Technology Options for Reducing UVic's District Energy System Greenhouse Gas Emissions

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Abstract

The University of Victoria has a natural gas powered district energy system (DES) that services heating loads in several buildings located around campus. The existing natural gas boilers are reaching their end of life and work has started to replace the existing boilers with higher efficiency units. The higher efficiency boilers will be housed in a newly constructed Energy Centre (EC) that will act as a centralized location to connect additional thermal energy to the DES.

UVic's long term goal is to reduce its overall greenhouse gas emissions. As of 2015, nearly 90% of all UVic emissions are associated with the use of natural gas to meet the energy demands of buildings across the campus; the natural gas powered DES is directly responsible for 68% of all natural gas related emissions [1]. The replacement of the boilers with higher efficiency units is the first major step for the University to meet its short term goal of a 20% reduction in carbon emissions from a 2007 baseline. In order to meet longer term emissions reductions targets, the University is hoping to offset natural gas consumption in the DES with some form of low or zero emissions energy. Some of the other goals of UVic for upgrading its DES network are to reduce operating expenses, and potentially improve UVic's academic/research/progressive credibility within the broader circle of University and government bodies.

This report summarizes the work of several previously commissioned reports in regards to energy generation on campus. Through the analysis in this report, the field size requirements for solar, geothermal, and seasonal thermal energy storage were identified and labeled upon maps to provide clarity as to where the facilities might be located and how much energy could potentially be supplied to the DES. The challenge of connecting low temperature sources of thermal energy to the high temperature DES was addressed through the identification of commercially available multi stage heat pumps capable of upgrading the temperature of the energy above that of the return temperature of the DES. Annual profiles of three combinations of geothermal, solar thermal and seasonal thermal storage were generated, and the resulting reductions in emissions were estimated. The best case scenario that used 20,000 m^2 of geothermal field, and 20,000 m^2 of solar thermal arrays in addition to seasonal thermal energy storage, was estimated to reduce GHG emissions to 38% of the baseline emissions associated with a strictly natural gas fired DES.

The viability of biomass was explored and refined based on the previously commissioned reports. These previous reports stated that urban wood residues were readily available to UVic, but current research found that not necessarily to be true. While urban wood residues are available, it would appear that they are mixed within existing MSW streams and are not easily extractable. It is not currently believed that the components of the MSW at the Hartland landfill are separated but further research might reveal this to be the case, which would mean that wood residue on its own could perhaps be used for a biomass system. Regardless of whether the wood residue can be separated or not, direct combustion is technically capable of supplying more energy than the future demand of the UVic DES requires. The limitation would be based upon where the facility is located on campus (truck access), what social license the campus is able to achieve in regards to a WTE facility, and what the detailed GHG accounting for a WTE facility would like. It is not clear how or if a WTE facility would reduce GHG emissions relative to the use of natural gas within the UVic DES. This uncertainty in emissions is tied to the biogenic component of the MSW. The biogenic component is the parts of the waste stream that are of non-fossil fuel origin and as such are ignored when accounting for GHG emissions according to BC Guidelines.

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1 Problem Introduction

The University of Victoria has a natural gas powered district energy system (DES) that services heating loads in several buildings located around campus. The existing natural gas boilers are reaching their end of life and work has started to replace the existing boilers with higher efficiency units. The new boileres will be housed in a newly constructed Energy Centre (EC) that will act as a centralized location to connect additional thermal energy to the DES.

UVic's long term goal is to reduce its overall greenhouse gas emissions across the campus. As of 2015, nearly 90% of all campus emissions are associated with the use of natural gas to meet the energy demands of buildings across campus; the natural gas powered DES is directly responsible for 68% of all natural gas related emissions on campus [1]. The replacement of the boilers with higher efficiency units is the first major step for the University to meet its short term goal of a 20% reduction in carbon emissions from a 2007 baseline. In order to meet longer term emissions reductions targets, the University is hoping to offset natural gas consumption in the DES with some form of low or zero emissions energy. Some of the other goals of UVic for upgrading its DES network are to reduce operating expenses, and potentially improve UVic's academic/research/progressive credibility within the broader circle of University and government bodies.

The purpose of this report is to determine which existing technologies are feasible for integration into the upgraded DES at UVic over the next 5-10 years. The technologies will be identified and investigated through a summary of existing UVic commissioned reports, a search of industry and academic sources, and some preliminary calculations assessing technical feasibility. This report also takes into consideration what UNBC/UBC/SFU are doing for their DES such that a novel solution can be implemented to leverage non-traditional funding sources to support a research/demonstration project.

This report begins with an overview of the existing district energy system in operation at UVic. The basic operating parameters of the DES are of importance in being able to determine which technologies are appropriate for further consideration, as well as determining which technologies are optimal. Next, a summary of the existing studies commissioned by UVic relating to energy generation or storage on campus are presented so that work is not repeated and so that insights can be leveraged to direct further work. After the preliminary knowledge is presented, the research into technology options appropriate for UVic is discussed. Several technologies receive a preliminary investigation to determine appropriate options to consider in more detail by the University for potential implementation.

1.1 System Parameters

The UVic DES services 32 buildings on campus and is supplied from a heating plant located in the Engineering Lab Wing (ELW) building as well as smaller heating plants at Clearihue (decommissioned), McKinnon, and Commons buildings. The predicted future annual thermal demand is summarized and compared to the current thermal demand in table 1 and is taken from the District Energy System Review Report (DESRR) [26].

The primary action items for the system upgrades are:

- All the existing boilers will be replaced with $3 \times 7.5MW$ (non-condensing) high efficiency boilers
- The new boiler plant will be constructed on parking lot 6, and connected to the DES (between the MacLaurin and Medical Sciences buildings)
- the upgrade will include distribution piping modifications, building Energy Transfer Stations (ETS) upgrades, and process load separation within several buildings

Table 1: DES current and future thermal demands predicted using UVic expected facilities growth [26]

Metric	**Current**	**Future**
Annual total energy demand [MWh_{th}]	29,000	41,500
Total peak power demand [kW_{th}]	18,700	24,600
Annual NG usage [GJ]	150,037	213,500

While energy conservation measures will reduce the existing demand placed on the DES, the large growth between current and future energy demand listed in table 1 comes from the potential connection of 5 to-be-constructed buildings and 4 currently unconnected existing buildings to the DES. This larger future DES, which accounts the growth of demand across campus, as well as the efficiency improvements recommended in the DESRR, is then used as the baseline for analytical assessment later in this report when determining the impacts of connecting other sources of energy generation to the DES.

2 Previous work

Over the past several years, UVic has commissioned a number of reports that investigate and characterize the feasibility of various energy systems for the UVic campus. This section covers some of the relevant findings from these reports in regards to recommended technologies, locations, or strategies for the district energy system at UVic. Five different studies are used to inform this report and are listed below in chronological order.

1. (2011) - University of Victoria Integrated Energy Master Plan (IEMP) [11]
2. (2012) - Resource recovery and use plan - business case [12]
3. (2014) - Biomass thermal energy plant feasibility study [13]
4. (2015) - University of Victoria sustainable site requirements study [27]
5. (2016) - District energy system review report [26]

2.1 Integrated Energy Master Plan

The IEMP offered information on the feasibility of a number of technology options for generating energy on the campus. This report will only focus on the options regarding thermal energy generation as B.C. has a very low carbon index for its electricity generation and the costs are relatively cheap when compared to most forms of distributed renewable electricity generation that might be contemplated on campus (not withstanding their visibility value, their electrical yield potential is limited).

The forms of thermal energy generation discussed in the IEMP were used as an entry point when researching available options for UVic to displace its natural gas consumption in the DES later in this report. The thermal energy generation options listed in the IEMP were:

- Sewage heat recovery
- Heat recovery from the Enterprise Data Centre (this option was not pursued during the latest UVic upgrades)

- Energy from solid organic wastes
- Geothermal energy (both near surface and boreholes)
- Biomass heating plant
- Solar thermal

According to the IEMP, of the options listed, only the enterprise data centre heat recovery, biomass heating plant, and solar thermal were recommended for further investigation. The other options were listed as “less appropriate” primarily due to perceived cost barriers. A ground source heat exchange system was connect to the newly built Centre for Athletics, Recreation and Special Abilities (CARSA), although this system and the building are not connected to the main UVic DES. Many quantitative assessments were performed and the data will be used for more in depth analysis of the options later in this project.

2.2 Resource recovery and use plan

The resource recovery and use plan was authored by the Capital Regional District (CRD) and details a number of options around the Greater Victoria region where thermal energy recovery from waste water may be possible. The option that is of interest to UVic is the East Coast Interceptor attenuation storage tank. The attenuation tank was originally planned to be completed in 2016 but was delayed due to timing constraints on receiving Federal and Provincial money; in 2014, the completion date was estimated to be the end of 2018. In a recent report, the size of the tank is reduced to 5000 m^3, less then the 12,000 m^3 originally proposed, and still less then the updated 9000 m^3 listed in the Resource Recovery and use plan [6].

The resource recovery plan details an attenuation tank with a volume of 9000 m^3 that is to be installed near UVic and that the construction of the tank presents an opportunity to integrate heat recovery equipment at a decreased capital cost since the tank is being installed regardless of interest from UVic. The resource recovery plan states that due to the high operating temperature of the UVic heating loop, it may prove to be too difficult to connect a heat recovery system from the attenuation tank to the UVic DES as they state that heat pumps have a hard time supplying high temperature heat; this concern is addressed in later analysis in section 3.

2.3 Biomass thermal energy plant feasibility study

The biomass thermal energy plant feasibility study investigated the suitability of a biomass plant on campus to supply hot water to the DES. While the proposed biomass thermal energy plant in the study was claimed to be financially feasible, it’s primary restriction was that the study was premised on a third party owning and operating the biomass plant and that UVic would simply pay for hot water from the third party operator. Additionally, since the facility was planned to be dual fired, in that it could run on both natural gas or biomass, it was not clear that if the third party operators failed to secure biomass they would simply revert to using natural gas and thus defeat the purpose of the facilities existence to begin with.

Even though the plan for a third party operator of a biomass plant was rejected by UVic, the option for UVic to own and operate a biomass plant is still under consideration. Some of the results that are taken from the feasibility study and used here are the assessment of biomass resources available to be incinerated on campus. According to the previous assessment performed in the feasibility study, there are sufficient accessible biomass resources to be used on campus to meet 87% of the current DES heating load [13]. The challenges then come in better understanding if the sources of biomass are actually carbon neutral, as the legitimacy of the biomass as a source of carbon neutral energy has come under question according to a petition delivered to UVic encourages it to consider other options. As well, further information is required as to what particular biomass technology is to be used or if perhaps an anaerobic digester is a valid option. Finally, there is concern about the amount of traffic required to deliver the biomass fuel, cited as an average of 8 deliveries a week with a peak of 17 [13]. Further details from the feasibility study are drawn in relevant sections later in this report.

2.4 University of Victoria sustainable site requirement study

The Sustainable Site Requirements Study investigated which geographical locations on campus are technically feasible for various energy generation technologies. The only analysis performed as to the technical feasibility of various thermal generation technologies was in relation to estimating how much any given fuel supply can displace natural gas on the DES. The thermal energy generation technologies considered in the site requirements study were:

- biomass,
- municipal solid waste combustion,
- anaerobic digestion,
- campus waste energy recovery, and
- geo-exchange.

The Sustainable Sites Requirements Study concluded that Biomass as an option requires further research to acquire a reliable fuel supply. Anaerobic digestion is suggested as an option with the CRD stated as having enough waste to supply 43% of UVic's energy demand. 4 locations around campus are shown in the Sustainable Sites Requirements Study in Appendix A that could potentially house a biomass energy plant able to supply up to 67% of UVic's annual thermal energy demands and that anything larger would require further research. The geo-exchange location suggested by the Sustainable Sites Requirements Study is the same as that listed later in this report in fig. 5.

2.5 District energy system review report

The DES review report covers in depth the operating parameters of the existing DES as well as outlining two proposed DES upgrade schemes: a partial optimization and a complete optimization. Both of the optimization options are focused on altering the thermal loads experienced by the DES, as well as upgrading the energy transfer stations in each of the buildings connected to the DES. The report did not focus on thermal energy generation technologies. At this point in time, UVic has decided to proceed with the partial optimization scheme which will significantly increase the ΔT for the DES loop as well as decrease overall energy use in the DES. The ΔT under various scenarios is outlined in fig. 1 reproduced from the District Energy System Review Report. The primary feature of the partial optimization is the building of a new Energy Centre in parking lot 6 which will house the 3 new natural gas fired boilers mentioned previously (3x7.5 MW non-condensing high efficiency boilers).

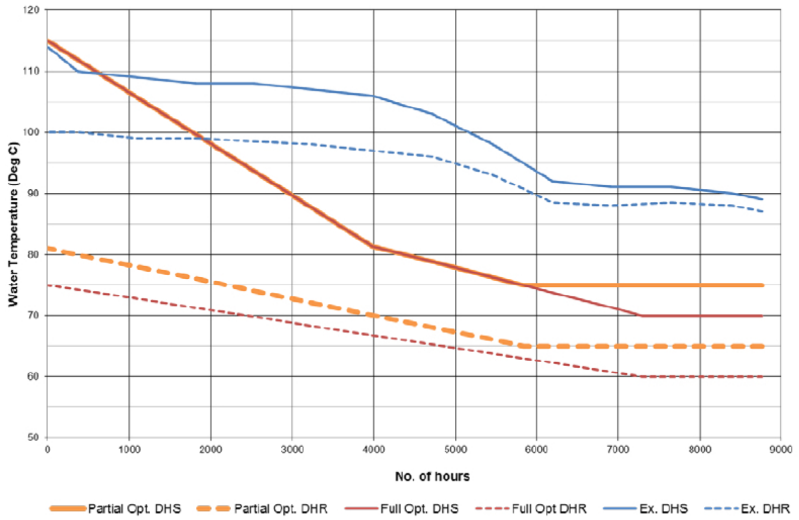

Figure 1: Temperature duration curves for the DES showing ΔT for various scenarios [26]

3 Technology Review

This section focuses on which technologies are technically capable of supplying the DES with thermal energy *without* an in-depth look at whether the technology is financially feasible. The primary limitations placed on any technology are:

- Is the technology capable of supplying thermal energy with a high enough temperature so that it can function with the DES heating loop operational temperatures?
- Is the fuel source required by the technology available to be used on campus?
- Is there sufficient land available on campus to make use of the technology?
- Is the technology available now or within the next 5 years for commercial use?

Working within the framework of those limitations, the technology options are categorized into either high grade heat or low grade heat; this choice is made to connect the similarities in technical requirement between various sources of energy in regards to connecting to the high temperature DES at UVic. Many of these options have already been assessed to some extent in the previous studies commisioned by UVic and described in section 2.

3.1 Low Grade Heat

The technologies categorized under low grade heat all require use of multi-stage heat pumps in order to be capable of supplying thermal energy to the DES. Since many sources of low grade thermal energy have already been assessed in the previous reports listed in section 2, one of the primary remaining hurdles facing these technologies is identifying multi-stage heat pumps with the technical capability to connect the thermal energy source to the DES.

Currently, the district Energy Transfer System (ETS) for each building consists of either a single shell and tube heat exchanger, or plate-type heat exchangers, with primary side (DES) and secondary side (building hydronic) water loops. The existing DES heating loop operates at high temperatures with minimal change throughout the year and low ΔT in summer months. It is assumed that with the boiler replacement and buildings ETS upgrade project, DES supply temperature could be reduced, especially during summer and shoulder seasons resulting in a larger change in return temperatures (larger ΔT).

Moreover, by supplying five small process loads separately (approximately 1.5% of the total annual energy demand, located in several different buildings supplied by the DES), the hot water system return temperature may be able to reach as low as 60^0C as shown in fig. 1 [26]. Lowering the return temperatures and separating the process loads will allow for easier integration of low-grade alternate energy sources for UVIC's DES system as well as system efficiency improvements.

3.1.1 Mutli-Stage Heat Pumps

Multi-stage heat pumps exist to upgrade low temperature thermal energy to to high temperature. Once the DES is upgraded using the proposed partial optimization steps, it is expected that the return temperature of the system should be approximately 65^0C with the exception of peak loads [26]. High output temperatures of around 70^0C to 80^0C from multi-stage heat pumps have been achieved at a district heating network in Marstal, Denmark [2]. The heat pump used in Marstal uses a 30^0 DES return water temperature and a thermal energy source temperature of approximately 23^0C to achieve its high temperature output. The Marstal heat pump uses carbon dioxide as its refrigerant and has 16 compressors producing 1.5MW of thermal power [2].

Several commercial manufacturers list high temperature heat pumps in their respective catalogs that have output temperatures in the range of the expected return temperature of the UVic DES after partial optimization. Bosch, NordicGHP, and others currently sell this technology, most often with Carbon Dioxide as the working refrigerant. The Bosch system in particular lists being able to capture waste energy of up to 40^0C and is able to upgrade this waste heat to temperatures of 110^0C [5].

The primary challenge with integrating heat pumps with low grade heat at UVic is getting a more explicit description of the technical limitations of each manufacturers technology, and determining the added cost of coupling the multi-stage heat pumps with the sources of low grade heat. In previously commissioned UVic studies, the sources of thermal energy listed in this report, were considered not-feasible for connection to the high temperature DES. The Site requirements study, Section 2.4, simply states that low grade heat can not be connected to the high temperature DES without giving any logical reasoning; no mention of difficulties in engineering, or financial constraints, simply that the two can not be connected. As was referenced from the Danish DES example [2], low grade thermal sources can and have been successfully connected to high temperature DES.

3.1.2 Geothermal

Geothermal energy is an abundant source of low-grade heat that can be accessed almost anywhere sufficient land area is available. For use at UVic, geothermal energy would require a multi-stage heat pump in order to upgrade the temperature to a point in which it can be adequately fed into the DES. As was mentioned previously, the new CARSA facility has its own independent low temperature heating system and the integration of shallow field geothermal was relatively straight forward.

The IEMP lists ground source heat exchange as unsuitable for connection to the DES due to it being too low in temperature (15-20^0C) compared to the UVic DES operating temperatures (see fig. 1) but states that geothermal as a source of energy is technically capable of displacing large portions of the thermal base load of the UVic DES for both heating and cooling. The primary concern, according to the IEMP, is that geothermal energy on campus would not be able to achieve sufficiently high temperatures to feed into the DES, and that the space required for a geothermal borehole field restricts its applicability at UVic. The IEMP states that approximately 20,000 m^2 is needed to supply 67% of UVic's domestic heating needs but that this can save approximately $ 90,000 CAD per year as calculated in 2011; these calculations assumed direct utilization of the low-grade heat. Updated numbers that consider upgrading the heat to connect directly to the DES will likely give different financial savings.

From the initial overview it would appear that geothermal can be compatible with the high temperature DES after the partial optimization lowers the return temperatures, but much like the recommendation outlined for further analysis of the multi-stage heat pumps, the geothermal option requires further clarification as to what temperatures a geothermal system would output based on the technology used. The relationship between land area and energy output also needs further clarification.

3.1.3 Waste heat recovery

Waste heat recovery for UVic can be found either from the Enterprise Data Centre (EDC) on campus or from nearby Municipal waste water lines. Both options would be able to supply low grade heat to the DES. According to the IEMP, the enterprise data centre on campus has the potential to supply 6500 MWh of thermal energy, which is equivalent to approximately 22% of current thermal energy demand placed on the DES (according to table 1). A major factor limiting the connection of the waste heat from the enterprise data centre to the high temperature DES is the geographical distance of the enterprise data centre and the existing DES; capital costs to connect the enterprise data centre to the DES could be quite large as the shortest distance between the two is approximately 365 metres and that route runs into multiple buildings and crosses a major roadway. According to the Sustainable Sites Requirement Study, trenched pipework costs of $3,500 would make the connection cost at least 1.2 million CAD$ in 2015 not accounting for additional connections or dealing within rerouting due to existing buildings [27].

The waste water lines as a source of thermal energy are appealing from the standpoint of innovative technology and would showcase UVic taking a novel approach to its DES but the main challenges listed in previous reports are that the capital costs are too high and would require separate low temperature heating loops [11]. While multi-stage heat pumps would allow for direct connection to the high temperature DES, there is nothing to change the prohibitive capital costs of the connection of the geographically distant waste water source.

Another CRD report, completed by Stantec Consulting [24], on waste water heat recovery was found and it analysed the potential opportunities for heat recovery from the Core Area Wastewater Treatment Project. Based on the provided data, the 2009 average daily sewage flow at the proposed Saanich East/North Oak Bay (SENOB) sewage treatment plant was 9.6 ML/d, which is projected to increase to 16.6 ML/day for 2030 and the estimated heat extractable from the projected flow could be 163,000 GJ [17]. This wasted thermal energy is approximately 66% of future natural gas energy demand of the partially optimized DES (table 1). The SENOB still faces the same challenge of geographic distance that the other wastewater energy source faced.

Summarizing this information, it would appear that municipal waste water has a lot of thermal energy available for capture but the challenges lay in the capital cost of the infrastructure required. In previous studies, only the enterprise data centre waste heat recovery was recommended for further consideration due to the other options having a combination of too large of a financial cost and too low of a $C0_2$ displacement. The updated information in this section tends to carry those same ideas through in that the waste water recovery option, while fitting into the category of technologically innovative for a University DES, would require too large of costs and would potentially push the per-unit energy costs spent on the DES above what is currently spent [11].

3.1.4 Thermal Energy storage

Borehole Thermal Energy Storage (BTES) is a technological pairing of boreholes for energy storage and solar thermal collectors. Excess solar thermal energy is collected in the summer and the heat is stored in the BTES field to be accessed during the winter. A horizontal view of a typical borehole and an aerial view of a borehole field is shown in fig. 2 and fig. 3.

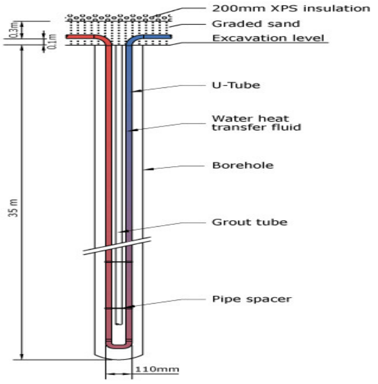

Figure 2: Side view of a typical borehole [21].

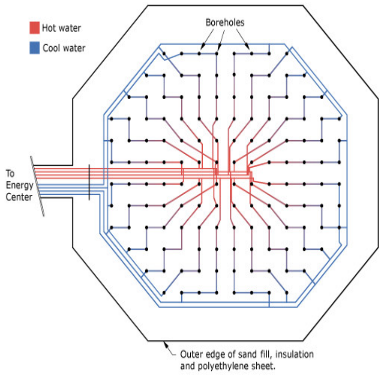

Figure 3: Aerial view of a typical borehole field [21]

An existing BTES project in Alberta was constructed in 2007 and has been operating successfully since then by supplying approximately 90% of annual space heating demands to a centralized residential development [21]. This project stores the excess solar thermal energy in 144 boreholes, that are 155mm in diameter, with a depth of 35m, separated by 2.5m that occupy about 34,000m^3 of earth [21]. The solar collectors have a total area of 2293 m^2. The Alberta system, as of 2014, delivered 1372 GJ of thermal energy to its local district heating loop with a storage efficiency of approximately 55% (they are able to take out 55% of the thermal energy they put in) [7]. The total project cost was CAN$14 million but this included the 52 houses as well as the energy centre [7]. A view of the BTES field under construction is shown in fig. 4.

Its important to note that the Alberta system doesn't employ heat pumps, but rather uses a system of buffer tanks and direct glycol/water pumping to interface the borehole storage to heat exchangers in each house. The ground temperature in the borehole area, when fully charged, is consistently around 50 ^{0}C [21]. While 50 ^{0}C is not high enough on its own to interface to the UVic DES, it is still a significant boost over typical ground temperatures of 10-15 ^{0}C and provides the opportunity for further investigation as to the limit of this type of system.

The success of this option for UVic would depend on whether UVic has suitable space for installing a borehole field. Solar thermal collection during summer is the most common pairing for seasonal thermal energy storage as most of the excess thermal energy captured during the summer months can be stored and reused during the winter months.

The IEMP investigated solar thermal energy as a means to meet UVic's demand for conventional hot water for buildings on campus but showed that the solar thermal generation profile was the inverse of some of the demand profiles [11]. When solar thermal collectors are paired with seasonal thermal energy storage, the excess energy produced by the solar thermal collector is then stored for later use thus minimizing any of the annualized temporal discrepancies between supply and demand

Figure 4: A view of the BTES field in the Alberta solar thermal storage project [21]

of thermal energy. By pairing solar thermal collectors, thermal energy storage, and mult-stage heat pumps, its possible that much of the UVic DES thermal demand could be met.

3.2 High grade heat

Just like technology options for low grade thermal energy, most of the technologies for high grade thermal energy generation have already received differing levels of assessment in previous reports commissioned by UVic. This report will elaborate on those studies and continue to outline how each given technology is or is not technically feasible for supplying thermal energy to the UVic DES. The high grade heat generation technologies assessed in this report are gasification and combustion of Biomass and anaerobic digestion of organic wastes. Each technology option relies on securing a reliable fuel source; anaerobic digestion technology uses organic waste comprised of proteins, fats and sugar, where as biomass typically uses wood residuals from industrial or residential processes.

3.2.1 Biomass

The first obstacle to investigate when it comes to checking the technical feasibility of biomass energy production is a reliable fuel supply. In the Biomass Feasibility Study, several sources of biomass feedstock were considered [13]:

- urban wood residuals from greater Victoria,

- Industrial wood residuals from the Cowichan valley,
- roadside wood residuals from Vancouver Island, and
- urban wood residuals from greater Vancouver.

From these waste sources, the biomass energy can be produced using either gasification, pyrolysis, or direct combustion. Gasification and pyrolysis mostly differ in the temperature used; both use high temperatures and restricted oxygen flow to convert the biomass to syngas. Pyrolysis leaves behind a carbon-char and ash, where as gasification uses higher temperatures to convert the carbon-char into further syngas leaving only ash. The syngas is then used as a fuel to create thermal energy for the DES. Direct combustion burns the biomass at lower temperatures with air to then heat a working fluid for transfer to the DES. Direct combustion is cheaper but has more airborne emissions, where as gasification is more costly to build and operate but typically has less airborne emissions as most of the waste is in the form of ash.

Of the previously mentioned fuel sources, the recommendation from the Biomass Feasibility Study is that the urban wood residuals from greater Victoria represent the most reliable and cost effective solution for a biomass fuel supply [13]. The Biomass Feasibility study states that the urban wood residuals from greater Victoria can supply approximately 31,000 MW_{th} (74% of future DES Demand) [13]. There is conflicting information between the Biomass Feasibility Study and the IEMP, the former states that 31,000 MW_{th} would require a maximum of 17 truck deliveries per week, the latter report states that supplying 36,000 MW_{th} (86% of future DES demand) of thermal energy from biomass would require a maximum of 30 truck deliveries per week during peak winter demands. Variations in fuel volume are likely due to different assumed moisture contents in the biomass, and thus extra weight/volume in the fuel. Regardless of the correct assessment of delivery requirements, both of these numbers represent a very significant potential increase in heavy truck traffic to UVic and must be considered when locating any potential biomass facility on campus. The storage of tens of tonnes of biomass must also be considered; the IEMP stated that there is space on campus for a biomass plant that contained sufficient storage to supply 24 hours of peak winter demand and stated that anything.

From most of the previous reports that assess biomass as an energy generation option for UVic, it is considered highly feasible with the understanding that further work is required to identify and secure a fuel supply, and to identify which technology is optimal for use with the DES. What was not addressed in the previous reports is the uncertainty surrounding the GHG emissions associated with Harvest Wood Products (HWP) as a feedstock for energy production. There is general concern that when combusting HWP as opposed to sequestering the GHG emissions through recycling or interment in a landfill, that the emissions must be accounted for. Current practices regarding HWP GHG emissions from biomass systems is to ignore them and consider the process to be carbon neutral. If HWP are to be used at UVic to generate thermal energy, then a more in-depth investigation as to the proper accounting method for GHG emissions should be undertaken.

3.2.2 Anaerobic Waste

The Sustainable Sites Requirements Study performed an assessment estimating how much organic waste is required to meet portions of UVic's current thermal energy demands; this table has been reproduced in table 2.

The Sustainable Sites Requirements Study estimates that UVic only generates 480 tonnes of organic food waste per year which is insufficient to supply a significant portion of the demanded thermal energy as seen in table 2 where as the Capital Regional District (CRD) generates 48,000

Table 2: Estimate of organic waste required to displace a stated share of thermal energy demand of UVic [27].

% of UVic annual heating demand displaced	Organic waste required (Tonnes)
43 %	48,000
50%	56,000
100%	112,000

tonnes of organic waste per year [27]. If a proper fuel stream can be identified than Anaerobic digestion has the potential to be a commercially viable technology for generating thermal energy on campus. Further research is required to determine the current state of commercial viability of anaerobic digestion systems.

4 Part II

This section contains the secondary set of analyses that improves upon the findings of previously completed reports to determine several quantitative measures for each of the technologies moving forward. The environmental performance is to be assessed to determine what GHG emission savings are possible when displacing natural gas. The thermodynamic performance of the various technologies is assessed to determine how much energy can be supplied in relation to available resources (land or fuel). Economic performance will be assessed by summarizing previously completed projects to relate energy production to capital and operating expenditure where data is available. All of the analyses in this section use the future thermal demands of the UVic DES outlined in table 1 as that is assumed to be the point in time at which any of these technologies would be integrated into the UVic DES.

4.1 Multi-Stage Heat Pumps

Several multi-stage heatpumps have been identified as capable of upgrading low grade heat to temperatures sufficient to supply thermal energy to the high temperature DES. The sufficiency was assessed by finding heat pumps capable of providing a Leaving Water Temperature (LWT) higher than the return temperature of the UVic DES. The other constraint placed on the heat pumps is the range of Entering Water Temperature (EWT) that the heat pump can operate with; the EWT, in the case of operating with a geothermal field can be closely approximated by the temperature of the geothermal field. The difference between LWT and EWT is one of the primary factors that affects the COP of each heat pump. Table 3 summarizes the performance characteristics of several commercial multi-stage heat pumps.

Table 3: Multi stage heat pump performance data

	Nordic WC-80-H	Multistack MS070AN	Sunstor4	SR Neatpump
Heating Capacity [kW]	27	85	1,500	12,000
Input Energy [kW]	11.9	39	454	4,000
COPh	2.27	2.2	3.4	3
ELT [C]	10	12	27	10
LWT [C]	71.1	79.5	75	90
Flow [L/s]	1.07	N/A	24	191

The data in table 3 allows for further analysis when coupled with either geothermal energy sources, or seasonal thermal energy storage. The output temperature of each heat pump was compared with the temperature duration curve of fig. 1 to determine how much time per year the low grade heat source was able to displace natural gas in the DES. From this qualitative comparison, the Neatpump is, from a technical standpoint, the best candidate to transfer low grade thermal energy into the DES network as the Neatpump output temperature is the highest; the higher the output temperature of the heat pump, the smaller a heat exchanger can be when connected between the heat pump and the DES. Additionally, it is assumed that the energy supplied to the DES through a multi stage heat pump is connected before the existing natural gas boiler further upgrades the temperature. This implies that during the winter months, the low grade energy source will not completely displace the natural gas usage as the output temperature required by the DES will be above that able to be achieved through the use of the high temperature heat pump.

Cost information for commercial heat pumps was more difficult to obtain. A brochure from the Star Refrigeration (SR) Neatpump website states a district energy heat pump cost of CAD$660 per kW of installed capacity with a utilization of 5000 hours per year [23]. Analysis using the Neatpump was performed in section 4.2.

4.2 Geothermal and Seasonal Thermal Energy Storage

The purpose of this section is to calculate how much natural gas consumption can be displaced through a combination of geothermal energy, high temperature heat pumps, and solar thermal collectors. Three different scenarios were investigated: the first scenario uses only geothermal energy connected to the upgraded DES, the second is of a rooftop solar thermal network and a geothermal field, and the third is a solar thermal network of sufficient size to allow for seasonal storage in addition to a geothermal field. The geothermal analysis in this section should only be considered an educated estimate as the soil and rock conditions of the proposed geothermal field are major factors in determining drilling costs and available geothermal energy and are currently unknown for locations around UVic.

Figure 5 illustrates representative and candidate land areas for the system components used in the following scenarios. Figure 6 shows an area near the new DES plant that could be used in addition to the scenarios, or in place of Parking lot A.

4.2.1 Scenario 1 - Geothermal Only

The first scenario represents a fairly safe approach to renewable energy generation on campus. Geothermal energy has been used extensively across North America for both heating and cooling loads and is technologically mature. The challenge for UVic comes in the form of the relatively novel approach of using geothermal energy to feed into a high temperature DES using a multi-stage heat pump. This novelty may present some financial uncertainty when pricing out a complete system installation but it also provides recognition to UVic as a thought leader in taking the path less traveled for its district energy system (when compared to the frequency at which other Academic institutions use biomass to feed district energy networks).

For a strictly geothermal system the configuration would consist of the geothermal field shown in fig. 5 feeding energy into a multi-stage heat pump. The heat pump would in turn be connected to the DES through a heat exchanger. Of the three scenarios, this configuration would be the simplest.

4.2.2 Scenario 2 - Geothermal and Distributed Solar Thermal

Scenario 2 combines the proven capability of geothermal with distributed solar thermal collection to almost entirely meet the summer demand. This configuration has the potential to allow for a complete shut down of the natural gas boilers in the summer while still meeting all of the demand of the future DES. The detailed configuration of scenario 2 would require more research to accurately optimize the sizing of the solar thermal array and the geothermal field. As for the physical configuration, the distributed solar thermal array could either be connected directly to the DES in each rooftop location or be fed back to the high temperature heat pump for a boost in temperature before exchanging energy with the DES. The nature of the connection between the solar thermal loop and the DES loop depends on the operating temperatures of the solar thermal system; evacuated solar thermal systems can operate at high temperatures of 70 C^0 to 90C^0 but the efficiency of the collectors decreases [18]. At the detailed design stage a decision would have to be made in regards to the operating temperature of the solar collectors as well as the nature of the connection to the DES. Much like scenario 1, scenario 2 has much to offer UVic in the realm of novelty in regards to district heating technologies.

4.2.3 Scenario 3 - Geothermal and Seasonal thermal energy storage

The final scenario consists of 20,000 m^2 of geothermal field below ground and 20,000 m^2 of evacuated tube solar thermal array above ground in the same location. The proximity of the two systems to each other was planned so that the excess production of the solar array can be stored in both a short term buffer tank and in the ground of the geothermal system. Again, the exact configuration of the system would depend upon detailed optimization of both system sizing and expected operation but typically the types of seasonal thermal energy storage systems use a short term storage tank as well as a geothermal field for longer term storage. Whether the solar thermal output requires thermal upgrading from the high temperature heat pump depends on the designed operating temperature of the solar array; it is possible that a solar array can output temperatures of 100 C^0 [29].

4.2.4 Scenario Analysis

Two different references are used to determine an estimate of the required area per kilowatt of power supplied for a geothermal borehole field listed in table 4. The first source was an ASHRAE supplied spreadsheet for determining geothermal field size based on hourly, monthly, and yearly power demands placed upon a geothermal field before a heatpump upgrades the quality of the heat. The power demands were taken from UVic's natural gas utiliy data for the year 2014 and then scaled down to a size that was within the limits of the ASHRAE spreadsheet; the ASHRAE spreadsheet was constrained based on the number of boreholes it could allow in the calculation due to the availability of validation data the original authors had access to.

The other source of geothermal field power density comes from the IEMP. There was some minor confusion as to the nature of the data given in that report. The peak load was given as 4000 kW but it was not clear if that was the campus thermal base load or the peak load placed on the geothermal field; both results are shown in table 4.

Seeing as the ASHRAE spreadsheet methodology was explicitly given and the result was relatively close and conservative when compared to those from the IEMP, the ASHRAE results were used to determine the energy density of a hypothetical geothermal field at UVic. There were significant assumptions associated with this analysis: without test bores performed at any proposed site for the geothermal field, the exact thermal properties of the soil were unknown and while estimates of the power a given field can supply were made using industry recommendations, the ability of the

Table 4: Power supplied per unit area for vertical geothermal borehole fields

Source	**Value [kW/m^2]**
IEMP field load	0.2
IEMP base load	0.15
ASHRAE Spreadsheet	0.12

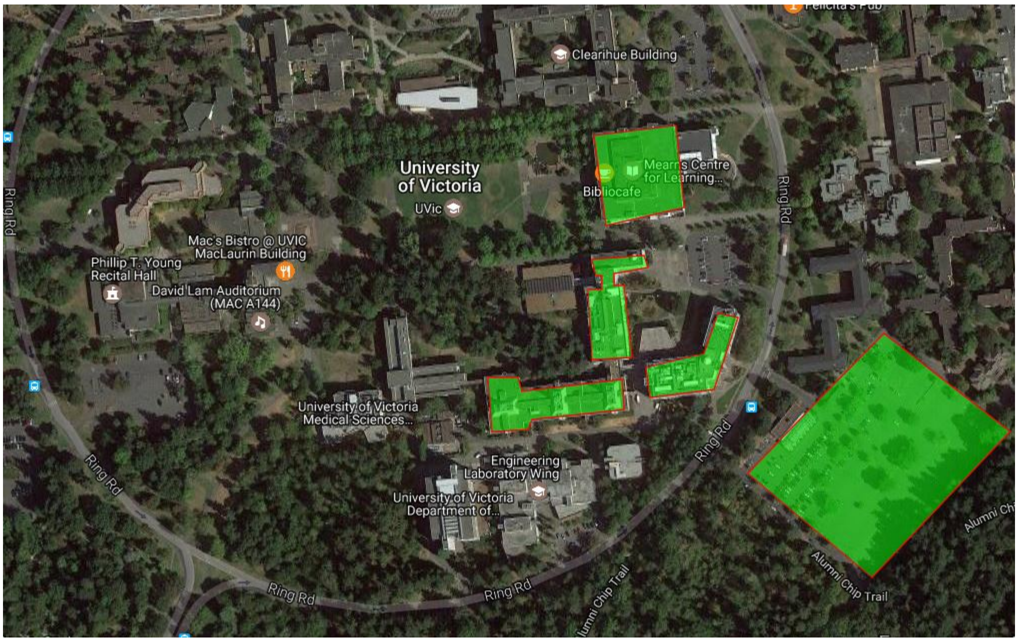

Figure 5: Lower right area represents geothermal field size required to output approximately 2600 kW before connection to a heatpump (20,000m^2), additional rooftop areas represent solar thermal collector areas (10,000 m^2)

soil to provide consistent annual energy was assumed only based on the observed behaviour of other projects not located at UVic. The area required to supply a peak geothermal power of 2600 kW according to the ASHRAE spreadsheet is shown below in fig. 5.

The geothermal field performance parameters were then combined with the multi-stage heatpump parameters to estimate how much energy could be supplied to the UVic DES. The references used for geothermal borefields ([15],[22]) imply that the average allowable utilization at the maximum rated power of the borefield is approximately half of the year, or alternately, the geothermal field can continuously supply half the peak power for the entire year. The other limiting factor on how much energy can effectively be transferred to the DES is the temperature difference between the heat pump EWT (90^{0}C) and the DES return water temperature (see fig. 1). Since detailed heat exchanger design is outside the scope of this report, it was assumed that a large enough heat exchanger is used between the heatpump and the DES such that all of the available energy can be transferred from the output of the heat-pump to the DES. Maximizing the temperature difference between the heat pump LWT and the DES return temperature was why the Neatpump was selected as it had the highest output temperature relative to the DES return temperature of the heat pumps investigated.

The future energy demand was estimated using existing natural gas consumption data for UVic

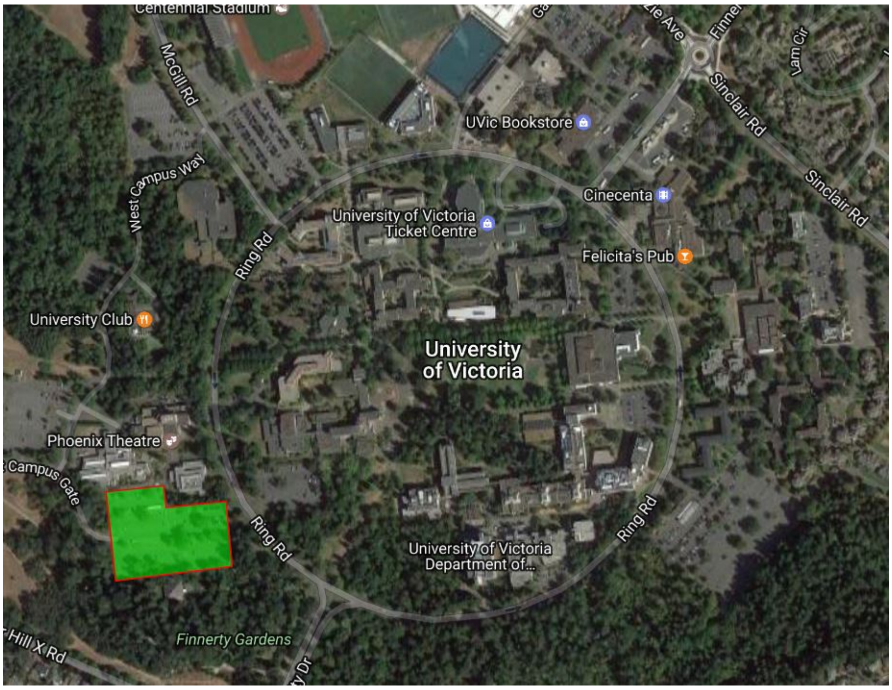

Figure 6: Alternative siting for combined geothermal, solar thermal field with approximately 16,000m^2 of available land. Not used in any scenario, only meant to show alternative siting possibilities.

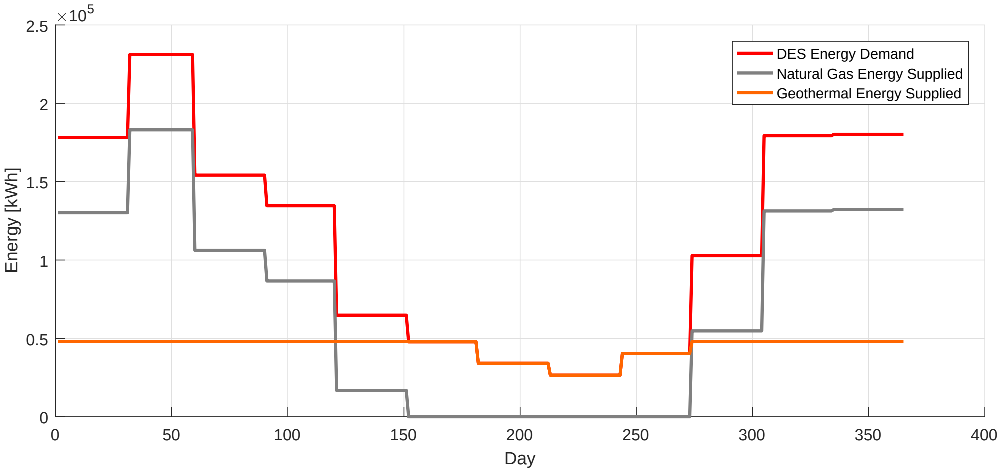

Figure 7: Scenario 1 - Modeled annual energy supplied by a 20,000 m^2 geothermal field in combination with the upgraded natural gas boilers

from the year 2014 and then scaled based on the predicted demand shown in table 1. The first scenario combining the future DES with a geothermal field of 20,000 m^2 is shown in fig. 7.

For the second scenario the same process as before was repeated but with the addition of 10,000 m^2 of solar thermal collectors located on rooftops at UVic. Evacuated tube solar collectors were modelled with an efficiency of 50%. Solar insolation data was taken from a Natural Resources Canada database for Victoria BC [8]. The solar thermal energy was prioritized for delivery to the DES, then the geothermal energy, and finally when those fail to meet the DES demand, the natural gas boilers were used to supply energy. No seasonal thermal energy storage is modelled in the second scenario. The annual energy supplied to the UVic DES for scenario 2 was summarized in fig. 8.

The third scenario used the same performance parameters as the second but with a larger solar field. In the third scenario it was assumed that the geothermal field shown in fig. 5 also represented the solar thermal collector area (geothermal below ground and solar thermal above ground), this included seasonal thermal energy storage as well since during the summer months the energy generation of the solar thermal array significantly exceeded the demands of the DES. The seasonal thermal storage system efficiency was taken from the Alberta seasonal thermal energy storage project discussed earlier in the report [21].

The three figures (fig. 7, fig. 8, and fig. 9) show the predicted behaviour of the systems in regards to how much energy is supplied from each source over the course of a typical year. In each case, the energy demanded from the existing natural gas boilers is reduced, in turn resulting in an emissions reduction. The energy and emissions for each scenario are summarized in table 5. The annual emissions are estimated using an emission intensity for natural gas of 56 kg/GJ [4] and a natural gas boiler efficiency of 85%.

The three scenarios depict different levels of investment in regards to sustainable energy generation and each would require a variation in layout in regards to heatpump, storage and transmission equipment, and energy generation equipment. A brief technical overview of each option is presented below. Each of the three scenarios is relatively novel when compared to the approach taken by other academic institutions in regards to thermal energy generation for DES. At this point, no other academic institution has been identified as using a combination of geothermal, solar thermal, and

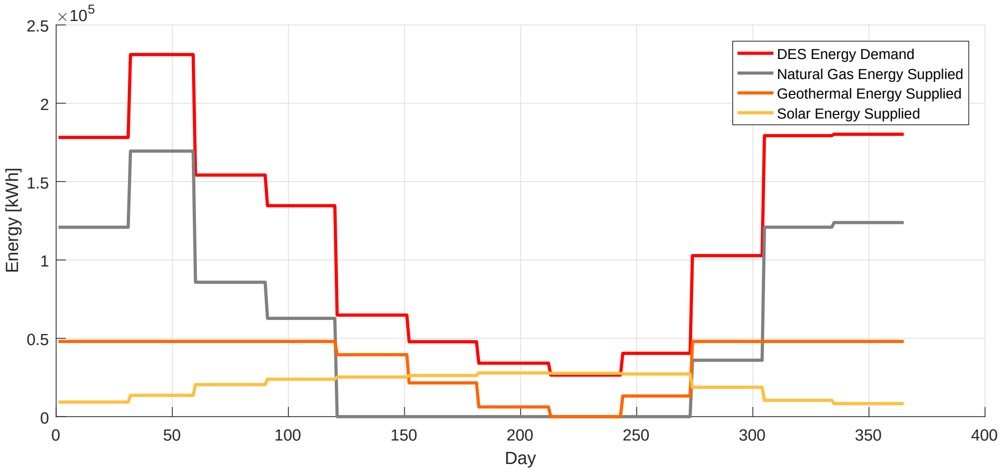

Figure 8: Scenario 2 - Modeled annual energy supplied by a 20,000 m^2 geothermal field in combination with the upgraded natural gas boilers and 10,000 m^2 of solar thermal collectors

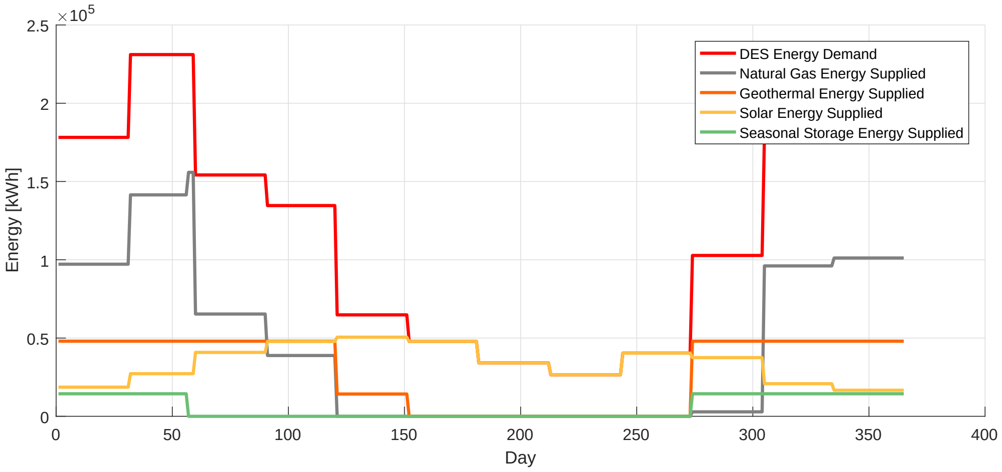

Figure 9: Scenario 3 - Modeled annual energy supplied by a 20,000 m^2 geothermal field, a 20,000 m^2 solar thermal array, and seasonal thermal energy storage

Table 5: Performance summary of three low grade energy supply scenarios and Baseline scenario of all natural gas powered thermal energy

	Baseline	**Scenario 1**	**Scenario 2**	**Scenario 3**
% of Demand met by GX	0	39	30	26
% of Demand met by SX	0	0	18	30
% of Demand met by Storage	0	0	0	5
% of Demand met by NG	100	69	52	39
Annual Emissions [tonnes CO2]	9,870	6,000	5,100	3,800

Table 6: Summary of projects that combine low grade thermal energy sources and high temperature DES

Location	**Technology**	**Annual Energy Production**	DES Temperature
Okotoks, Alberta	Geothermal, Solar Thermal, Seasonal Storage	833 MWh Annually	50-60 ^{0}C
Marstall, Denmark	Solar Thermal, Seasonal Storage, Biomass, High temperature HP	28,000 MWh Annually	70-72 ^{0}C
Drammen, Norway	High Temperature HP, Biomass, Oil	67,000 MWh	90 ^{0}C

seasonal storage for its DES.

4.2.5 Existing Projects

There are several projects around the world that combine low grade thermal energy sources and high temperature DES. There are also existing installations that combine solar thermal energy, geothermal, and DES. In Alberta, there is a DES powered by natural gas boilers, solar collectors, geothermal seasonal energy storage that has been running continuously since 2007. In Marstall, Denmark there is a DES network for an entire village using solar thermal, geothermal, and a water based seasonal thermal energy storage system as part of a European Union funded research project. The third existing project referenced is in Drammen, Norway and uses a multi-stage heatpump to collect thermal energy from the ocean and boost it up to 90^{0}C before providing energy to local commercial and residential buildings.

Each of these projects use commercially available components (Heat pumps, geothermal field equipment, and solar thermal collectors) and as such could be adapted to fit different environments such as UVic. The limits on any low grade energy source being connected to the UVic DES are the need for a better understanding the availability of the energy source (soil conditions, location on campus, etc.) and on optimizing the system arrangement to best match the time varying outputs of the energy source and the time varying demands of the UVic DES.

4.3 Biomass

Biomass has the capability to be relatively easily integrated into the existing DES along side the new natural gas boilers due to the high temperature output of biomass systems. This high quality heat simplifies the requirements for heat exchangers between the biomass system and the UVic DES, as well as allowing the output of the biomass system to exceed the temperature limitations of the UVic DES shown in fig. 1.

The primary technical challenges of biomass as an option for the UVic DES are feedstock identification, technology identification, and more clearly quantifying the environmental performance. Of the technologies mentioned previously in the report only direct combustion and anaerobic digestion were investigated further as they were the only technologies that appeared to have relative commercial success [24].

4.3.1 Local Availability of feedstock

Municipal Solid Waste (MSW) was the only feedstock available in significant quantities within the Victoria setting. An overview of the MSW produced in Victoria is outlined in table 7; this data was obtained from a report created for the CRD documenting the waste entering the Hartland landfill in 2016.

Table 7: Composition of MSW entering Hartland Landfill from the CRD for the year 2016 [14]

Composition	**Percent of total MSW**	**Annual mass [tonnes]**
compostable organics	21.2	28,620
wood and wood products	17.0	22,950
paper	15.4	20,790
plastic	14.3	19,305

According to a 2015 report by FPInnovations, of the various biomass feedstocks within BC, forest and urban wood residues represent the best value options for district heating in regards to reliability of feedstock and the technical maturity of the biomass technologies [19]. While urban wood residues comprise a significant portion of the MSW present at Hartland landfill (17%), separating any of the non-metallic components of MSW has no easy solutions that don't involve pre-collection diversion on the part of the CRD. This limits the options of any biomass system being strictly fed wood residues from the MSW streams available in Victoria.

From table 7, the majority of the MSW (68%) can be used for direct combustion. As well, the annual quantities are significant, with typical energy contents for those feedstocks listed in table 8. One of the largest challenges when working with these type of MSW sources is the screening that is quite often necessary prior to combustion. There are many different processes in place for sorting the MSW and they appear to be dependent on the specific composition of the MSW. A typical apparatus for sorting MSW is shown in fig. 10; this particular configuration produces Refuse Derived Fuel which is a homogeneous output comprised of all the MSW inputs evenly disbursed and sized in the output. The waste typically undergoes some or all of a combination of size-reduction, screening, magnetic separation, and density separation.

Table 8: Energy and content of typical North American MSW feedstocks [3]

feedstock type	**Heating value [GJ/tonne]**	**Moisture Content**	**Ash content**
Typical North American MSW	11 to 12	30 to 40%	25 to 35%
Paper within MSW	17	N/A	N/A
Plastics within MSW	32	N/A	N/A

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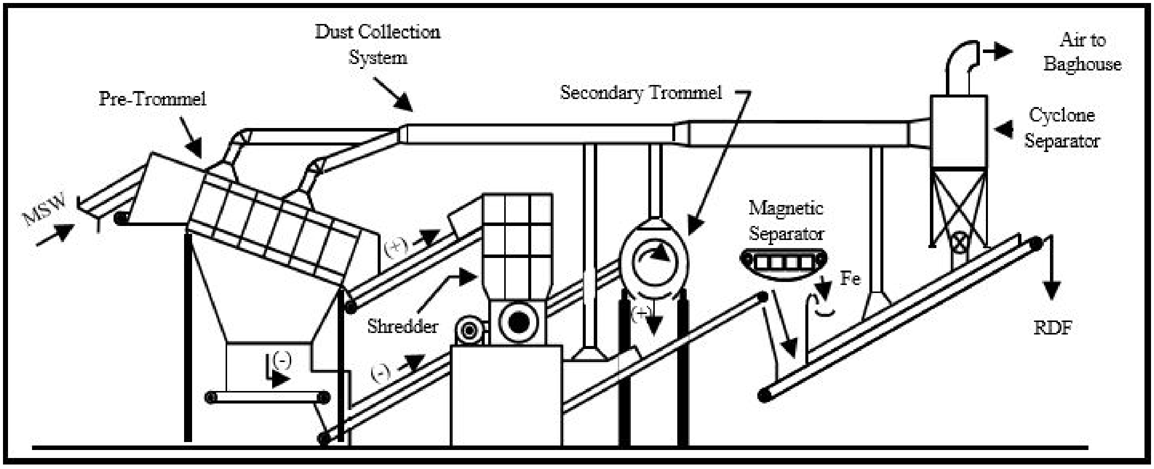

Figure 10: Schematic of a typical MSW sorting process that produces Refuse-Derived Fueld (RDF) [3]

When compared to isolated wood waste or agricultural waste, MSW typically requires much stricter environmental controls on the outputs (ash and emissions controls) as well as more pre-screening. These additional levels of pre and post screening can add significantly to the costs of energy production but with MSW being relatively cheap to procure (see table 12) this can balance out depending on specific local conditions. Gasification typically requires all metals and glass to removed from the feedstock prior to use, where as direct combustion can handle removing them from the output ash.

Further details of the existing waste streams within the CRD were given in a Request for Expressions of Interest (RFEOI) developed by the CRD Integrated Resource Management Advisory Committee. This RFEOI outlined the desire for interested parties to submit plans to convert waste streams within the CRD to energy [20]. The detailed waste stream data is reproduced in table 9. The general municipal refuse listed in table 9 has already been detailed in table 7 but the other streams have potential to be used for either direct combustion or gasification. These significant quantities of waste have the potential to displace large amounts of natural gas consumption within the UVic DES.

Table 9: CRD waste streams available for use in Waste to energy (WTE) projects as listed in 2017 RFEOI [20]

Waste Type	**Annually available amount [tonnes]**
Biosolids	35,000
General municipal refuse	120,000 to 135,000
Controlled waste (incl. sludge from existing wastewater plants)	8,000 to 12,500
Source separated household organics	15,000 to 20,000
Yard and garden wastes	15,000 to 18,000

The options from the CRD waste streams would be either to take bulk quantities back to a sorting facility at UVic and use direct combustion, or to come to an arrangement with the CRD to have some sort of screening process at an external site (likely the Hartland landfill) such that only specific controlled waste streams (such as wood waste, or RDF) are delivered to UVic and then used to generate thermal energy. Further details on the capabilities of direct combustion are detailed in the next section.

4.3.2 Direct Combustion

Direct combustion as an option for generating thermal energy from the available waste streams carries with it some strict requirements: The technology currently exists for direct combustion of MSW to meet European and North American air quality standards but it does require a strict regime of pollution control and monitoring equipment. The outputs that require monitoring and management are the bottom ash (from the combustion chamber) and the fly ash (from the exhaust stack). There are methods that use bottom ash as a filler in concrete but if the hazardous content of the ash exceeds particular guidelines it can be classified as a hazardous material and require the appropriate disposal methods and handling procedures.

Mass burn technology (or grate fired combustion) is the most common type of waste to energy technology. It requires minimal pre-sorting and the combustion process usually has several stages: the first dries and degases the waste, then a burn that oxidizes the more easily combustible material, followed by a more intense burn that oxidizes the fixed carbon. Typical Mass Burn WTE facilities have an energy conversion efficiency of approximately 60% or more when converting to thermal energy [28]. There is currently one large scale mass burn biomass generator operating in Vancouver. It has been in operation since 1988 and has a capacity of 3x240 tonnes per day of waste incineration. The per-ton performance of the Vancouver WTE facility is listed in table 10.

Table 10: Process outputs per 1 tonne of MSW incinerated at Metro Vancouver WTE Facility [28]

Process output	**Amount**
Metals recovered	29 kg
Trace air emissions	2.9 kg
Bottom ash	161 kg
Fly ash	42 kg
Phosphoric acid	5.8 kg
Carbon Dioxide	1105 kg (65% biogenic)

There are numerous vendors worldwide that supply either components of a direct combustion WTE facility or provide turnkey solutions for an entire WTE facility; it is a mature technology with well understood inputs, outputs, and performance metrics that have been continuously improved over several decades.

One of the primary human health concerns surrounding the emissions outputs of WTE direct combustion facilities is dioxins which are associated with numerous chronic health issues from infant deaths to lymphoma [9]. The Vancouver WTE facility has been repeatedly measured as having dioxin emissions that are 40,000 times less than the emissions associated with adverse health impacts in several epidemiological studies and are 32 to 1600 times less then current regulatory standards for dioxin emissions [9]. There are a number of other emissions associated with direct combustion but a report from the BC Centre for Disease Control shows that the Vancouver facility operates to a standard that exceeds all regulatory requirements for emissions controls in a BC context [9]. This evidence shows that direct combustion facilities can be operated safely within the BC regulatory environment.

From an energy production perspective, using the previously stated minimum 60% thermal energy conversion efficiency for direct combustion WTE facilities, and the CRD waste streams identified in

Table 11: Annual emissions and energy output for a typical combustion WTE Facility using 60% thermal energy conversion efficiency, 65% biogenic emissions, and MSW listed in table 7.

Source	**Annual Energy [MWh]**	**Percent of Future UVic Demand**
Aggregate MSW	246,000	590
Paper isolated MSW	65,000	150
Wood isolated MSW	110,000	260

Table 12: Cost estimates for direct Combustion WTE facilities in a BC context in 2009 CDN [25]

Median Reported Capital Cost	$775/annual design tonne +/- 50% (2009$ CDN)
Median Reported Operating Cost	$65/tonne +/- 30% (2009$ CDN)

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[14], estimates for the annual energy production capable at UVic have been estimated and reported in table 11. Each of the three waste sources listed in table 11 is capable of supplying more annual energy than will be demanded by the future UVic DES demands listed in table 1 and so even partial waste streams from the CRD have the potential to be diverted to UVic to displace significant quantities of natural gas consumption.

Another element of concern with combustion of MSW is the GHG emissions associated with the incineration of waste. The IPCC has a technical report that details some proposed methods for quantifying the GHG emissions of MSW combustion and has listed a typical German WTE combustion facility as producing 0.7-1.2 tonnes of CO2 per tonne of MSW input [16]. The biogenic (non fossil fuel based) component of this waste stream is the first factor that determines how much of the emissions must be accounted for in GHG accounting, the second is in regards to whether the consumption of MSW is displacing other fossil fuels. Both of these factors would require some detailed analysis of the particular waste stream being used at UVic and the size of a potential WTE system in regards to natural gas displacement.

Cost estimates for a conventional combustion WTE facility were created in 2011 by Stantec Consulting for the Government of British Columbia and are summarized in table 12.

4.3.3 Anaerobic Digestion

Anaerobic digestion (AD) as a technology option for UVic can use either the biosolids or household organics listed in the CRD waste output in table 9. AD will struggle with wood-based waste sources as the bacteria used in AD has difficulty in processing the lignin found in wood wastes. The AD process creates a methane rich biogas which can then be used for generating thermal energy by directly injecting biogas into the UVic DES. Prior to use as a substitute for natural gas, the biogas requires significant treatment as its original composition can be as much as 50% CO2. Additionally, the AD process can be highly sensitive to variations in composition of the input feedstock as the bacteria used in the digestion process are usually tailored for a specific composition for maximum efficiency. These two issues combined have been cited as a reason why AD is not suitable for conversion of MSW to energy [20].

With that aside, the most common form of AD facility is in a rural setting converting agricultural waste to biogas as the feedstock tends to be very homogenous in composition. To better understand how AD could be used for the UVic DES, the annual variation in the CRD waste streams would need to be better understood, as well as further research into the capability of the CRD waste streams to be separated into component parts prior to feeding into an AD facility.

Table 13: Summary of current operating WTE facilities recreated from several sources [24] [20]

Location	**Technology**	**Size**	**Start-up date**
Metro Vancouver	Mass Burn	273,000 tonnes/year	1988
Quebec City	Mass Burn	293,000 tonnes/year	1974
Levis, Quebec	Combustion with afterburner	24,700 tonnes/year	1974
Brampton, Ontario	2 stage combustion	147,700 tonnes/year	1992
Charlottetown, PEI	2 stage combustion	25,623 tonnes/year	1997
Hartland Landfill	Methane Capture	1.6 MW	2003

4.3.4 Existing Projects Summary

This section is intended to give an overview of some existing WTE facilities that use direct combustion to generate energy (thermal or electric) along with some performance and system parameters. This data is summarized in table 13.

The local Hartland landfill methane capture system does not impact any of the waste streams mentioned in table 9 or table 7. The methane capture system captures fugitive methane emissions that occur from the existing landfilled waste. Of the other Canadian WTE projects listed in table 13, only the Levis, Quebec plant does not use energy recovery technology (as of 2010) and is only used to reduce the waste diverted to the local landfill. The rest of the facilities listed in table 13 generate electricity from the thermal energy generated in the combustion of the MSW.

5 Conclusion and Future Work

The previous research completed for UVic that investigated what technological options are available to UVic for generating both thermal and electrical energy were reviewed.. These reports provided good quality analysis but appeared to prematurely discount the applicability of low grade heat sources for connection to the UVic DES. Geothermal energy, solar thermal energy, and seasonal thermal energy storage provide technically viable and environmentally beneficial technology options for integration into the high temperature UVic DES. By connecting these systems to a multi stage heat pump, the output can transfer significant amounts of thermal energy into the return water of the DES. The benefits are significant from a number of perspectives but the downsides are harder to quantify at this stage; the land required for a geothermal field and a solar thermal array are significant if they are to displace a meaningful amount of natural gas consumption.

Perhaps with a system optimization study the sizing of both a geothermal field and a solar thermal array could be designed such that the land requirements are minimized based on when they provide energy over the course of the year. Uncertainty in the analysis in this report centers on the energy content of the ground and the actual space required for a geothermal field sufficient to meet the DES demand; the values used in this report were conservative in nature and as such, it is likely that any subsequent analysis will find that an appropriately sized geothermal field is smaller than this report states. An additional benefit of a solar thermal/geothermal/season storage system is the potential support of research funding due to the novelty of such a system for district heating in Canada; research funding could help offset any of the risk associated with such a project.

The viability of biomass was explored and refined based on the previously commissioned reports. These previous reports stated that urban wood residues were readily available to UVic, but current research found that not necessarily to be true. While urban wood residues are available, it would appear that they are mixed within existing MSW streams and are not easily extractable. It is not currently believed that the components of the MSW at the Hartland landfill are separated but further research might reveal this to be the case, which would mean that wood residue on its own could perhaps be used for a biomass system. Regardless of whether the wood residue can be separated or not, direct combustion is technically capable of supplying more energy than the future demand of the UVic DES requires. The limitation would be based upon where the facility is located on campus (truck access), what social license the campus is able to achieve in regards to a WTE facility, and what the detailed GHG accounting for a WTE facility would like. It is not clear how or if a WTE facility would reduce overall GHG emissions from a full life cycle perspective relative to the use of natural gas within the UVic DES. This uncertainty in emissions is tied to the biogenic component of the MSW. The biogenic component is the parts of the waste stream that are of non-fossil fuel origin and as such are ignored when accounting for GHG emissions according to BC Guidelines.

Future steps based on this work could involve an optimization study for some combination of geothermal, solar thermal, and seasonal energy storage to determine what size fields best match the temporal variations in energy demand placed upon the DES. Alternatively, finding a commercial partner with experience in the realm of geothermal energy generation who would be willing to help in the design of a potential system at UVic would further refine any cost and land requirements. For a WTE facility, UVic could consider reaching out to a commercial partner to consider a submittal to the CRD RFEOI to determine how the MSW feedstock available in Victoria could benefit UVic in it's desires to reduce natural gas consumption within its DES. Further refinement of either avenue will rely upon more detailed analysis of either the technical performance of low grade energy sources, or on the economic cost and feedstock composition of a WTE facility.

Another recommendation for UVic facilities management would be to introduce a renewable energy assessment for any new major projects on campus to determine how such a project might either be a source of renewable energy to UVic (such as the Enterprise Data Centre) or a consumer of renewable energy. This analysis would then determine whether the geographic placement of such a project is in line with future plans for reducing GHG emissions on campus. If a new facility can be a source of waste energy but is placed to far geographically from any connection point such that the waste energy can be economically harvested, then this should be considered a wasted opportunity for UVic and taken into consideration during the planning phase. The decision to not interconnect waste heat from the EDC is a very unfortunate missed opportunity for making use of a large scale on-campus waste heat source which must not be repeated in future facility citing decisions if UVic is to achieve GHG reduction targets.

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