January 1, 2024

PRE-FEASIBILITY STUDY (SAMPLE)

Project X

Final Report

Attention: ABC Company

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Pre-Feasibility Study (Sample) : Project X

To:	ABC Company
From:	Rathco ENG
Date:	January 1, 2024
Project Number:	XX-XXXX-X
Project Name:	Project X

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LIST OF ABBREVIATIONS

BAU	*Business-As-Usual*
BH	*Borehole*
CO2	*Carbon Dioxide*
CO2e	*Carbon Dioxide Equivalent*
DES	*District Energy System*
DHW	*Domestic Hot Water*
ETS	*Energy Transfer Station*
Geo	*Geo-Exchange*
GFA	*Gross Floor Area*
GHG	*Greenhouse Gas*
GHGI	*Greenhouse Gas Intensity*
HP	*Heat Pump*
HVAC	*Heating, Ventilation, and Air Conditioning*
HX	*Heat Exchanger*
ISHP	*In-Suite Heat Pumps*
ITC	*Investment Tax Credit*
kWh	*Kilowatt Hour*
LCOE	*Levelized Cost of Energy*
MUA	*Makeup Air*
MW	*Megawatt*
MWh	*Megawatt Hour*
SPA	*Site Plan Approval*
TEDI	*Thermal Energy Demand Intensity*
TEUI	*Total Energy Use Intensity*
WEE	*Wastewater Energy Exchange*

EXECUTIVE SUMMARY

The Project team completed a pre-feasibility study for ABC Company's 123 Example Rd. mixed-use development to compare low carbon thermal energy systems to the business-as-usual (BAU).

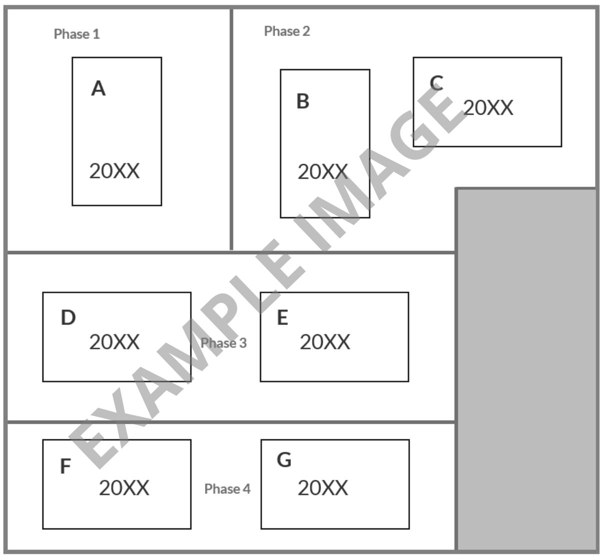

Figure 1: Site plan

The project goals identified for this pre-feasibility energy study were as follows:

- 10% operating GHG reductions from baseline
- Cost-neutral construction costs for the developer
- Operating cost savings for the homeowners

Concept Development

Technologies were grouped to form energy scenarios capable of providing space heating, cooling, and domestic hot water (DHW) heating for the site.

ABC Company selected four energy scenarios for assessment against the baseline (BAU).

1. Geo-Exchange
2. Air Source Heat Pumps (ASHP)
3. Wastewater Energy Exchange DES
4. Biomass Boilers DES

Comparative Analysis

The scenarios were compared using GHG emissions and the levelized cost of energy (LCOE).

GHG Emissions: The CO2 equivalent emissions of the energy system (including fuels consumed onsite and offsite through the electrical grid) per m2 over the course of one year.

Levelized Cost of Energy (LCOE): The LCOE is the life cycle cost of the energy system. It is presented in $/MWh, which is a measure of the cost per unit of thermal energy demand met.

The low carbon scenarios all had GHG emissions lower than the BAU, exceeding the project goal of 10% emissions reductions. The geo scenarios had similar emissions reductions with wastewater showing the most reductions. The Biomass DES system showed the most reduction compared to the BAU due to the emissions associated with the electricity grid (higher amounts in the geo scenarios) as well as carbon emissions of the biomass fuel source being counted in the forestry sector and not at the point of combustion.

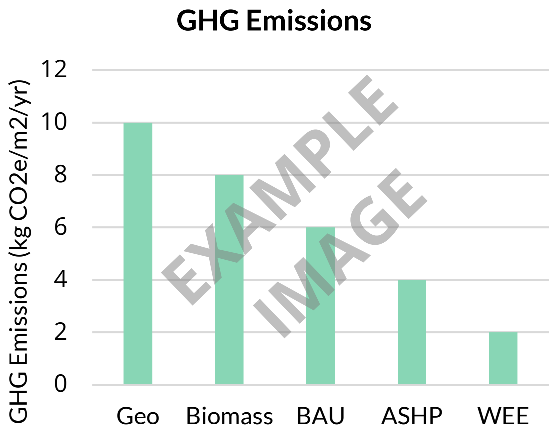

Figure 2: GHG emissions results

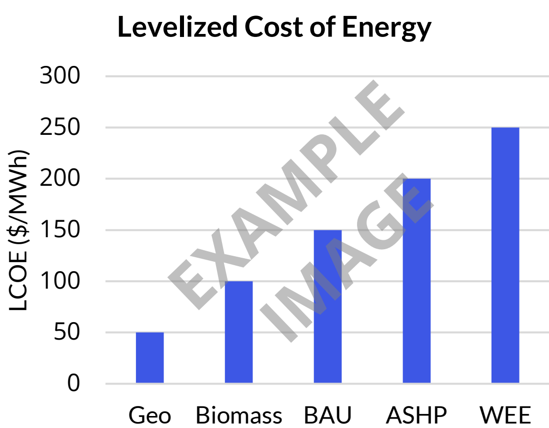

Figure 3: LCOE results

The LCOE results showed the biomass DES system to have a higher LCOE when compared to the BAU due to the capital cost associated with biomass plants and the limited operating cost savings. The wastewater system saw the lowest LCOE due to significant operational cost savings. These savings were a result of substantial reduction of natural gas use, reducing the carbon tax payable, and high efficiency of the system relative to the BAU.

Preferred Scenario: Geo-Exchange

The geo-exchange scenario used geo-exchange to provide space heating, space cooling, DHW preheat, and MUA. Supplemental natural gas boilers were required for peak DHW. Fluid coolers will be required for peak cooling.

The geo system was sized to meet 100% of the heating loads identified. This development was found to be cooling dominant, requiring a peak cooling plant for peak cooling needs and an alternate means of heat rejection for borefield temperature balancing. Each building would require a fluid cooler if not connected to a DES.

Equipment (Total for all phases)	Geo-Exchange Boreholes (325 @ 850 ft) Natural gas boilers for DHW (X MW) Fluid coolers for peak cooling (X MW)
Total Space Requirement	Geo-Mechanical Rooms: XXX-XXX m2 Rooftops: XXX-XXX m2 (Total phases 1-4. For detailed breakdown see Section 5.1)
Customer Connection	Each tower has its own system (no DES). *Where there are two buildings per phase sharing a common podium, a geo system will be shared.
Capital Cost	$ XX M (2023 CAD)
Annual Operating Cost	$X M/yr (escalated to 20XX CAD – the year of full build-out)

1 INTRODUCTION

The project team was engaged by ABC Company (ABC Co.) to complete a pre-feasibility study for 123 Example Rd. mixed-use development. The purpose of this study was to investigate low or zero carbon thermal energy solutions.

This Pre-Feasibility Study provides ABC Company's leadership with the information required to make a decision on how low or zero carbon thermal energy (space heating, cooling, and domestic hot water) can fit within the project's strategic plan. The project team understands the challenges ahead to develop a plan to meet the immediate demands of the development while recognizing the need for a longer-term roadmap to safeguard the future of ABC Company's vision.

1.1 Background

The development is located at 123 Example Rd in Example city, Example province. The project is located at the intersection of ABC Ave and CDF Ave. It includes seven towers split over four phases. Towers A and B share a common podium, and towers F and G share a common podium. The entire development shares a common parkade below grade.

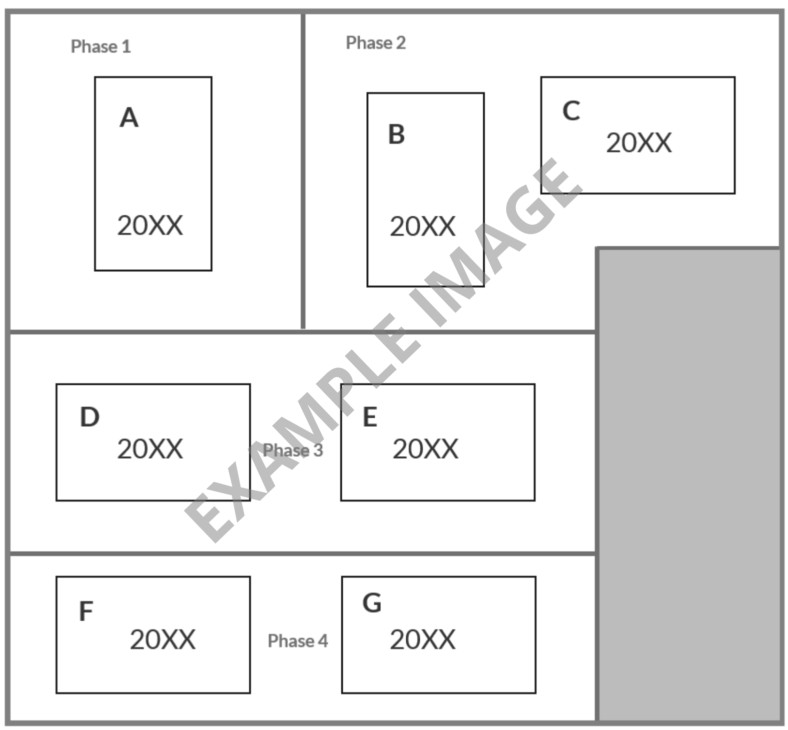

Figure 4: Development overview with building lettering, storeys, and phasing.

1.2 Scope

The scope of work for this pre-feasibility energy study is included below. The project team and ABC Company met several times throughout the study process to share results and develop consensus on the proposed solutions. These regular touchpoints served as a platform for the ABC Company team to provide input and feedback to the ongoing study and the opportunity for the project team to more clearly understand the goals and vision for the development and align the project with ABC Company's needs.

This report is the Final Report deliverable included in the scope. The information contained in this report supersedes all previous deliverables. This report summarizes all work completed in the project as per the scope below.

This pre-feasibility study was completed to a Class D level of accuracy (+/- 30-40%).

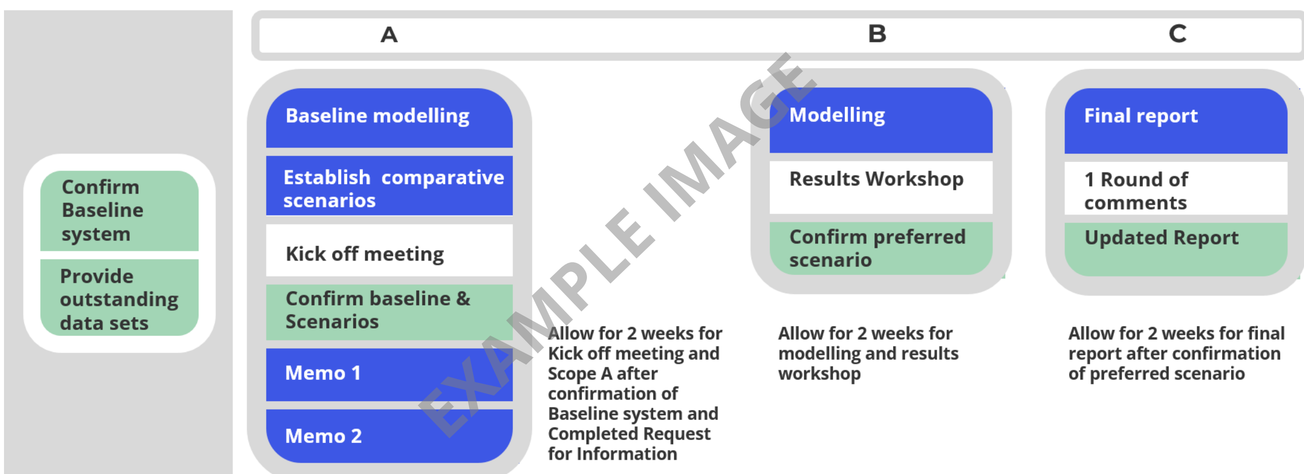

Figure 5: Study scope of work

1.3 Project Inputs

The costs and results of this study were dependent on the inputs provided by ABC Company. Any changes to the inputs and assumptions used in this study could impact the results presented.

The following documents were provided by ABC Company:

- Architectural drawings by Consultant X
    - Elevations dated XX XX, 20XX
    - Master Plan dated XX XX, 20XX
    - Plans dated XX XX, 20XX
    - Site Plan dated XX XX, 20XX
- Project Statistics by Consultant X dated XX XX, 20XX
- Civil engineering plans by Consultant X dated XX XX, 20XX
- Operational Parametric Analysis by Consultant X dated XX XX, 20XX

- Functional Servicing and Stormwater Management Report by Consultant X dated XX XX, 20XX
- Load information (8760 demands)
- Development phasing and timeline by ABC Company received XX XX, 20XX
- Energy Efficiency Reports by Consultant X dated XX XX, 20XX

1.4 Project Goals

The ABC Company team identified specific goals for consideration for this project:

- 10% operating GHG reductions from baseline scenario
- Cost-neutral construction costs for the developer
- Operating cost savings for the homeowners

The low carbon scenarios were compared against the baseline in the comparative analysis phase of the project. GHG emissions are one of the metrics that was used in the comparison. In developing energy scenarios and evaluating results, 10% GHG emissions reduction from the baseline was the minimum for determining a viable energy system.

In discussions with ABC Company, it was understood that a utility or energy as a service (EaaS) model is likely required to meet the goal to have cost-neutral construction costs for the developer.

This pre-feasibility study assessed energy systems using a global benefit model, where costs related to the thermal energy systems were not allocated to different groups (i.e., developer, homeowner, utility, etc.). While construction cost neutrality for the developer and operating cost savings for the homeowners are not goals that can be assessed in this study, the results can be used to advise on the potential to meet these goals. For example, in reviewing the overall operating cost comparisons for the BAU versus the low carbon energy systems, it will be clear if there is an operating cost savings potential that could be passed on to the homeowners, depending on the agreements between entities.

2 ESTABLISH BASELINE

The baseline model formed the platform against which all energy scenarios were compared. It represents the business-as-usual for these types of buildings.

2.1 Basis of Assessment

The following table summarizes the basis of assessment for this study.

Note that the gross floor area (GFA) totals used in this study included indoor amenity space as these spaces require heating and cooling.

Table 1: Building information used as basis of assessment

	A	B	C	D	E	F	G
Building HVAC	In-suite heat pumps	In-suite heat pumps	In-suite heat pumps	In-suite heat pumps	In-suite heat pumps	In-suite heat pumps	In-suite heat pumps
Use Type	Residential + office	Residential + daycare	Residential + retail	Residential + retail	Residential + retail	Residential + retail	Residential + retail
Phasing	Phase 1 (20XX)	Phase 1 (20XX)	Phase 2 (20XX)	Phase 3 (20XX)	Phase 3 (20XX)	Phase 4 (20XX)	Phase 4 (20XX)
GFA (m2)	XX,XXX	XX,XXX	XX,XXX	XX,XXX	XX,XXX	XX,XXX	XX,XXX
Number of Units	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Sustainability Target	20%	20%	20%	20%	20%	20%	20%

The development is predominantly residential, with some allowances for non-residential uses in the podium levels, such as retail and daycare.

2.2 Demands

The thermal energy demands for the 123 Example Ave. development used the hourly energy profiles provided by ABC Company for buildings A, B, and C, and were estimated using the GFAs provided by ABC Company for the remainder of the buildings.

The peak and total energy demands for each domestic hot water (DHW), space heating, and cooling are shown below. Each of the buildings were considered separately for the baseline energy model, as no interconnection was assumed.

Table 2: Thermal energy demands

Tower/Building	DHW		Space Heating		Cooling	
	Peak MW	Annual MWh	Peak MW	Annual MWh	Peak MW	Annual MWh
A	X.X	XXX	X.X	X,XXX	X.X	X,XXX
B	X.X	XXX	X.X	X,XXX	X.X	X,XXX
C	X.X	XXX	X.X	X,XXX	X.X	X,XXX
D	X.X	XXX	X.X	X,XXX	X.X	X,XXX
E	X.X	XXX	X.X	X,XXX	X.X	X,XXX
F	X.X	XXX	X.X	X,XXX	X.X	X,XXX
G	X.X	XXX	X.X	X,XXX	X.X	X,XXX
Total	X.X	X,XXX	X.X	X,XXX	X.X	X,XXX

Note: Table 2 is to outline energy demands only and should not be used to outline equipment sizing. Additional safety factors may be added for equipment sizing.

The hourly demands for space heating and cooling for the full site are shown below. The DHW demands are not shown as they are consistent throughout the year.

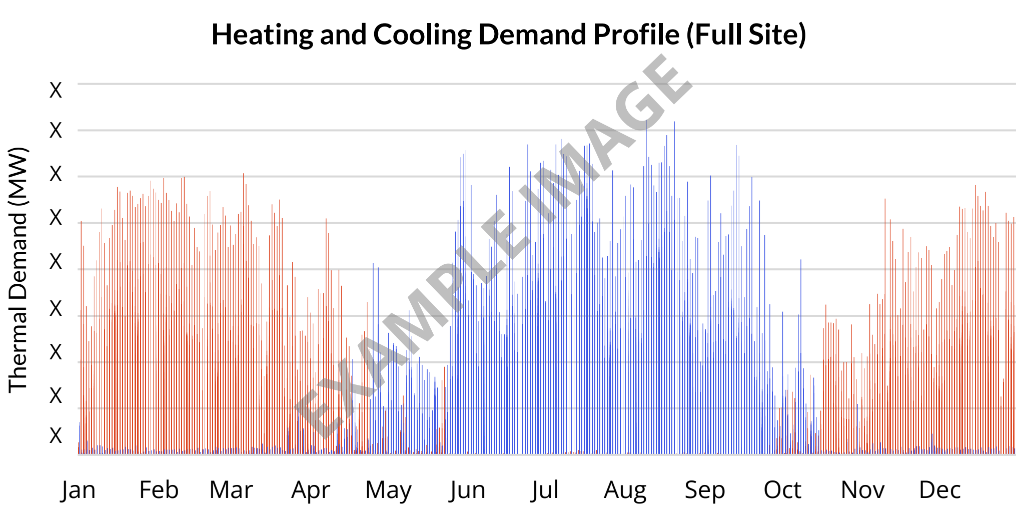

Figure 6: Full site hourly space heating and cooling demands.

2.3 Energy Demand Phasing

The phasing of the site results in the following annual energy demand growth over time.

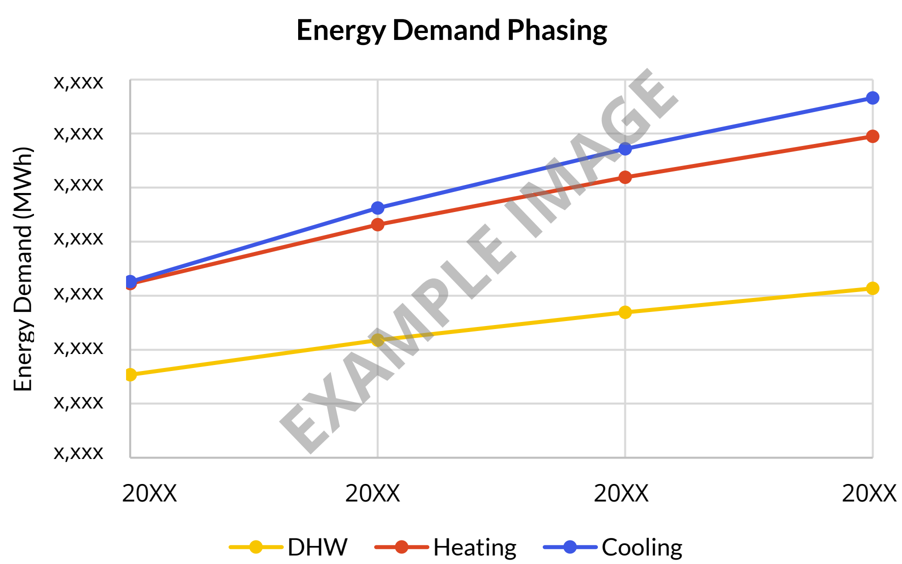

Figure 7: Phased annual energy demands

2.4 BAU Concept

The baseline system consists of natural gas boilers sized for the full space heating and domestic hot water (DHW) loads. The full cooling load will be provided by fluid coolers. Traditional cooling towers make use of evaporation of the circulated fluid for cooling, whereas fluid coolers allow for a closed loop system without the use of evaporation of the circulated fluid thus using less water. The buildings operate independently from each other and are not interconnected. Each tower is assumed to have its own heating and cooling systems.

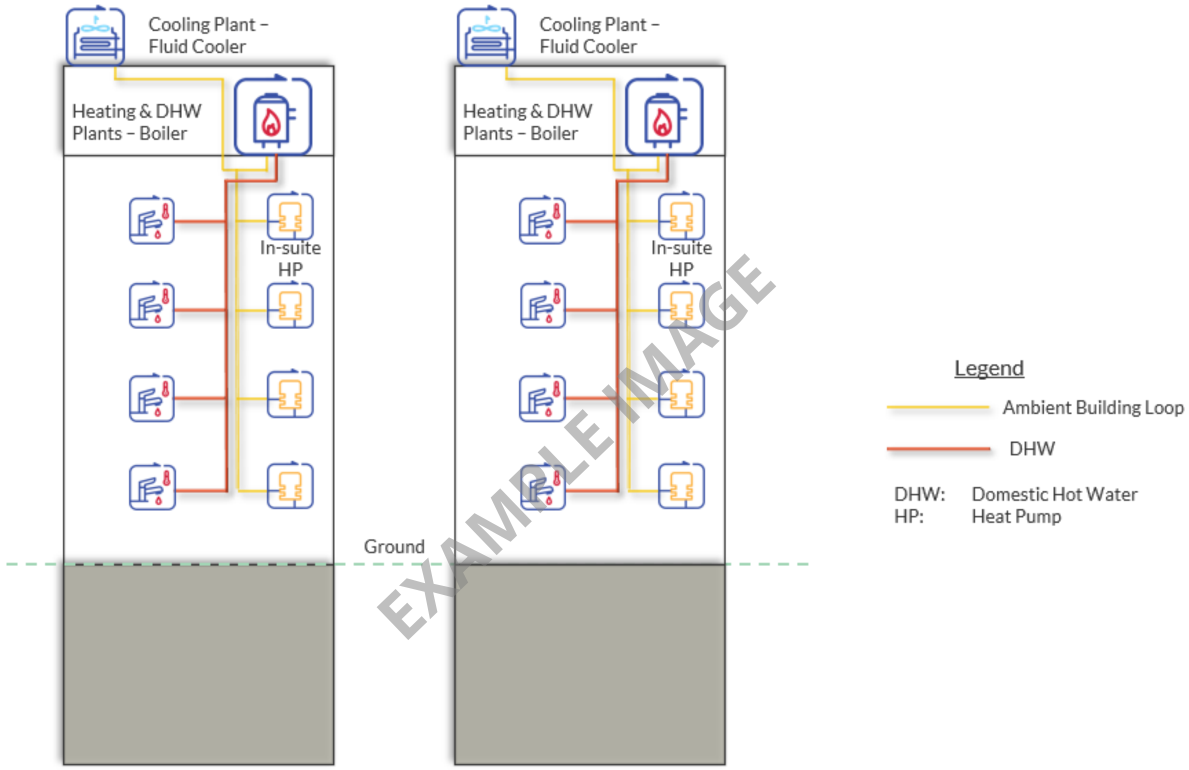

Figure 8: BAU scenario diagram

2.5 Energy Consumption and GHG Emissions

The energy consumption and GHG emissions for the baseline is as follows for the thermal energy system only.

The energy consumption and carbon emissions for the baseline model were calculated using the following assumptions. The emissions factors are from the Example Building Code. The results represent the energy consumption and emissions for the thermal system only.

- Natural gas emissions intensity: 1.899 kg CO2e/m3
- Grid electricity emissions intensity: 50 kg CO2e/MWh

Table 3: Baseline thermal energy consumption and GHG emissions.

	Energy Consumption (MWh/yr)	Emissions (tonnes CO2e/yr)
Natural Gas	X,XXX	X,XXX
Grid Electricity	X,XXX	X,XXX
Total	X,XXX	X,XXX

3 CONCEPT DEVELOPMENT

This section contains brief descriptions of the energy scenarios considered for the site and a high-level qualitative assessment comparing these scenarios relative to the baseline.

3.1 Process

Only technologies that can meaningfully contribute to ABC Company's goals were considered in the development of energy concepts. Additionally, the assessment focused on technologies that are currently available in the market and leveraged Rathco's industry experience.

The technologies were grouped together to form energy scenarios that can meet all the space heating, space cooling, and domestic hot water (DHW) heating requirements for the site.

A set of seven potential energy scenarios for the site was presented to ABC Company at Workshop 1. A final set of four low carbon scenarios was selected by the ABC Company team to be modelled in Memo 2, alongside the baseline set out in Memo 1. These four energy scenarios are described in the following sections. A qualitative assessment of the scenarios considered is also included.

3.2 Scenario Descriptions

Conceptual-level diagrams showing the major pieces of equipment and the systems they serve for the energy scenarios that were selected during Workshop 1 are shown below. The following energy scenarios were considered. Each scenario includes other equipment as necessary to meet all the thermal needs of the site, with only the primary technologies included in the titles.

Some scenarios considered district energy systems (DES), while others considered standalone single-building systems that would not be connected to a DES.

1. Baseline
2. Geo-Exchange
3. Air Source Heat Pump
4. Wastewater Energy Exchange
5. Biomass Boilers

Assumptions:

- Scenarios 1-4 assumed in-suite water source heat pumps with an ambient temperature loop as the building distribution system. This was agreed during the onset of the project to be the baseline assumption.
- The biomass scenario will be assumed to use four-pipe fan coil units for space heating and cooling as heat pumps are not required.

The energy demands for each energy scenario are as described in Section 2.

3.2.1 Baseline

See Section 2.4.

3.2.2 Geo-Exchange

The geo-exchange borefield sizing depends on the available area under the building footprint for drilling and the loads of each building. Larger peak heating and cooling demands will be served by a combination of geo-exchange and peaking plants. This combination of peaking plants and geo-exchange is intended to reduce costs and optimize the energy use of the geo system. Borefields are typically sized to provide 100% of the smaller peak energy demands (100% of heating or 100% of cooling). The peaking plants would be natural gas boilers for heating and DHW and/or fluid coolers for cooling.

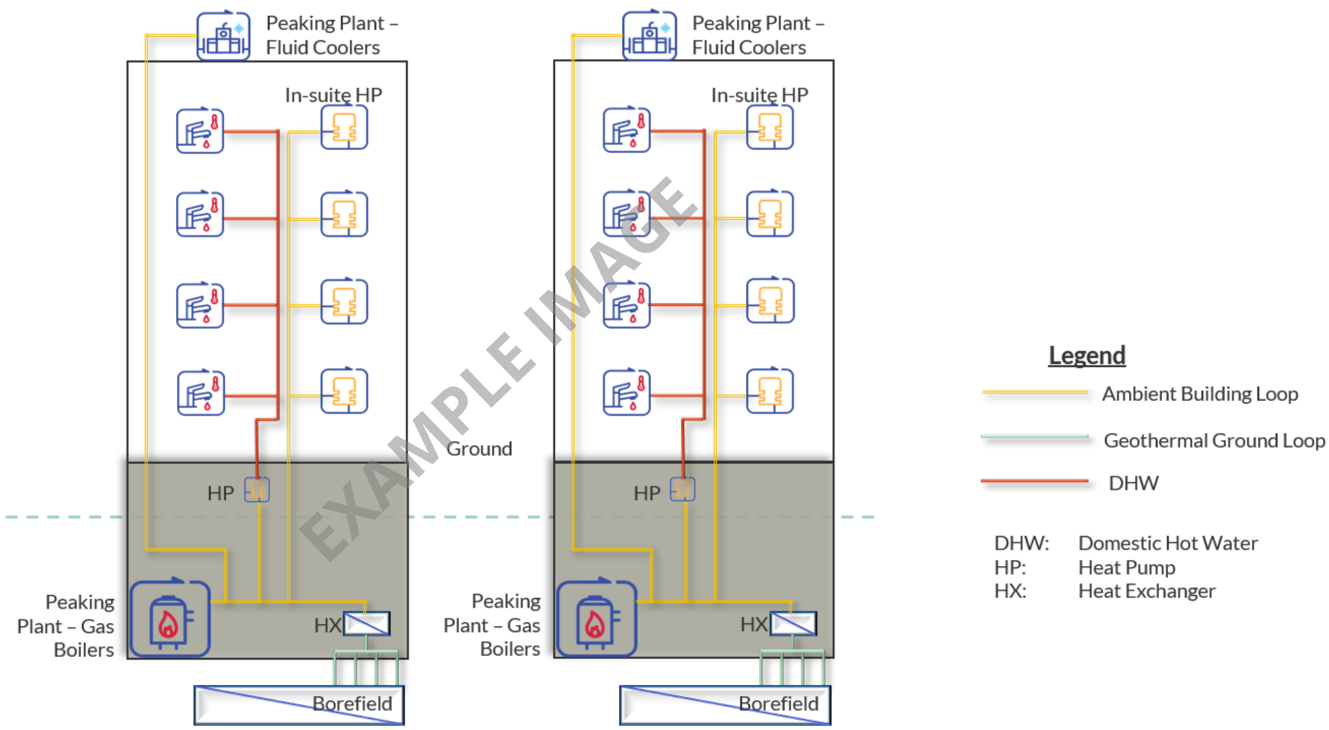

Figure 9: Geo-exchange energy scenario diagram

The following energy loads were considered for connection to the geo-exchange system:

- Space heating
- Cooling
- DHW Preheat
- Makeup air (MUA)

3.2.3 ASHP

Air-source heat pumps use outdoor air as the system's heating or cooling source. Due to the wide variation in summer and winter temperatures, air-source heat pumps are not as efficient as ground—or water-source heat pumps and thus cost more to operate. However, they are more versatile in use as the system would only need access to outdoor air.

Other heating and cooling technologies will be considered as needed to provide all the heating and cooling requirements for the site (i.e., boilers, chillers, etc.).

Although some air-source heat pump models can provide high enough temperatures to meet design day heating requirements in the winter, they are expensive. Considering the winter temperatures in Example City, this technology might result in significant capital costs and a higher levelized cost of energy (LCOE). Peak heating boilers will be considered as backup to the ASHPs.

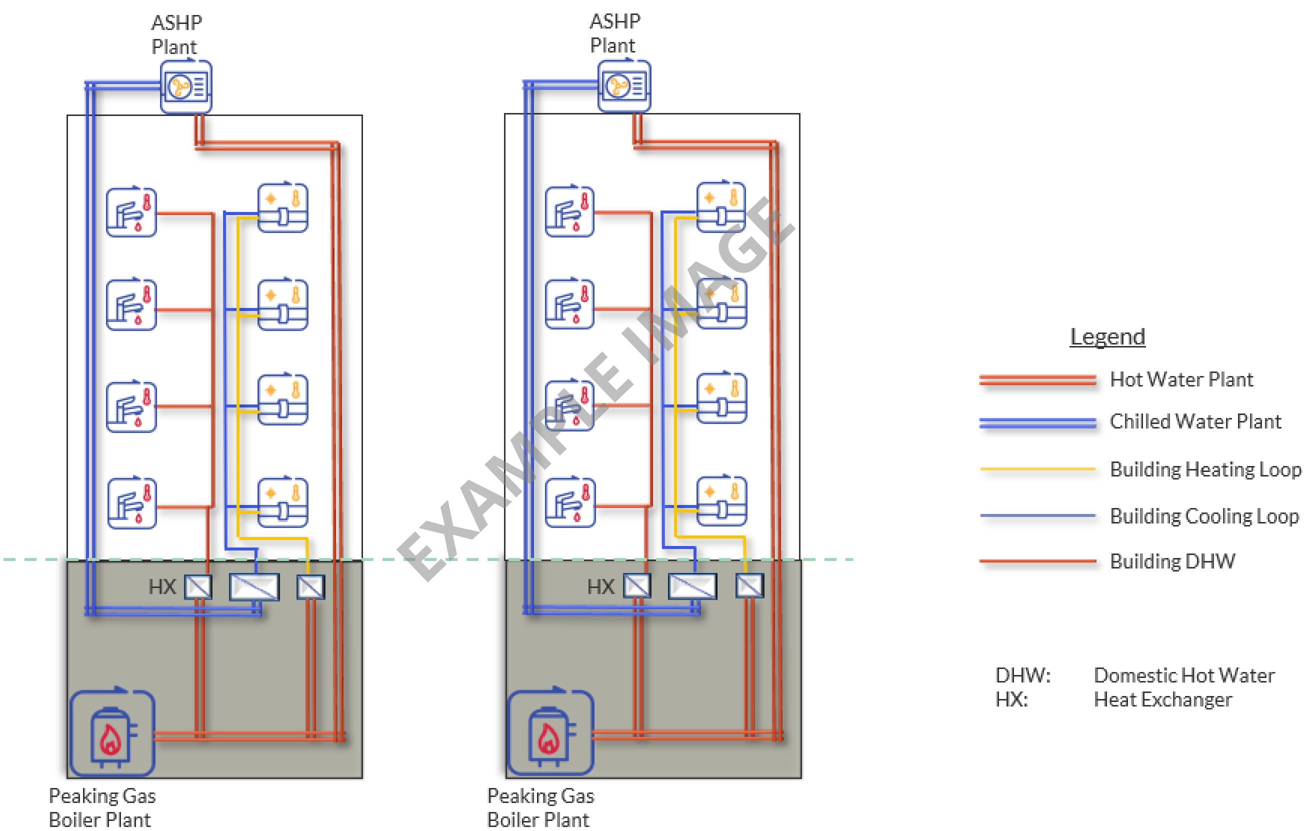

Figure 10: ASHP energy scenario diagram

3.2.4 Wastewater Energy Exchange DES

ABC Company selected the wastewater energy exchange DES as a scenario to be included in the analysis. The project team decided that the most cost-effective solution in this category would be the DES solution. Providing energy from the site sanitary to each tower independently would add considerable capital cost to the project, as the wastewater energy equipment would be purchased for each building. In addition, this would require space in each building. Centralizing the wastewater energy equipment to one DES location would both save space and reduce the capital cost. In addition, the DES can connect to the municipal sewer and potentially make use of the sanitary flows from future new developments. While the flows from future developments were not included in this analysis, there is an upside that it could be beneficial if these developments happen.

The wastewater energy exchange concept is similar to the previous geo-exchange energy scenario but adds wastewater energy exchange to complement the geo-exchange systems and to provide another low carbon source of heating and cooling. The wastewater energy capacity will offset geo-exchange capacity. It can also be used as a balancing mechanism for the borefields. Balancing is required for all borefields. Wastewater is a constantly renewing resource that would reduce energy consumption and emissions associated with balancing compared to a traditional geo-exchange system. At this site, there is not enough wastewater energy to provide full heating, cooling, and DHW, so it was paired with geo-exchange.

The Functional Servicing Report and site sanitary plan were used to advise the location and potential capacity of the local sewers. Assuming connection to the ABC Ave sewer north of all ABC Company sanitary connections for this site, the maximum capacity of the sewer is about XX MW using only ABC Company flows. There is minimal flow from the existing development upstream. This represents a conservative view for the potential of this technology.

As this sewer is an Example City asset, coordination with the City will be required. Roadwork would be required in the existing right-of-way. To service the development, reduce impact to the community, and to share costs, there is an opportunity to install connection infrastructure while the Phase 1 connection is underway and/or when the ABC Ave sewer is being lowered.

The wastewater energy equipment can be housed in one of the connected buildings or in the common parkade. A separate small building can also be considered to house the energy transfer equipment.

Connection to the municipal sewer requires a DES to allow all buildings to utilize the available resources.

The addition of wastewater storage to the system (via maintenance hole, tank, or other) will allow for more consistency in periods of low flow in the sewer and reduce the frequency of requiring auxiliary systems.

All buildings will require space for ETSs. Some buildings will require space for the geo-mechanical equipment. Based on the capacity of the sewer considered, the geo-exchange capacity will be slightly reduced from the previous scenario. At least one building will also require space for peaking plant as the peaking plants can be consolidated into one location with the DES. There will be one location for the wastewater energy exchange equipment.

It was assumed that DHW heating would be provided separately to each tower using natural gas boilers. As these assets are not connected to the DES, they can be located in the mechanical penthouse if desired.

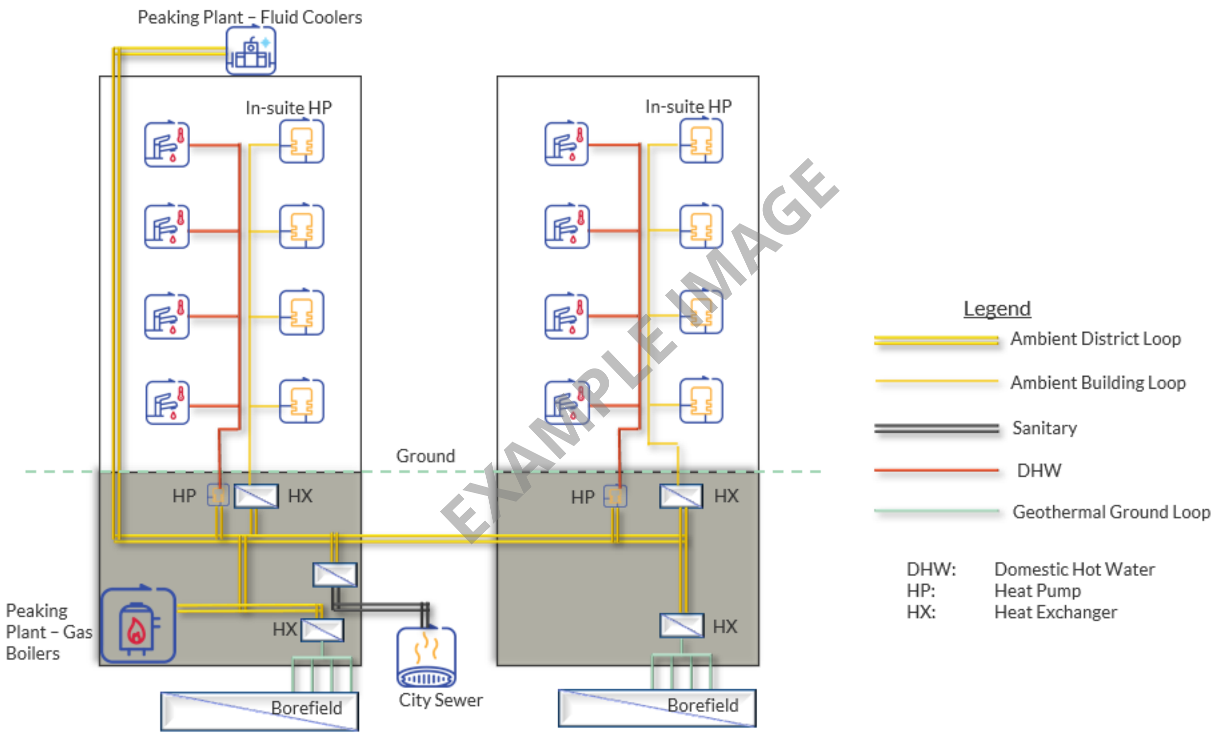

Figure 11: Geo-exchange and wastewater energy exchange district energy concept diagram

3.2.5 Biomass Boilers DES

The final energy scenario is the biomass boilers DES scenario. It requires delivery access and solid fuel storage. The storage space is estimated to be at least XX m3 and can be located below grade. Given the high temperature heating supply in this scenario, a 4th generation DES was selected. Hot and chilled water would be supplied to each connected building. This type of system does not require heat pumps, so fan coil units will be assumed to provide the heating and cooling distribution in the buildings for cost savings.

Due to the size of the biomass equipment, an additional central plant building would be required at the site. This building can also house the fuel storage below grade. Trucking access to this fuel storage area would be required for solid fuel deliveries. The frequency of fuel deliveries depends on the available storage space. Deliveries can be timed to be weekly or biweekly for larger fuel storage areas or more frequently for smaller.

The required central cooling plant is comprised of chillers and fluid coolers. A peaking natural gas boiler plant is required to be included to provide the DHW and space heating needed during peak times as biomass boilers are typically sized to meet only baseload heating demands.

All buildings will require space for ETSs. The peaking plants can be centralized or distributed throughout the development.

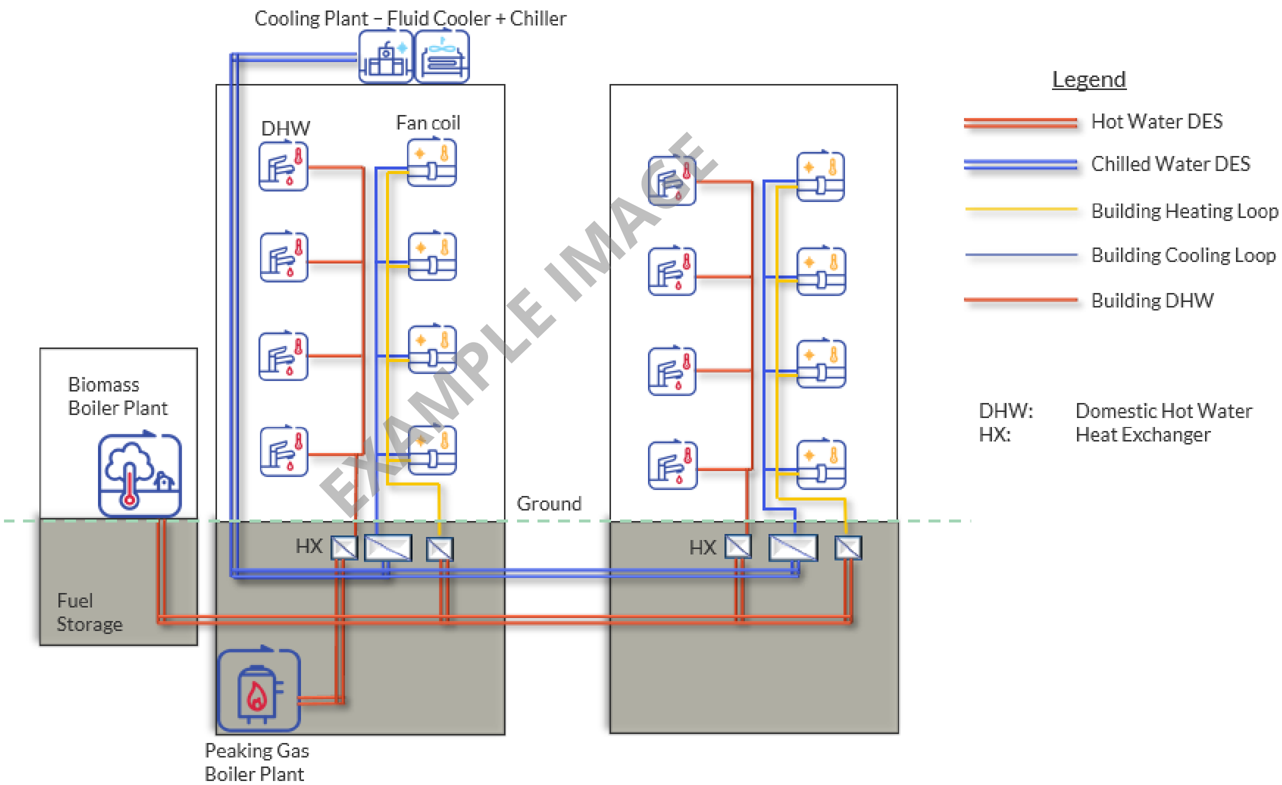

Figure 12: Biomass boiler district energy concept diagram

4 COMPARATIVE ANALYSIS

A comparative analysis was completed to assess low carbon energy scenarios against the baseline.

4.1 Concepts Selected for Assessment

After Workshop 2, ABC Company selected four energy scenarios for assessment against the baseline (BAU).

1. Geo-Exchange
2. Air Source Heat Pump
3. Waste Water Energy Exchange
4. Biomass Boilers

4.2 Metrics

The following metrics were calculated in the analysis:

GHG Emissions: The CO2 equivalent emissions of the energy system (including fuels consumed onsite and offsite through the electrical grid) per m2 of building over the course of one year.

Levelized Cost of Energy (LCOE): The LCOE is the life cycle cost of the energy system. It is presented in $/MWh, which is a measure of the cost per unit of thermal energy demand met.

Initial Capital Costs (part of LCOE calculation): The initial investment of capital to procure, install, and commission the equipment and infrastructure to operate the energy system. The costs include soft costs and contingency. The capital costs are presented in 2023 Canadian Dollars.

Annual Operating Costs (part of LCOE calculation): The annual operating costs include all recurring costs to operate the system, including fuel, carbon tax, electricity, operations and maintenance (O&M), water and chemical costs, and equipment replacement. These costs are presented for the first year of operating the full build-out of the project (escalated to 20XX Canadian Dollars).

A further description of each of the operating cost categories included is shown below. The LCOE includes all the following costs over the lifetime of the project plus the initial capital cost.

1. **Replacement Costs:** Captures replacement of thermal equipment over the life cycle of the project. Assumes expected future costs set aside on an annual basis.
2. **Operating & Maintenance Costs:** Includes regular maintenance, water and chemical costs, operator staff, administrative, and insurance costs for central thermal equipment.
3. **Fuel Costs:** Natural gas and biomass costs.
4. **Electricity Costs:** Electricity costs (only the inputs for thermal energy supply are included).
5. **Carbon Tax:** Carbon tax payable as a result of the use of combustion on-site for thermal purposes.

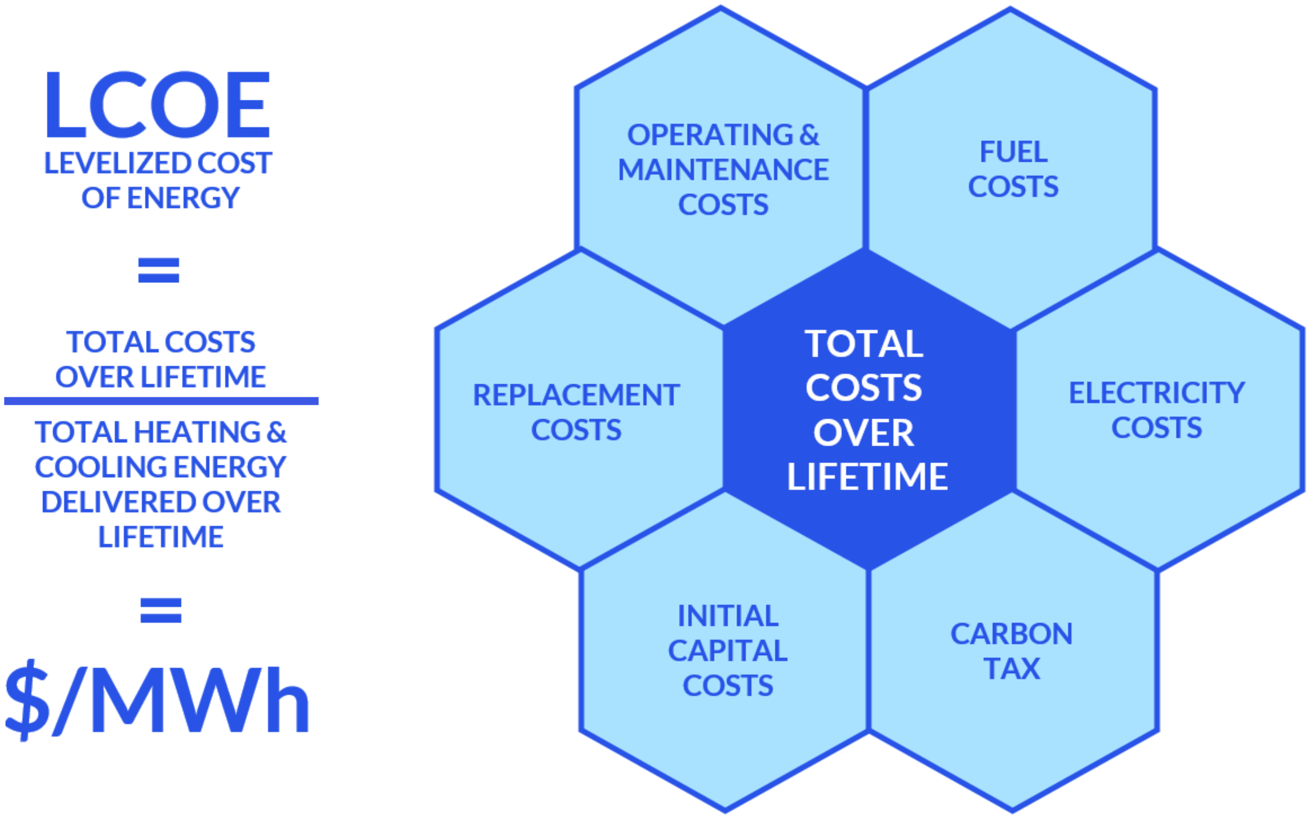

Figure 13: LCOE explanation graphic

4.3 GHG Emissions Results

The GHG emissions consider the emissions related to thermal energy only and include emissions from both natural gas and electricity. Note that WEE is wastewater energy exchange.

The GHG results show that the BAU has the highest emissions due to natural gas heating. WEE DES and ASHP saw similar reductions. Biomass DES saw the most reduction in GHG emissions compared to the natural gas BAU.

The three geo-exchange scenarios saw similar emissions results because all three scenarios completely electrified space heating using heat pumps with similar efficiencies across the scenarios. These scenarios still relied on natural gas for most of DHW heating, which comprises a large part of the remaining emissions.

Biomass had the most GHG reductions because biomass heating has fewer emissions than electric heat pump heating due to the GHG emissions intensity of the Example grid. In addition, biomass was used for DHW heating. The CO2 component of biomass emissions in energy systems is not counted in the emissions total as these emissions are counted in the forestry sector. Counting the CO2 emissions at the point of combustion in the energy system would be double counting the CO2 emissions from that resource. Biomass does have a small amount of non-CO2 emissions that must be counted for carbon tax purposes and accounting purposes.

All low carbon scenarios exceeded the project target of 10% GHG emissions reductions from the BAU.

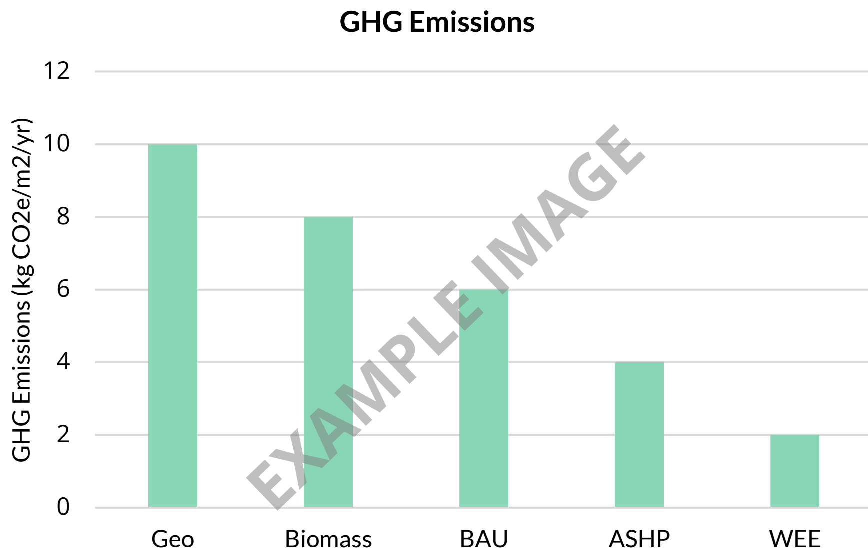

Figure 14: GHG emissions results

4.4 LCOE Results

The LCOE results are shown below.

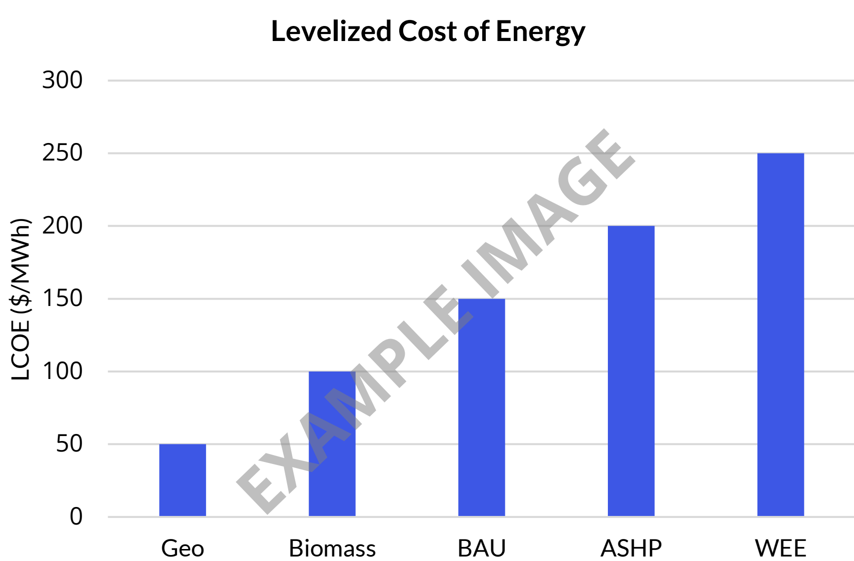

Figure 15: LCOE results

The BAU and Biomass DES scenarios had the highest LCOEs. The BAU had a high life cycle cost due to the operating costs associated with natural gas boilers for heating once the carbon tax increases to $170/tonne.

The Biomass DES scenario had the highest LCOE. While there were some operational savings found, predominantly due to carbon tax reductions from the baseline, the high capital cost of the biomass plant made this scenario have an overall high life cycle cost. The biomass plant would require an additional building at the site, which increased the capital cost. The minimal operating cost savings relative to the BAU were not enough to justify the expenditures to install the biomass plant.

The geo-exchange scenario saw the lowest life cycle costs due to significant operational cost savings. These savings were realized due to the significant reduction in gas use that reduced the carbon tax payable, as well as the reductions in equipment replacement. The borefields make up the majority of the energy systems, and these assets have very long lifetimes. The boreholes drilled in the ground do not have any moving parts that need to be replaced and could last 50-100 years or more. The remainder of the geo system comprises of smaller investment items that would need replacement, such as pumps and heat exchangers. Compared to the BAU and Biomass DES scenarios, the budget for equipment replacement would be a lot lower for the geo scenario.

Between the remainder of the scenarios, there was found to be minimal difference in the life cycle cost. The results were within the margin of error. The reason why the two DES scenarios had a higher cost was because of the additional capital to install the DES pipes and pumps to connect the buildings. This capital cost was more than the cost savings of slightly lower peak capacities required, due to the diversity assumptions. There was also some operational cost savings associated with the DES due to energy sharing and centralization of peaking equipment that would lead to easier maintenance, but these savings were not enough to offset the higher capital cost of the system.

4.4.1 Capital Costs

The capital costs of the full build-out were broken out for each scenario to show the cost implications of pursuing a low carbon energy system. The costs are presented in 2023 Canadian Dollars.

The low carbon scenarios all had significantly higher initial capital costs than the BAU, which is expected when compared against natural gas boiler systems such as the BAU.

The ASHP scenario reflects the cost of installing ASHPs for each tower. The geo-exchange DES scenarios (WEE DES) had higher capital costs due to the high cost of DES piping installation in addition to drilling and installing the borefields. Reduction of borefield capacity in the Geo & WEE scenario was offset by the increased capacity of the fluid coolers and the installation of the WEE system.

The biomass DES scenario required an additional building (with an allowance for the cost of the building included in the energy system capital). In addition, the DES network for the biomass system would have twice as many pipes to distribute hot and chilled water separately instead of an ambient system, bringing the cost of the DES network up. A cost savings allowance for the fan coil system compared to the in-suite heat pumps included in the rest of the scenarios was also included.

For all geo and biomass equipment (including the cost of drilling boreholes), the Government of Canada's Clean Technology 30% Investment Tax Credit[1,2,3] was applied and reflected in the amounts shown. No other rebates or incentives were included.

Construction cost neutrality (or reduction) for the developer may be possible with an EaaS or utility model.

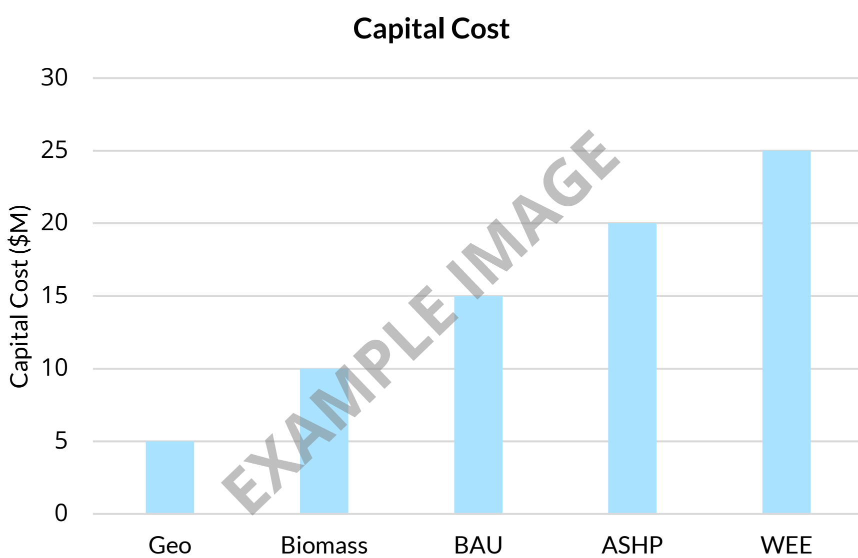

Figure 16: Capital cost results of the full build-out (costs in 2023 Canadian Dollars)

4.4.2 Operating Costs

The operating costs are shown for the full build-out, with costs presented at the year of full build-out escalated to 20XX Canadian Dollars (the year of full build-out).

The operating costs include all lifetime costs beyond the initial capital, as described in Section 4.2.

[1] 2023 Fall Economic Statement (canada.ca)

[2] 2022 Fall Economic Statement (canada.ca)

[3] Budget 2023 (canada.ca)

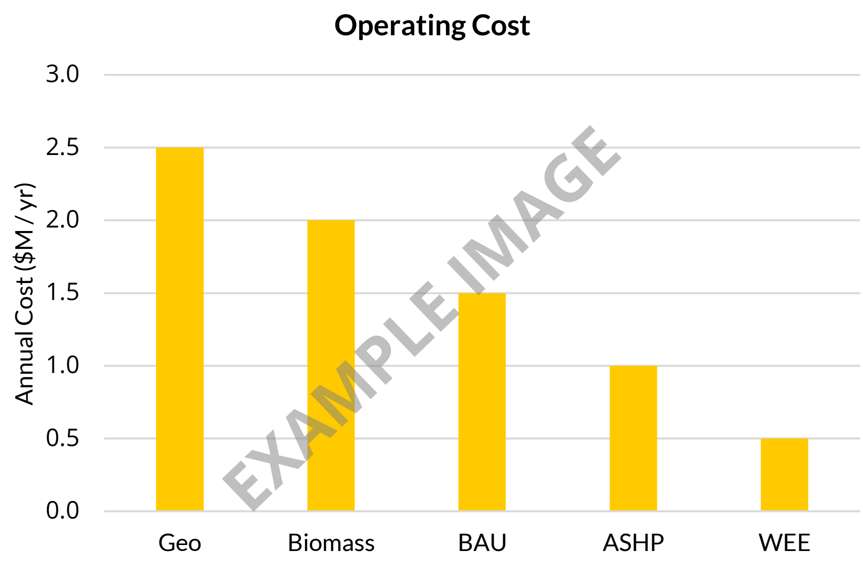

Figure 17: Operating cost results of full build-out (shown for year 20XX in Canadian Dollars)

The operating costs had the reverse trend of the capital costs for all scenarios except Biomass DES. The higher capital cost scenarios were the lower operating cost scenarios for all Geo-related scenarios. The geo scenarios saw the lowest operating costs, with a XX% reduction compared to the BAU.

The BAU saw the highest operating cost as a result of the high natural gas consumption and carbon tax. In addition, the BAU had higher O&M costs than the geo scenarios due to more use of the fluid coolers (requiring water and chemicals plus more maintenance associated with more run time) and greater use of the boilers. Also, the BAU had higher equipment replacement costs than the geo scenarios as the geo systems have less equipment that needs to be replaced.

The Biomass DES saw the second highest operating cost. The fuel and electricity costs of the biomass scenario were lower than the BAU, largely due to the elimination of heat pumps, which lowered electricity consumption. The primary reason why there were not significant operating cost savings from the BAU was because of the need to budget for equipment replacement as the biomass plant equipment was more expensive than the BAU.

The geo scenarios all had higher electricity costs than the BAU due to the full electrification of space heating, but this increase in cost did not outweigh the cost savings in other categories. The geo-exchange systems have the highest overall efficiency, leading to lower total use of fuel and electricity.

Operating cost savings for the homeowners may be possible for the geo-exchange scenarios, given the total operating cost reduction from the BAU. The amount of savings depends on how the benefit of the cost reduction is shared between entities. For example, under a utility scenario, the savings that the homeowners would see is dependent on the contracted rates agreed with the utility.

4.5 Results Summary

A summary of the results is included below.

Table 4: Comparative analysis results summary

	BAU	Geo	ASHP	WEE DES	Biomass DES
LCOE ($/MWh)	XX	XX	XX	XX	XX
Capital Cost ($M 2023)	XX	XX	XX	XX	XX
Annual Operating Cost at Full Build Out ($M/yr 20XX)	XX	XX	XX	XX	XX
GHG Emissions (kg CO2e/m2/yr)	XX	XX	XX	XX	XX

5 PREFERRED SCENARIO – GEO-EXCHANGE

After the Results Workshop, ABC Company selected Geo-Exchange as the preferred scenario. This section details a technical summary, costs, and implementation considerations for that scenario. The details presented in this report are at a pre-feasibility level of design (Class D, +/- 30-40%) and are not intended to be used for construction. Further technical investigation is required to enable improved levels of detail in the design and cost estimates.

5.1 Technical Summary

This scenario was structured to align with borefield space availability at each building.

For all geo-exchange systems, careful monitoring of the energy flows into and out of the borefield is required to ensure the ground temperature does not drift significantly year over year. Changes in borefield temperature (and therefore geo supply temperature to the system) over time would reduce the efficiency of the heat transfer between the fluid and the ground and reduce the efficiency of the heat pumps on the system until the system is eventually not operable. Borefields should be balanced on an annual basis, meaning that the heat put into the ground from cooling should equal the heat drawn out of the ground for heating. Auxiliary systems should be installed to make up the difference when the demands on the system are not balanced. Balancing was considered and included in the modelling for each building at the site. The borefield balancing mechanisms and auxiliary system requirements should be revisited through the design stage.

The geo-exchange system was assumed to connect to the space heating and cooling systems, the makeup air system and DHW preheat. DHW heating beyond the preheat would be provided by a separate natural gas boiler system. DHW preheat can be directly connected to the geo system through a heat exchanger or it can be connected to the building heat pump condenser loop, as shown in Figure 18. The role of the DHW preheat system is to preheat the incoming City water passively prior to it entering the DHW system. Passive DHW preheat is predominantly used in the summer as during the summer months heat pump condenser loop and geo loops are at their warmest. During the winter, the system temperatures cool thus providing less of an opportunity to use that heat to passively preheat the DHW.

The geo system was sized to meet 100% of the heating loads described. The system was found to be cooling dominant, meaning that there is a greater amount of heat to be rejected from the building to cool the space than heat needed to be injected into the building to heat the space. Because of this cooling dominance, there needs to be a peak cooling plant to meet the peak cooling needs and to provide an alternate means of heat rejection in order to maintain balanced heating and cooling energy to and from the ground. The peak cooling plant is fluid coolers. Each building requires a fluid cooler, but these units would be smaller than otherwise needed for the BAU scenario.

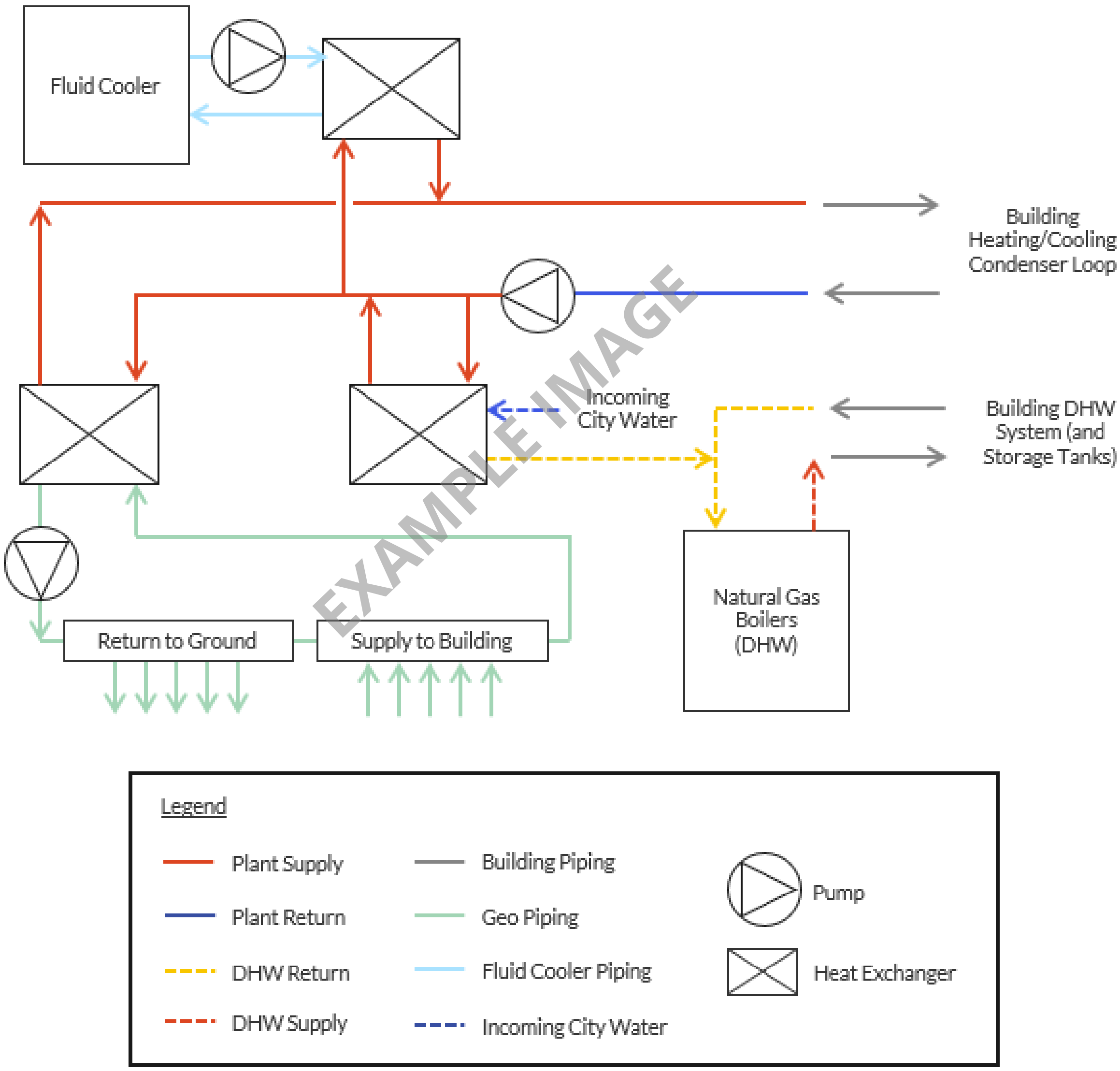

Figure 18: Thermal system process flow diagram

Heating and cooling would begin with energy sharing to make use of the ambient temperature in the condenser loop, this loop shares the heating and cooling allowing for units to share energy should one unit require heating, and one unit require cooling. In the summer, energy sharing can also occur between the warm condenser return line (or geo return line) and the DHW system for DHW preheat. The remainder of DHW heating is to occur using natural gas boilers. Then, use geo-exchange to provide low carbon heating and cooling. When there is not enough capacity in the geo-exchange system or when borefield balancing is required, the peaking plant fluid coolers are to be used. The fluid coolers should be controlled to maintain the temperature of the system within a specified range, for example, a maximum supply temperature of 30 °C. The fluid coolers can also be used to provide an alternate heat rejection mechanism to ensure a balanced borefield. The temperature range should be optimized through the design stages to minimize energy consumption and equipment capacities while meeting GHG and cost targets.

A list of the major pieces of equipment, capacities required (can be split into multiple units), and location is included below for each building. As each building operates independently, the timing of the equipment should align with the planned construction and occupancy schedule of the building. Boreholes were assumed to be 850 ft depth in this study, but that can be optimized through the design stage.

Table 5: Equipment list by building

Building	A	B	C	D	E	F	G
Geo-Exchange Boreholes* *(below building)*	80	85	70	10	40	30	10
Natural Gas Boiler - DHW *(mechanical room)*	XX MW	XX MW	XX MW	XX MW	XX MW	XX MW	XX MW
Fluid Cooler *(rooftop)*	XX MW	XX MW	XX MW	XX MW	XX MW	XX MW	XX MW

*It was assumed that neighbouring towers within a common phase would share a borefield. So, the total borefield size for Buildings A and B (common podium) would be 165 boreholes. The total borefield size for Buildings D and E would be 50 boreholes. The total borefield size for Buildings F and G (common podium) would be 40 boreholes. There would be one shared mechanical room with heat exchangers for service to each tower. In addition to sharing a borefield, these towers were also assumed to share a fluid cooler, resulting in rooftop space savings for one tower per phase where there were two towers.

The plant room(s) in each building would include the geo-mechanical equipment, DHW boilers, heat exchangers, pumps, and other auxiliary equipment necessary to operate these systems. This equipment can be split into separate locations as required, for example, the space heating and cooling equipment may be located in a separate location from the DHW heating equipment. The geo-exchange equipment will ideally be located on the lower levels of the parking garage.

Approximate space requirements for planning purposes are shown below. Detailed design and equipment selections were not completed as part of this study. Space allowances for potential future DES connections are included in the estimates below.

Table 6: Approximate space requirements by building

Phase	1	2	3	4
Geo-Mechanical Room (m2)	XXX	XXX	XXX	XXX
Rooftop (m2)	XXX	XXX	XXX	XXX

Mechanical layouts and borefield layouts are provided for space planning purposes only in Appendix B: Concept Drawings.

Through the detailed design stage, there may be some space constraints or conflicts with other disciplines (i.e., footings, drain piping) that limit the capacity of the borefields, in addition to what was assessed in this study. This may impact the location of boreholes, spacing of boreholes, and the total maximum quantity of boreholes possible at the site. Detailed consideration of the borehole layout is required should geo-exchange be pursued at each building. Changes to the number of boreholes may change the configuration of the auxiliary heating and cooling plants, space requirements, costs, and emissions if more auxiliary capacity is required. Phase 1 is likely to be the phase with the most constraints as the borehole count used in this study used most of the available footprint.

5.2 Capital Cost Breakdown

The capital cost breakdown is provided below for each building. DHW heating plants are the natural gas boilers. Auxiliary cooling plants are the fluid coolers.

The new Clean Technology Investment Tax Credit (ITC) of 30% of the capital cost of the geo-exchange system was included in the geo-exchange category as a 30% discount. It was applied to the boreholes (including drilling costs), pumps, heat exchangers, and other auxiliary equipment required in the geo-exchange system. At the time of this report, this measure has not been legislated, so there remains some uncertainty as to how it will be applied.

These costs include the thermal plant equipment only. No in-building costs (i.e., in-suite heat pumps or distribution) have been included. Costs include installation and soft costs. A 25% continency was added to the total before the ITC was applied.

As described above, buildings with a common podium were assumed to use a common borefield. The cost breakdown reflects the portion of the cost associated with each tower.

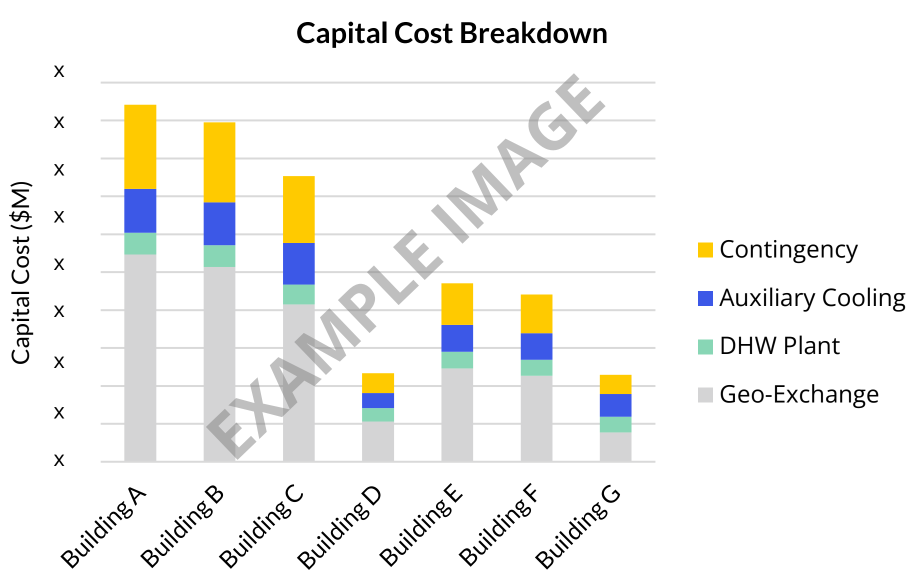

Figure 19: Capital cost breakdown by building in $M Canadian Dollars (2023)

5.3 Operating Cost Breakdown

The operating cost breakdown is shown below for the full site. The operating costs are shown annually for 30 years after the first phase comes online. The costs were escalated over time. For details on the assumptions used to generate these results, refer to Appendix A.

The electricity costs were split into two categories for clarity: central and in-suite heat pumps (ISHP). The central category includes the electricity costs for all central thermal equipment, including the geo-exchange systems and the fluid coolers. The in-suite heat pump electricity includes electricity to provide heating and cooling to the spaces using the heat pumps.

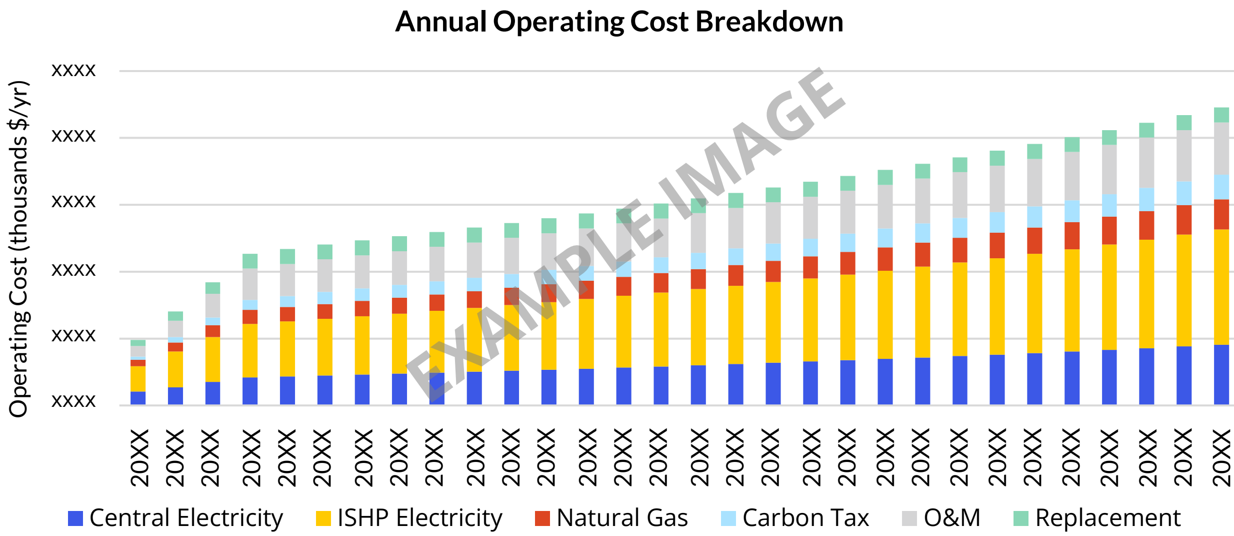

Figure 20: Annual operating costs escalated over time in thousands of Canadian Dollars

Phase 1 is shown in Year 1. The costs in that year represent Buildings A and B only. The remainder of phases come online as per the phasing described in Figure 4. Once the final phase (Buildings F and G) comes online in 20XX, the full cost of operations will be realized.

The most significant cost of the system operation is expected to be the electricity as most of the thermal demands are met with an electric system, aside from DHW heating. The in-suite heat pump costs make up a large portion of the annual costs, highlighting the potential impact to the building occupants should they be responsible for these costs.

5.4 Implementation Considerations

5.4.1 Building Design

Building design measures to reduce peak space heating and cooling demands would reduce the overall capital cost of the system by reducing the total capacity of equipment.

As building envelopes improve, it is often seen that space heating demands decrease while cooling demands may increase. This increasing cooling dominance is challenging for geo-exchange systems as thermal balancing is required. When a building has a higher total heat rejection annual energy amount (from cooling) than heat injection required for space heating, alternate means of heat rejection are required. So, reducing this total heat rejection requirement reduces the need for auxiliary cooling equipment (thus, reducing cost). Building design measures to reduce cooling would be beneficial for the system.

If required, an active DHW heating solution could be explored as a heat rejection system using a water-to-water heat pump instead of a passive preheat system using a heat exchanger. The use of a water-to-water heat pump increases the capital cost and operational complexity of the system, while further decarbonizing DHW heating.

5.4.2 Building Mechanical Design

Fluid with freeze protection is recommended in the building systems connected to geo-exchange as temperatures in the geo-exchange system can be at or below freezing. Design temperatures are a key item to coordinate during design stage.

Typical geo-exchange supply temperatures (on the geo-exchange side of the heat exchanger) are between 30 to 90 °F (-1 to 32 °C).

5.4.3 Ground Conditions

The ground conditions at this site were assumed in order to assess the thermal potential of geo-exchange systems based on conversations with geo-exchange providers and local data available. Significant deviations from these assumptions will impact the sizing of the borefields. It is understood that a thermal conductivity test was since completed at this site. The results of this test should be used to verify the ground conditions to refine the design through the detailed design stage.

5.4.4 Borefield Footprint

For phases with ample space beneath the building footprint (Phases 2-4), additional boreholes should be able to be accommodated. Phase 1 is more constrained, so there is the possibility that the borefield size could be limited due to physical space limitations. Furthermore, building design details such as footings, drain piping, etc. were not available for this study, so there may be less space available than anticipated. A more detailed assessment of energy demands, ground conditions, and space constraints is required for all buildings when the design of each building has progressed to confirm the ability of geo-exchange to meet the required loads within the available budget. Additional peaking plant (both heating and cooling) may need to be considered to meet the loads if there is not enough space for the borefields.

5.4.5 Ownership

Ownership options should be considered for the geo-exchange systems, and a discussion of options is presented in Section 6.2. It is understood that ABC Company plans to own and operate the geo-exchange system through their in-house geo provider.

The geo-exchange component of the capital costs makes up a large portion of the total cost. Should this cost be borne by a utility (instead of the developer), construction cost neutrality is very likely, with the possibility of significant construction cost savings from the BAU (up to $XXM for the full development), pending agreements with the utility. Generally, more capital cost savings for the developer translates to lower operating cost savings for the homeowner as the utility must charge higher rates to recoup the upfront costs.

5.4.6 Potential Future DES

Of interest to ABC Company is the possibility of connecting all phases as a district energy system within the ABC Company site in the future. To enable this possibility, there are design considerations to incorporate into the earliest phases.

First, a location should be included in the design to allow for future pipe installations between phases. For example, the following approaches could be considered: a spool piece connection between isolation valves, or a stub-out connection. In addition, it is recommended to allow space for a potential future heat exchanger. Consideration for future sensors should also be considered in the control strategy.

Second, consideration should be given in the Phase 1 system design to allow for the auxiliary cooling system to be used by a future DES.

Third, recommissioning is recommended after the system is modified should a DES be added after initial commissioning of the system.

6 RECOMMENDATIONS AND NEXT STEPS

The primary goal, but not the only goal, of any pre-feasibility study is to identify projects that fulfill the client's goals and to facilitate the movement of those projects forward. Below, the next steps that are needed to fully realize the value contained within this report are broken down. They are:

- Continued Technical Investigations
- Ownership and Governance Strategies

6.1 Continued Technical Investigations

This pre-feasibility study has developed the geo-exchange concept to a level of detail that has allowed for a Class D cost estimate (+/- 40%). To reduce the variability of the cost estimate, the level of design of the concept needs to be continued so that a Class C cost estimate is possible (+/- 30%). Depending on the technology and complexity, certain portions of the design can go beyond a Class C estimate enabling even greater reductions in risk around the business model.

The building and site design, energy demands, ground conditions, and the impact to the energy system should be refined as the project progresses. Key items to consider:

- Thermal conductivity testing results of ground at the site should be incorporated into geo-exchange modelling and borefield sizing
- Building energy models and peak thermal load requirements for the proposed buildings
- Coordination with building mechanical HVAC systems
- Mechanical room designs furthered to greater detail
    - Plant room space coordination
    - Equipment selection
    - Room layouts
- Consideration of future district energy system connection between phases

6.2 Ownership and Governance Strategies

This pre-feasibility model looked at the global benefit of the energy systems relative to the baseline. No consideration was given to different ownership models in the analysis.

As this project moves from pre-feasibility to detailed feasibility or design, the importance of establishing the preferred ownership and governance model will crystallize. Work must be done within ABC Company to determine the internal appetite for owning/financing/operating the energy system(s).

Below is a summary of the potential options available to ABC Company and the asset ownership under each potential scenario.

Fully ABC Company Owned	• ABC Company designs and develops the project. • ABC Company engages providers to design and construct the system. • ABC Company provides capital funding for the project. ABC Company is also responsible for raising the appropriate debt financing. • ABC Company owns and operates the system (operation can be outsourced). • ABC Company can sell the assets in the future.
ABC Company Utility Company	• Same as Fully ABC Company Owned above, but ABC Company establishes a utility company to own and operate the central energy equipment separate from the ownership of the in-suite and building distribution systems. • The utility company would retain ownership of the energy assets at sale. • Requires ABC Company to navigate the legal, tax, and commercial complexities of establishing a new utility.
Joint Venture	• ABC Company enters into a partnership to design, develop, and finance the project. • The ownership of the assets is split based on percentage investment between partners. • ABC Company would benefit from the skills and experience of the partner (and funding brought to the table). • The partner may benefit from the lower cost of money available to ABC Company (if applicable), therefore reducing their initial capital outlay. Construction financing may also be available under this structure, significantly improving returns for all parties. • Proceeds from future sale would be split between parties as per their contract.
Fully Utility Owned	• ABC Company aids the development of the project through supportive building/site design and facilitates stakeholder and community engagement. • Private financing and capacity are sought to help design, finance, develop, and operate the project. • Proceeds from future sale would go directly to the utility. • ABC Company reduces capital expenditures for HVAC equipment relative to the business-as-usual scenario.

Once ABC Company's preferred role in a future system is determined, the governance structures to support the energy system can then be developed. The amount of work involved in this largely depends on the approach taken, i.e., governance for a fully private utility system would be quite straightforward as there are companies already offering this in Canada, whereas alternate options may involve more time and effort to establish.

APPENDIX A: ASSUMPTIONS

Table 7: Key assumptions

Description	Assumption	Notes/Source
Project Life Cycle		
Contingency		
Natural Gas Cost		
Electricity Consumption Charge		
Electricity Capacity Charge		
Natural Gas Emissions Intensity		
Grid Electricity Emissions Intensity		
Carbon Tax – 2023		
Carbon Tax Annual Increase – 2023-2030		
Carbon Tax – 2030		
Inflation		
Natural Gas Escalation Rate		
Electricity Escalation Rate		
Carbon Tax Escalation Rate – Post 2030		

APPENDIX B: CONCEPT DRAWINGS

Concept drawings are provided for space planning purposes only. Detailed design has not been completed.

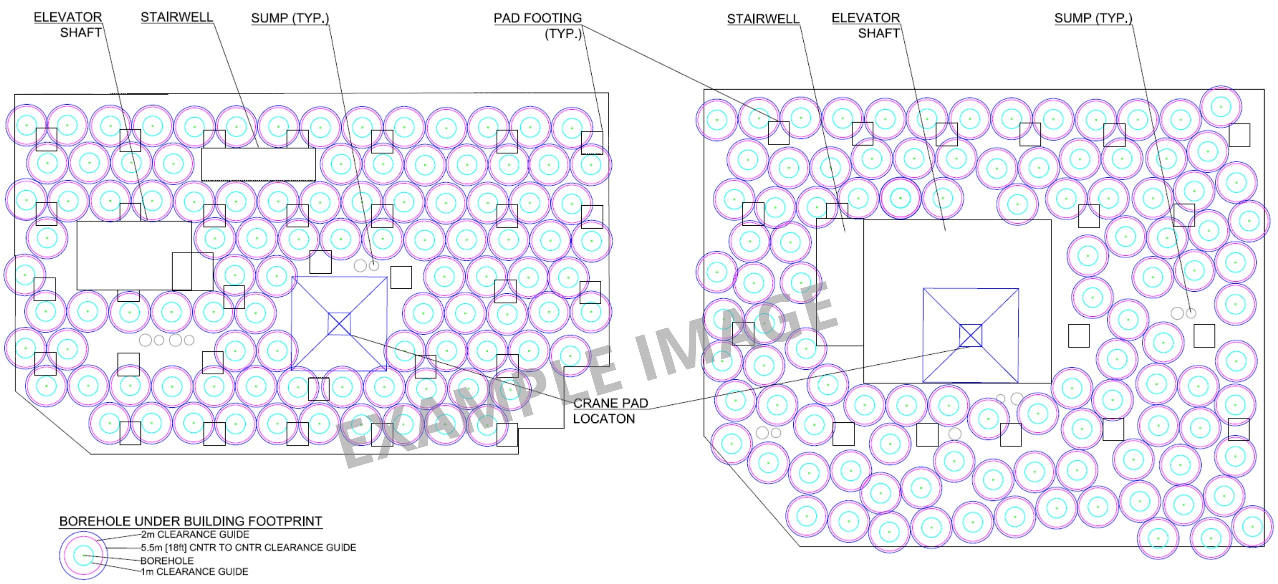

Figure 21: Borehole layout concept drawing. Circles represent borehole spacing.

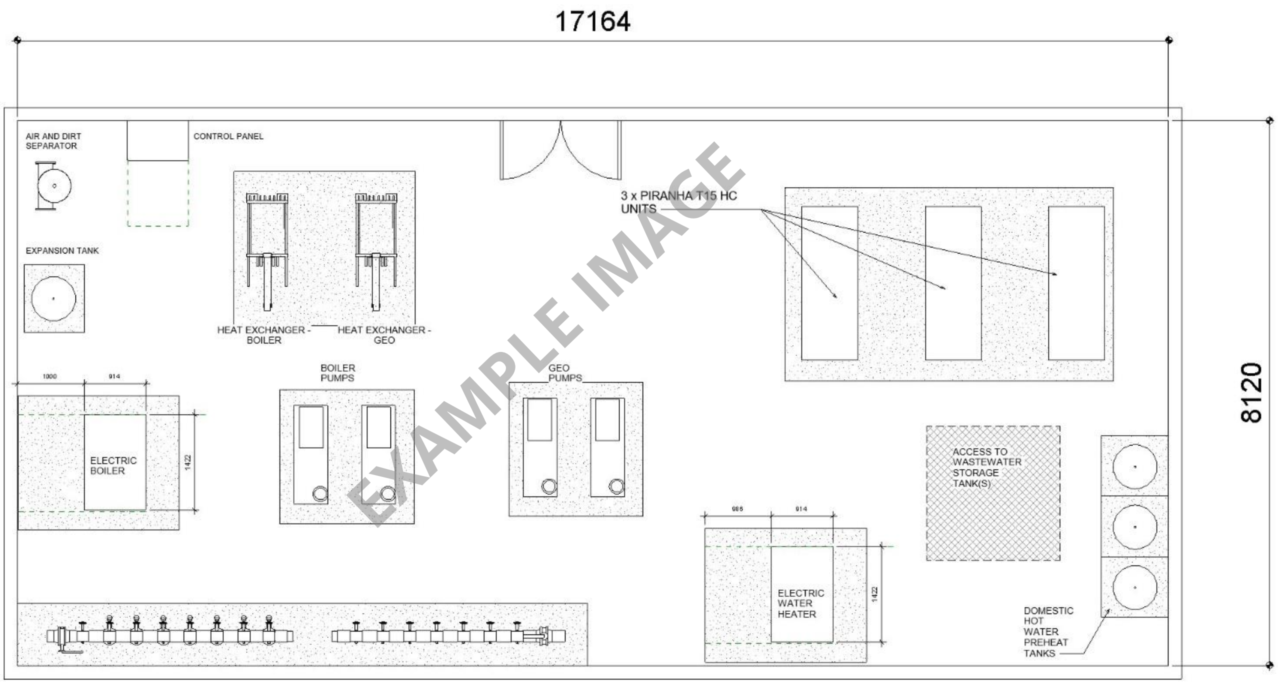

Figure 22: Mechanical room layout for Phase 1 – concept drawing

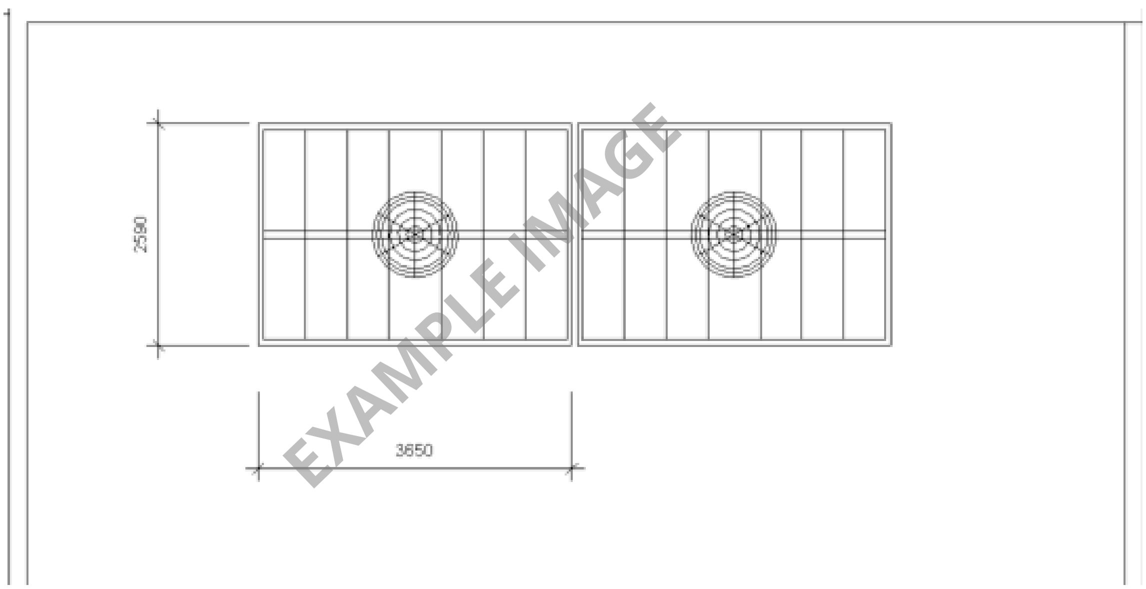

Figure 23: Roof layout for Phase 1 – concept drawing

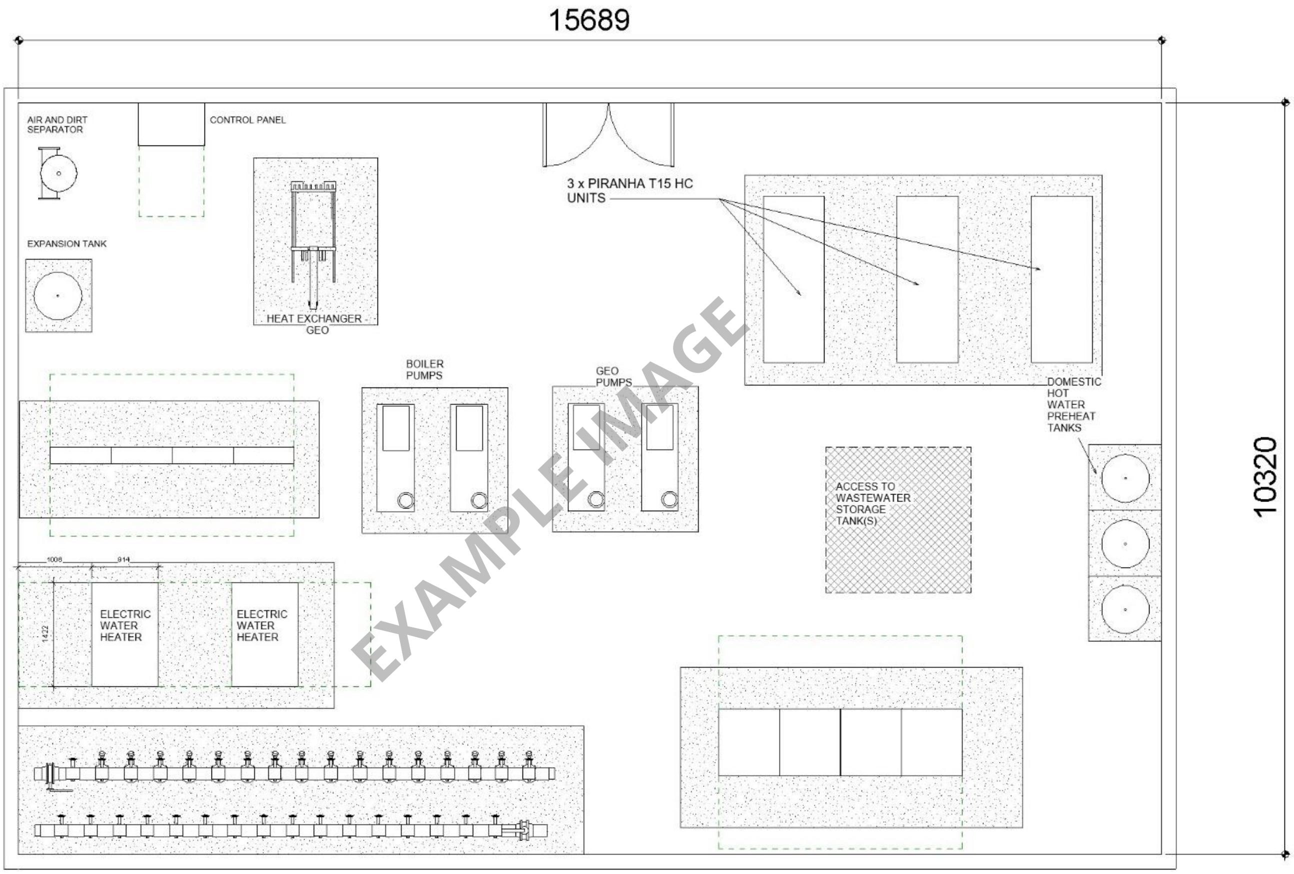

Figure 24: Mechanical room layout for Phase 2 – concept drawing