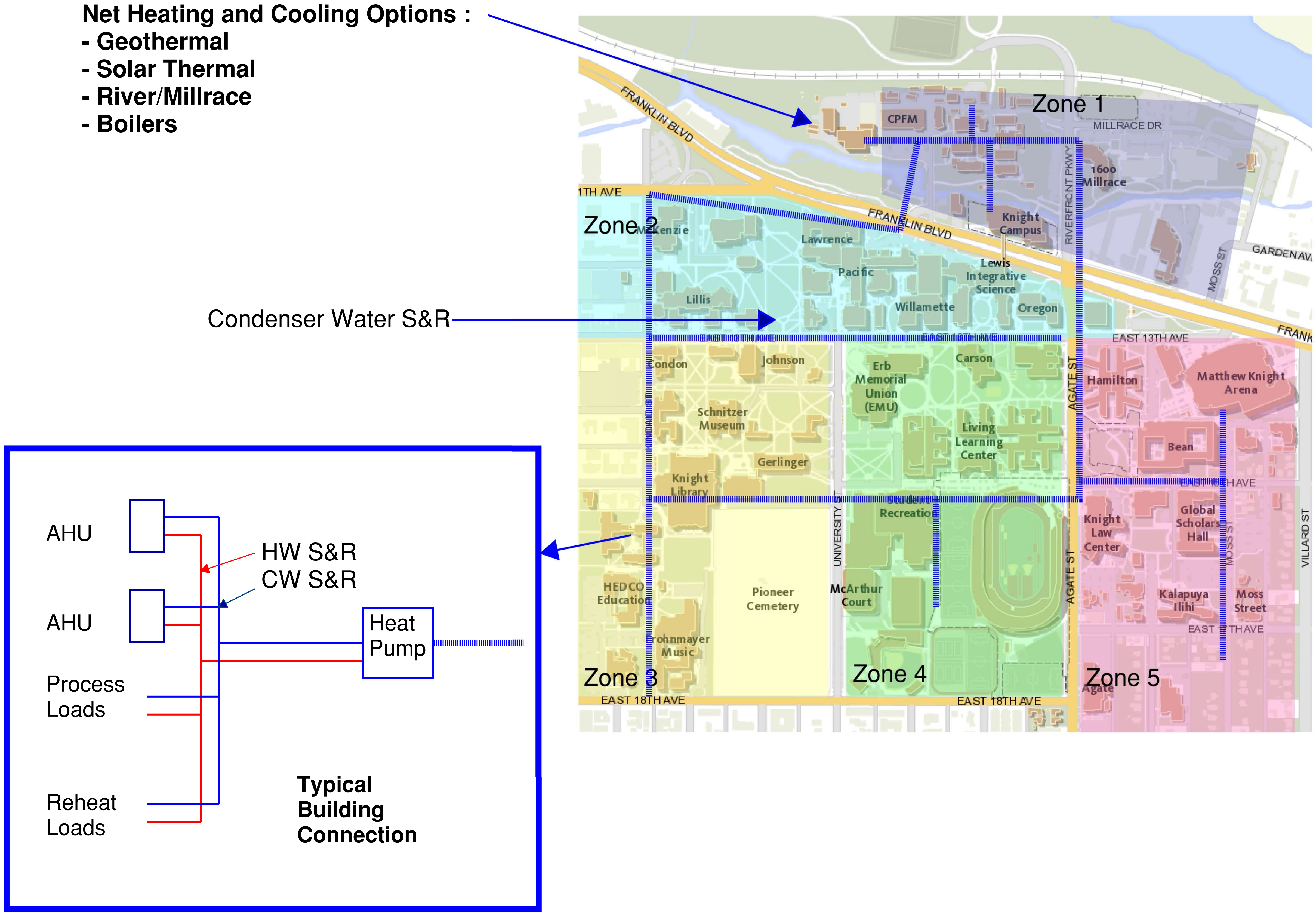
OPTION 4b: Hot Water Conversion with Alternate Sources (2 of 2)

Affiliated Engineers



OPTION 5: Campus Condensing Loop with Nodal Heat Pumps

Affiliated Engineers



OPTION 5a: Campus Condensing Loop with Building Heat Pumps

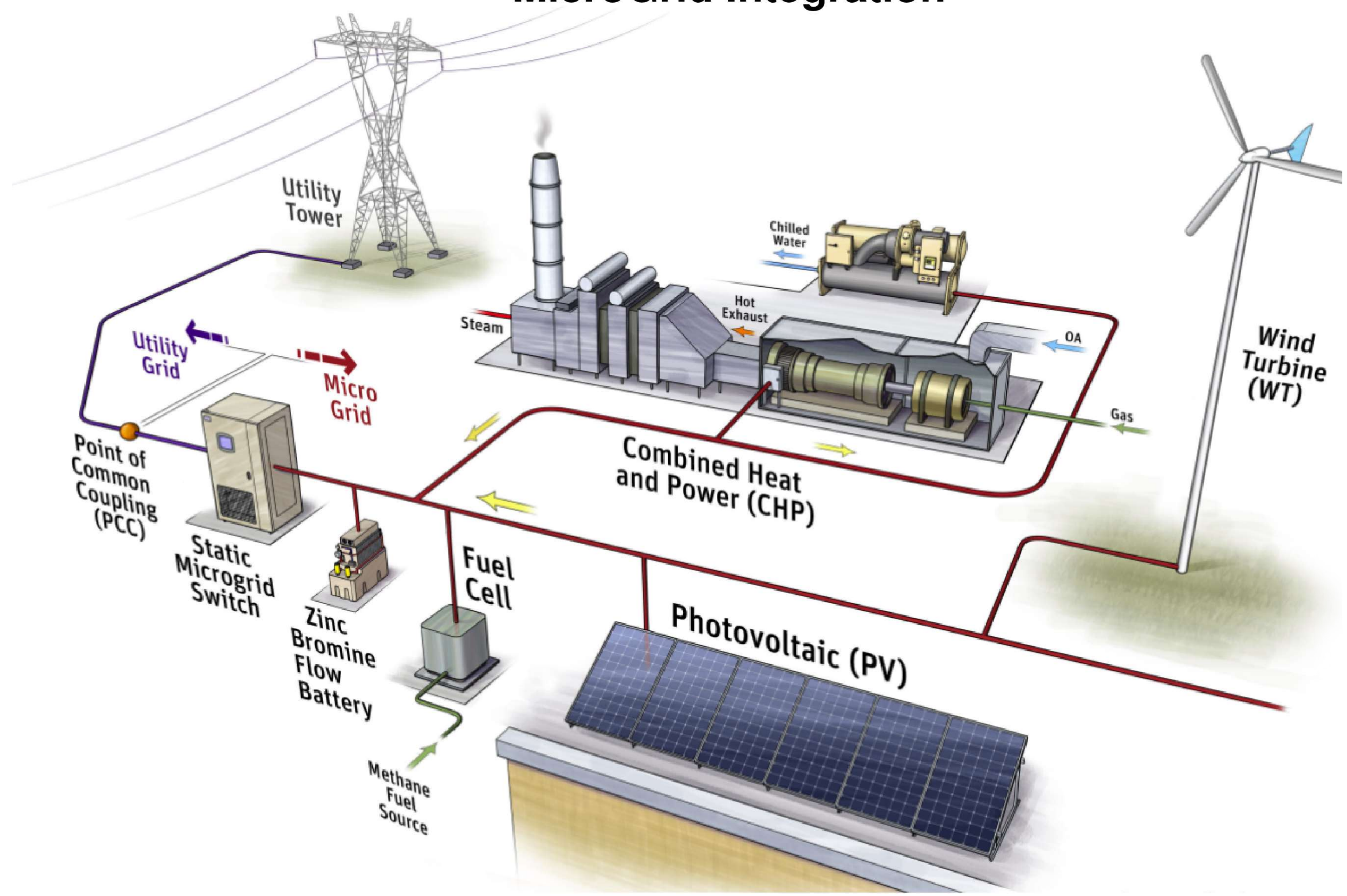
Affiliated Engineers

Fuel Cells

Solar PV

Solar PV with Storage

MicroGrid Integration



OPTION 6: Renewable Strategies

Appendix B: Building Heating Hot Water Conversions

Buildings on at the University of Oregon central campus were surveyed to identify the feasibility and cost considerations for converting buildings that are currently served by campus steam to heating hot water. The inventory of the sixty-six buildings included in the survey are listed in “Building Summary Table” following the Appendix.

Existing conditions:

Buildings included in the survey are currently served by the main campus steam distribution system originating at the Central Plant Services building and routed in tunnel systems directly to each building. Two separate steam services originate at the plant: 60 psig campus steam used for heating and domestic services, and 60 psi untreated steam that is used for autoclaves and other process uses.

In general, the primary end use of campus steam in buildings is for heating hot water and domestic hot water. For buildings surveyed the primary end use equipment in order of prevalence is:

- 140F- 220F heating hot water generated at shell and tube heat exchangers. Most buildings surveyed used 180F heating hot water and were designed for 140F return water temperature. Heating water end uses at air handler coils, reheat terminal units, unit heaters, convectors and finned tube.
- Instantaneous steam to domestic hot water heat exchangers.
- Direct steam heating coils in air handling units.
- Unitary steam equipment (finned tube, cast iron radiators).
- Untreated steam distribution serves buildings in the Lokey Science cluster limited to main distribution at between Streisinger/Huestis steam tunnel and Onyx Bridge/Cascade Annex.

Design considerations:

- Building heating water system connections: Each building will be provided with a single walled heat exchanger to isolate campus heating water distribution from the existing building distribution. The campus side heating water will be controlled with a two-way control valve and an energy metering system at the heat exchanger skid. The building side of the heat exchanger will tie into the existing heating water return piping upstream of the existing steam heat exchangers and circulate through a decoupled connection with new pumps located on the skid. The heat exchanger will isolate chemical treatment and potential leak issues at the building level as well as provide pressure isolation. It is desired to keep steam heat exchangers to be used as a backup or supplemental heating during phased installation of the heating water systems. The main challenge and cost consideration will be to design equipment spaces for accessibility which may involve reconfiguration of the existing equipment.

- System design temperatures. The proposed leaving water temperature from the heating plant is 150-160F. Most buildings are designed for 180F heating water – LISB and the Student Recreation Center were confirmed to have been designed to accept 140 F heating water. Potential modifications to the existing HVAC systems will be discussed below
- System low Delta-T. Building water return temperatures that are too high will limit the capacity of and efficiency of central heat pump equipment. Improvements to each building heating water distribution potentially include: VFD installation on pumps, three-way valves retrofit to two-way, coil replacement.
- Design and implementation of low temperature hot water distribution system for each building will require testing performance of the existing building by incrementally reducing the heating water leaving temperature during design conditions and evaluating if space temperatures are acceptable. Some buildings may not need substantial conversion.
- Heating equipment that uses steam directly will need to be replaced. Historic buildings using cast iron radiators, finned tube or other direct steam equipment may have a substantial impact to the interior of the building. Phased installation of heating water equipment may coincide with building renewal projects.
- Process steam equipment fed from untreated steam or 60 psig plant steam will be replaced by electric steam generation either point-of-use or at the central utility plant.
- Domestic and laboratory hot water generators will be replaced by double-walled heat exchangers. Existing steam heat exchangers may be phased out but may remain during implementation as backup. In some cases it may be more practical to install small electric hot water heaters. Kitchen equipment or process hot water loads that required above 140F hot water may be electric.

Methodology

The current building inventory of campus buildings that are served by campus steam were evaluated using a combination of building as-built drawings, field surveys, steam meter load data and reports from the 2020 ISES Building Assessment study. Each building was assigned a cost based on the following considerations:

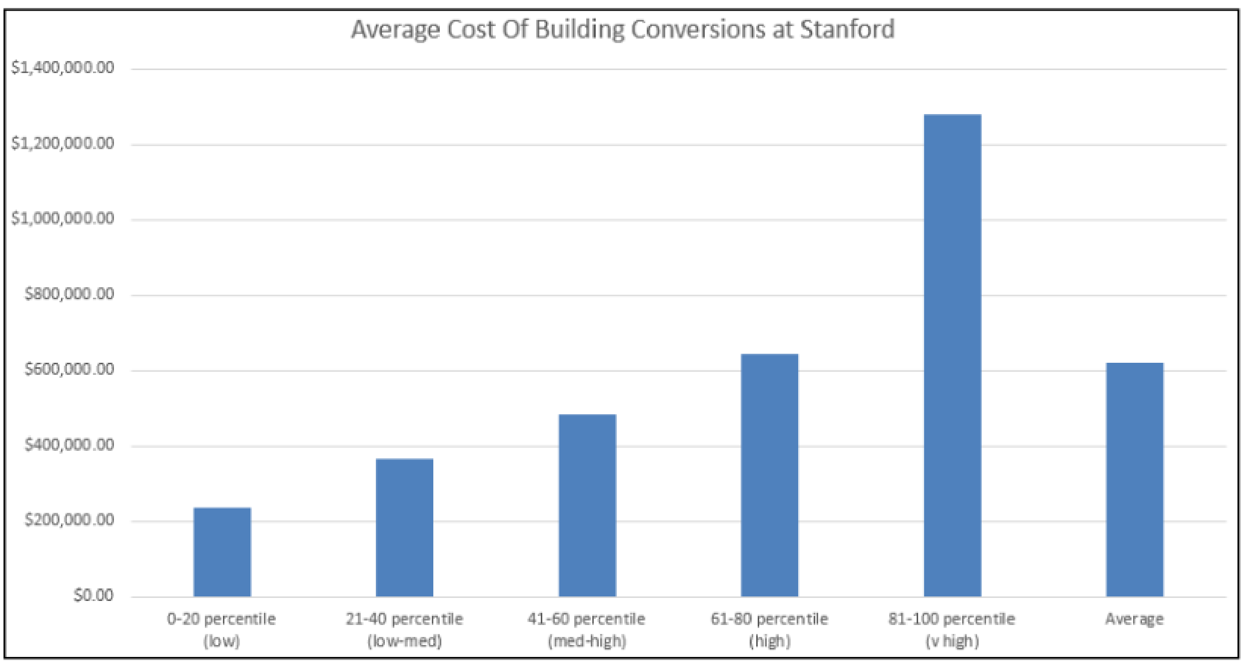
- High cost considerations for buildings with direct steam fed equipment that is to be replaced.
- Historic or vintage buildings carrying premium costs for retrofit.
- Laboratory buildings generally include higher costs for:
- 100% OSA ventilation air handlers will likely consider coil replacement.
- Coil replacement for terminal equipment sized for high ventilation air flows.
- Higher heating demand generally providing higher capacity equipment in congested mechanical spaces that require reconfiguration.

- Replacement of process steam equipment.
- Temporary equipment required to mitigate impact of shutdown to operating research laboratories.
- Higher cost for buildings with heating equipment not located in a ground floor or basement mechanical room (e.g. Willamette). Costs for routing campus heating water through existing buildings.
- Congestion of local buildings located within the Lokey complex.
- Lower cost consideration for non-laboratory buildings, buildings that have been recently upgraded, or buildings constructed in the last 10 years with modern hydronic equipment.

Cost Estimates

Building cost data from the heating water conversion project at Stanford University was referenced for construction costs. The Stanford SESI project converted 155 buildings (6.8 million sf) from steam to low temperature hot water in 2014-2015 for approximately $59M resulting in an average cost of $8.60/sf.

Cost distribution for the building conversions on the Stanford SESI project ranged from $220K to $1.25M per building.



Regional construction costs from the Bay Area in higher education on average are roughly 35% higher than in the Portland Metro area (data from Cummings - https://ccorpinsights.com/costs-per-square-foot/) and expected to be similar for Eugene. In collaboration with the University, this cost data was escalated to account for inflation, market conditions, and contingency funding for inclusion in the study.

Appendix C: Heating Hot Water Distribution

Buildings that will be converted to heating hot water from central steam will be served by new direct buried pre-insulated heating water supply and return piping originating at the CPS boiler plant routed through campus. Site conditions were investigated for cost and feasibility considerations, but specific pipe routing and design of the campus heating water distribution was not included as part of the scope of this study. For the study a civil engineering consultant with experience in campus utilities at University of Oregon (KPFF Engineering) was retained to supplement further understanding of site conditions in general and support estimates of cost impacts expected.

The proposed heating water distribution system considered for this study is similar to what was constructed for the Stanford SESI project; manufactured pre-insulated schedule 10 or 20 carbon steel service piping with polyurethane insulation and HDPE jacket, direct buried in shallow trenching with integral leak detection. Thin walled pipe offers greater flexibility in routing configurations and reduces the number of expansion loops and welds.

Concepts for heating water distribution design include:

- Looped piping distribution in the central campus
- Sectionalizing valves to isolate regions of piping.
- Pipe sizing to accommodate load growth and capital planning
- Reuse of existing tunnel networks where possible.

Several design challenges were acknowledged in the site investigation and are noted on the attached campus plan.

1. Crossing Franklin Boulevard. Previous plans to upgrade chilled water distribution involved construction of a new utility tunnel from CPS under Franklin Boulevard near Lawrence Hall. Construction costs for a new pre-cast utility tunnel under Franklin were included in this conceptual estimate.

2. Crossing Millrace. Routing over existing bridges should be considered as direct buried piping under the millrace will not be serviceable in the future.

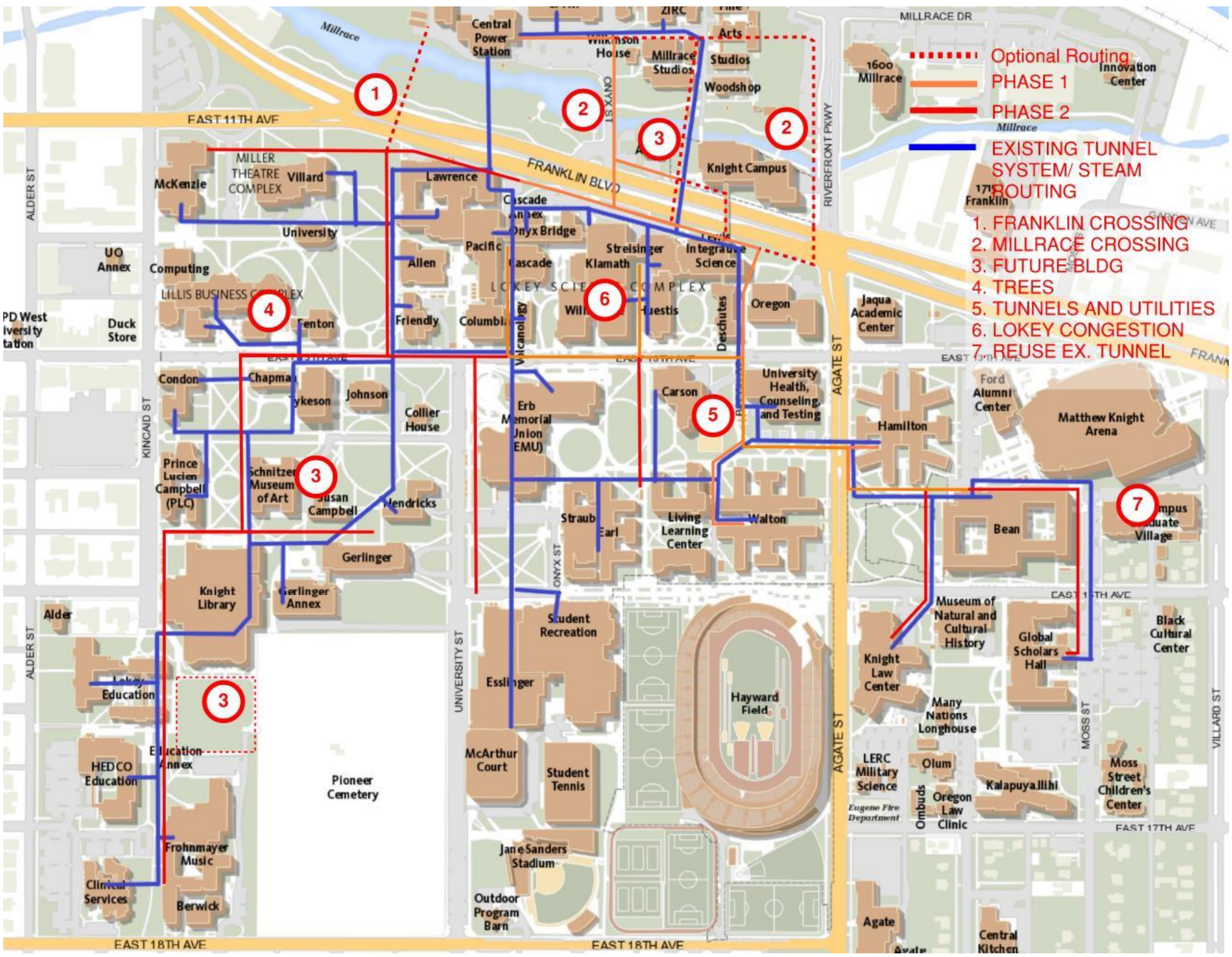
3. Avoid routing in campus green spaces and spaces reserved for future buildings based on capital planning. In general the pipe routing should follow the existing paved surfaces, roads, paths and parking. As estimated, heating water pipe distribution follows existing steam tunnels.

4. Impact to Campus Tree Plan. Pipe routing around significant trees needs to be identified. Trees in the Historic Core and older parts of campus have large root protection zone and should be avoided. Routing to buildings located in dense tree zones may require strategic tree removal.

5. Conflict with existing buried utilities and existing tunnels. Campus tunnel systems are relatively shallow and will require rework to accommodate any utility crossings. Sewer, storm and water piping to buildings is generally direct buried in the right of way and routing near buildings may impact laterals.

6. Building connections into Lokey Science Complex may only be served from the south due to potential conflicts with the existing tunnel system. Where existing utilities serve basement mechanical rooms from internal tunnels, new heating water distribution will require exposing new points of entry to each building, and routing piping within the existing buildings.

7. Reuse of tunnel systems. The only tunnel that was identified available for new piping routing was a section near Global Scholars Hall.



Appendix D: Life Cycle Cost Analysis Worksheets

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 1 - BUSINESS AS USUAL

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	2.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2032	$ 15,625,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ -	$ -	$ -	$ -	$ -	$ 485,676	$ 1,839,877	$ 195,948	$ 425,471	$ 2,946,971	$ 2,946,971	$ 740,215	$ 740,215	$ 3,687,186
2	2024	$ -	$ -	$ -	$ -	$ -	$ 529,689	$ 1,863,445	$ 216,706	$ 460,056	$ 3,069,896	$ 2,916,765	$ 2,919,324	$ 2,773,705	$ 5,690,470
3	2025	$ -	$ -	$ -	$ -	$ -	$ 577,691	$ 1,887,315	$ 239,663	$ 497,464	$ 3,202,133	$ 2,890,647	$ 1,133,412	$ 1,023,160	$ 3,913,808
4	2026	$ -	$ -	$ -	$ -	$ -	$ 605,811	$ 1,929,062	$ 254,857	$ 542,681	$ 3,332,412	$ 2,858,198	$ 1,074,403	$ 921,512	$ 3,779,710
5	2027	$ -	$ -	$ -	$ -	$ -	$ 635,299	$ 1,971,733	$ 271,015	$ 592,009	$ 3,470,056	$ 2,827,796	$ 795,015	$ 647,869	$ 3,475,665
6	2028	$ -	$ -	$ -	$ -	$ -	$ 666,223	$ 2,015,348	$ 288,198	$ 645,821	$ 3,615,589	$ 2,799,423	$ 820,100	$ 634,974	$ 3,434,398
7	2029	$ -	$ -	$ -	$ -	$ -	$ 698,652	$ 2,059,927	$ 306,469	$ 704,525	$ 3,769,574	$ 2,773,062	$ 3,491,489	$ 2,568,491	$ 5,341,553
8	2030	$ -	$ -	$ -	$ -	$ -	$ 732,660	$ 2,105,493	$ 325,899	$ 768,566	$ 3,932,619	$ 2,748,698	$ 2,886,989	$ 2,017,857	$ 4,766,555
9	2031	$ -	$ -	$ -	$ -	$ -	$ 758,705	$ 2,146,739	$ 342,223	$ 813,061	$ 4,060,728	$ 2,696,665	$ 1,478,244	$ 981,679	$ 3,678,344
10	2032	$ 15,625,000	$ -	$ -	$ -	$ -	$ 785,675	$ 2,188,794	$ 359,364	$ 860,130	$ 4,193,964	$ 2,646,219	$ 2,261,350	$ 1,426,819	$ 4,073,038
11	2033	$ -	$ 820,313	$ 316,260	$ 1,136,573	$ 647,372	$ 813,605	$ 2,231,672	$ 377,364	$ 909,925	$ 4,332,567	$ 2,597,313	$ 1,282,433	$ 768,801	$ 4,013,486
12	2034	$ -	$ 803,709	$ 332,864	$ 1,136,573	$ 615,081	$ 842,527	$ 2,275,391	$ 396,266	$ 962,603	$ 4,476,787	$ 2,549,901	$ 1,286,324	$ 732,668	$ 3,897,649
13	2035	$ -	$ 786,233	$ 350,339	$ 1,136,573	$ 584,400	$ 872,478	$ 2,319,966	$ 416,114	$ 1,018,331	$ 4,626,888	$ 2,503,939	$ 1,341,669	$ 726,072	$ 3,814,411
14	2036	$ -	$ 767,841	$ 368,732	$ 1,136,573	$ 555,249	$ 903,493	$ 2,365,414	$ 436,956	$ 1,077,284	$ 4,783,147	$ 2,459,384	$ 1,173,866	$ 603,575	$ 3,618,208
15	2037	$ -	$ 748,482	$ 388,091	$ 1,136,573	$ 527,552	$ 935,610	$ 2,411,752	$ 458,842	$ 1,139,651	$ 4,945,856	$ 2,416,195	$ 4,183,410	$ 2,043,718	$ 4,987,466
16	2038	$ -	$ 728,107	$ 408,465	$ 1,136,573	$ 501,238	$ 968,870	$ 2,458,999	$ 481,825	$ 1,205,628	$ 5,115,322	$ 2,374,332	$ 1,386,392	$ 643,509	$ 3,519,078
17	2039	$ -	$ 706,663	$ 429,910	$ 1,136,573	$ 476,235	$ 1,003,311	$ 2,507,170	$ 505,958	$ 1,275,425	$ 5,291,866	$ 2,333,754	$ 5,138,593	$ 2,266,160	$ 5,076,149
18	2040	$ -	$ 684,093	$ 452,480	$ 1,136,573	$ 452,480	$ 1,038,977	$ 2,556,286	$ 531,301	$ 1,349,263	$ 5,475,827	$ 2,294,426	$ 6,631,655	$ 2,778,729	$ 5,525,634
19	2041	$ -	$ 660,338	$ 476,235	$ 1,136,573	$ 429,910	$ 1,075,911	$ 2,606,363	$ 557,913	$ 1,427,375	$ 5,667,563	$ 2,256,308	$ 2,222,058	$ 884,622	$ 3,570,840
20	2042	$ -	$ 635,335	$ 501,238	$ 1,136,573	$ 408,465	$ 1,114,158	$ 2,657,422	$ 585,857	$ 1,510,010	$ 5,867,448	$ 2,219,368	$ 1,104,720	$ 417,861	$ 3,045,694
21	2043	$ -	$ 609,020	$ 527,552	$ 1,136,573	$ 388,091	$ 1,153,765	$ 2,709,481	$ 615,202	$ 1,597,429	$ 6,075,876	$ 2,183,569	$ 1,679,605	$ 603,622	$ 3,175,281
22	2044	$ -	$ 581,324	$ 555,249	$ 1,136,573	$ 368,732	$ 1,194,779	$ 2,762,560	$ 646,016	$ 1,689,908	$ 6,293,263	$ 2,148,878	$ 1,892,364	$ 646,161	$ 3,163,770
23	2045	$ -	$ 552,173	$ 584,400	$ 1,136,573	$ 350,339	$ 1,237,251	$ 2,816,678	$ 678,374	$ 1,787,742	$ 6,520,045	$ 2,115,263	$ 1,748,691	$ 567,318	$ 3,032,920
24	2046	$ -	$ 521,492	$ 615,081	$ 1,136,573	$ 332,864	$ 1,281,234	$ 2,871,857	$ 712,352	$ 1,891,239	$ 6,756,682	$ 2,082,692	$ 1,543,808	$ 475,866	$ 2,891,422
25	2047	$ -	$ 489,200	$ 647,372	$ 1,136,573	$ 316,260	$ 1,326,779	$ 2,928,117	$ 748,032	$ 2,000,729	$ 7,003,657	$ 2,051,136	$ 1,694,680	$ 496,315	$ 2,863,711
26	2048	$ -	$ 455,213	$ 681,359	$ 1,136,573	$ 300,485	$ 1,373,944	$ 2,985,478	$ 785,500	$ 2,116,557	$ 7,261,479	$ 2,020,563	$ 2,228,738	$ 620,164	$ 2,941,212
27	2049	$ -	$ 419,442	$ 717,131	$ 1,136,573	$ 285,496	$ 1,422,786	$ 3,043,964	$ 824,844	$ 2,239,091	$ 7,530,684	$ 1,990,947	$ 5,629,893	$ 1,488,420	$ 3,764,863
28	2050	$ -	$ 381,793	$ 754,780	$ 1,136,573	$ 271,255	$ 1,473,363	$ 3,103,595	$ 866,159	$ 2,368,718	$ 7,811,836	$ 1,962,259	$ 3,558,916	$ 893,966	$ 3,127,480
29	2051	$ -	$ 342,167	$ 794,406	$ 1,136,573	$ 257,725	$ 1,525,739	$ 3,164,395	$ 909,543	$ 2,505,851	$ 8,105,527	$ 1,934,471	$ 1,415,328	$ 337,783	$ 2,529,980
30	2052	$ -	$ 300,460	$ 836,112	$ 1,136,573	$ 244,869	$ 1,579,976	$ 3,226,385	$ 955,100	$ 2,650,922	$ 8,412,384	$ 1,907,559	$ 2,496,340	$ 566,060	$ 2,718,489
TOTAL		**$ 15,625,000**	**$ 11,993,399**	**$ 10,738,056**	**$ 22,731,455**	**$ 8,314,098**	**$ 29,614,640**	**$ 74,010,677**	**$ 15,289,861**	**$ 39,033,468**	**$ 157,948,646**	**$ 72,506,703**	**$ 67,240,021**	**$ 32,297,668**	**$ 113,118,469**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 1 - BUSINESS AS USUAL

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	4.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2032	$ 18,125,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ -	$ -	$ -	$ -	$ -	$ 485,676	$ 1,839,877	$ 195,948	$ 425,471	$ 2,946,971	$ 2,946,971	$ 753,682	$ 753,682	$ 3,700,653
2	2024	$ -	$ -	$ -	$ -	$ -	$ 529,689	$ 1,863,445	$ 216,706	$ 460,056	$ 3,069,896	$ 2,916,765	$ 2,972,623	$ 2,824,345	$ 5,741,111
3	2025	$ -	$ -	$ -	$ -	$ -	$ 577,691	$ 1,887,315	$ 239,663	$ 497,464	$ 3,202,133	$ 2,890,647	$ 1,193,198	$ 1,077,131	$ 3,967,778
4	2026	$ -	$ -	$ -	$ -	$ -	$ 605,811	$ 1,929,062	$ 254,857	$ 542,681	$ 3,332,412	$ 2,858,198	$ 1,152,541	$ 988,531	$ 3,846,729
5	2027	$ -	$ -	$ -	$ -	$ -	$ 635,299	$ 1,971,733	$ 271,015	$ 592,009	$ 3,470,056	$ 2,827,796	$ 865,683	$ 705,457	$ 3,533,253
6	2028	$ -	$ -	$ -	$ -	$ -	$ 666,223	$ 2,015,348	$ 288,198	$ 645,821	$ 3,615,589	$ 2,799,423	$ 905,675	$ 701,232	$ 3,500,656
7	2029	$ -	$ -	$ -	$ -	$ -	$ 698,652	$ 2,059,927	$ 306,469	$ 704,525	$ 3,769,574	$ 2,773,062	$ 3,907,496	$ 2,874,524	$ 5,647,586
8	2030	$ -	$ -	$ -	$ -	$ -	$ 732,660	$ 2,105,493	$ 325,899	$ 768,566	$ 3,932,619	$ 2,748,698	$ 3,271,921	$ 2,286,905	$ 5,035,603
9	2031	$ -	$ -	$ -	$ -	$ -	$ 758,705	$ 2,146,739	$ 342,223	$ 813,061	$ 4,060,728	$ 2,696,665	$ 1,695,456	$ 1,125,925	$ 3,822,591
10	2032	$ 18,125,000	$ -	$ -	$ -	$ -	$ 785,675	$ 2,188,794	$ 359,364	$ 860,130	$ 4,193,964	$ 2,646,219	$ 2,623,166	$ 1,655,110	$ 4,301,329
11	2033	$ -	$ 951,563	$ 366,862	$ 1,318,424	$ 750,952	$ 813,605	$ 2,231,672	$ 377,364	$ 909,925	$ 4,332,567	$ 2,597,313	$ 1,503,716	$ 901,456	$ 4,249,721
12	2034	$ -	$ 932,302	$ 386,122	$ 1,318,424	$ 713,493	$ 842,527	$ 2,275,391	$ 396,266	$ 962,603	$ 4,476,787	$ 2,549,901	$ 1,523,799	$ 867,930	$ 4,131,324
13	2035	$ -	$ 912,031	$ 406,394	$ 1,318,424	$ 677,904	$ 872,478	$ 2,319,966	$ 416,114	$ 1,018,331	$ 4,626,888	$ 2,503,939	$ 1,604,939	$ 868,547	$ 4,050,389
14	2036	$ -	$ 890,695	$ 427,729	$ 1,318,424	$ 644,089	$ 903,493	$ 2,365,414	$ 436,956	$ 1,077,284	$ 4,783,147	$ 2,459,384	$ 1,417,334	$ 728,760	$ 3,832,233
15	2037	$ -	$ 868,239	$ 450,185	$ 1,318,424	$ 611,961	$ 935,610	$ 2,411,752	$ 458,842	$ 1,139,651	$ 4,945,856	$ 2,416,195	$ 5,096,154	$ 2,489,620	$ 5,517,776
16	2038	$ -	$ 844,605	$ 473,820	$ 1,318,424	$ 581,436	$ 968,870	$ 2,458,999	$ 481,825	$ 1,205,628	$ 5,115,322	$ 2,374,332	$ 1,703,282	$ 790,596	$ 3,746,364
17	2039	$ -	$ 819,729	$ 498,695	$ 1,318,424	$ 552,433	$ 1,003,311	$ 2,507,170	$ 505,958	$ 1,275,425	$ 5,291,866	$ 2,333,754	$ 6,364,643	$ 2,806,858	$ 5,693,045
18	2040	$ -	$ 793,548	$ 524,877	$ 1,318,424	$ 524,877	$ 1,038,977	$ 2,556,286	$ 531,301	$ 1,349,263	$ 5,475,827	$ 2,294,426	$ 8,278,135	$ 3,468,620	$ 6,287,922
19	2041	$ -	$ 765,992	$ 552,433	$ 1,318,424	$ 498,695	$ 1,075,911	$ 2,606,363	$ 557,913	$ 1,427,375	$ 5,667,563	$ 2,256,308	$ 2,794,520	$ 1,112,524	$ 3,867,528
20	2042	$ -	$ 736,989	$ 581,436	$ 1,318,424	$ 473,820	$ 1,114,158	$ 2,657,422	$ 585,857	$ 1,510,010	$ 5,867,448	$ 2,219,368	$ 1,399,312	$ 529,291	$ 3,222,478
21	2043	$ -	$ 706,464	$ 611,961	$ 1,318,424	$ 450,185	$ 1,153,765	$ 2,709,481	$ 615,202	$ 1,597,429	$ 6,075,876	$ 2,183,569	$ 2,142,184	$ 769,865	$ 3,403,619
22	2044	$ -	$ 674,336	$ 644,089	$ 1,318,424	$ 427,729	$ 1,194,779	$ 2,762,560	$ 646,016	$ 1,689,908	$ 6,293,263	$ 2,148,878	$ 2,429,551	$ 829,587	$ 3,406,194
23	2045	$ -	$ 640,521	$ 677,904	$ 1,318,424	$ 406,394	$ 1,237,251	$ 2,816,678	$ 678,374	$ 1,787,742	$ 6,520,045	$ 2,115,263	$ 2,259,420	$ 733,011	$ 3,254,668
24	2046	$ -	$ 604,931	$ 713,493	$ 1,318,424	$ 386,122	$ 1,281,234	$ 2,871,857	$ 712,352	$ 1,891,239	$ 6,756,682	$ 2,082,692	$ 2,006,950	$ 618,626	$ 3,087,440
25	2047	$ -	$ 567,473	$ 750,952	$ 1,318,424	$ 366,862	$ 1,326,779	$ 2,928,117	$ 748,032	$ 2,000,729	$ 7,003,657	$ 2,051,136	$ 2,216,120	$ 649,027	$ 3,067,025
26	2048	$ -	$ 528,048	$ 790,377	$ 1,318,424	$ 348,562	$ 1,373,944	$ 2,985,478	$ 785,500	$ 2,116,557	$ 7,261,479	$ 2,020,563	$ 2,931,128	$ 815,609	$ 3,184,735
27	2049	$ -	$ 486,553	$ 831,872	$ 1,318,424	$ 331,176	$ 1,422,786	$ 3,043,964	$ 824,844	$ 2,239,091	$ 7,530,684	$ 1,990,947	$ 7,444,903	$ 1,968,268	$ 4,290,391
28	2050	$ -	$ 442,880	$ 875,545	$ 1,318,424	$ 314,656	$ 1,473,363	$ 3,103,595	$ 866,159	$ 2,368,718	$ 7,811,836	$ 1,962,259	$ 4,731,265	$ 1,188,449	$ 3,465,364
29	2051	$ -	$ 396,913	$ 921,511	$ 1,318,424	$ 298,961	$ 1,525,739	$ 3,164,395	$ 909,543	$ 2,505,851	$ 8,105,527	$ 1,934,471	$ 1,891,206	$ 451,357	$ 2,684,789
30	2052	$ -	$ 348,534	$ 969,890	$ 1,318,424	$ 284,048	$ 1,579,976	$ 3,226,385	$ 955,100	$ 2,650,922	$ 8,412,384	$ 1,907,559	$ 3,352,228	$ 760,138	$ 2,951,746
TOTAL		**$ 18,125,000**	**$ 13,912,343**	**$ 12,456,145**	**$ 26,368,488**	**$ 9,644,354**	**$ 29,614,640**	**$ 74,010,677**	**$ 15,289,861**	**$ 39,033,468**	**$ 157,948,646**	**$ 72,506,703**	**$ 82,432,230**	**$ 38,340,982**	**$ 120,492,039**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 2 - ELECTRODE STEAM BOILER

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	2.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 2,640,000	25
2032	$ 15,625,000	25
2043	$ 2,897,500	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 2,640,000	$ -	$ -	$ -	$ -	$ 5,134,975	$ 49,725	$ 187,343	$ 49,278	$ 5,421,321	$ 5,421,321	$ 740,215	$ 740,215	$ 6,161,536
2	2024	$ -	$ 138,600	$ 53,435	$ 192,035	$ 173,355	$ 5,392,346	$ 50,663	$ 204,111	$ 53,484	$ 5,700,604	$ 5,416,250	$ 2,919,324	$ 2,773,705	$ 8,363,310
3	2025	$ -	$ 135,795	$ 56,241	$ 192,035	$ 164,708	$ 5,663,522	$ 51,617	$ 222,379	$ 58,057	$ 5,995,575	$ 5,412,359	$ 1,133,412	$ 1,023,160	$ 6,600,228
4	2026	$ -	$ 132,842	$ 59,193	$ 192,035	$ 156,492	$ 5,966,225	$ 56,728	$ 233,587	$ 64,343	$ 6,320,884	$ 5,421,400	$ 1,074,403	$ 921,512	$ 6,499,404
5	2027	$ -	$ 129,734	$ 62,301	$ 192,035	$ 148,686	$ 6,284,681	$ 62,205	$ 245,360	$ 71,338	$ 6,663,584	$ 5,430,245	$ 795,015	$ 647,869	$ 6,226,800
6	2028	$ -	$ 126,464	$ 65,572	$ 192,035	$ 141,270	$ 6,620,023	$ 68,148	$ 257,726	$ 79,145	$ 7,025,043	$ 5,439,243	$ 820,100	$ 634,974	$ 6,215,487
7	2029	$ -	$ 123,021	$ 69,014	$ 192,035	$ 134,223	$ 6,973,491	$ 74,540	$ 270,716	$ 87,849	$ 7,406,596	$ 5,448,614	$ 3,491,489	$ 2,568,491	$ 8,151,328
8	2030	$ -	$ 119,398	$ 72,638	$ 192,035	$ 127,528	$ 7,345,009	$ 81,346	$ 284,360	$ 97,537	$ 7,808,251	$ 5,457,567	$ 2,886,989	$ 2,017,857	$ 7,602,951
9	2031	$ -	$ 115,584	$ 76,451	$ 192,035	$ 121,166	$ 7,721,516	$ 87,001	$ 297,952	$ 104,579	$ 8,211,047	$ 5,452,827	$ 1,478,244	$ 981,679	$ 6,555,672
10	2032	$ 15,625,000	$ 111,571	$ 80,465	$ 192,035	$ 115,122	$ 8,116,367	$ 92,970	$ 312,194	$ 112,154	$ 8,633,685	$ 5,447,500	$ 2,261,350	$ 1,426,819	$ 6,989,442
11	2033	$ -	$ 927,659	$ 400,949	$ 1,328,608	$ 756,752	$ 8,531,334	$ 99,251	$ 327,117	$ 120,297	$ 9,077,999	$ 5,442,132	$ 1,282,433	$ 768,801	$ 6,967,685
12	2034	$ -	$ 906,609	$ 421,999	$ 1,328,608	$ 719,005	$ 8,966,861	$ 105,847	$ 342,753	$ 129,047	$ 9,544,508	$ 5,436,387	$ 1,286,324	$ 732,668	$ 6,888,060
13	2035	$ -	$ 884,454	$ 444,154	$ 1,328,608	$ 683,140	$ 9,424,659	$ 112,780	$ 359,137	$ 138,453	$ 10,035,030	$ 5,430,670	$ 1,341,669	$ 726,072	$ 6,839,882
14	2036	$ -	$ 861,136	$ 467,472	$ 1,328,608	$ 649,064	$ 9,906,440	$ 120,070	$ 376,304	$ 148,568	$ 10,551,383	$ 5,425,278	$ 1,173,866	$ 603,575	$ 6,677,917
15	2037	$ -	$ 836,594	$ 492,015	$ 1,328,608	$ 616,688	$ 10,410,926	$ 127,730	$ 394,291	$ 159,445	$ 11,092,392	$ 5,418,958	$ 4,183,410	$ 2,043,718	$ 8,079,363
16	2038	$ -	$ 810,763	$ 517,845	$ 1,328,608	$ 585,927	$ 10,940,399	$ 135,775	$ 413,138	$ 171,142	$ 11,660,454	$ 5,412,325	$ 1,386,392	$ 643,509	$ 6,641,761
17	2039	$ -	$ 783,576	$ 545,032	$ 1,328,608	$ 556,700	$ 11,496,503	$ 144,257	$ 432,886	$ 183,737	$ 12,257,382	$ 5,405,602	$ 5,138,593	$ 2,266,160	$ 8,228,462
18	2040	$ -	$ 754,962	$ 573,646	$ 1,328,608	$ 528,931	$ 12,079,637	$ 153,146	$ 453,578	$ 197,278	$ 12,883,638	$ 5,398,371	$ 6,631,655	$ 2,778,729	$ 8,706,031
19	2041	$ -	$ 724,845	$ 603,763	$ 1,328,608	$ 502,547	$ 12,690,983	$ 162,440	$ 475,259	$ 211,826	$ 13,540,508	$ 5,390,600	$ 2,222,058	$ 884,622	$ 6,777,769
20	2042	$ -	$ 693,148	$ 635,460	$ 1,328,608	$ 477,480	$ 13,332,537	$ 172,146	$ 497,976	$ 227,453	$ 14,230,113	$ 5,382,554	$ 1,104,720	$ 417,861	$ 6,277,895
21	2043	$ 2,897,500	$ 659,786	$ 668,822	$ 1,328,608	$ 453,662	$ 14,006,689	$ 182,275	$ 521,780	$ 244,236	$ 14,954,979	$ 5,374,570	$ 1,679,605	$ 603,622	$ 6,431,854
22	2044	$ -	$ 776,792	$ 762,582	$ 1,539,374	$ 499,411	$ 14,715,821	$ 192,866	$ 546,721	$ 262,272	$ 15,717,680	$ 5,366,909	$ 1,892,364	$ 646,161	$ 6,512,480
23	2045	$ -	$ 736,756	$ 802,618	$ 1,539,374	$ 474,500	$ 15,461,939	$ 203,920	$ 572,854	$ 281,645	$ 16,520,358	$ 5,359,609	$ 1,748,691	$ 567,318	$ 6,401,427
24	2046	$ -	$ 694,619	$ 844,756	$ 1,539,374	$ 450,831	$ 16,241,594	$ 215,464	$ 600,236	$ 302,461	$ 17,359,756	$ 5,351,003	$ 1,543,808	$ 475,866	$ 6,277,700
25	2047	$ -	$ 650,269	$ 889,105	$ 1,539,374	$ 428,343	$ 17,058,867	$ 227,485	$ 628,928	$ 324,807	$ 18,240,087	$ 5,341,908	$ 1,694,680	$ 496,315	$ 6,266,566
26	2048	$ -	$ 603,591	$ 935,783	$ 1,539,374	$ 406,977	$ 17,917,668	$ 240,008	$ 658,991	$ 348,799	$ 19,165,467	$ 5,332,941	$ 2,228,738	$ 620,164	$ 6,360,081
27	2049	$ -	$ 554,462	$ 792,876	$ 1,347,339	$ 338,439	$ 18,819,600	$ 253,037	$ 690,490	$ 374,550	$ 20,137,678	$ 5,323,959	$ 5,629,893	$ 1,488,420	$ 7,150,817
28	2050	$ -	$ 512,836	$ 834,503	$ 1,347,339	$ 321,557	$ 19,764,644	$ 266,566	$ 723,496	$ 402,168	$ 21,156,873	$ 5,314,405	$ 3,558,916	$ 893,966	$ 6,529,928
29	2051	$ -	$ 469,025	$ 878,314	$ 1,347,339	$ 305,517	$ 20,756,832	$ 280,635	$ 758,079	$ 431,807	$ 22,227,353	$ 5,304,798	$ 1,415,328	$ 337,783	$ 5,948,098
30	2052	$ -	$ 422,913	$ 924,425	$ 1,347,339	$ 290,278	$ 21,798,154	$ 295,263	$ 794,315	$ 463,611	$ 23,351,343	$ 5,295,059	$ 2,119,250	$ 480,553	$ 6,065,890
TOTAL		**$ 21,162,500**	**$ 15,397,802**	**$ 14,031,431**	**$ 29,429,233**	**$ 11,328,297**	**$ 349,540,242**	**$ 4,365,905**	**$ 13,084,057**	**$ 5,901,366**	**$ 372,891,570**	**$ 161,855,366**	**$ 66,862,931**	**$ 32,212,160**	**$ 205,395,823**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.
[2] – Annual interest rate provide by Owner
[3] – Minimum annual positive cash flow requirement provided by Owner
[4] – M&O costs provided by Owner
[5] – M&O escalation provided by Owner
[6] – No debt service for construction year "0". Energy savings also omitted.

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 2 - ELECTRODE STEAM BOILER

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	4.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 2,508,000	25
2032	$ 18,125,000	25
2043	$ 3,695,500	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 2,508,000	$ -	$ -	$ -	$ -	$ 5,134,975	$ 49,725	$ 187,343	$ 49,278	$ 5,421,321	$ 5,421,321	$ 753,682	$ 753,682	$ 6,175,003
2	2024	$ -	$ 131,670	$ 50,764	$ 182,434	$ 164,687	$ 5,392,346	$ 50,663	$ 204,111	$ 53,484	$ 5,700,604	$ 5,416,250	$ 2,972,623	$ 2,824,345	$ 8,405,283
3	2025	$ -	$ 129,005	$ 53,429	$ 182,434	$ 156,473	$ 5,663,522	$ 51,617	$ 222,379	$ 58,057	$ 5,995,575	$ 5,412,359	$ 1,193,198	$ 1,077,131	$ 6,645,962
4	2026	$ -	$ 126,200	$ 56,234	$ 182,434	$ 148,668	$ 5,966,225	$ 56,728	$ 233,587	$ 64,343	$ 6,320,884	$ 5,421,400	$ 1,152,541	$ 988,531	$ 6,558,599
5	2027	$ -	$ 123,248	$ 59,186	$ 182,434	$ 141,252	$ 6,284,681	$ 62,205	$ 245,360	$ 71,338	$ 6,663,584	$ 5,430,245	$ 865,683	$ 705,457	$ 6,276,954
6	2028	$ -	$ 120,140	$ 62,293	$ 182,434	$ 134,206	$ 6,620,023	$ 68,148	$ 257,726	$ 79,145	$ 7,025,043	$ 5,439,243	$ 905,675	$ 701,232	$ 6,274,681
7	2029	$ -	$ 116,870	$ 65,564	$ 182,434	$ 127,512	$ 6,973,491	$ 74,540	$ 270,716	$ 87,849	$ 7,406,596	$ 5,448,614	$ 3,907,496	$ 2,874,524	$ 8,450,650
8	2030	$ -	$ 113,428	$ 69,006	$ 182,434	$ 121,151	$ 7,345,009	$ 81,346	$ 284,360	$ 97,537	$ 7,808,251	$ 5,457,567	$ 3,271,921	$ 2,286,905	$ 7,865,622
9	2031	$ -	$ 109,805	$ 72,628	$ 182,434	$ 115,108	$ 7,721,516	$ 87,001	$ 297,952	$ 104,579	$ 8,211,047	$ 5,452,827	$ 1,695,456	$ 1,125,925	$ 6,693,860
10	2032	$ 18,125,000	$ 105,992	$ 76,441	$ 182,434	$ 109,366	$ 8,116,367	$ 92,970	$ 312,194	$ 112,154	$ 8,633,685	$ 5,447,500	$ 2,623,166	$ 1,655,110	$ 7,211,977
11	2033	$ -	$ 1,053,541	$ 447,317	$ 1,500,858	$ 854,863	$ 8,531,334	$ 99,251	$ 327,117	$ 120,297	$ 9,077,999	$ 5,442,132	$ 1,503,716	$ 901,456	$ 7,198,451
12	2034	$ -	$ 1,030,057	$ 470,801	$ 1,500,858	$ 812,221	$ 8,966,861	$ 105,847	$ 342,753	$ 129,047	$ 9,544,508	$ 5,436,387	$ 1,523,799	$ 867,930	$ 7,116,538
13	2035	$ -	$ 1,005,340	$ 495,518	$ 1,500,858	$ 771,707	$ 9,424,659	$ 112,780	$ 359,137	$ 138,453	$ 10,035,030	$ 5,430,670	$ 1,604,939	$ 868,547	$ 7,070,924
14	2036	$ -	$ 979,326	$ 521,532	$ 1,500,858	$ 733,213	$ 9,906,440	$ 120,070	$ 376,304	$ 148,568	$ 10,551,383	$ 5,425,278	$ 1,417,334	$ 728,760	$ 6,887,252
15	2037	$ -	$ 951,945	$ 548,913	$ 1,500,858	$ 696,639	$ 10,410,926	$ 127,730	$ 394,291	$ 159,445	$ 11,092,392	$ 5,418,958	$ 5,096,154	$ 2,489,620	$ 8,605,217
16	2038	$ -	$ 923,127	$ 577,731	$ 1,500,858	$ 661,890	$ 10,940,399	$ 135,775	$ 413,138	$ 171,142	$ 11,660,454	$ 5,412,325	$ 1,703,282	$ 790,596	$ 6,864,812
17	2039	$ -	$ 892,796	$ 608,062	$ 1,500,858	$ 628,874	$ 11,496,503	$ 144,257	$ 432,886	$ 183,737	$ 12,257,382	$ 5,405,602	$ 6,364,643	$ 2,806,858	$ 8,841,334
18	2040	$ -	$ 860,873	$ 639,985	$ 1,500,858	$ 597,505	$ 12,079,637	$ 153,146	$ 453,578	$ 197,278	$ 12,883,638	$ 5,398,371	$ 8,278,135	$ 3,468,620	$ 9,464,496
19	2041	$ -	$ 827,274	$ 673,584	$ 1,500,858	$ 567,701	$ 12,690,983	$ 162,440	$ 475,259	$ 211,826	$ 13,540,508	$ 5,390,600	$ 2,794,520	$ 1,112,524	$ 7,070,825
20	2042	$ -	$ 791,911	$ 708,947	$ 1,500,858	$ 539,383	$ 13,332,537	$ 172,146	$ 497,976	$ 227,453	$ 14,230,113	$ 5,382,554	$ 1,399,312	$ 529,291	$ 6,451,228
21	2043	$ 3,695,500	$ 754,691	$ 746,167	$ 1,500,858	$ 512,478	$ 14,006,689	$ 182,275	$ 521,780	$ 244,236	$ 14,954,979	$ 5,374,570	$ 2,142,184	$ 769,865	$ 6,656,913
22	2044	$ -	$ 909,531	$ 860,140	$ 1,769,671	$ 574,125	$ 14,715,821	$ 192,866	$ 546,721	$ 262,272	$ 15,717,680	$ 5,366,909	$ 2,429,551	$ 829,587	$ 6,770,621
23	2045	$ -	$ 864,374	$ 905,297	$ 1,769,671	$ 545,487	$ 15,461,939	$ 203,920	$ 572,854	$ 281,645	$ 16,520,358	$ 5,359,609	$ 2,259,420	$ 733,011	$ 6,638,107
24	2046	$ -	$ 816,846	$ 952,826	$ 1,769,671	$ 518,277	$ 16,241,594	$ 215,464	$ 600,236	$ 302,461	$ 17,359,756	$ 5,351,003	$ 2,006,950	$ 618,626	$ 6,487,906
25	2047	$ -	$ 766,822	$ 1,002,849	$ 1,769,671	$ 492,425	$ 17,058,867	$ 227,485	$ 628,928	$ 324,807	$ 18,240,087	$ 5,341,908	$ 2,216,120	$ 649,027	$ 6,483,360
26	2048	$ -	$ 714,173	$ 1,055,498	$ 1,769,671	$ 467,862	$ 17,917,668	$ 240,008	$ 658,991	$ 348,799	$ 19,165,467	$ 5,332,941	$ 2,931,128	$ 815,609	$ 6,616,412
27	2049	$ -	$ 658,759	$ 928,479	$ 1,587,238	$ 398,699	$ 18,819,600	$ 253,037	$ 690,490	$ 374,550	$ 20,137,678	$ 5,323,959	$ 7,444,903	$ 1,968,268	$ 7,690,926
28	2050	$ -	$ 610,014	$ 977,224	$ 1,587,238	$ 378,811	$ 19,764,644	$ 266,566	$ 723,496	$ 402,168	$ 21,156,873	$ 5,314,405	$ 4,731,265	$ 1,188,449	$ 6,881,665
29	2051	$ -	$ 558,710	$ 1,028,528	$ 1,587,238	$ 359,916	$ 20,756,832	$ 280,635	$ 758,079	$ 431,807	$ 22,227,353	$ 5,304,798	$ 1,891,206	$ 451,357	$ 6,116,070
30	2052	$ -	$ 504,712	$ 1,082,526	$ 1,587,238	$ 341,963	$ 21,798,154	$ 295,263	$ 794,315	$ 463,611	$ 23,351,343	$ 5,295,059	$ 3,352,228	$ 760,138	$ 6,397,160
TOTAL		**$ 24,328,500**	**$ 17,551,180**	**$ 15,797,466**	**$ 33,348,645**	**$ 12,672,463**	**$ 349,540,242**	**$ 4,365,905**	**$ 13,084,057**	**$ 5,901,366**	**$ 372,891,570**	**$ 161,855,366**	**$ 82,432,230**	**$ 38,340,982**	**$ 212,868,810**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Affiliated Engineers

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 3 - HEAT RECOVERY CHILLER - SIMULTANEOUS

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	2.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 99,807,742	25
2032	$ 134,704,259	25
2043	$ 152,500	25
2046	$ 4,897,500	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 99,807,742	$ -	$ -	$ -	$ -	$ 681,058	$ 1,155,402	$ 121,556	$ 269,407	$ 2,227,423	$ 2,227,423	$ 740,215	$ 740,215	$ 2,967,637
2	2024	$ -	$ 5,239,906	$ 2,020,174	$ 7,260,081	$ 6,553,861	$ 734,515	$ 1,159,579	$ 137,469	$ 288,797	$ 2,320,361	$ 2,204,618	$ 2,919,324	$ 2,773,705	$ 11,532,184
3	2025	$ -	$ 5,133,847	$ 2,126,233	$ 7,260,081	$ 6,226,947	$ 792,104	$ 1,164,210	$ 155,403	$ 309,713	$ 2,421,431	$ 2,185,888	$ 1,133,412	$ 1,023,160	$ 9,435,994
4	2026	$ -	$ 5,022,220	$ 2,237,861	$ 7,260,081	$ 5,916,339	$ 828,233	$ 1,189,032	$ 166,184	$ 337,625	$ 2,521,075	$ 2,162,317	$ 1,074,403	$ 921,512	$ 9,000,168
5	2027	$ -	$ 4,904,732	$ 2,355,348	$ 7,260,081	$ 5,621,224	$ 865,956	$ 1,214,557	$ 177,730	$ 368,105	$ 2,626,348	$ 2,140,247	$ 795,015	$ 647,869	$ 8,409,340
6	2028	$ -	$ 4,781,077	$ 2,479,004	$ 7,260,081	$ 5,340,831	$ 905,341	$ 1,240,816	$ 190,095	$ 401,396	$ 2,737,649	$ 2,119,665	$ 820,100	$ 634,974	$ 8,095,470
7	2029	$ -	$ 4,650,929	$ 2,609,152	$ 7,260,081	$ 5,074,424	$ 946,467	$ 1,267,816	$ 203,336	$ 437,757	$ 2,855,375	$ 2,100,538	$ 3,491,489	$ 2,568,491	$ 9,743,453
8	2030	$ -	$ 4,513,948	$ 2,746,132	$ 7,260,081	$ 4,821,305	$ 989,412	$ 1,295,579	$ 217,511	$ 477,475	$ 2,979,976	$ 2,082,850	$ 2,886,989	$ 2,017,857	$ 8,922,012
9	2031	$ -	$ 4,369,776	$ 2,890,304	$ 7,260,081	$ 4,580,812	$ 1,023,527	$ 1,321,913	$ 228,851	$ 505,476	$ 3,079,766	$ 2,045,224	$ 1,478,244	$ 981,679	$ 7,607,715
10	2032	$ 134,704,259	$ 4,218,035	$ 3,042,045	$ 7,260,081	$ 4,352,316	$ 1,206,407	$ 788,860	$ 181,469	$ 318,045	$ 2,494,781	$ 1,574,104	$ 2,211,350	$ 1,395,271	$ 7,321,691
11	2033	$ -	$ 11,130,302	$ 5,928,255	$ 17,058,557	$ 9,716,260	$ 1,248,510	$ 803,606	$ 190,812	$ 336,184	$ 2,579,112	$ 1,546,141	$ 1,231,433	$ 738,227	$ 12,000,628
12	2034	$ -	$ 10,819,068	$ 6,239,489	$ 17,058,557	$ 9,231,601	$ 1,292,069	$ 818,662	$ 200,643	$ 355,371	$ 2,666,745	$ 1,518,932	$ 1,234,324	$ 703,050	$ 11,453,583
13	2035	$ -	$ 10,491,495	$ 6,567,062	$ 17,058,557	$ 8,771,118	$ 1,337,135	$ 834,031	$ 210,986	$ 375,667	$ 2,757,820	$ 1,492,453	$ 1,288,669	$ 697,390	$ 10,960,961
14	2036	$ -	$ 10,146,724	$ 6,911,833	$ 17,058,557	$ 8,333,603	$ 1,383,760	$ 849,719	$ 221,870	$ 397,136	$ 2,852,485	$ 1,466,682	$ 1,086,116	$ 558,456	$ 10,358,741
15	2037	$ -	$ 9,783,853	$ 7,274,704	$ 17,058,557	$ 7,917,913	$ 1,431,999	$ 865,731	$ 233,322	$ 419,846	$ 2,950,898	$ 1,441,600	$ 3,984,035	$ 1,946,317	$ 11,305,830
16	2038	$ -	$ 9,401,931	$ 7,656,626	$ 17,058,557	$ 7,522,958	$ 1,481,905	$ 882,080	$ 245,372	$ 443,870	$ 3,053,227	$ 1,417,188	$ 1,295,392	$ 601,270	$ 9,541,416
17	2039	$ -	$ 8,999,958	$ 8,058,599	$ 17,058,557	$ 7,147,703	$ 1,533,530	$ 898,785	$ 258,056	$ 469,294	$ 3,159,664	$ 1,393,437	$ 5,045,968	$ 2,225,311	$ 10,766,451
18	2040	$ -	$ 8,576,882	$ 8,481,675	$ 17,058,557	$ 6,791,167	$ 1,586,927	$ 915,862	$ 271,409	$ 496,203	$ 3,270,401	$ 1,370,330	$ 6,537,405	$ 2,739,237	$ 10,900,734
19	2041	$ -	$ 8,131,594	$ 8,926,963	$ 17,058,557	$ 6,452,415	$ 1,642,156	$ 933,326	$ 285,468	$ 524,687	$ 3,385,637	$ 1,347,853	$ 2,126,183	$ 846,453	$ 8,646,721
20	2042	$ -	$ 7,662,928	$ 9,395,629	$ 17,058,557	$ 6,130,561	$ 1,699,289	$ 951,160	$ 300,265	$ 554,829	$ 3,505,544	$ 1,325,975	$ 1,007,220	$ 380,982	$ 7,837,518
21	2043	$ 152,500	$ 7,169,658	$ 9,888,899	$ 17,058,557	$ 5,824,761	$ 1,758,395	$ 969,372	$ 315,838	$ 586,722	$ 3,630,327	$ 1,304,679	$ 1,580,480	$ 567,998	$ 7,697,438
22	2044	$ -	$ 6,658,497	$ 10,411,153	$ 17,069,650	$ 5,537,813	$ 1,819,528	$ 987,995	$ 332,235	$ 620,487	$ 3,760,244	$ 1,283,961	$ 1,791,614	$ 611,759	$ 7,433,533
23	2045	$ -	$ 6,111,911	$ 10,957,739	$ 17,069,650	$ 5,261,580	$ 1,882,761	$ 1,007,026	$ 349,496	$ 656,227	$ 3,895,510	$ 1,263,799	$ 1,646,316	$ 534,105	$ 7,059,485
24	2046	$ 4,897,500	$ 5,536,630	$ 11,533,020	$ 17,069,650	$ 4,999,126	$ 1,948,168	$ 1,026,477	$ 367,668	$ 694,059	$ 4,036,372	$ 1,244,179	$ 1,439,808	$ 443,809	$ 6,687,114
25	2047	$ -	$ 5,188,265	$ 12,237,632	$ 17,425,897	$ 4,848,892	$ 2,015,819	$ 1,046,362	$ 386,801	$ 734,111	$ 4,183,093	$ 1,225,087	$ 1,589,055	$ 465,381	$ 6,539,360
26	2048	$ -	$ 4,545,790	$ 12,880,108	$ 17,425,897	$ 4,607,024	$ 2,085,787	$ 1,066,697	$ 406,949	$ 776,521	$ 4,335,953	$ 1,206,513	$ 2,121,488	$ 590,320	$ 6,403,857
27	2049	$ -	$ 3,869,584	$ 6,296,233	$ 10,165,817	$ 2,553,556	$ 2,158,136	$ 1,087,518	$ 428,173	$ 821,446	$ 4,495,273	$ 1,188,451	$ 5,521,018	$ 1,459,636	$ 5,201,643
28	2050	$ -	$ 3,539,032	$ 6,626,785	$ 10,165,817	$ 2,426,182	$ 2,232,960	$ 1,108,816	$ 450,524	$ 869,022	$ 4,661,323	$ 1,170,880	$ 3,448,416	$ 866,209	$ 4,463,271
29	2051	$ -	$ 3,191,126	$ 6,974,691	$ 10,165,817	$ 2,305,161	$ 2,310,348	$ 1,130,592	$ 474,060	$ 919,402	$ 4,834,402	$ 1,153,782	$ 1,303,203	$ 311,023	$ 3,769,967
30	2052	$ -	$ 2,824,954	$ 7,340,862	$ 10,165,817	$ 2,190,177	$ 2,390,365	$ 1,152,881	$ 498,853	$ 972,770	$ 5,014,869	$ 1,137,152	$ 2,382,590	$ 540,267	$ 3,867,596
TOTAL		$ 239,562,001	$ 186,614,655	$ 193,094,210	$ 379,708,865	$ 167,057,631	$ 44,212,567	$ 31,134,461	$ 8,208,406	$ 15,737,649	$ 99,293,083	$ 47,341,949	$ 65,211,271	$ 31,531,932	$ 245,931,512

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.
[2] – Annual interest rate provide by Owner
[3] – Minimum annual positive cash flow requirement provided by Owner
[4] – M&O costs provided by Owner
[5] – M&O escalation provided by Owner
[6] – No debt service for construction year "0". Energy savings also omitted.

Project Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 3 - HEAT RECOVERY CHILLER - SIMULTANEOUS

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	4.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 101,755,210	25
2032	$ 156,256,940	25
2043	$ 194,500	25
2046	$ 6,367,500	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 101,755,210	$ -	$ -	$ -	$ -	$ 681,058	$ 1,155,402	$ 121,556	$ 269,407	$ 2,227,423	$ 2,227,423	$ 753,682	$ 753,682	$ 2,981,105
2	2024	$ -	$ 5,342,149	$ 2,059,592	$ 7,401,741	$ 6,681,741	$ 734,515	$ 1,159,579	$ 137,469	$ 288,797	$ 2,320,361	$ 2,204,618	$ 2,972,623	$ 2,824,345	$ 11,710,705
3	2025	$ -	$ 5,234,020	$ 2,167,721	$ 7,401,741	$ 6,348,448	$ 792,104	$ 1,164,210	$ 155,403	$ 309,713	$ 2,421,431	$ 2,185,888	$ 1,193,198	$ 1,077,131	$ 9,611,466
4	2026	$ -	$ 5,120,215	$ 2,281,526	$ 7,401,741	$ 6,031,780	$ 828,233	$ 1,189,032	$ 166,184	$ 337,625	$ 2,521,075	$ 2,162,317	$ 1,152,541	$ 988,531	$ 9,182,628
5	2027	$ -	$ 5,000,434	$ 2,401,306	$ 7,401,741	$ 5,730,907	$ 865,956	$ 1,214,557	$ 177,730	$ 368,105	$ 2,626,348	$ 2,140,247	$ 865,683	$ 705,457	$ 8,576,610
6	2028	$ -	$ 4,874,366	$ 2,527,375	$ 7,401,741	$ 5,445,042	$ 905,341	$ 1,240,816	$ 190,095	$ 401,396	$ 2,737,649	$ 2,119,665	$ 905,675	$ 701,232	$ 8,265,939
7	2029	$ -	$ 4,741,679	$ 2,660,062	$ 7,401,741	$ 5,173,437	$ 946,467	$ 1,267,816	$ 203,336	$ 437,757	$ 2,855,375	$ 2,100,538	$ 3,907,496	$ 2,874,524	$ 10,148,499
8	2030	$ -	$ 4,602,025	$ 2,799,715	$ 7,401,741	$ 4,915,379	$ 989,412	$ 1,295,579	$ 217,511	$ 477,475	$ 2,979,976	$ 2,082,850	$ 3,271,921	$ 2,286,905	$ 9,285,134
9	2031	$ -	$ 4,455,040	$ 2,946,700	$ 7,401,741	$ 4,670,194	$ 1,023,527	$ 1,321,913	$ 228,851	$ 505,476	$ 3,079,766	$ 2,045,224	$ 1,695,456	$ 1,125,925	$ 7,841,343
10	2032	$ 156,256,940	$ 4,300,339	$ 3,101,402	$ 7,401,741	$ 4,437,239	$ 1,206,407	$ 788,860	$ 181,469	$ 318,045	$ 2,494,781	$ 1,574,104	$ 2,565,166	$ 1,618,514	$ 7,629,857
11	2033	$ -	$ 12,341,004	$ 6,426,969	$ 18,767,973	$ 10,689,914	$ 1,248,510	$ 803,606	$ 190,812	$ 336,184	$ 2,579,112	$ 1,546,141	$ 1,443,916	$ 865,607	$ 13,101,663
12	2034	$ -	$ 12,003,588	$ 6,764,385	$ 18,767,973	$ 10,156,688	$ 1,292,069	$ 818,662	$ 200,643	$ 355,371	$ 2,666,745	$ 1,518,932	$ 1,462,199	$ 832,843	$ 12,508,464
13	2035	$ -	$ 11,648,458	$ 7,119,515	$ 18,767,973	$ 9,650,060	$ 1,337,135	$ 834,031	$ 210,986	$ 375,667	$ 2,757,820	$ 1,492,453	$ 1,541,539	$ 834,237	$ 11,976,750
14	2036	$ -	$ 11,274,684	$ 7,493,290	$ 18,767,973	$ 9,168,703	$ 1,383,760	$ 849,719	$ 221,870	$ 397,136	$ 2,852,485	$ 1,466,682	$ 1,311,384	$ 674,283	$ 11,309,669
15	2037	$ -	$ 10,881,286	$ 7,886,687	$ 18,767,973	$ 8,711,357	$ 1,431,999	$ 865,731	$ 233,322	$ 419,846	$ 2,950,898	$ 1,441,600	$ 4,853,279	$ 2,370,969	$ 12,523,925
16	2038	$ -	$ 10,467,235	$ 8,300,738	$ 18,767,973	$ 8,276,824	$ 1,481,905	$ 882,080	$ 245,372	$ 443,870	$ 3,053,227	$ 1,417,188	$ 1,591,482	$ 738,703	$ 10,432,715
17	2039	$ -	$ 10,031,446	$ 8,736,527	$ 18,767,973	$ 7,863,966	$ 1,533,530	$ 898,785	$ 258,056	$ 469,294	$ 3,159,664	$ 1,393,437	$ 6,249,918	$ 2,756,263	$ 12,013,665
18	2040	$ -	$ 9,572,778	$ 9,195,195	$ 18,767,973	$ 7,471,701	$ 1,586,927	$ 915,862	$ 271,409	$ 496,203	$ 3,270,401	$ 1,370,330	$ 8,160,485	$ 3,419,323	$ 12,261,355
19	2041	$ -	$ 9,090,031	$ 9,677,943	$ 18,767,973	$ 7,099,004	$ 1,642,156	$ 933,326	$ 285,468	$ 524,687	$ 3,385,637	$ 1,347,853	$ 2,673,945	$ 1,064,522	$ 9,511,378
20	2042	$ -	$ 8,581,939	$ 10,186,035	$ 18,767,973	$ 6,744,896	$ 1,699,289	$ 951,160	$ 300,265	$ 554,829	$ 3,505,544	$ 1,325,975	$ 1,275,812	$ 482,577	$ 8,553,449
21	2043	$ 194,500	$ 8,047,172	$ 10,720,801	$ 18,767,973	$ 6,408,453	$ 1,758,395	$ 969,372	$ 315,838	$ 586,722	$ 3,630,327	$ 1,304,679	$ 2,015,759	$ 724,430	$ 8,437,562
22	2044	$ -	$ 7,494,541	$ 11,287,580	$ 18,782,121	$ 6,093,381	$ 1,819,528	$ 987,995	$ 332,235	$ 620,487	$ 3,760,244	$ 1,283,961	$ 2,300,201	$ 785,419	$ 8,162,762
23	2045	$ -	$ 6,901,943	$ 11,880,178	$ 18,782,121	$ 5,789,436	$ 1,882,761	$ 1,007,026	$ 349,496	$ 656,227	$ 3,895,510	$ 1,263,799	$ 2,127,145	$ 690,098	$ 7,743,333
24	2046	$ 6,367,500	$ 6,278,234	$ 12,503,888	$ 18,782,121	$ 5,500,652	$ 1,948,168	$ 1,026,477	$ 367,668	$ 694,059	$ 4,036,372	$ 1,244,179	$ 1,871,750	$ 576,952	$ 7,321,782
25	2047	$ -	$ 5,956,073	$ 13,289,224	$ 19,245,298	$ 5,355,155	$ 2,015,819	$ 1,046,362	$ 386,801	$ 734,111	$ 4,183,093	$ 1,225,087	$ 2,077,995	$ 608,575	$ 7,188,817
26	2048	$ -	$ 5,258,389	$ 13,986,908	$ 19,245,298	$ 5,088,033	$ 2,085,787	$ 1,066,697	$ 406,949	$ 776,521	$ 4,335,953	$ 1,206,513	$ 2,790,078	$ 776,361	$ 7,070,907
27	2049	$ -	$ 4,524,076	$ 7,319,480	$ 11,843,557	$ 2,974,989	$ 2,158,136	$ 1,087,518	$ 428,173	$ 821,446	$ 4,495,273	$ 1,188,451	$ 7,300,928	$ 1,930,205	$ 6,093,645
28	2050	$ -	$ 4,139,804	$ 7,703,753	$ 11,843,557	$ 2,826,593	$ 2,232,960	$ 1,108,816	$ 450,524	$ 869,022	$ 4,661,323	$ 1,170,880	$ 4,584,365	$ 1,151,549	$ 5,149,021
29	2051	$ -	$ 3,735,357	$ 8,108,200	$ 11,843,557	$ 2,685,599	$ 2,310,348	$ 1,130,592	$ 474,060	$ 919,402	$ 4,834,402	$ 1,153,782	$ 1,741,381	$ 415,599	$ 4,254,980
30	2052	$ -	$ 3,309,676	$ 8,533,880	$ 11,843,557	$ 2,551,638	$ 2,390,365	$ 1,152,881	$ 498,853	$ 972,770	$ 5,014,869	$ 1,137,152	$ 3,199,478	$ 725,501	$ 4,414,291
TOTAL		**$ 264,574,150**	**$ 205,207,982**	**$ 210,066,579**	**$ 415,274,561**	**$ 180,541,207**	**$ 44,212,567**	**$ 31,134,461**	**$ 8,208,406**	**$ 15,737,649**	**$ 99,293,083**	**$ 47,341,949**	**$ 79,856,480**	**$ 37,380,263**	**$ 265,263,419**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Affiliated Engineers

Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 4 - HEAT RECOVERY CHILLER - ALT. SOURCE

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	2.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 154,183,992	25
2032	$ 141,141,759	25
2043	$ 228,750	25
2046	$ 9,600,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 154,183,992	$ -	$ -	$ -	$ -	$ 852,024	$ 923,088	$ 120,161	$ 217,158	$ 2,112,432	$ 2,112,432	$ 521,387	$ 521,387	$ 2,633,819
2	2024	$ -	$ 8,094,660	$ 3,120,785	$ 11,215,445	$ 10,124,470	$ 900,660	$ 934,944	$ 135,579	$ 234,874	$ 2,206,057	$ 2,096,016	$ 2,673,110	$ 2,539,771	$ 14,760,258
3	2025	$ -	$ 7,930,818	$ 3,284,627	$ 11,215,445	$ 9,619,449	$ 953,192	$ 946,953	$ 152,867	$ 254,047	$ 2,307,058	$ 2,082,641	$ 937,236	$ 846,067	$ 12,548,156
4	2026	$ -	$ 7,758,375	$ 3,457,069	$ 11,215,445	$ 9,139,619	$ 993,123	$ 968,333	$ 163,183	$ 277,273	$ 2,401,913	$ 2,060,113	$ 816,464	$ 700,278	$ 11,900,010
5	2027	$ -	$ 7,576,879	$ 3,638,566	$ 11,215,445	$ 8,683,723	$ 1,034,863	$ 990,245	$ 174,193	$ 302,637	$ 2,501,938	$ 2,038,863	$ 589,714	$ 480,566	$ 11,203,152
6	2028	$ -	$ 7,385,855	$ 3,829,590	$ 11,215,445	$ 8,250,569	$ 1,078,379	$ 1,012,708	$ 185,943	$ 330,339	$ 2,607,368	$ 2,018,793	$ 589,881	$ 456,724	$ 10,726,086
7	2029	$ -	$ 7,184,801	$ 4,030,644	$ 11,215,445	$ 7,839,020	$ 1,123,749	$ 1,035,733	$ 198,480	$ 360,594	$ 2,718,557	$ 1,999,888	$ 3,277,063	$ 2,410,750	$ 12,249,659
8	2030	$ -	$ 6,973,192	$ 4,242,253	$ 11,215,445	$ 7,448,000	$ 1,171,167	$ 1,059,327	$ 211,858	$ 393,638	$ 2,835,990	$ 1,982,212	$ 2,668,001	$ 1,864,796	$ 11,295,007
9	2031	$ -	$ 6,750,474	$ 4,464,971	$ 11,215,445	$ 7,076,485	$ 1,211,047	$ 1,080,638	$ 222,618	$ 416,637	$ 2,930,939	$ 1,946,391	$ 1,190,994	$ 790,920	$ 9,813,795
10	2032	$ 141,141,759	$ 6,516,063	$ 4,699,382	$ 11,215,445	$ 6,723,501	$ 1,918,500	$ -	$ 180,871	$ 17,040	$ 2,116,411	$ 1,335,368	$ 1,933,238	$ 1,219,793	$ 9,278,663
11	2033	$ -	$ 13,679,288	$ 7,802,901	$ 21,482,189	$ 12,235,885	$ 1,983,630	$ -	$ 190,117	$ 18,037	$ 2,191,784	$ 1,313,943	$ 959,234	$ 575,047	$ 14,124,875
12	2034	$ -	$ 13,269,636	$ 8,212,554	$ 21,482,189	$ 11,625,544	$ 2,050,974	$ -	$ 199,836	$ 19,092	$ 2,269,902	$ 1,292,897	$ 997,087	$ 567,924	$ 13,486,364
13	2035	$ -	$ 12,838,477	$ 8,643,713	$ 21,482,189	$ 11,045,647	$ 2,120,607	$ -	$ 210,051	$ 20,210	$ 2,350,868	$ 1,272,222	$ 1,046,869	$ 566,536	$ 12,884,405
14	2036	$ -	$ 12,384,682	$ 9,097,508	$ 21,482,189	$ 10,494,677	$ 2,192,607	$ -	$ 220,788	$ 21,392	$ 2,434,787	$ 1,251,912	$ 600,804	$ 308,920	$ 12,055,508
15	2037	$ -	$ 11,907,062	$ 9,575,127	$ 21,482,189	$ 9,971,189	$ 2,267,055	$ -	$ 232,073	$ 22,644	$ 2,521,773	$ 1,231,960	$ 3,385,236	$ 1,653,787	$ 12,856,936
16	2038	$ -	$ 11,404,368	$ 10,077,821	$ 21,482,189	$ 9,473,814	$ 2,344,033	$ -	$ 243,936	$ 23,969	$ 2,611,938	$ 1,212,359	$ 771,526	$ 358,112	$ 11,044,286
17	2039	$ -	$ 10,875,283	$ 10,606,906	$ 21,482,189	$ 9,001,249	$ 2,423,629	$ -	$ 256,404	$ 25,372	$ 2,705,405	$ 1,193,105	$ 4,555,070	$ 2,008,821	$ 12,203,175
18	2040	$ -	$ 10,318,420	$ 11,163,769	$ 21,482,189	$ 8,552,255	$ 2,505,931	$ -	$ 269,509	$ 26,857	$ 2,802,297	$ 1,174,190	$ 6,001,644	$ 2,514,748	$ 12,241,193
19	2041	$ -	$ 9,732,322	$ 11,749,867	$ 21,482,189	$ 8,125,658	$ 2,591,032	$ -	$ 283,284	$ 28,429	$ 2,902,745	$ 1,155,609	$ 955,785	$ 380,507	$ 9,661,774
20	2042	$ -	$ 9,115,454	$ 12,366,735	$ 21,482,189	$ 7,720,340	$ 2,679,026	$ -	$ 297,763	$ 30,093	$ 3,006,882	$ 1,137,356	$ 385,485	$ 145,810	$ 9,003,506
21	2043	$ 228,750	$ 8,466,201	$ 13,015,989	$ 21,482,189	$ 7,335,240	$ 2,770,012	$ -	$ 312,982	$ 31,854	$ 3,114,848	$ 1,119,425	$ 981,932	$ 352,890	$ 8,807,555
22	2044	$ -	$ 7,794,871	$ 13,703,958	$ 21,498,829	$ 6,974,748	$ 2,864,046	$ 1	$ 328,978	$ 33,719	$ 3,226,744	$ 1,101,794	$ 1,409,555	$ 481,302	$ 8,557,843
23	2045	$ -	$ 7,075,413	$ 14,423,416	$ 21,498,829	$ 6,626,839	$ 2,961,034	$ 5	$ 345,791	$ 35,695	$ 3,342,525	$ 1,084,397	$ 1,176,194	$ 381,586	$ 8,092,822
24	2046	$ 9,600,000	$ 6,318,184	$ 15,180,645	$ 21,498,829	$ 6,296,284	$ 3,061,069	$ 14	$ 363,462	$ 37,790	$ 3,462,336	$ 1,067,237	$ 957,424	$ 295,118	$ 7,658,639
25	2047	$ -	$ 6,025,200	$ 16,171,939	$ 22,197,139	$ 6,176,528	$ 3,164,320	$ 30	$ 382,036	$ 40,013	$ 3,586,398	$ 1,050,335	$ 653,884	$ 191,501	$ 7,418,363
26	2048	$ -	$ 5,176,173	$ 17,020,966	$ 22,197,139	$ 5,868,435	$ 3,270,869	$ 48	$ 401,559	$ 42,367	$ 3,714,843	$ 1,033,684	$ 1,589,874	$ 442,395	$ 7,344,514
27	2049	$ -	$ 4,282,572	$ 6,699,122	$ 10,981,694	$ 2,758,497	$ 3,381,014	$ 73	$ 422,079	$ 44,864	$ 3,848,029	$ 1,017,334	$ 4,726,247	$ 1,249,516	$ 5,025,347
28	2050	$ -	$ 3,930,868	$ 7,050,826	$ 10,981,694	$ 2,620,900	$ 3,494,875	$ 103	$ 443,646	$ 47,512	$ 3,986,135	$ 1,001,279	$ 2,179,383	$ 547,440	$ 4,169,619
29	2051	$ -	$ 3,560,700	$ 7,420,994	$ 10,981,694	$ 2,490,166	$ 3,612,393	$ 154	$ 466,315	$ 50,331	$ 4,129,192	$ 985,476	$ 641,683	$ 153,145	$ 3,628,787
30	2052	$ -	$ 3,171,098	$ 7,810,596	$ 10,981,694	$ 2,365,953	$ 3,733,701	$ 216	$ 490,141	$ 53,324	$ 4,277,382	$ 969,922	$ 451,483	$ 102,376	$ 3,438,252
TOTAL		$ 305,154,501	$ 237,497,388	$ 252,563,237	$ 490,060,624	$ 222,664,684	$ 66,708,561	$ 8,952,612	$ 8,106,502	$ 3,457,802	$ 87,225,477	$ 42,339,154	$ 49,623,485	$ 25,108,533	$ 290,112,370

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 4 - HEAT RECOVERY CHILLER - ALT. SOURCE

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	4.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 157,192,460	25
2032	$ 163,724,440	25
2043	$ 291,750	25
2046	$ 12,480,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 157,192,460	$ -	$ -	$ -	$ -	$ 852,024	$ 923,088	$ 120,161	$ 217,158	$ 2,112,432	$ 2,112,432	$ 530,585	$ 530,585	$ 2,643,017
2	2024	$ -	$ 8,252,604	$ 3,181,679	$ 11,434,283	$ 10,322,021	$ 900,660	$ 934,944	$ 135,579	$ 234,874	$ 2,206,057	$ 2,096,016	$ 2,717,029	$ 2,581,500	$ 14,999,537
3	2025	$ -	$ 8,085,566	$ 3,348,717	$ 11,434,283	$ 9,807,145	$ 953,192	$ 946,953	$ 152,867	$ 254,047	$ 2,307,058	$ 2,082,641	$ 986,072	$ 890,152	$ 12,779,939
4	2026	$ -	$ 7,909,758	$ 3,524,524	$ 11,434,283	$ 9,317,953	$ 993,123	$ 968,333	$ 163,183	$ 277,273	$ 2,401,913	$ 2,060,113	$ 875,843	$ 751,208	$ 12,129,273
5	2027	$ -	$ 7,724,721	$ 3,709,562	$ 11,434,283	$ 8,853,162	$ 1,034,863	$ 990,245	$ 174,193	$ 302,637	$ 2,501,938	$ 2,038,863	$ 642,133	$ 523,283	$ 11,415,308
6	2028	$ -	$ 7,529,969	$ 3,904,314	$ 11,434,283	$ 8,411,555	$ 1,078,379	$ 1,012,708	$ 185,943	$ 330,339	$ 2,607,368	$ 2,018,793	$ 651,434	$ 504,382	$ 10,934,731
7	2029	$ -	$ 7,324,992	$ 4,109,290	$ 11,434,283	$ 7,991,977	$ 1,123,749	$ 1,035,733	$ 198,480	$ 360,594	$ 2,718,557	$ 1,999,888	$ 3,667,522	$ 2,697,988	$ 12,689,853
8	2030	$ -	$ 7,109,255	$ 4,325,028	$ 11,434,283	$ 7,593,327	$ 1,171,167	$ 1,059,327	$ 211,858	$ 393,638	$ 2,835,990	$ 1,982,212	$ 3,023,734	$ 2,113,435	$ 11,688,973
9	2031	$ -	$ 6,882,191	$ 4,552,092	$ 11,434,283	$ 7,214,562	$ 1,211,047	$ 1,080,638	$ 222,618	$ 416,637	$ 2,930,939	$ 1,946,391	$ 1,365,997	$ 907,137	$ 10,068,090
10	2032	$ 163,724,440	$ 6,643,206	$ 4,791,077	$ 11,434,283	$ 6,854,691	$ 1,918,500	$ -	$ 180,871	$ 17,040	$ 2,116,411	$ 1,335,368	$ 2,242,556	$ 1,414,960	$ 9,605,020
11	2033	$ -	$ 14,987,207	$ 8,356,499	$ 23,343,706	$ 13,296,173	$ 1,983,630	$ -	$ 190,117	$ 18,037	$ 2,191,784	$ 1,313,943	$ 1,124,748	$ 674,271	$ 15,284,387
12	2034	$ -	$ 14,548,491	$ 8,795,215	$ 23,343,706	$ 12,632,944	$ 2,050,974	$ -	$ 199,836	$ 19,092	$ 2,269,902	$ 1,292,897	$ 1,181,165	$ 672,771	$ 14,598,611
13	2035	$ -	$ 14,086,742	$ 9,256,964	$ 23,343,706	$ 12,002,797	$ 2,120,607	$ -	$ 210,051	$ 20,210	$ 2,350,868	$ 1,272,222	$ 1,252,293	$ 677,705	$ 13,952,724
14	2036	$ -	$ 13,600,752	$ 9,742,954	$ 23,343,706	$ 11,404,082	$ 2,192,607	$ -	$ 220,788	$ 21,392	$ 2,434,787	$ 1,251,912	$ 725,415	$ 372,992	$ 13,028,986
15	2037	$ -	$ 13,089,247	$ 10,254,460	$ 23,343,706	$ 10,835,233	$ 2,267,055	$ -	$ 232,073	$ 22,644	$ 2,521,773	$ 1,231,960	$ 4,123,833	$ 2,014,613	$ 14,081,805
16	2038	$ -	$ 12,550,888	$ 10,792,819	$ 23,343,706	$ 10,294,758	$ 2,344,033	$ -	$ 243,936	$ 23,969	$ 2,611,938	$ 1,212,359	$ 947,875	$ 439,966	$ 11,947,083
17	2039	$ -	$ 11,984,265	$ 11,359,442	$ 23,343,706	$ 9,781,243	$ 2,423,629	$ -	$ 256,404	$ 25,372	$ 2,705,405	$ 1,193,105	$ 5,641,893	$ 2,488,119	$ 13,462,467
18	2040	$ -	$ 11,387,894	$ 11,955,812	$ 23,343,706	$ 9,293,342	$ 2,505,931	$ -	$ 269,509	$ 26,857	$ 2,802,297	$ 1,174,190	$ 7,491,708	$ 3,139,099	$ 13,606,632
19	2041	$ -	$ 10,760,214	$ 12,583,492	$ 23,343,706	$ 8,829,779	$ 2,591,032	$ -	$ 283,284	$ 28,429	$ 2,902,745	$ 1,155,609	$ 1,202,021	$ 478,536	$ 10,463,924
20	2042	$ -	$ 10,099,580	$ 13,244,126	$ 23,343,706	$ 8,389,339	$ 2,679,026	$ -	$ 297,763	$ 30,093	$ 3,006,882	$ 1,137,356	$ 488,281	$ 184,693	$ 9,711,387
21	2043	$ 291,750	$ 9,404,264	$ 13,939,442	$ 23,343,706	$ 7,970,868	$ 2,770,012	$ -	$ 312,982	$ 31,854	$ 3,114,848	$ 1,119,425	$ 1,252,366	$ 450,079	$ 9,540,372
22	2044	$ -	$ 8,687,760	$ 14,677,168	$ 23,364,928	$ 7,580,156	$ 2,864,046	$ 1	$ 328,978	$ 33,719	$ 3,226,744	$ 1,101,794	$ 1,809,686	$ 617,930	$ 9,299,879
23	2045	$ -	$ 7,917,209	$ 15,447,720	$ 23,364,928	$ 7,202,049	$ 2,961,034	$ 5	$ 345,791	$ 35,695	$ 3,342,525	$ 1,084,397	$ 1,519,718	$ 493,034	$ 8,779,480
24	2046	$ 12,480,000	$ 7,106,203	$ 16,258,725	$ 23,364,928	$ 6,842,802	$ 3,061,069	$ 14	$ 363,462	$ 37,790	$ 3,462,336	$ 1,067,237	$ 1,244,651	$ 383,654	$ 8,293,692
25	2047	$ -	$ 6,907,820	$ 17,364,911	$ 24,272,732	$ 6,754,078	$ 3,164,320	$ 30	$ 382,036	$ 40,013	$ 3,586,398	$ 1,050,335	$ 855,079	$ 250,424	$ 8,054,837
26	2048	$ -	$ 5,996,162	$ 18,276,569	$ 24,272,732	$ 6,417,176	$ 3,270,869	$ 48	$ 401,559	$ 42,367	$ 3,714,843	$ 1,033,684	$ 2,090,925	$ 581,816	$ 8,032,676
27	2049	$ -	$ 5,036,643	$ 7,801,806	$ 12,838,449	$ 3,224,896	$ 3,381,014	$ 73	$ 422,079	$ 44,864	$ 3,848,029	$ 1,017,334	$ 6,249,933	$ 1,652,345	$ 5,894,575
28	2050	$ -	$ 4,627,048	$ 8,211,401	$ 12,838,449	$ 3,064,034	$ 3,494,875	$ 103	$ 443,646	$ 47,512	$ 3,986,135	$ 1,001,279	$ 2,897,297	$ 727,774	$ 4,793,087
29	2051	$ -	$ 4,195,949	$ 8,642,500	$ 12,838,449	$ 2,911,197	$ 3,612,393	$ 154	$ 466,315	$ 50,331	$ 4,129,192	$ 985,476	$ 857,437	$ 204,637	$ 4,101,309
30	2052	$ -	$ 3,742,218	$ 9,096,231	$ 12,838,449	$ 2,765,982	$ 3,733,701	$ 216	$ 490,141	$ 53,324	$ 4,277,382	$ 969,922	$ 606,277	$ 137,477	$ 3,873,382
TOTAL		**$ 333,688,650**	**$ 258,178,817**	**$ 271,504,541**	**$ 529,683,357**	**$ 237,859,318**	**$ 66,708,561**	**$ 8,952,612**	**$ 8,106,502**	**$ 3,457,802**	**$ 87,225,477**	**$ 42,339,154**	**$ 60,265,505**	**$ 29,556,564**	**$ 309,755,036**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Affiliated Engineers

Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 5 - DISTRIBUTED HEAT RECOVERY PLANTS

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	2.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 296,457,484	25
2046	$ 81,280,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 296,457,484	$ -	$ -	$ -	$ -	$ 918,410	$ 921,842	$ 129,106	$ 217,283	$ 2,186,641	$ 2,186,641	$ 414,787	$ 414,787	$ 2,601,428
2	2024	$ -	$ 15,564,018	$ 6,000,494	$ 21,564,512	$ 19,466,839	$ 968,848	$ 933,673	$ 145,177	$ 235,011	$ 2,282,710	$ 2,168,846	$ 2,476,770	$ 2,353,226	$ 23,988,910
3	2025	$ -	$ 15,248,992	$ 6,315,520	$ 21,564,512	$ 18,495,809	$ 1,023,620	$ 945,657	$ 163,168	$ 254,197	$ 2,386,642	$ 2,154,483	$ 845,871	$ 763,590	$ 21,413,882
4	2026	$ -	$ 14,917,427	$ 6,647,085	$ 21,564,512	$ 17,573,215	$ 1,066,291	$ 966,880	$ 174,073	$ 277,403	$ 2,484,647	$ 2,131,073	$ 780,175	$ 669,153	$ 20,373,441
5	2027	$ -	$ 14,568,455	$ 6,996,057	$ 21,564,512	$ 16,696,641	$ 1,110,731	$ 988,613	$ 185,703	$ 302,736	$ 2,587,784	$ 2,108,820	$ 485,100	$ 395,315	$ 19,200,776
6	2028	$ -	$ 14,201,162	$ 7,363,350	$ 21,564,512	$ 15,863,792	$ 1,157,161	$ 1,010,866	$ 198,106	$ 330,394	$ 2,696,527	$ 2,087,826	$ 450,858	$ 349,083	$ 18,300,701
7	2029	$ -	$ 13,814,586	$ 7,749,926	$ 21,564,512	$ 15,072,487	$ 1,205,605	$ 1,033,652	$ 211,335	$ 360,590	$ 2,811,182	$ 2,068,028	$ 2,910,475	$ 2,141,072	$ 19,281,586
8	2030	$ -	$ 13,407,715	$ 8,156,797	$ 21,564,512	$ 14,320,652	$ 1,256,106	$ 1,057,001	$ 225,442	$ 393,564	$ 2,932,113	$ 2,049,396	$ 3,406,013	$ 2,380,628	$ 18,750,677
9	2031	$ -	$ 12,979,483	$ 8,585,029	$ 21,564,512	$ 13,606,321	$ 1,298,877	$ 1,078,113	$ 236,865	$ 416,502	$ 3,030,357	$ 2,012,412	$ 1,086,881	$ 721,781	$ 16,340,513
10	2032	$ -	$ 12,528,769	$ 9,035,743	$ 21,564,512	$ 12,927,620	$ 2,082,685	$ -	$ 201,485	$ 18,560	$ 2,302,729	$ 1,452,927	$ 1,892,000	$ 1,193,774	$ 15,574,322
11	2033	$ -	$ 12,054,393	$ 9,510,119	$ 21,564,512	$ 12,282,775	$ 2,153,330	$ -	$ 211,744	$ 19,645	$ 2,384,719	$ 1,429,605	$ 909,649	$ 545,322	$ 14,257,702
12	2034	$ -	$ 11,555,112	$ 10,009,401	$ 21,564,512	$ 11,670,095	$ 2,226,374	$ -	$ 222,525	$ 20,794	$ 2,469,693	$ 1,406,695	$ 954,200	$ 543,496	$ 13,620,285
13	2035	$ -	$ 11,029,618	$ 10,534,894	$ 21,564,512	$ 11,087,976	$ 2,301,898	$ -	$ 233,855	$ 22,010	$ 2,557,764	$ 1,384,188	$ 934,258	$ 505,593	$ 12,977,758
14	2036	$ -	$ 10,476,536	$ 11,087,976	$ 21,564,512	$ 10,534,894	$ 2,379,987	$ -	$ 245,761	$ 23,298	$ 2,649,046	$ 1,362,079	$ 415,868	$ 213,830	$ 12,110,802
15	2037	$ -	$ 9,894,417	$ 11,670,095	$ 21,564,512	$ 10,009,401	$ 2,460,727	$ -	$ 258,273	$ 24,661	$ 2,743,661	$ 1,340,359	$ 4,148,375	$ 2,026,602	$ 13,376,362
16	2038	$ -	$ 9,281,737	$ 12,282,775	$ 21,564,512	$ 9,510,119	$ 2,544,210	$ -	$ 271,422	$ 26,103	$ 2,841,735	$ 1,319,022	$ 529,480	$ 245,764	$ 11,074,905
17	2039	$ -	$ 8,636,892	$ 12,927,620	$ 21,564,512	$ 9,035,743	$ 2,630,528	$ -	$ 285,240	$ 27,630	$ 2,943,398	$ 1,298,062	$ 4,113,334	$ 1,814,013	$ 12,147,817
18	2040	$ -	$ 7,958,192	$ 13,606,321	$ 21,564,512	$ 8,585,029	$ 2,719,778	$ -	$ 299,761	$ 29,246	$ 3,048,785	$ 1,277,471	$ 5,878,409	$ 2,463,111	$ 12,325,611
19	2041	$ -	$ 7,243,860	$ 14,320,652	$ 21,564,512	$ 8,156,797	$ 2,812,059	$ -	$ 315,021	$ 30,957	$ 3,158,037	$ 1,257,243	$ 907,125	$ 361,135	$ 9,775,175
20	2042	$ -	$ 6,492,026	$ 15,072,487	$ 21,564,512	$ 7,749,926	$ 2,907,475	$ -	$ 331,057	$ 32,768	$ 3,271,301	$ 1,237,373	$ 258,000	$ 97,589	$ 9,084,887
21	2043	$ -	$ 5,700,720	$ 15,863,792	$ 21,564,512	$ 7,363,350	$ 3,006,133	$ -	$ 347,910	$ 34,685	$ 3,388,728	$ 1,217,852	$ 764,025	$ 274,578	$ 8,855,780
22	2044	$ -	$ 4,867,871	$ 16,696,641	$ 21,564,512	$ 6,996,057	$ 3,108,141	$ -	$ 365,620	$ 36,715	$ 3,510,476	$ 1,198,676	$ 2,362,820	$ 806,801	$ 9,001,534
23	2045	$ -	$ 3,991,297	$ 17,573,215	$ 21,564,512	$ 6,647,085	$ 3,213,615	$ -	$ 384,231	$ 38,863	$ 3,636,709	$ 1,179,838	$ 1,042,335	$ 338,159	$ 8,165,082
24	2046	$ 81,280,000	$ 3,068,703	$ 18,495,809	$ 21,564,512	$ 6,315,520	$ 3,322,672	$ -	$ 403,789	$ 41,136	$ 3,767,597	$ 1,161,331	$ 904,640	$ 278,848	$ 7,755,699
25	2047	$ -	$ 6,364,874	$ 21,111,999	$ 27,476,873	$ 7,645,655	$ 3,435,434	$ -	$ 424,342	$ 43,543	$ 3,903,319	$ 1,143,151	$ 502,775	$ 147,246	$ 8,936,052
26	2048	$ -	$ 5,256,494	$ 22,220,379	$ 27,476,873	$ 7,264,280	$ 3,552,027	$ -	$ 445,941	$ 46,091	$ 4,044,059	$ 1,125,291	$ 1,476,206	$ 410,766	$ 8,800,337
27	2049	$ -	$ 4,089,924	$ 1,822,437	$ 5,912,361	$ 1,485,129	$ 3,672,541	$ 1	$ 468,640	$ 48,788	$ 4,189,970	$ 1,107,736	$ 4,290,764	$ 1,134,383	$ 3,727,248
28	2050	$ -	$ 3,994,246	$ 1,918,115	$ 5,912,361	$ 1,411,049	$ 3,796,823	$ 5	$ 492,494	$ 51,646	$ 4,340,968	$ 1,090,410	$ 1,946,500	$ 488,942	$ 2,990,401
29	2051	$ -	$ 3,893,545	$ 2,018,816	$ 5,912,361	$ 1,340,664	$ 3,925,040	$ 15	$ 517,561	$ 54,675	$ 4,497,291	$ 1,073,327	$ 1,702,575	$ 406,338	$ 2,820,329
30	2052	$ -	$ 3,787,557	$ 2,124,804	$ 5,912,361	$ 1,273,790	$ 4,057,364	$ 32	$ 543,905	$ 57,888	$ 4,659,188	$ 1,056,499	$ 302,750	$ 68,650	$ 2,398,939
TOTAL		**$ 377,737,484**	**$ 266,868,621**	**$ 307,718,348**	**$ 574,586,969**	**$ 290,388,708**	**$ 72,314,490**	**$ 8,936,349**	**$ 8,939,554**	**$ 3,517,384**	**$ 93,707,777**	**$ 45,086,660**	**$ 49,093,016**	**$ 24,553,574**	**$ 360,028,942**

[1] – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

[2] – Annual interest rate provide by Owner

[3] – Minimum annual positive cash flow requirement provided by Owner

[4] – M&O costs provided by Owner

[5] – M&O escalation provided by Owner

[6] – No debt service for construction year "0". Energy savings also omitted.

Life Cycle Cost Worksheet

Client	University of Oregon
Project	Thermal Systems Transition Study
Alternative Description	OPTION 5 - DISTRIBUTED HEAT RECOVERY PLANTS

Inputs

Study Period (Years)	30	2023	Base Year
O&M Inflation Rate[5]	4.5%	5.25%	Discount Rate
		5.25%	Interest Rate

CapEx

Year	Cost	Term
2023	$ 302,242,020	25
2046	$ 105,664,000	25

Annual Cash Flow

		Investment Cost					Utility Costs						O&M Costs		
Year in Study Period	Year	CapEx	Interest	Principal Repayment	Payment	PV Investment Cost	Electricity Cost	Natural Gas Cost	Sewer and Water Cost	GHG Cost	Utility Cost	PV Utility Cost	Non-Recurring O&M Costs	PV O&M Cost	Total PV Cost
1	2023	$ 302,242,020	$ -	$ -	$ -	$ -	$ 918,410	$ 921,842	$ 129,106	$ 217,283	$ 2,186,641	$ 2,186,641	$ 421,905	$ 421,905	$ 2,608,546
2	2024	$ -	$ 15,867,706	$ 6,117,577	$ 21,985,283	$ 19,846,679	$ 968,848	$ 933,673	$ 145,177	$ 235,011	$ 2,282,710	$ 2,168,846	$ 2,549,169	$ 2,422,013	$ 24,437,539
3	2025	$ -	$ 15,546,533	$ 6,438,750	$ 21,985,283	$ 18,856,703	$ 1,023,620	$ 945,657	$ 163,168	$ 254,197	$ 2,386,642	$ 2,154,483	$ 927,052	$ 836,874	$ 21,848,059
4	2026	$ -	$ 15,208,499	$ 6,776,784	$ 21,985,283	$ 17,916,107	$ 1,066,291	$ 966,880	$ 174,073	$ 277,403	$ 2,484,647	$ 2,131,073	$ 875,843	$ 751,208	$ 20,798,388
5	2027	$ -	$ 14,852,718	$ 7,132,565	$ 21,985,283	$ 17,022,429	$ 1,110,731	$ 988,613	$ 185,703	$ 302,736	$ 2,587,784	$ 2,108,820	$ 568,633	$ 463,387	$ 19,594,636
6	2028	$ -	$ 14,478,258	$ 7,507,025	$ 21,985,283	$ 16,173,330	$ 1,157,161	$ 1,010,866	$ 198,106	$ 330,394	$ 2,696,527	$ 2,087,826	$ 547,294	$ 423,750	$ 18,684,905
7	2029	$ -	$ 14,084,139	$ 7,901,144	$ 21,985,283	$ 15,366,584	$ 1,205,605	$ 1,033,652	$ 211,335	$ 360,590	$ 2,811,182	$ 2,068,028	$ 3,300,637	$ 2,428,092	$ 19,862,703
8	2030	$ -	$ 13,669,329	$ 8,315,954	$ 21,985,283	$ 14,600,080	$ 1,256,106	$ 1,057,001	$ 225,442	$ 393,564	$ 2,932,113	$ 2,049,396	$ 3,905,014	$ 2,729,404	$ 19,378,881
9	2031	$ -	$ 13,232,742	$ 8,752,542	$ 21,985,283	$ 13,871,810	$ 1,298,877	$ 1,078,113	$ 236,865	$ 416,502	$ 3,030,357	$ 2,012,412	$ 1,292,937	$ 858,619	$ 16,742,841
10	2032	$ -	$ 12,773,233	$ 9,212,050	$ 21,985,283	$ 13,179,867	$ 2,082,685	$ -	$ 201,485	$ 18,560	$ 2,302,729	$ 1,452,927	$ 2,242,556	$ 1,414,960	$ 16,047,754
11	2033	$ -	$ 12,289,601	$ 9,695,683	$ 21,985,283	$ 12,522,439	$ 2,153,330	$ -	$ 211,744	$ 19,645	$ 2,384,719	$ 1,429,605	$ 1,124,748	$ 674,271	$ 14,626,315
12	2034	$ -	$ 11,780,577	$ 10,204,706	$ 21,985,283	$ 11,897,804	$ 2,226,374	$ -	$ 222,525	$ 20,794	$ 2,469,693	$ 1,406,695	$ 1,181,165	$ 672,771	$ 13,977,270
13	2035	$ -	$ 11,244,830	$ 10,740,453	$ 21,985,283	$ 11,304,327	$ 2,301,898	$ -	$ 233,855	$ 22,010	$ 2,557,764	$ 1,384,188	$ 1,169,873	$ 633,101	$ 13,321,616
14	2036	$ -	$ 10,680,956	$ 11,304,327	$ 21,985,283	$ 10,740,453	$ 2,379,987	$ -	$ 245,761	$ 23,298	$ 2,649,046	$ 1,362,079	$ 555,895	$ 285,829	$ 12,388,360
15	2037	$ -	$ 10,087,479	$ 11,897,804	$ 21,985,283	$ 10,204,706	$ 2,460,727	$ -	$ 258,273	$ 24,661	$ 2,743,661	$ 1,340,359	$ 5,108,733	$ 2,495,765	$ 14,040,830
16	2038	$ -	$ 9,462,844	$ 12,522,439	$ 21,985,283	$ 9,695,683	$ 2,544,210	$ -	$ 271,422	$ 26,103	$ 2,841,735	$ 1,319,022	$ 717,395	$ 332,987	$ 11,347,691
17	2039	$ -	$ 8,805,416	$ 13,179,867	$ 21,985,283	$ 9,212,050	$ 2,630,528	$ -	$ 285,240	$ 27,630	$ 2,943,398	$ 1,298,062	$ 5,152,988	$ 2,272,508	$ 12,782,620
18	2040	$ -	$ 8,113,473	$ 13,871,810	$ 21,985,283	$ 8,752,542	$ 2,719,778	$ -	$ 299,761	$ 29,246	$ 3,048,785	$ 1,277,471	$ 7,397,588	$ 3,099,662	$ 13,129,675
19	2041	$ -	$ 7,385,203	$ 14,600,080	$ 21,985,283	$ 8,315,954	$ 2,812,059	$ -	$ 315,021	$ 30,957	$ 3,158,037	$ 1,257,243	$ 1,202,021	$ 478,536	$ 10,051,733
20	2042	$ -	$ 6,618,699	$ 15,366,584	$ 21,985,283	$ 7,901,144	$ 2,907,475	$ -	$ 331,057	$ 32,768	$ 3,271,301	$ 1,237,373	$ 389,481	$ 147,322	$ 9,285,838
21	2043	$ -	$ 5,811,954	$ 16,173,330	$ 21,985,283	$ 7,507,025	$ 3,006,133	$ -	$ 347,910	$ 34,685	$ 3,388,728	$ 1,217,852	$ 1,050,086	$ 377,383	$ 9,102,261
22	2044	$ -	$ 4,962,854	$ 17,022,429	$ 21,985,283	$ 7,132,565	$ 3,108,141	$ -	$ 365,620	$ 36,715	$ 3,510,476	$ 1,198,676	$ 3,099,206	$ 1,058,245	$ 9,389,486
23	2045	$ -	$ 4,069,176	$ 17,916,107	$ 21,985,283	$ 6,776,784	$ 3,213,615	$ -	$ 384,231	$ 38,863	$ 3,636,709	$ 1,179,838	$ 1,413,898	$ 458,703	$ 8,415,325
24	2046	$ 105,664,000	$ 3,128,581	$ 18,856,703	$ 21,985,283	$ 6,438,750	$ 3,322,672	$ -	$ 403,789	$ 41,136	$ 3,767,597	$ 1,161,331	$ 1,244,651	$ 383,654	$ 7,983,735
25	2047	$ -	$ 7,685,964	$ 21,985,388	$ 29,671,352	$ 8,256,286	$ 3,435,434	$ -	$ 424,342	$ 43,543	$ 3,903,319	$ 1,143,151	$ 727,579	$ 213,083	$ 9,612,520
26	2048	$ -	$ 6,531,731	$ 23,139,621	$ 29,671,352	$ 7,844,452	$ 3,552,027	$ -	$ 445,941	$ 46,091	$ 4,044,059	$ 1,125,291	$ 2,025,825	$ 563,702	$ 9,533,445
27	2049	$ -	$ 5,316,901	$ 2,369,168	$ 7,686,069	$ 1,930,667	$ 3,672,541	$ 1	$ 468,640	$ 48,788	$ 4,189,970	$ 1,107,736	$ 5,747,128	$ 1,519,414	$ 4,557,817
28	2050	$ -	$ 5,192,519	$ 2,493,549	$ 7,686,069	$ 1,834,363	$ 3,796,823	$ 5	$ 492,494	$ 51,646	$ 4,340,968	$ 1,090,410	$ 2,662,257	$ 668,734	$ 3,593,507
29	2051	$ -	$ 5,061,608	$ 2,624,461	$ 7,686,069	$ 1,742,863	$ 3,925,040	$ 15	$ 517,561	$ 54,675	$ 4,497,291	$ 1,073,327	$ 2,351,077	$ 561,110	$ 3,377,300
30	2052	$ -	$ 4,923,824	$ 2,762,245	$ 7,686,069	$ 1,655,927	$ 4,057,364	$ 32	$ 543,905	$ 57,888	$ 4,659,188	$ 1,056,499	$ 484,077	$ 109,767	$ 2,822,193
TOTAL		**$ 407,906,020**	**$ 278,867,349**	**$ 316,881,143**	**$ 595,748,492**	**$ 298,500,372**	**$ 72,314,490**	**$ 8,936,349**	**$ 8,939,554**	**$ 3,517,384**	**$ 93,707,777**	**$ 45,086,660**	**$ 61,436,710**	**$ 29,756,759**	**$ 373,343,790**

1 – Project cost includes total cost of implementing the ECMs, construction costs, CM fees, design fees, and contingencies.

2 – Annual interest rate provide by Owner

3 – Minimum annual positive cash flow requirement provided by Owner

4 – M&O costs provided by Owner

5 – M&O escalation provided by Owner

6 – No debt service for construction year "0". Energy savings also omitted.