Decarbonizing UBC's District Energy System: District Energy Heat Pump Technology

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DECARBONIZING UBC'S DISTRICT ENERGY SYSTEM – DISTRICT ENERGY HEAT PUMP TECHNOLOGY

PREPARED FOR UBC SEEDS & ENERGY AND WATER SERVICES

BY

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Executive Summary

UBC is working on initiatives to meet its climate action target of achieving carbon neutrality by the year 2050. A major percentage of UBC's GHG emissions occur in buildings operations, specifically, in space heating and domestic hot water heating to meet the thermal demand of the campus. Though UBC's steam power plant for campus heating has been replaced with natural gas boilers of high efficiency and biomass plants that utilize clean wood waste, there is still a significant amount of GHG emissions released during the operation of natural gas boilers. Hence, there is a need to reduce the reliance on natural gas for district heating to aid GHG emissions reduction on campus. Integrating renewable sources of energy such as sea water heat pumps into UBC's District Energy System (DES) can be one possible solution to reduce or eliminate the fossil-fuel reliance for district heating. Four different sea water heat pump technologies were studied that could meet the thermal demand of the campus, and the operating temperature of the DES. Each heat pump was integrated separately into the business as usual model, and the related energy consumption, operational costs and GHG emissions were analysed and compared with the business as usual scenario from the year 2024 till 2050. The business as usual scenario consists of the natural gas boilers, the biomass plant, the new biomass expansion plant to be installed by 2024 and the cogeneration plant. The new model consists of all these facilities along with the sea water heat pump unit. By comparing both the models technically and financially, the GHG emissions savings, operational expenses savings, the payback periods, and other financial parameters were calculated. It was observed that the heat pumps contributed to around 32% to 83% of GHG reduction when compared with the base case under different carbon tax scenarios. There was also notable reduction in operational expenses from the business as usual scenario. However, one major financial challenge encountered was the longer payback period, which was more than the actual replacement period or life span of the heat pumps. On the other hand, under circumstances where carbon taxes could go as high as 200$/tCO2, the payback period declined drastically. Therefore, it can be interpreted from the study that the sea water heat pump technology can help UBC progress towards its carbon neutrality goal, but a financial trade-off must be made in terms of longer payback periods if the carbon taxes do not increase and stay as consistent as now. However, under high carbon tax scenario, the results showed that the sea water heat pumps would become both technically and financially viable to UBC.

1. Introduction

UBC's DES (District Energy System) serves both the hot water and the heating demand of the campus. The two major sources of energy input to DES are clean wood waste to the Bioenergy Research & Demonstration Facility (BRDF) and natural gas to the boilers at Campus Energy Centre (CEC). A CHP plant also supplies a small portion of hot water to the campus by taking in natural gas or renewable natural gas. Therefore, the CEC receives 70% of the total energy input in the form of natural gas, BRDF receives around 25% of input in the form of clean wood waste while the CHP receives 5% of input in the form of both the natural gas and renewable natural gas (Figure 1). It has been estimated that around 90% of UBC's GHG emissions arise from the use of natural gas as energy input to the DES system (UBC Sustainability Report, 2018). UBC has a planned expansion of BRDF facility by 2021 (expected to be 2024) by which the energy input to the BRDF will increase by 45%, from the existing 25% to 70% (Figure 2). However, the remaining energy input of 25% has still to be supplied by natural gas even after the proposed BRDF expansion. This urges UBC to find alternative renewable energy solutions for DES to reduce this natural gas reliance so that it would be able to meet its carbon neutral target by 2050.

UBC's SEEDS (Social Ecological Economic Development Studies) Sustainability Program in collaboration with UBC Energy & Water services is looking for solutions to decarbonise the DES with a suitable district energy heat pump technology that could reduce the natural gas consumption in the campus after the BRDF expansion.

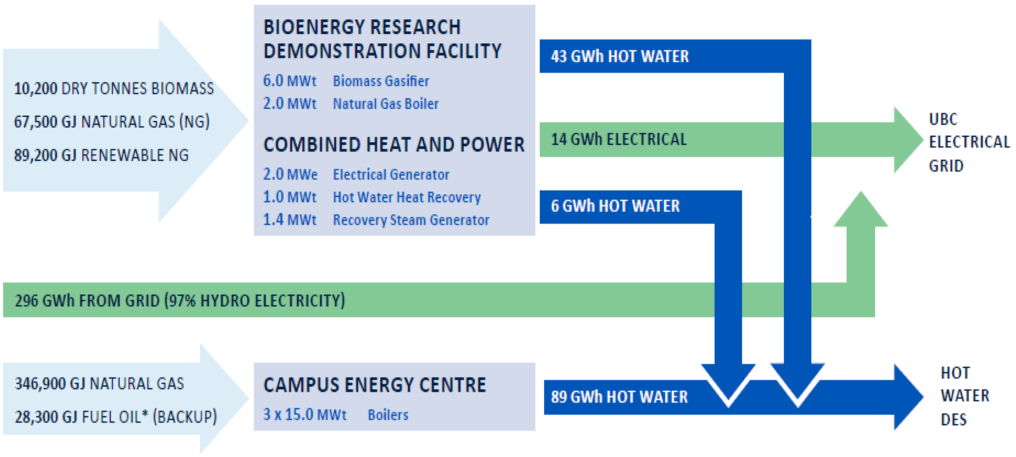

Figure 1: Existing allocation of energy input to UBC DES (UBC Energy and Water Services, 2019)

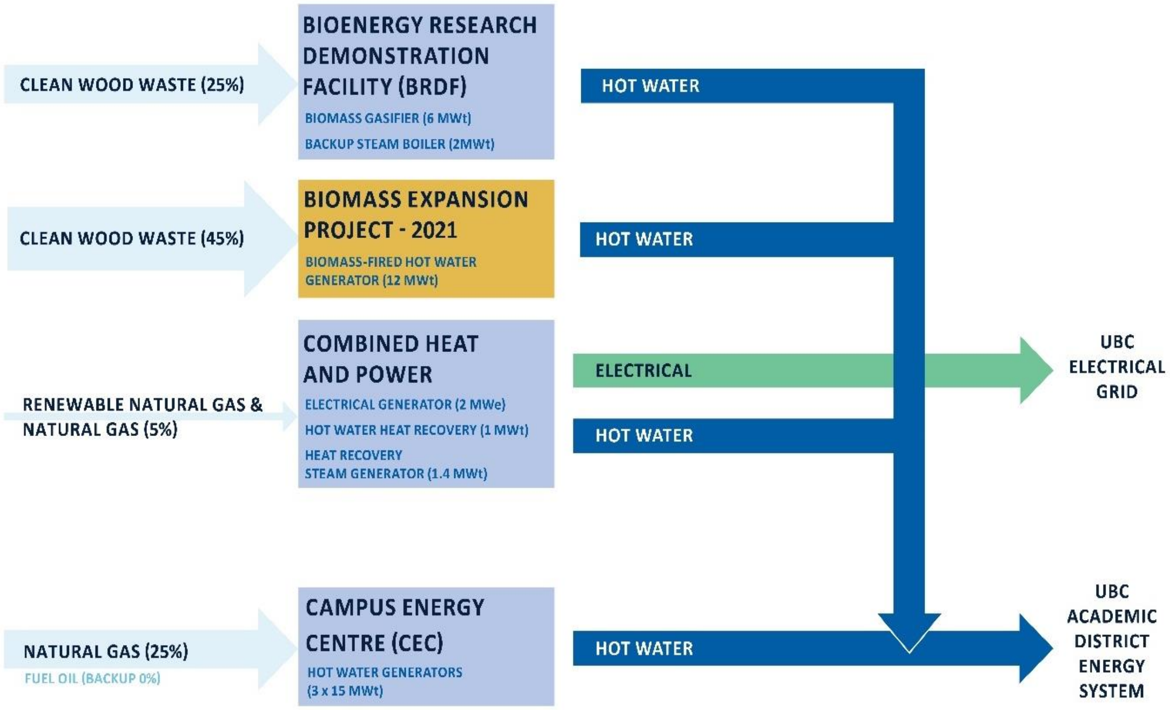

Figure 2: Allocation of energy input to UBC DES after BRDF expansion (UBC Energy and Water Services, 2019)

2. Purpose

The scope of this project is to conduct a feasibility study on a heat pump technology suitable to UBC in terms of both technical & economic viability, that could reduce the reliance on natural gas boilers for UBC’s District Energy System (DES) and also help UBC achieve its 2050 climate action target of becoming carbon neutral.

3. Objectives

- To perform a technical feasibility analysis of integrating sea water heat pumps with UBC’s District Energy System (DES) to identify if the heat pumps could reduce GHG emissions from DES and help UBC achieve its 2050 carbon neutral target.

- To conduct a cost-benefit analysis to check the economic feasibility of the proposed system by projecting the financial results to 2050.

- To perform a stakeholder analysis to locate the stakeholders of the project.

4. Background

UBC has an ambitious Climate Action Plan (CAP) to reduce GHG emissions to zero by 2050 in order to support regional and global climate change goals. In 2018, UBC achieved a 38% reduction in GHG emissions based on a 2007 baseline of 62,000 tCO2 (Refer Appendix). However, 90% of UBC's GHG emissions arise from the use of fossil fuels, primarily natural gas for the District Energy System (DES) that distributes hot water around campus.

Energy is provided to the DES using natural gas boilers in the Campus Energy Centre (CEC) together with renewable energy from the Bioenergy Research & Demonstration Facility (BRDF). A planned expansion to the BRDF will significantly reduce UBC's GHG emissions, while additional renewable energy projects will be needed to further decarbonize the energy system. This project aims to investigate the feasibility of heat pump technology options to provide heating energy directly into the DES, thereby reducing GHG emissions and reliance on natural gas.

4.1. UBC Energy & Water Services

UBC's Energy and Water Services (EWS) manages and operates UBC's utility assets, delivers utility master plans, load forecasts, and associated capital upgrades. Therefore, EWS is responsible for the District Energy System (DES). The three sub-systems in DES that help to meet the thermal demand are:

1. Cogeneration unit at BRDF

2. Biomass unit at BRDF

3. Campus Energy Centre

4.1.1. Cogeneration unit

UBC's electrical and thermal energy systems are base loaded with the Bioenergy Research & Demonstration Facility's (BRDF) 2 MWe cogeneration engine (UBC Energy and Water Services, 2019). It was recognised as North America's first demonstrational unit of a community-scale ICE based CHP system with biomass as a fuel. From 2014, it is being run on a combination of natural gas and processed biogas and serves around 5% of UBC's electricity needs. The unit consists of a heat recovery steam generator of 1.4 MWt and a heat exchanger that produces 1 MWt of hot water by recovering heat from the unit's cooling systems. Therefore, the thermal heat recovered from this unit can usually be considered as a waste heat recovery. The engine has an efficiency of 64% (UBC Energy and Water Services, 2019).

4.1.2. Biomass plant

After the cogeneration plant, DES is base loaded with the BRDF's 6 MWt clean wood waste gasifier and steam boiler (UBC Energy and Water Services, 2019). Clean wood is a renewable fuel source that is available in plenty domestically. By combusting clean wood, 25% of the thermal demand on campus is met. This facility also has a 2 MWt natural gas steam boiler as a backup. UBC has achieved a 14% reduction in GHG emissions with the help of this facility (Figure 4). The average efficiency of this facility is 70% (UBC Energy and Water Services, 2019).

The existing biomass plant capacity is expected to be tripled by 2021(Figure 3) with additional 12 MW to be integrated with the existing 6 MW thus making a total of 18 MW. But the expected year of completion for the plant expansion is 2024. It has to be noted that the steam from both the cogeneration and biomass units is fed into the hot water DES via steam to hot water converters.

4.1.3. Campus Energy Centre

The Campus Energy Centre, also referred as CEC, has a total capacity of 45 MWt (UBC Energy and Water Services, 2019) with three 15 MWt hot water boilers fuelled by natural gas. CEC supplies heat during the peak thermal loads of the campus and has an average efficiency of 87% (UBC Energy and Water Services, 2019).

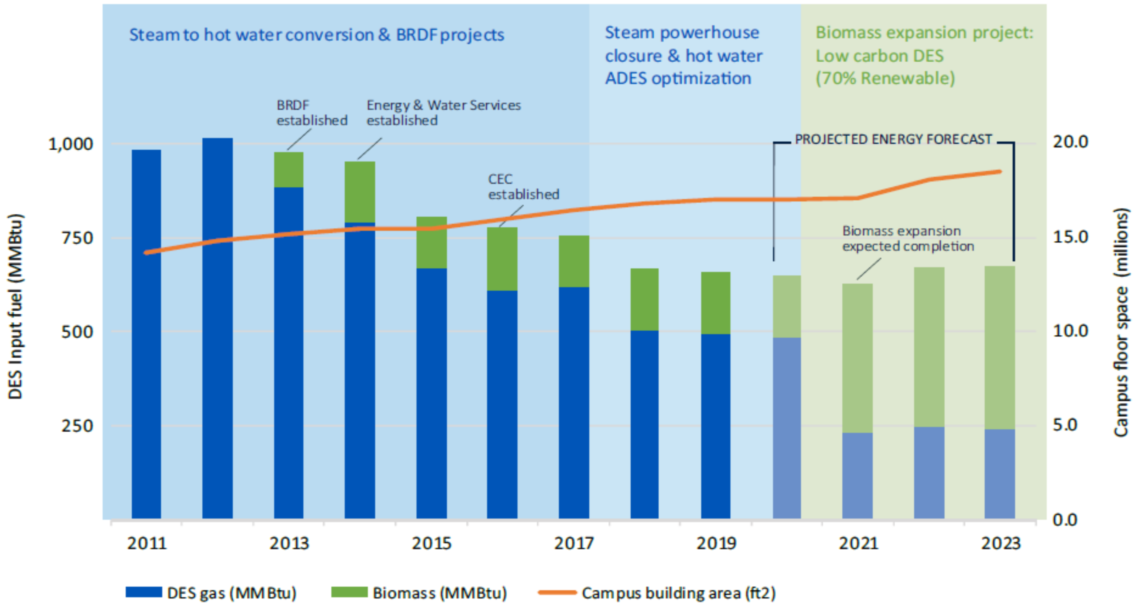

Figure 3: Historical and forecasted energy use by type

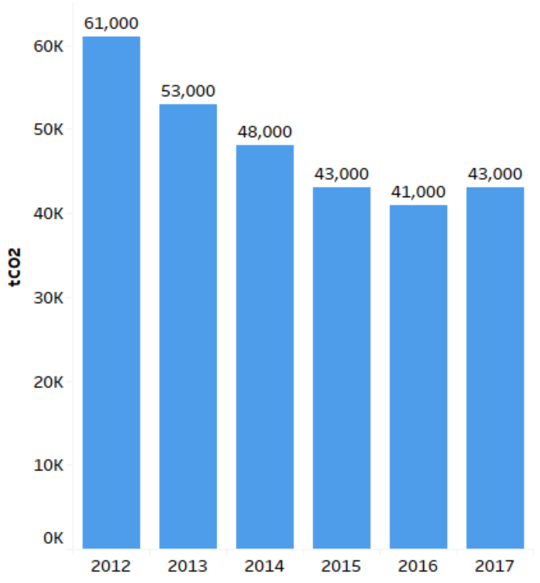

Figure 4: UBC's total annual emission reduction after establishment of BRDF

4.2. UBC's emission reduction targets

UBC is committed to climate action to avoid and minimize the impacts of climate change, demonstrate its leadership in research, innovation and learning, reduction in operational costs, and to create sustainable solutions for the university (UBC Sustainability Report, 2018). Starting from 2006, it has been maintaining its GHG emissions inventory. From 2010, UBC is also paying carbon offsets of around $1 million each year on its direct and indirect emissions

(UBC Sustainability Report, 2018). Despite an increase in floor space and student population on campus, UBC managed to achieve its Kyoto Protocol targets in 2007 by reducing its GHG emissions by 6% below 1990 levels and also met its 2015 GHG emissions reduction target from a 2007 baseline (Table 1). All the climate action targets include reducing the reliance on natural gas and utilising less carbon intensive hydroelectricity. The success in 2015 GHG emissions reduction target against the 2007 baseline, despite a 16% increase in floor space and a 23% increase in student population (UBC Sustainability Report, 2018), was driven by the following initiatives.

- The steam-based DES was replaced with hot water-based DES which increased the system efficiency by 24% (UBC Sustainability Report, 2018).
- The reliance on natural gas was reduced by 25% by switching to biomass (UBC Sustainability Report, 2018).
- An energy conservation team was formed to minimize energy usage and optimize building performance. This resulted in energy savings well-enough to offset the increasing campus space and population (UBC Sustainability Report, 2018).

Baseline Year	Target Year	Target Percentage
2007 62000 tCO2	2015	33%
	2020	67%
	2050	100%

Table 1: UBC Vancouver Campus - 2010 Climate Action GHG reduction targets (UBC Sustainability Report, 2018)

Also, to advance UBC's Vancouver campus towards the 2020 target of reducing the emissions by 67% below 2007 levels, 24 initiatives were developed in 2017. One of the initiatives was to triple the biomass capacity to reduce the reliance on natural gas.

5. Literature Review

There are various heat pump options available to UBC. The two major concerns associated with installing any heat pump technology in UBC for DES are:

1) It should have the potential to serve the thermal demand of the campus.

2) It should be economically viable.

According to the Alternative Energy Report published by Stantec Consulting for UBC, there are many heat pump options available to UBC such as GSHPs (Ground Source Heat Pumps), Deep Aquifer, Sanitary Sewer, Data Centre Heat Recovery, Ocean water pumps and Sewage water pumps from Iona Waste Water Treatment plant operated by Metro Vancouver across Fraser River. The Stantec report estimates that GSHPs, Deep Aquifer, Sanitary Sewer, Data Centre Heat Recovery technologies could serve only less than 5% GHG reduction from 2009 baseline of 58000 tonnes and are not capable of meeting growing thermal energy demand (Stantec Consulting, 2009). Whereas, the Iona hot and cold-water heat pumps or the ocean water heat pumps can achieve around 52% of significant GHG reductions from the 2009 baseline. Even though Iona has the potential to serve around 100 MWt after the secondary expansion of the plant (Stantec Consulting, 2009), it has the following drawbacks:

- Very capital intensive.
- There might be pressure on not having additional effluent on campus.
- Rights of pathway for the piping would have to be negotiated with the various parties to run the piping from Iona to UBC.

Due to these reasons, it cannot be recommended, thus leaving the only option of ocean/sea water heat pumps. Sea water heat pumps are capable of utilising free thermal energy from sea. However, they have their own challenges as mentioned below by few research studies.

- Sea water temperature fluctuations (Song, Akashi & Yee, 2019).
- Higher energy consumption compared to equivalent boilers of same thermal capacity (Hiawen et al., 2016).

- If the temperature difference between the supply and return lines is small due to the lower sea water temperature conditions or atmospheric conditions, the mass flow rate of the water must be increased. If not properly monitored, there are chances for freezing of sea water which will interrupt the whole system operation and might result in unnecessary expenses (Hani & Koiv, 2012).

- Heat Pumps generally have longer pay back periods.

It is to be noted that the challenges related to sea water temperature changes and freezing are not in scope of this study due to the lack of depth-wise sea water temperature data.

6. Proposed design layout

The below schematic represents the basic design layout of integrating the sea water heat pump into the DES system.[1]

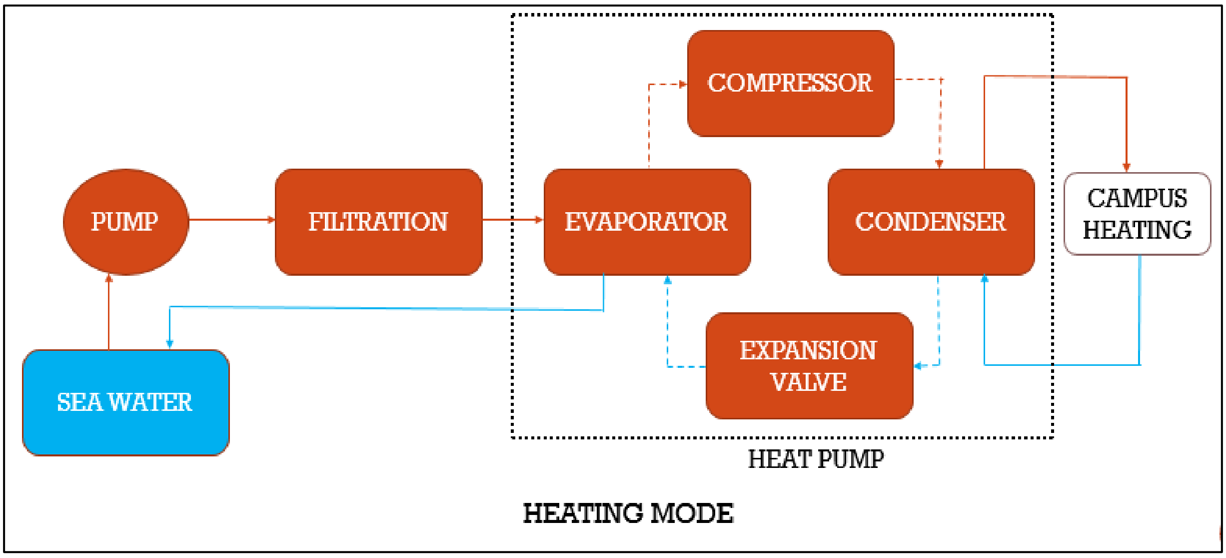

Figure 5: Sea water heat pump in heating mode

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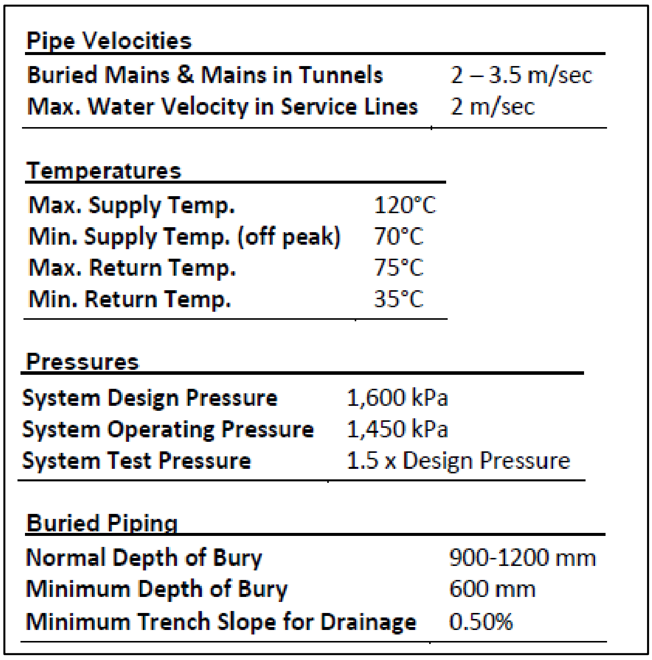
[1] Note that the filtration units have not been considered for the study.

7. Equipment guidelines & sizing

7.1. UBC Technical guidelines for DES

Before designing the new district heat pump system, it is necessary to understand the following major technical guidelines listed out by UBC (UBC Technical Guidelines, 2019) for District Energy System (DES) and the existing functionalities & design parameters.

- The hot water is distributed to each customer or building on the campus through a two-pipe (one supply and one return) buried distribution piping network. The hot water is used for building heating and domestic hot water heating. The direct buried supply and return distribution lines (also referred as 'Distribution Piping System/DPS') for the hot water system should be Logstor prefabricated, pre-insulated steel pipes.



Pipe Velocities	
Buried Mains & Mains in Tunnels	2 – 3.5 m/sec
Max. Water Velocity in Service Lines	2 m/sec
Temperatures	
Max. Supply Temp.	120°C
Min. Supply Temp. (off peak)	70°C
Max. Return Temp.	75°C
Min. Return Temp.	35°C
Pressures	
System Design Pressure	1,600 kPa
System Operating Pressure	1,450 kPa
System Test Pressure	1.5 x Design Pressure
Buried Piping	
Normal Depth of Bury	900-1200 mm
Minimum Depth of Bury	600 mm
Minimum Trench Slope for Drainage	0.50%

Figure 6: UBC Design Requirements for Distribution Piping System (DPS)

- Energy transfer stations (Figure 7) are employed to transfer the thermal energy from any heating facility through the distribution network to the customer via heat exchangers to satisfy the buildings' heating needs. The energy transfer stations therefore replace the steam converters in existing buildings or the traditional boiler or furnace system and hot water heaters in new buildings.

- DES has a variable flow and supply water temperature strategy. Both parameters will be varied depending on the outside atmospheric conditions and load demand. Each building will be connected to the distribution system indirectly through an energy transfer station. The motorized control valves situated on the distribution system side (or primary district heating side) of the energy transfer station can be modulated to control the actual thermal load delivered to the customer. This strategy helps in increasing the system efficiency.
- The medium temperature hot water system operates at a maximum supply temperature of 120°C during peak demand days and a maximum return temperature of 75°C. The design pressure for this system is 1600 kPa.
- The pipe velocity is around 2- 3.5 m/s.

The functionalities of different components in DES are discussed below:

Energy Transfer Stations (ETS)

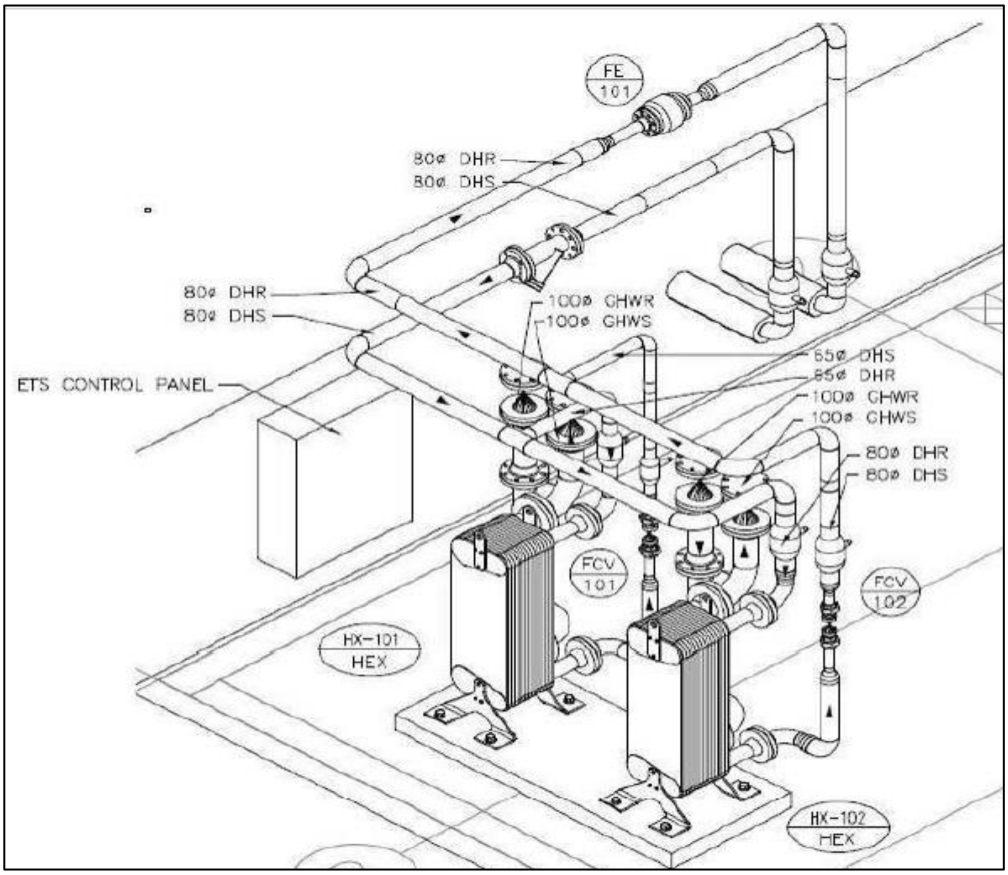


Figure 7: Energy Transfer Station Layout

The ETS connects the distribution system with the consumer’s space heating and domestic hot water systems via heat exchangers. An ETS comprises of heat exchangers, isolation valves, strainers, control package and energy metering package. The control package includes controller, control valves, temperature sensors and the energy metering package includes flow meter, temperature transmitters, and energy calculator. The controller captures the building’s heat load demand and modulates the two-way control valves situated on the primary side return of the ETS to control the amount of thermal energy delivered.

Pressures	
ETS Primary Side Operating ΔP	150 – 550 kPa
Customer Side Design Pressure	≤1,600 kPa
Customer Side Operating ΔP	As required
System Test Pressures	1.5 x Design Pressure

Table 2: Pressure design parameters for ETS

Temperatures			
		Winter	**Summer**
District Heating Side	Max. Supply Temperature	120°C	70°C
	Max. Return Temperature	<55°C	<55°C

Table 3: Temperature design parameters for ETS

Heat Exchangers

Each building's internal heating and domestic hot water systems on the secondary side are isolated from the distribution system on the primary side by means of a heat exchanger. Provided below is the summary of the guidelines for selection of heat exchangers.

- **Space heating:** Brazed Plate heat exchangers.
- **DHW:** Double-walled brazed plate or double walled plate and frame with end plate leak detection.
- Shell & tube heat exchangers should not be used.

The design pressure on the hot side (District Heating side) of the heat exchanger will be 1600 kPa. Whereas, on the cold side, it will be determined by the hot water system pressure of the building. The maximum cold side pressure will be 1600 kPa.

Space Heating Heat Exchanger Selection Criteria - New Buildings					
Hot Side Conditions			Cold Side Conditions		
Inlet Temp	Outlet Temp	Max. ΔP	Inlet Temp	Outlet Temp	Max. ΔP
120°C	55°C	50 kPa	50°C	70°C	35 kPa

Table 4: Design Parameters for space heating heat exchangers

Domestic Hot Water Heat Exchanger Selection Criteria					
Hot Side Conditions			Cold Side Conditions		
Inlet Temp	Outlet Temp	Max. ΔP	Inlet Temp	Outlet Temp	Max. ΔP
70°C	35°C	50 kPa	5°C	60°C	50 kPa

Table 5: Design Parameters for DHW heat exchangers

Strainer

The inlets of the heat exchangers are to be protected from debris and other suspended impurities both on the hot and cold sides. Strainer can serve this purpose. Installing strainers on the primary side will safeguard the flow meters and control valves. The preferred strainer screen/mesh sizes as per the technical guidelines are:

1. Brazed Plate heat exchangers: 1/8” stainless steel perforated screen with 0.5 mm mesh.
2. Plate heat exchangers: 3/64” stainless steel perforated screen.

Hot water

The DES operating temperature varies between 70°C and 120°C. To conserve energy, it is maintained low outside the peak conditions. For new buildings, the secondary side return temperature cannot be more than 50°C. The control system will provide the minimum supply temperature possible that will still meet the customer’s load requirements by maximizing the temperature difference between the supply and return distribution piping. However, during summer, this minimum supply temperature is limited to 70°C to maintain the storage tanks of the DHW systems at a minimum of 60°C to prevent Legionella bacterial growth.

System water concentrations

- Iron levels should be below 2 ppm.
- Hardness should be below 2 ppm.
- Chloride levels should be maximum 250 ppm if 316 Stainless Steel Heat Exchanger plate material is used or 50 ppm for 304 Stainless Steel.
- pH level of 9.5-10

7.2. Sea Water Heat Pump Models

Two models of sea water heat pumps (Heat Pump Model 1 & 2 discussed below) were chosen based on the operating temperature requirements for DES and refrigerant with low GWP (Global Warming Potential). Heat Pump Model 1 which has two units could operate either in single unit mode or in series mode. A third model of heat pump of 6 MW heating capacity and

COP 3 was also studied to understand how a heat pump of lower heating capacity compared to the other pumps can work in DES.

It must be noted that the heat exchangers used in both the models were assumed to satisfy the UBC technical guidelines due to data gaps. However, both the manufacturers can design the models based on client's requests and specifications which allows the possibilities for installing these models with the heat exchanger types specified in the technical guidelines in future. The life span of all the heat pumps were assumed to be 15 years and they were considered to be corrosion-resistant. Therefore, the replacement is to be made every 15 years.

a) Heat Pump Model 1: 2 Unitop 43/28 BPY heat pumps from Friotherm

This model has two units, designed to allow single stage or double stage operation. In other words, the entire model can be operated either in series or with a single unit. The operating temperature range is closer to the existing DES range. The refrigerant used is Solstice 1234ze with a GWP <1. The specifications are listed below in Table 6.

Operating Seasons	**Winter**	
Units operating in	**Single unit**	**Series**
Heating capacity	8286 kW	16249 kW
Hot water in/out	58/81°C	65/80°C
Cold water in/out	4.9/2.5°C	4.9/2.5°C
COP	4.42	4.42

Table 6: Heat Pump Model 1 technical specifications

Figure 8: Unitop 43/28 BPY heat pumps from Friotherm during installation

Figure 9: Unitop 43/28 BPY heat pumps from Friotherm in operation

b) Heat Pump Model 2: Star Refrigeration’s Drammen Case Heat Pump Model

Star Refrigeration’s Drammen district heating project at Norway involves three units of this model which serve 85% of the district heating demand with the supply and return temperatures of 90℃ and 60℃ respectively. The Drammen municipality consists of around 63000 people. The same can be employed in UBC’s district heating system. This model also uses ammonia (R717), a carbon-neutral refrigerant and the operating temperature range is closer to that of the existing DES range. The specifications are listed below in Table 7.

Parameter	Value
Heating Capacity	13.2 MW
COP	3.05
Heating source	River/sea water in at 8°C and out at 4°C
Supply Temperature	90°C
Return Temperature	60°C

Table 7: Heat Pump Model 2 technical specifications

Figure 10: Star Refrigeration Heat Pumps in Drammen

c) Heat Pump Model 3:

A heat pump of capacity lower than the other two models was also considered. The heating capacity of this model was 6 MW with a COP of 3. This was done to understand how a lower capacity heat pump works in the new model and hence no specific product model was chosen.

7.3. Water Intake Pump Model

The intake pump capacity was fixed based on the volumetric flow rate of around 97.7 L/s to 100 L/s. The YOKOTA Seawater Resistant Stainless Steel YST130N sea water intake pump can handle a volumetric flow rate of 7 m3/min which is 116 L/s. It can operate up to a head range of 75 m and has a rated capacity of 120 KW. The capital cost of this pump was based on the general market rates. The installation, maintenance and replacements costs were not considered in this study as they were small compared to the costs of other equipment in the new system. The specifications are listed below in Table 8.

Parameter	Value
Volumetric flow rate	116 L/s
Head range	75 m
RPM	1800 rpm
Capacity	120 KW

Table 8: Intake pump technical specifications

7.4. Piping

Piping material

The materials that are being commonly used in seawater piping are carbon steel, copper nickel alloys, stainless steel and titanium alloys. Stainless steel and titanium alloys can withstand corrosion to a certain extent under conditions that are not severe. Whereas, carbon steel and copper nickel alloys have the characteristics of corroding at a low and predictable rate (Gartland, Johnsen, Valen, Rogne & Drugli, 1996). Having combinations of materials in the piping system may also result in galvanic corrosion which may be unpredictable. An example is cement lined carbon steel piping partly replaced by titanium or stainless steel. If there is any failure in the cement lining, it will render the carbon steel more exposed to corrosion with a much severe galvanic corrosion in areas where coupling is done (Gartland, Johnsen, Valen, Rogne & Drugli, 1996). Hence, great care must be taken in selecting the material of the pipelines.

Galvanized steel, on the other hand, coated with a thin layer of zinc can help guard against corrosion. It works well against water but not saline sea water (Bob Vila Academy, 2019). Stainless steel, on the other hand, can withstand saline water and due to its strength and resistance to rust, it is largely used in construction and marine environments. But too much exposure to Chlorine can degrade the coating on the metal and can cause rust (Bob Vila Academy, 2019). So, it must be made sure that, if used, Stainless Steel pipeline has to be well-coated with Chlorine-resistant materials. Titanium can also be considered for piping. It resists sea water corrosion even at temperatures as high as 260°C and can also resist erosion by high velocity seawater. Even high velocities in the range of 120 ft/s cause only a minimal erosion. Moreover, abrasive particles such as sand, has only a small effect on the corrosion resistance of Titanium. It is also considered as one of the best cavitation resistant materials available for seawater services. Though titanium has better chemical properties, for this study, Stainless Steel was considered because of the data availability on prices.

Piping diameter

The inner diameter of the piping was fixed based on the flow rate and velocity of the water. It was done with the below formula:

$$\text{Pipe diameter} = \sqrt{\frac{4*flow\ rate}{3.14*velocity}}$$

For a flow rate of around 100 L/s (standard volumetric flow in DES is 97.7 L/s, value was rounded off) and maximum pipe velocity of 3.5 m/s, the pipe diameter was found to be 0.1907 metres which is equal to 7.50 inches. Thus, the piping inner diameter should be 7.50 inches for the system. Based on the market price of 200$ per foot of SCH10 type Stainless Steel pipe (MetalsDepot, 2019) and the total pipe length of 1.5 km, the capital cost was calculated.

7.5. Strainer selection

As mentioned in the earlier part of the study, strainers are essential to filter out substances that can damage the entire system and to prevent fouling and plugging of heat exchanger tubes. Strainers are usually made of steel or cast iron and are protected by paint and/or cathodic protection. Primary filtration is generally carried out by a robust grid or trash rack to eliminate large pieces of debris such as bottles and timber pieces. The intake system should have trash tracks followed by stationary or traveling screens and fine filters within the system. Therefore, the challenge lies in the removal of air from the system during filtration. The presence of air can enhance the erosion-corrosion effect of seawater and has the potential to stimulate impingement attack on the strainer material. Provision should be made for air release from the high parts of components where it may accumulate. However, strainers were not considered in this study as the costs were negligible compared to the other larger components.

7.6. Influence of sea water conditions

The initial few centimetres of the sea surface absorbs most of the heat energy radiated from sunlight during the day and gets heated. While at night, the heat energy that has been absorbed during the day is radiated back to space and the surface gets colder. Closer to the surface layer, waves mix with the water and the heat gets distributed to deeper water in such a way that there exists relatively uniform temperature in the upper 100 metres. This also depends on how stronger the waves are, and the surface turbulence created by currents. However, the temperature becomes more stable beneath this mixed layer and stays constant over days and nights. It must be noted that the freezing point of saline water is “−2.3 °C” and the temperature near the sea surface is usually closer to zero degrees. Therefore, great care must be taken while pumping the saline water to the heat pump, as there are possibilities for freezing with respect to lower sea water temperature conditions.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min °C	6.2	5.9	5.9	6.3	6.9	7.4	9.3	9.9	10.3	8.7	7.6	6.8
Max °C	7.8	7.8	8.3	8.4	9.8	10.8	11.5	12.7	12.3	11.6	9.9	8.5

Table 9: Average Sea Surface Temperature (SST), Vancouver (World Sea Temperatures, 2019)

However, there was no specific depth-wise Sea Surface Temperature data available related to this study. For heat pump modelling, the values of depth-wise temperature profile were assumed to serve the supply temperature of the DES with the help of the heat pump.

7.7. Location of the intake pumps

The location for installation of the intake pumps is a big challenge, provided the unavailability of the data related to depth-wise temperature variations from sea surface. However, studies say that water intakes could be located approximately 12 m from sea surface at low tides (Stantec Consulting, 2009) or at least must be located below 10 m at low tide to capture more stable water temperatures not affected by the winter weather. One study says that averagely the depth will increase 5 m by additional distance of 1 km from the coast and economically it would be efficient to search deeper locations in coastal areas less than 500 m (Hani & Koiv, 2012). Usually, the depth of 25 m is located 500 m from the coastal area. Hence, it had been interpreted that in combination of distance less than 500 m from the shore and depth of approximately 20 m which is less affected by active tides and temperature fluctuations, the intake pipes can be located, and the intake pump can be located on shore above the ground approximately 500 m from the point of intake. As the closest available location from the main campus is Wreck beach, it had been considered as a viable location in terms of piping length and cost.

8. Data & Assumptions

Data collection

All the data and statistics used in the study were gathered from UBC Energy & Water Services, UBC 2019 technical guidelines and climate action reports. The data for historical and projected heating demand of the campus, energy consumption, operational costs and GHG emissions of the plants operating within DES was provided by UBC Energy & Water Services. The supply and return temperature data of the DES and the standard technical guidelines[2] for the sea water heat pumps were retrieved from UBC DES Technical guidelines document.

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[2] Since there were challenges in getting some technical data (data such as type of heat exchanger that is used in the heat pumps studied) for the heat pump models considered in this study, the compatibility of the heat pump models considered with the DES should be reviewed further in future works.

Assumptions

- The annual thermal load of the campus was assumed to increase by 1% each year.
- The cogeneration waste heat recovery will not add any significance to the financial analysis, as it is basically free (or) waste heat and the related costs are also negligible. Also, after 2027, this heat recovery system will not be operational and thus not considered for analysis after the year 2027.
- While comparing the base case to the new models, the capital costs of natural gas boilers at CEC, existing biomass plant, biomass plant expansion and cogeneration unit were not considered since they were common to both the cases.
- The maintenance costs of CEC, existing biomass plant, biomass plant expansion and cogeneration unit were considered to be negligible as maintenance is very rare as per information received from UBC Energy & Water Services.
- The maximum total volumetric flow rate of the DES was assumed to be around 100 L/s and the same was used for piping system modelling. The intake pump was also sized to 120 KW based on this flow rate.
- The technical specifications for the heat pumps, the intake pump and the piping were retrieved from the corresponding websites of the manufacturers. Unfortunately, there were challenges in receiving the related price quotations for calculating capital investments and the associated maintenance costs from the manufacturers. Therefore, the financial parameters were assumed based on the current market prices and the information provided by experts in the field. Hence, the results from financial analysis may be susceptible to some data gaps.
- The turndown efficiency of the sea water heat pumps was assumed to be 10%.
- The electricity to be supplied to the heat pumps and the intake pump is considered to have a carbon intensity of 10.67 kgCO2eq/MWh.
- The installation cost of the heat pump was assumed to be twice the heat pump cost.
- The maintenance cost of the heat pump was assumed to increase 1% every year.
- The life span of the heat pumps was considered to be 15 years, thus NPV (Net Present Value) was calculated in time window of every 15 years from 2024-2050.
- The analysis to identify a feasible location for the intake of sea water had been carried out, but the results may be liable to certain level of uncertainty due to the very limited

information available for Sea Surface Temperature (SST), specifically, the depth-wise temperature data at a specific distance from the shore and sea surface for Vancouver sea conditions. Due to this data gap, the heat pumps were assumed to convert the captured sea water temperatures into the operating supply temperature for DES.

- The route of the pipeline was considered to be between Main Mall, where the sea water heat pump could be installed, through University Boulevard & Trail 6 till the intersection of Foreshore trail. The estimated pipe length through this route was assumed to be around 1.5 km.
- Stainless Steel was chosen as the piping material as it is more corrosion-resistant than the other materials and because of the availability of market prices for the piping. The parameters for sizing the piping such as diameter were calculated based on several research studies and marine forums & associations.
- Desalination or filtration of the sea water was not in the scope of this project and all the equipment considered in the study were assumed to be corrosion-resistant and meet the UBC technical guidelines due to lack of data.
- If there arises a need where there is a demand for both cooling and heating on a day-to-day basis, further study needs to be carried out as it is not in the scope of this project.

9. Methodology

The methodology involves comparing the business as usual model with the different versions of new model constructed by integrating each heat pump technology to the base model. The operating facilities involved in both the models are listed below (Table 10). Note that the numbers in the table show the sequence in which all these facilities are base loaded.

Business as usual model	New model
1. Cogeneration plant 2. BRDF plant 3. Biomass Expansion Plant 4. CEC	1. Cogeneration plant 2. BRDF plant 3. Biomass Expansion Plant 4. Sea Water Heat Pump 5. CEC

Table 10: Operating facilities involved in base case & new models

9.1. Techno-economic analysis

The methodology for the techno-economic analysis (objectives 1 & 2) was carried out in following three phases.

1. Data Modelling
2. Analysis
3. Comparison

9.1.1. Data Modelling

Two models were created using MS Excel:

1) Business as usual model (also referred as base case model)

2) Versions of new model with each heat pump technology integrated to the base model

- **Business as usual model:** UBC Energy & Water Services had already developed a data model projecting the campus heat demand, energy requirements, operational costs and GHG emissions starting from the year 2018 till 2041 including the cogeneration, existing biomass plant, CEC and also considering the new biomass expansion of 12 MW which is expected to be completed by the beginning of 2024. Even though the rated capacity is estimated to be 12 MW, the operating capacity of the expanded biomass plant is assumed to be 10.5 MW considering the 20% turndown efficiency. This existing model was extended till 2050 and the time range 2024-2050 was considered for the study, rationale being that the biomass plant expansion is assumed to be finished at the beginning of 2024 and 2050 is the year at which UBC should become carbon neutral. This extended data model was the base model against which the new models were compared.
- **New models:** The following heat pump technologies (Table 11) were considered for constructing various versions of the new model.

Heat Pump (HP) Model	**Heating Capacity (MW)**	**COP**
HP Model 1 – Single Unit Mode	8.286	4.42
HP Model 1 – Series Mode	16.249	4.42
HP Model 2	13.2	3.05
HP Model 3	6	3

Table 11: Summary of Heat Pump model specifications

The new models were developed from the existing base data model by integrating each sea water heat pump technology separately to the base model. As four different heat pump technologies were considered, this integration will result in four different versions of new model (heat pump model 1 alone has single & series mode operation). These were the new models and were compared against the base data model for analysis. It must be noted that based on the existing temperature requirements for the DES and other technical standards as specified in UBC's technical guidelines for DES, the heat pump units, water intake pumps, piping were chosen for the new models.

- In both the models, the total annual thermal load of the campus was assumed to increase by 1% each year starting from 2018. Base on this annual thermal load, the load sharing among different facilities was modelled from 2024 till 2050 for the purpose of this study. Similarly, the hour-based thermal loads were also calculated for every year and were assumed to increase by a specific percentage from the hour-based loads of a baseline model considered. This percentage was calculated by dividing the actual annual thermal load for each year by the total thermal load of the baseline model. It must be noted that this baseline model is not referring to the business as usual model which has to be compared against the new model, but another model on which the business as usual model itself is based on.

- Before biomass expansion, the total annual thermal load is to be shared between the cogeneration plant, existing biomass plant and CEC in sequence. Once the biomass expansion of 12 MW is in place by the beginning of 2024, the load sharing will also include this new biomass unit along with the other facilities (this was the reason why the data modelling was done from the year 2024, that is, after the biomass expansion). All these four facilities constitute the business as usual model and the load sharing will be among the cogeneration plant, existing biomass plant, biomass expansion plant and CEC in sequence. The same had been modelled for each year and the corresponding load sharing capacity of all the facilities and the output thermal energy delivered by each individual facility were calculated annually from 2024 - 2050.

- If any sea water heat pump technology is to be integrated into the base model DES from 2024 (creates a new model), the total thermal load of the campus in the new model will be shared among cogeneration plant, existing biomass plant, expanded biomass plant, the sea water heat pump and CEC in sequence. The same had been modelled for each year and the corresponding load sharing capacity of all the facilities and the output thermal energy delivered by each individual facility were calculated annually from 2024 - 2050.

- Both the base case and the new case data modelling was done in such a way that one can vary the heating capacity, COP, capital costs of heat pump, intake pump or vary the length and cost of the piping and interpret the technical and the cost-benefit analysis.

9.1.2. Analysis

1. Technical analysis

- **Energy Consumption:** The energy consumption for all the facilities in both the models was calculated based on the output thermal energy delivered by each facility and the efficiency of each facility. In the new models, based on the output energy that should be served by heat pumps, and COP, the electricity consumption for the heat pumps was calculated. The energy consumption was calculated only to find the related GHG emissions and operational costs. This data will not be considered for any further analysis.

- **GHG emissions:** Once the yearly energy consumption for all the facilities was known, the associated GHG emissions were calculated based on the carbon intensities of fuel input to each facility (Table 12). Also, the percentage reduction in GHG emissions in the new model compared with the base model was calculated using the below formula:

$$\text{Percentage reduction in GHG emissions} = \frac{\text{Annual GHG savings}}{\text{Annual base case GHG emissions}} \times 100$$

$$\text{Annual GHG savings} = \text{GHG emissions in base case model} - \text{GHG emissions in new model}$$

Fuel	**kgCO2e/GJ**
Biomass	2.24
Natural Gas	49.87

Table 12: CO2 intensity of fuels

2. Financial analysis

The financial analysis was carried out considering a 15-year time window (2024-2038), assuming the life span of the heat pumps to be 15 years.

- **Operational expenses:** Based on the yearly energy consumption of all the facilities, the consumption/operational costs were calculated yearly from 2024-2050. However, for financial analysis, only the period 2024-2038 was considered as stated. It must be noted that the operational cost per GJ of natural gas might be cheaper than that of electricity, but the kgCO2 equivalency per GJ of natural gas is higher than that of electricity from BC Hydro. If there arise any financial constraints and CEC is to be operated prior to the heat pumps for load sharing, then the trade-off has to be made with GHG emissions which might contradict UBC’s goal of becoming carbon neutral.

  The energy costs/MWh of heat delivered was also calculated for both the models using the below formula.

$$\text{Energy costs/MWh of heat delivered (per year)} = \frac{\text{Total operational costs in \$}}{\text{Total heat output delivered in MWh}}$$

Once the energy costs/MWh of heat delivered was calculated for each year, the average of energy costs from 2024 till 2038 gives the average energy costs/MWh of heat delivered for the 15-year time period 2024-2038. This was calculated for both the base model and the versions of new model.

- **NPV:** The operational costs, the capital costs and the maintenance expenses assumed for the heat pumps, intake pump and piping were considered in calculating the NPV of new models. Whereas, while calculating the NPV of base model, only the operational costs were considered, as all the facilities in the base model were assumed to have negligible maintenance costs. The discount rate was 5.75% as given by UBC Energy & Water Services.

  Once the NPV of the base and the new models were calculated, the incremental NPV cost/MtCO2 saved in new model was calculated with the below formula.

$$\text{Incremental NPV cost/MtCO2} = \frac{\text{NPV of new model} - \text{NPV of base case}}{\text{Total GHG savings}}$$

  In other words, the value for Incremental NPV cost/MtCO2 represents the additional dollars that must be spent to avoid one MtCO2 in the new models compared with the base model.

- **Payback period:** The payback period for the new models was calculated as time required to have a return on investment (profits) by considering the financial savings achieved with the new models compared with the base case. The formula used is given below:

$$\text{Payback} = \frac{\text{First cost (Capital cost)}}{\text{Financial savings compared to base case}}$$

9.1.3. Comparison

Both the technical and financial analysis of the base case and the new models were tested under different carbon tax scenarios provided the GHG emissions in both models being constant under both tax scenarios. The two carbon tax scenarios considered were:

1. **Low carbon tax scenario:** Carbon tax of 50$/tCO2 from 2024 to 2050.

2. **High carbon tax scenario:** The carbon tax was considered to increase by 10$/tCO2 each year, starting from 2024 with a rate of 90$/tCO2 (current value being 40$/tCO2 in 2019 and assumed to increase by 10$/tCO2 each year till 2019 to 90$/tCO2) to reach the provincial government's expected target of 200$/tCO2 in 2035. After 2035, the price was assumed to be stable till 2050.

9.2. Stakeholder analysis

Three areas were identified where UBC might have to negotiate with certain parties or might have to satisfy the regulation requirements of specific governmental bodies in order to proceed with the sea water heat pump technology. They were:

1. Routing of piping from UBC to Wreck beach.
2. Sea water intake and discharge regulations.
3. Electricity requirements for intake pump at Wreck beach.

10. Results & Discussion

10.1. Results of technical analysis

For the purpose of this study, more emphasis was made on GHG emissions than the energy consumption with respect to technical analysis. The GHG emissions in both the base case and new models will remain constant under both carbon tax scenarios, as only costs will be affected if the tax changes, not the GHG emissions. The percentage reduction in GHG emissions that have been achieved with the new models compared with the base model is shown in Figure 12. It can be seen that the new models can achieve emissions reduction in the range of 32% to 83% depending upon the type of heat pump technology (heating capacity & COP) chosen. The heat pump model 1 in series mode achieved the maximum percentage of GHG reduction (83%), as it has a higher heating capacity (16 MW) compared to the other heat pumps considered for this study. It can also be noted that as time progresses the percentage reduction in GHG emissions declines. This is due to the fact that as GHG emissions in both the base and new models increase each year due to the growing heat demand of the campus, the annual GHG savings also increase (Figure 11). This increase in annual GHG savings each year and the increase in annual base case GHG emissions contribute to the decline in the percentage reduction of GHG emissions in successive years (Refer to the percentage reduction in GHG emissions formula).

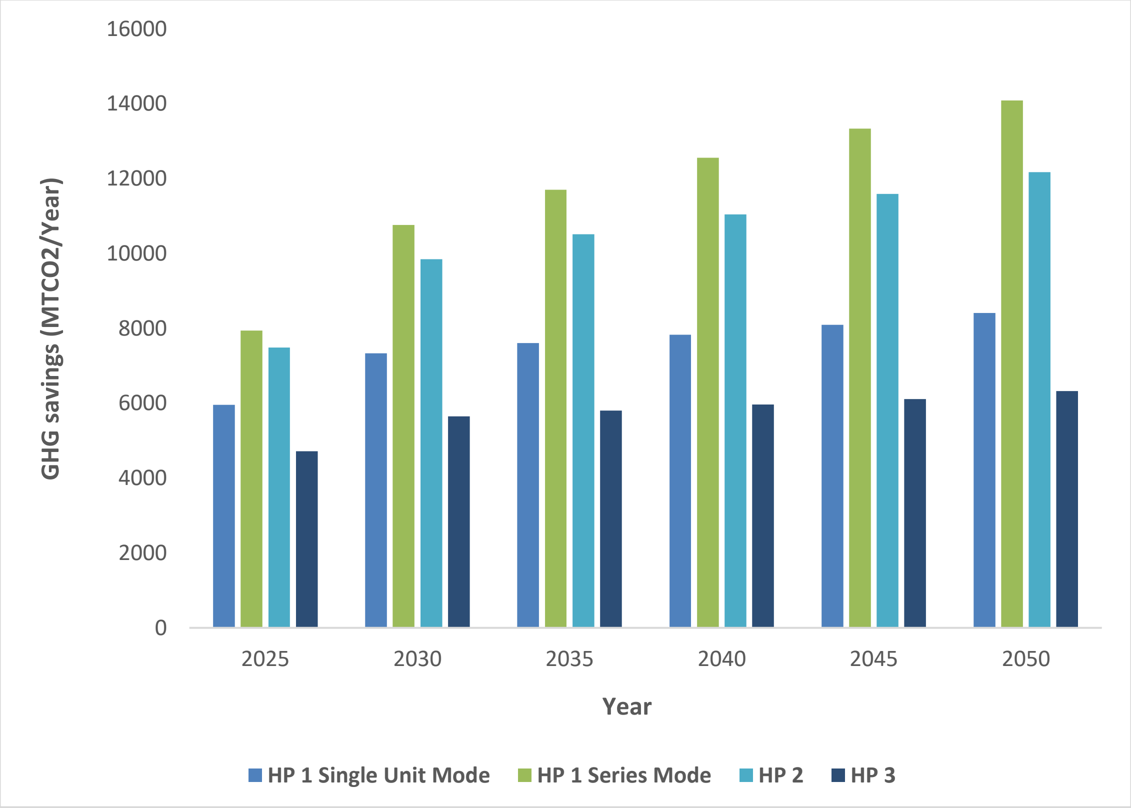

Figure 11: GHG savings with new models (MTCO2/year)

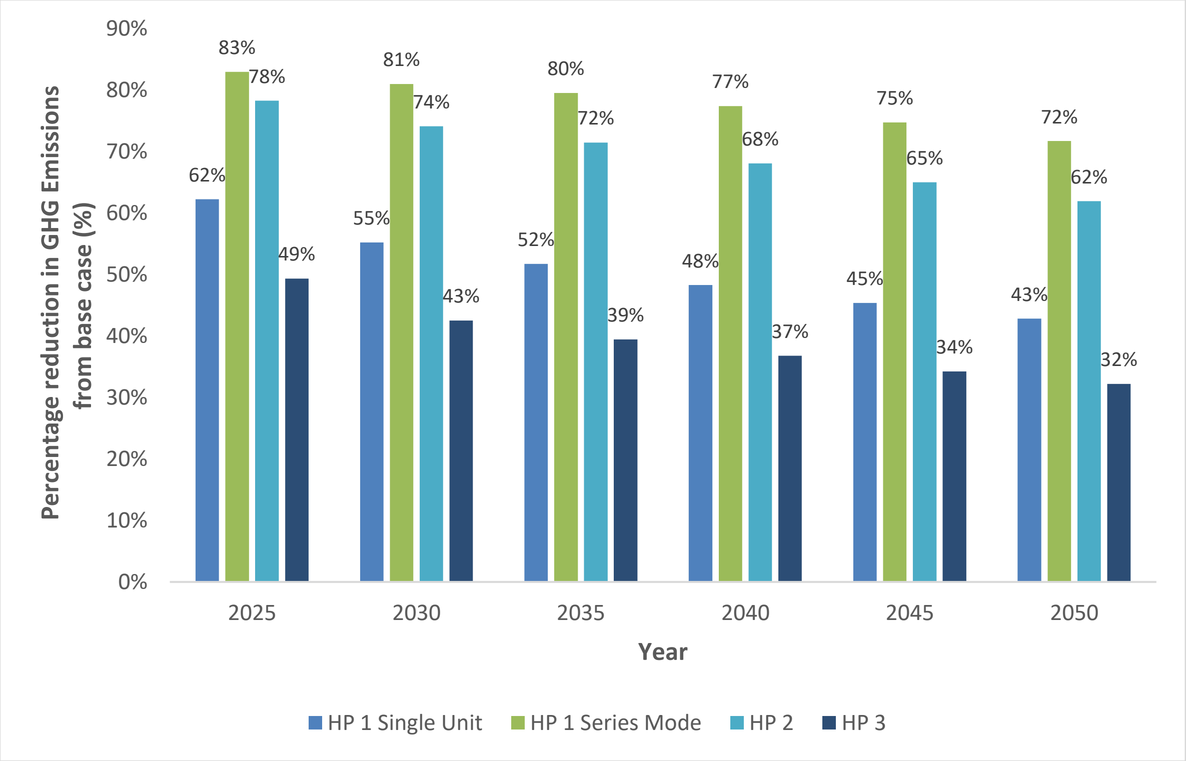

Figure 12: Percentage reduction in GHG emissions from base case

10.2. Results of financial analysis

10.2.1. Average energy costs/MWh of heat delivered

The average energy costs/MWh of heat delivered of both the base case and new models for the period 2024-2038 are plotted in the below chart (Figure 13). The average energy costs/MWh of heat delivered in new models were lower compared with that of the base model. The reason is that, in case of new models with sea water heat pump technologies, the amount of heat to be delivered by the sea water heat pumps (equivalent to a portion of heat that the sea water heat pump would replace in the base case served by natural gas) requires lesser energy consumption(electricity) than compared with the energy consumption (natural gas) for the same amount of heat to be delivered in the base case by natural gas. This is again due to the fact that the heat pumps perform better (considering COP & free thermal energy from sea water) compared to the natural gas boilers. If we consider the carbon tax scenarios, the average energy costs/MWh of heat delivered in high carbon tax scenario are higher than that of the low carbon tax scenario. This is because the increase in carbon tax increases the operational costs of natural gas consumption from that in the low carbon tax scenario.

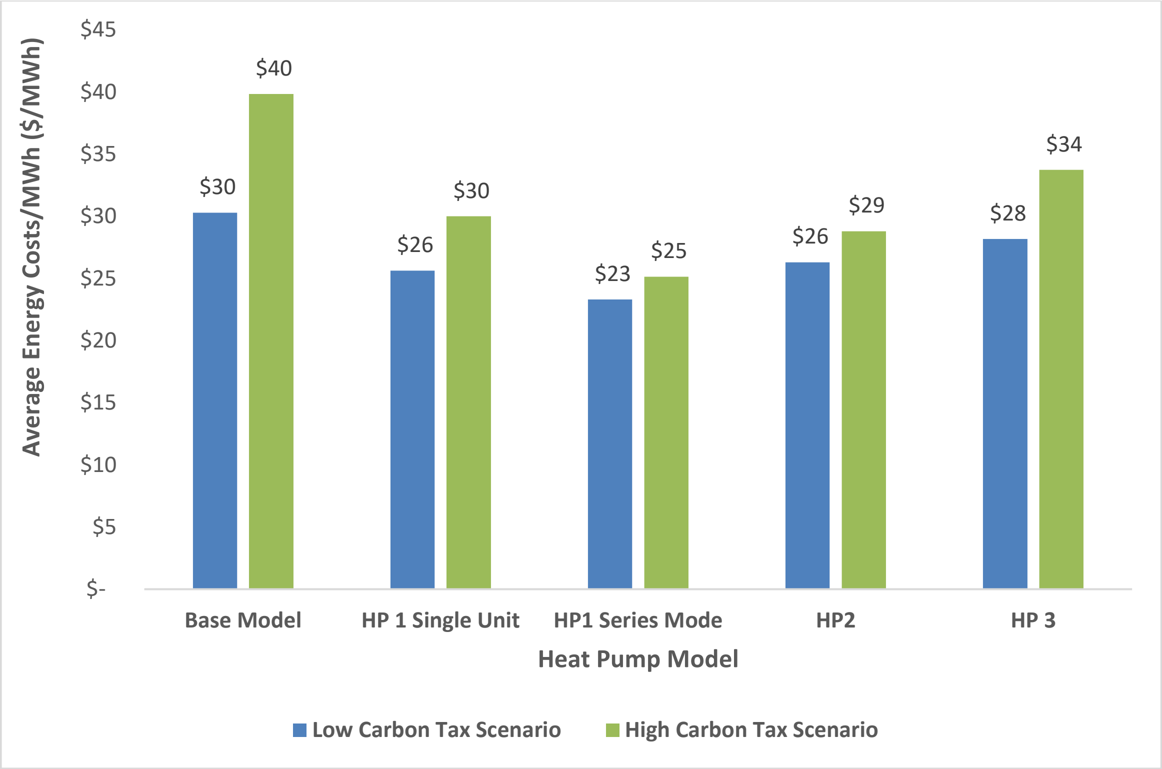

Figure 13: Average energy costs/MWh of heat delivered

10.2.2. Incremental NPV cost/MTCO2 saved

The incremental NPV cost/MTCO2 abated in the new models is studied for all the four heat pump technologies under both carbon tax scenarios. The results are plotted in the below graph (Figure 14). The incremental NPV cost declines in high carbon tax scenario compared with the low carbon tax scenario. The reason is that in the high carbon tax scenario, the NPV of base case increases drastically as the operational costs for natural gas consumption increase sharply from the low carbon tax scenario due to the rise in carbon tax. Due to this reason, the difference between the NPV of new model and NPV of base case reduces compared to that in the low carbon tax scenario, with the total amount of GHG emissions abated being constant (Refer the formula for Incremental NPV cost/MTCO2 saved). This is why the values are lower in the high carbon tax scenario. Moreover, the lower values represent that, to abate one MTCO2 during high carbon tax scenario, UBC could spend only half the amount of money that is actually required to abate one MTCO2 in low carbon tax scenario.

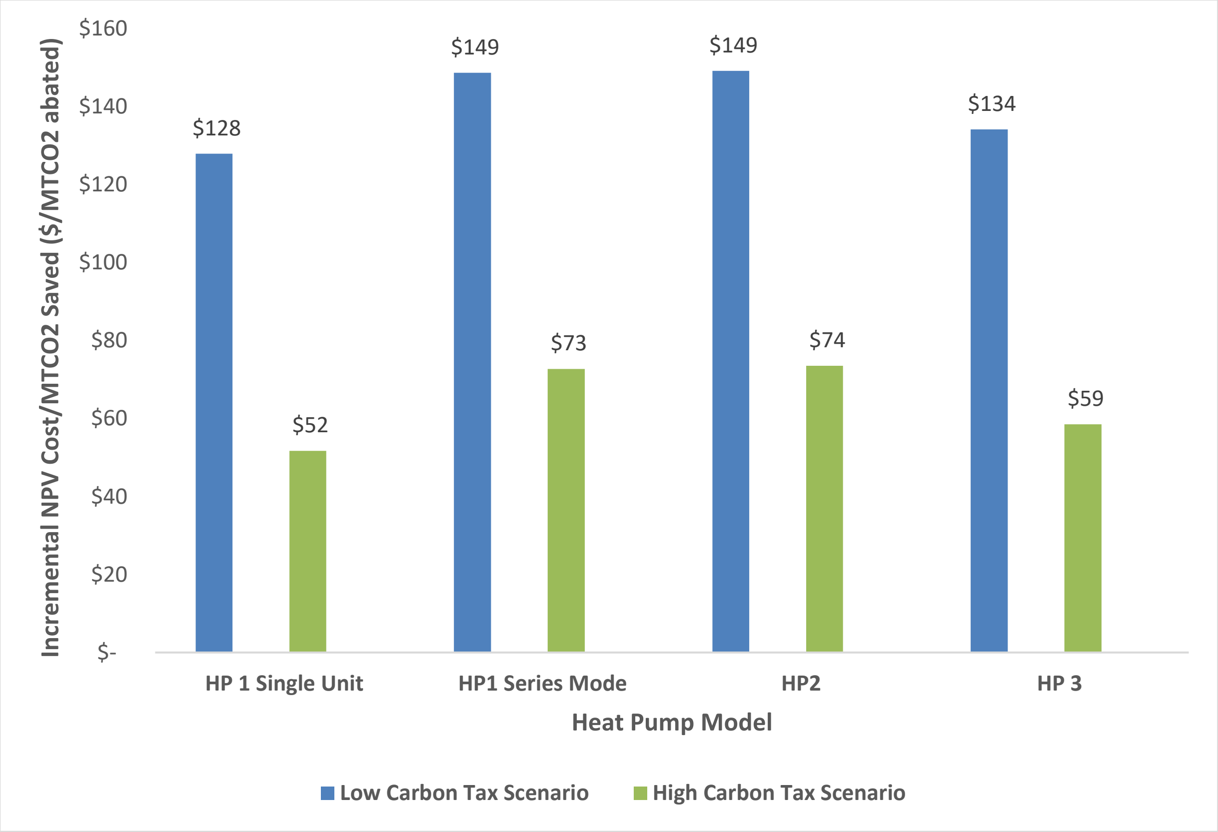

Figure 14: Incremental NPV cost/MTCO2 abated

10.2.3. Payback period

The payback period is calculated for all the four heat pump technologies (Figure 15). Under low carbon tax scenario, the payback period is very high in the range of 29 to 46 years as the annual financial savings achieved with the new models compared to the base models would be low in this case due to low carbon taxes (Refer to the payback period formula). On the other hand, under high carbon tax scenario, the payback period drops to the range of 13 to 15 years. The reason is that the annual financial savings would increase as the operational expenses in both the models increase with high carbon taxes (Refer to the payback period formula), thus making the payback period low.

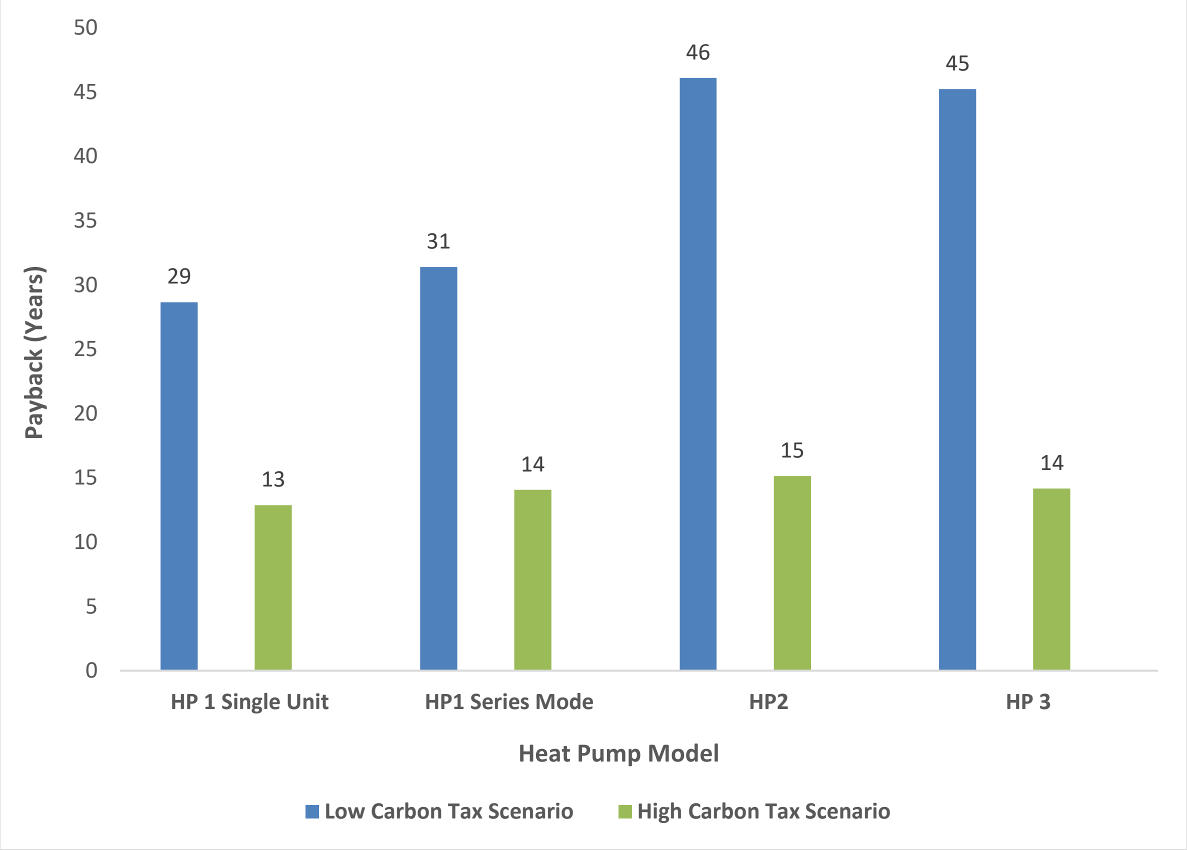

Figure 15: Payback period for the heat pump technologies

10.3. Results of stakeholder analysis

The major stakeholders for this project will be:

1. Metro Vancouver
2. Fisheries and Oceans Canada
3. BC Hydro

From the stakeholder analysis done, it is expected that there will be some significant challenges in negotiating a route with Metro Vancouver for the piping, and Fisheries & Oceans Canada for sea water intake and discharge. The water intake pump at Wreck beach will require additional transmission line which pulls BC Hydro into the picture.

11. Conclusion & Significance of project

All the sea water heat pump integrated DES models showed reduction in total GHG emissions from DES by the range of 32% up to 83% compared with the base case, depending on the model of heat pump chosen, irrespective of the tax scenario. However, the heat pumps showed longer payback periods in the range of 29 to 46 years in case of low carbon tax scenario. On the other hand, under high carbon tax scenario, the payback periods reduced to the range of 13 to 15 years. The average energy costs/MWh of heat delivered were also significantly reduced when compared to the base case, in both tax scenario. Moreover, the incremental NPV cost that has to be spent to avoid one MTCO2 in the new models compared with the base model, largely reduced during high carbon tax scenario.

Therefore, the results from the study show that the sea water heat pumps are highly capable of reducing UBC's GHG emissions from 2007 levels of 62000 tCO2 to the minimum levels possible by 2050 (to achieve carbon-neutrality goal) irrespective of the tax scenario considered. Though integrating sea water heat pumps into DES can be the best available solution to progress UBC towards its 2050 Climate Action Plan of carbon neutrality, the major drawback is the longer payback period which is due to the high capital investments. However, under high carbon tax scenario, the sea water heat pumps can perform well, both technically & financially, as a reasonable payback period can be achieved with significant reduction in GHG emissions & operational expenses. Therefore, under high carbon tax scenario, it is evident that integrating sea water heat pumps into DES can become financially viable and can reduce UBC's GHG emissions significantly by 2050 thus helping UBC in progressing towards its carbon neutrality goal.

12. Recommendations for future work

It was studied from the literature research that integrating sea water heat pumps to DES might tend to have some drawbacks such as the sea temperature changes, salinity and high energy consumption in case of low temperature difference between supply and return lines due to lower sea temperature conditions. Further research can be carried out on studying depth-wise sea water temperatures around UBC to position the intake pipe both from the shore and the sea surface accurately, and to capture more stable sea water temperatures. By this way, we can also eliminate the possibilities of freezing of saline water under lower temperatures by monitoring the sea temperature changes. Also, research can be done in locating the heat pump in campus other than Main Mall as it requires large space. The pressure and velocity gradients of the piping system can also be investigated. Even though UBC's electricity demand is being met by clean, renewable BC Hydro power and the sea water heat pumps are expected to be powered with the same, the economical aspect of increase in electricity consumption might be a major challenge to deal with. And, in case of lower temperature differences between the supply and return lines, the mass flow rate of water must be increased to prevent freezing which would increase the pump/compressor work thus resulting in increased electricity consumption. Future studies could consider this fact while calculating the energy consumption and related consumption costs of the heat pumps.

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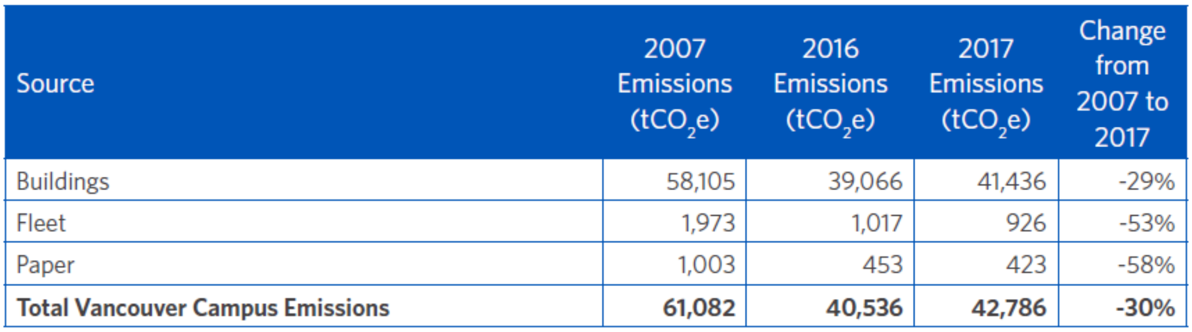
Appendix



Source	2007 Emissions (tCO_2e)	2016 Emissions (tCO_2e)	2017 Emissions (tCO_2e)	Change from 2007 to 2017
Buildings	58,105	39,066	41,436	-29%
Fleet	1,973	1,017	926	-53%
Paper	1,003	453	423	-58%
Total Vancouver Campus Emissions	**61,082**	**40,536**	**42,786**	**-30%**

GHG emission comparison by source 2007, 2016 & 2017 (UBC Sustainability Report, 2018)