

WASTEWATER HEAT RECOVERY IN WATERLOO REGION

Prepared for WR Community Energy



ACKNOWLEDGEMENTS

The work of WR Community Energy is directed by an innovative Governance Committee which includes high-level representatives from the Region of Waterloo, its three urban municipalities, and five local gas and electric utilities.





Wastewater Heat Recovery

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Wastewater heat loss in Victoria Park, Kitchener.

Photo Credit: Matthew Day

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1.0 EXECUTIVE SUMMARY

Every time you take a shower, do the laundry, wash dishes, or flush the toilet, valuable thermal energy is lost down the drain. On average, the wastewater flowing from homes and buildings is at a temperature around 20 - 22°C. The thermal energy (heat) from the wastewater could be captured and utilized to condition buildings (heating and cooling) or heat incoming water. Globally proven heat recovery technologies capture this energy and generate renewable energy while also reducing greenhouse gas emissions. The efficiency of these technologies is constantly improving.

This report is written for planners and energy or property developers to enable the adoption and utilization of this renewable energy source. This report is focused on trunk sewer lines with dry flow in excess of 100 liters per second. This amounts to 40 MW_{th} of sustainable year-round energy: the equivalent of **providing a baseload of heating and cooling for about 1,300,000 m²** - roughly the amount of 7,000 single detached homesⁱⁱ. Put another way, capitalizing on this technology would reduce natural gas consumption by 240 m³ per hour in a natural gas fired boiler operating at 80% efficiency. That translates into a reduction of 1,600 tonnes of CO₂e during the annual heating season (5 months per year).

The thermal energy in wastewater is recovered by using heat exchanger and heat pump technologies. Heat pumps take the available heat (thermal energy) and electrically increases it to a more useful temperature (roughly 70°C). The hot water is then distributed through insulated piping either within a building or a broader district energy network to efficiently condition spaces. During summer weather the heat pump can be reversed allowing the removal of heat from buildings and providing air conditioning duty, and the sewage receives the rejected heat. An additional benefit is the removal of unsightly cooling towers on building roofs.

Currently there are several sewage heat recovery projects around in the Greater Toronto Area underway or being contemplated (Toronto Western Hospital, Humber River WWTP and the Christie 26-acre development, Golden Mile in Scarborough, and Lakeview WWTP). In Waterloo region, the City of Kitchener is exploring this renewable energy resource as part of the proposed district energy system in downtown Kitchener.

When a new development is being considered, please review the GIS thermal maps to identify a suitable trunk sewer line to supplement the heating and cooling of the proposed development.

2.0 HOW TO USE THIS DOCUMENT

This paper provides a high-level overview of the sewer system and identifies a simple way to calculate the thermal heat recovery potential based on the sewage flow in Section 4.0. A wastewater heat recovery heat map was created through a collaboration with our urban area municipalities and Region where project opportunities are discovered. Finally, several case studies and alternative technologies are discussed.

A wastewater heat recovery (WWHR) system captures the heat from a wastewater discharge pipe exiting a building and is used to preheat incoming water for the domestic hot water tanks or for space heating. This type of heat recovery system can be utilized in a single residential building or a larger building (industrial or commercial). Section 3 details Sewer Heat Recovery Systems, Section 4 outlines Thermal Heat Recovery Calculations, Section 5 provides Thermal Heat Mapping, Section 6 outlines Heat Recovery Technology and Case Studies, and 7.0 provides Policy Recommendations.

The ideal time to explore WWHR is during the early phase of zoning and planning of new developments. A stand-alone heating system could be considered for a large building or for a larger development a district energy node which could service multiple buildings from a central energy plant. Included in this report are detailed GIS base thermal maps indicating heat recovery opportunities in specific regional areas and locations of the trunk sewers across the cities of Cambridge, Kitchener, and Waterloo.

To meet established climate change goals, addressing the energy efficiency and decarbonisation of building heating and cooling systems is essential. Smart district energy networks are a key solution for integration and achieving energy efficiency goals within the cities. Recovering heat from sewer and geothermal heating are ideal solutions for our cities, and in addition we can also reject heat during summer to cool buildings.

Key Terms

- Wastewater (or sewage)
- Wastewater heat recovery (WWHR)
- District Energy (System)
- Wastewater Treatment Plant (WWTP)
- Drain water heat recovery (DWHR)
- Water source heat pumps (WSHP)

3.0 DESCRIPTION OF THE SEWER HEAT RECOVERY SYSTEMS

A wastewater heat recovery (WWHR) system captures the heat from a wastewater discharge pipe exiting a building and is used to preheat incoming water for the domestic hot water tanks or for space heating. This type of heat recovery system can be utilized in a single residential building or a larger building (industrial or commercial).

The three main wastewater treatment plants (WWTP) in Waterloo Region (Kitchener, Waterloo, and Galt) represent 80% of the overall flow and the main opportunities for heat recovery. But there are additional heat recovery opportunities from the trunk sewers upstream of the WWTP. They come from individual industrial, commercial, and residential developments from the following wastewater sources:

- Residential drain wastewater heat recovery;
- Medium building wastewater heat recovery;
- Trunk sewers heat recovery (flow > 100 liters/second); and
- Discharge effluent from the wastewater treatment plants.

3.1.1 Drain (residential) wastewater heat recovery

Wastewater is discharged into the sanitary sewer network at a temperature of approximately 20 - 22°C and sometimes higher. A heat recovery system could capture about 25% of the heat required to maintain the potable hot water tank at temperature. The drain water heat recovery (DWHR) pipe is a simple technology used to preheat the incoming supply water to the hot water tank. The heat exchanger is made from copper pipes strapped to the main drain water line before it exits the residential dwelling.

Approximately 20% of the energy used in a Canadian home is for water heating. The current Ontario Building Code now mandates new homes to install a drain water heat recovery system.

3.1.2 Medium building heat recovery system

There are systems designed to recover heat from wastewater leaving a single building to preheat incoming water used for potable domestic hot water. As an example, Piranha by Sharc Energy, utilizes a brazed plate and frame heat exchanger and a heat pump to elevate the recovered thermal energy. The energy recovered is typically less than 50 kW_{th}.

The resulting hot water could be used for potable hot water storage tanks or for hydronic heating in the building.

3.1.3 Trunk sewer heat recovery

Throughout the urban core areas of Cambridge, Kitchener, and Waterloo, there are multiple locations with large sewage flows of around 100 liters per second translating into a heat recovery opportunity of 2 MW_{th} (for calculations see Section 4.0). The anticipated intensification in the core areas surrounding the Light Rail Transit (LRT) corridor could produce additional heat recovery growth and potential. This could support the individual heat recovery systems for large buildings located close to trunk sewers or be part of a district energy system.

The main trunk sewers through downtown Kitchener and uptown Waterloo are in close proximity to these high-density developments and intensification areas. This creates an opportunity to construct sewer heat recovery systems and provide a renewable thermal energy source for building heating and cooling. Please see Section 6 and 7 of this report for further discussion of alternative technologies.

Wastewater heat recovery opportunities in the cities can be identified by energy and property developers in conjunction with city planners and the GIS thermal maps (Pending – will be included in this report). Each city can serve a regulatory role in allocating this resource to new developments without having to invest in the projects.

3.1.4 WWTP Heat Recovery

Energy from wastewater treatment plant discharge can be recovered during the heating season (winter) and rejected during cooling season (summer). The extent of heating and cooling from the WWTP discharge will be subject to allowable discharge temperature into the Grand River and the approval by Ministry of the Environment, Conservation and Parks (MOECP). Please see Section 6 for discussion on suitable technologies.

The heat recovery from WWTP occurs at the discharge side of the plant. As such, the water will be much cleaner and will reduce the fouling of heat exchanger surfaces. The temperature difference between current discharge temperature and the typical river temperature during winter conditions will potentially allow the recovery of more thermal energy than estimated below and subject to approval by MOECP. From the City of Kitchener WWTP about 17 MW_{th} could be potentially recovered (assuming a temperature difference of 5°C).

There are added complexities with recovering heat at the WWTP. For example, operators would be required to coordinate flow and temperature controls in addition to their standard work. It should be noted that the newly installed digester gas cogeneration plants in the 3 largest WWTP in Waterloo region will also be able to supplement thermal energy to the production of hot water from a heat recovery system. A future energy plant at the WWTP could potentially be managed jointly between a city and an energy developer.

4.0 THERMAL HEAT RECOVERY CALCULATIONS

To calculate the available heat in the sanitary sewer lines the following formula was used:

Thermal Energy (kW_{th}) = Flow (m³/h) x Specific Thermal Capacity (kWh/m³ x °C) x Temperature difference (°C)

Example: Flow = 360 m³/hour (or 100 liters/second)

Specific Thermal Capacity Wastewater = 1.16 kWh/m³ x °C¹

Temperature difference = 13 - 8 = 5 °Celsius

Thermal Energy = 360 x 1.16 x 5 = 2,088 kW_{th}

The thermal energy from 100 liters per second sewage flow will translate to:

2 MW_{th} is enough to provide baseload of heating and cooling for a 65,000 m² building. This translates into a natural gas consumption of 240 m³ per hour in a natural gas fired boiler operating at 80% efficiency during heating seasonⁱⁱⁱ.

A few notes on the calculations:

1. Flows varies with time of day, time of the year, and weather conditions

Seasonal fluctuations can be managed by storage basins at the energy station. It is worth noting that unlike other energy infrastructure, heat capture is not impacted by working from home. The same volume of wastewater is created whether people are working in their home or at an office. Unlike the potential to match utility infrastructure to accommodate various places of demand, waste heat capture is resilient to changing work environments.

2. Temperature of the sewers varies by:
 - a. Season
 - b. Land use. Food and beverage industries will typically have a higher temperature. Health services also have above average thermal discharge.
 - c. Proximity to source. However, we currently do not track the temperature of wastewater in the pipes
3. These calculations are used for our study and should not be used for system design. Before a project will be ready for implementation, a more complete and site-specific study is required.

Regional WWTP are designed to require a minimum incoming temperature of 8 degrees celsius. Any upstream WWHR system must not withdraw heat that affects this minimum threshold.

¹ www.mdpi.com/journal/energies "Suitability Pre-Assessment of in-Sewer Heat Recovery Sites Combining Energy and Wastewater Perspectives"

5.0 THERMAL MAPPING OF THE AREA

This WWHR report, commissioned by WR Community Energy, includes a preliminary investigation of the trunk sewer heat recovery opportunities and is based on data collected from the cities of Cambridge, Kitchener, and Waterloo and mapped by the Region of Waterloo.

WWHR mapping is uncommon but not unique in North American municipalities. While this report resulted in an online GIS map, other municipalities are taking more advanced approaches. The City of Seattle, for example, has developed an interactive sewer heat model. The City of Toronto is working on a similar project designed to allow energy developers to investigate opportunities adjacent to future large-scale developments. The City of Toronto model will have to be updated on a periodic basis to incorporate energy 'takers'. It will also include energy discharge into the sewage system during air-conditioning season.

The Waterloo region data collection methodology has been focused on understanding the temperature profile of sewage during the heating and cooling seasons. We have received temperature and flow data from the Region of Waterloo's main wastewater treatment plant for 2018 and 2019. We have also received key flow and capacity information from the cities of Kitchener, Waterloo, and Cambridge.

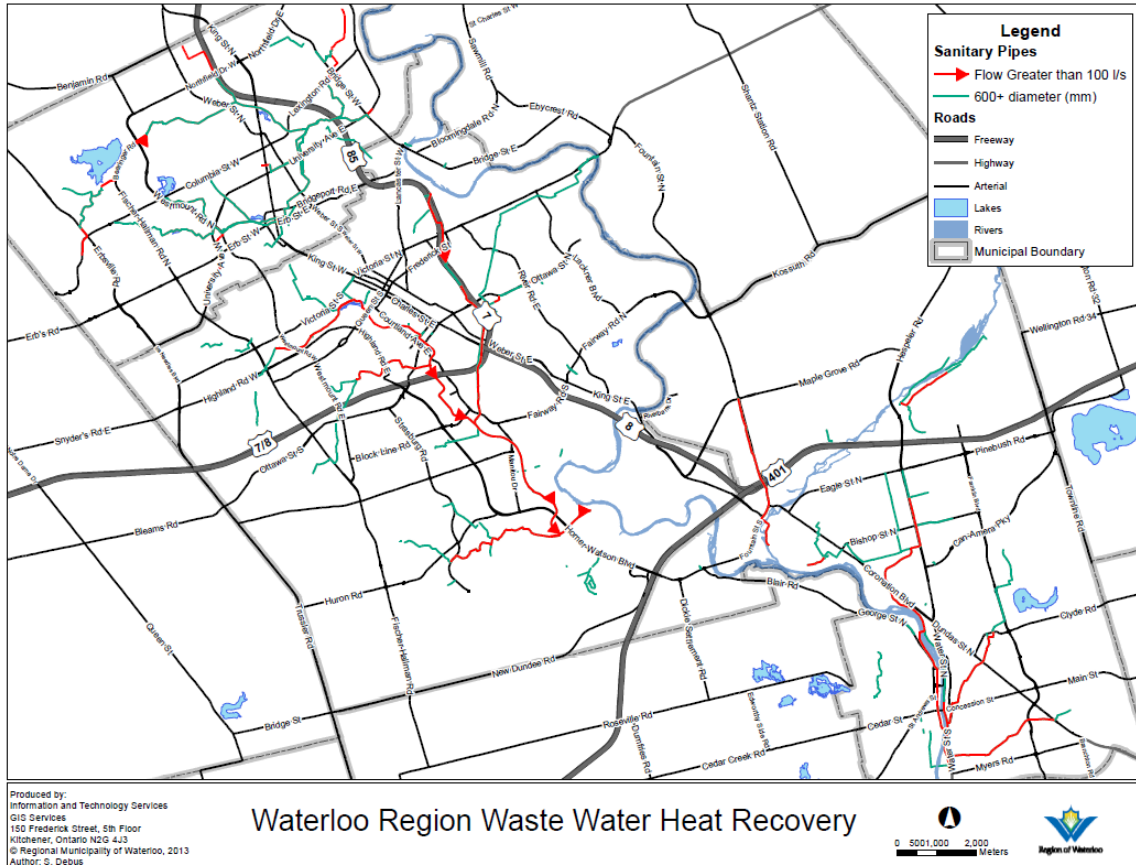
The focus has been on large flows and dry average sewage flows above 100 liters per second. This flow rate provides a substantial amount of energy and is feasibility for cost effective installation of the proposed technology. The information is presented in a PDF and online map. With minimal investments, the map could be expanded to become an interactive model pending interest.

Below are high-level WWHR potential maps for Cambridge, Kitchener, and Waterloo.

Aside from heat capture at the wastewater treatment facilities, there are three WWHR opportunities in Kitchener, four in Waterloo, and four in Cambridge.

If all heat is recovered in trunks with flows over 100lps, the three cities could save 864,000m³ of Natural Gas a year. With a GHG emission factor of .185 kg / m³, that would save 1,598 tonnes of greenhouse gases a year – roughly the same amount of savings the City of Waterloo saw between 2013 and 2021.

If wastewater heat is captured upstream, it could impact how it is capture downstream. It is recommended the local area municipalities coordinate a waste heat management approach for the long-term. We suggest regional staff connect with representatives from other municipalities (ex: City of Toronto, Mississauga) who are currently working on implementation.



5.1 City of Cambridge

The average flow feeding the Galt WWTP (the largest in Cambridge) is approximately 348 liters per second. This represents 19% of total heat recovery opportunities from the three cities and other municipalities included in the 2018 Wastewater Treatment Master Plan for the Region of Waterloo.

In addition, there are lower flows to Preston and Hespeler WWTP at about 110 liters per second and 82 liters per second. The total flows between the three WWTPs is estimated to $19+5+4 = 28\%$ of total heat recovery opportunities for from the three cities and other municipalities included in the 2018 Wastewater Treatment Master Plan for the Region of Waterloo.

Outside of the WWTP there are several sites in Cambridge that would be worth considering further.

- **Galt City Centre**
Ainslie St. S and Water St. S
- **South End Flows**
Water Street near the entrance to Churchill Park
- **North End Flows**
Queen St. W in Hespeler

5.2 City of Kitchener

The average flow feeding the largest Wastewater Treatment Plant in Kitchener is about 807 liters per second. This represents 37% of total heat recovery opportunities from the three cities and other municipalities included in the 2018 Wastewater Treatment Master Plan for the Region of Waterloo.

Outside of the WWTP there are three sites in Kitchener that would be worth considering further.

- **North End Flows**
Jubilee Dr. and Heinz Ave. (89 to 244 liters per second)
- **East End Flows**
Weber St. E. and Montgomery Rd. (73 to 229 liters per second)
Shelley Dr. and Courtland Ave. E (111 to 287 liters per second)
- **South End Flows**
Pioneer Dr. and Homer Watson Blvd. (379 to 858 litres per second)

5.3 City of Waterloo

The average flow feeding the Waterloo WWTP (the largest in Waterloo) is estimated to about 488 liters per second. This represents 24% of total heat recovery opportunities from the three cities and other municipalities included in the 2018 Wastewater Treatment Master Plan for the Region of Waterloo.

Outside of the WWTP there are three sites in Waterloo that would be worth considering further.

- **North West End Flows**
Pumping station south of Laurel Creek Reservoir
Lexington Rd. and Marsland Dr. (180 liters per second).
- **Uptown Flows**
Bridgeport Rd. and Pepler St. (138 liters per second)
- **East End Flows**
Entering the WWTP (148 liters per second)

5.4 Municipalities outside of the three cities

As we have focused on identifying the main sewer flows in trunk sewers at about 100 liters per second the outlying areas (townships) will have lower flows. Most heat recovery opportunities will be in the high-density areas of the three cities discussed above.

6.0 HEAT RECOVERY TECHNOLOGIES AND CASE STUDIES

There are different technologies for recovering waste heat from sewage water and various heat exchanger technologies used in combination with various heat pump types. Below are some technologies commonly used.

The two main solutions are as follows:

1. External sewer unit heat exchangers; and
2. In-sewer heat exchanger.

The external sewer technologies have high technical flexibility and installation. They are also easier to access and maintain. The in-sewer design is limited by the state of the existing sewer system, the length of straight runs and slopes. The in-sewer system has lower power consumption. Each system needs to be evaluated on a case by case basis.

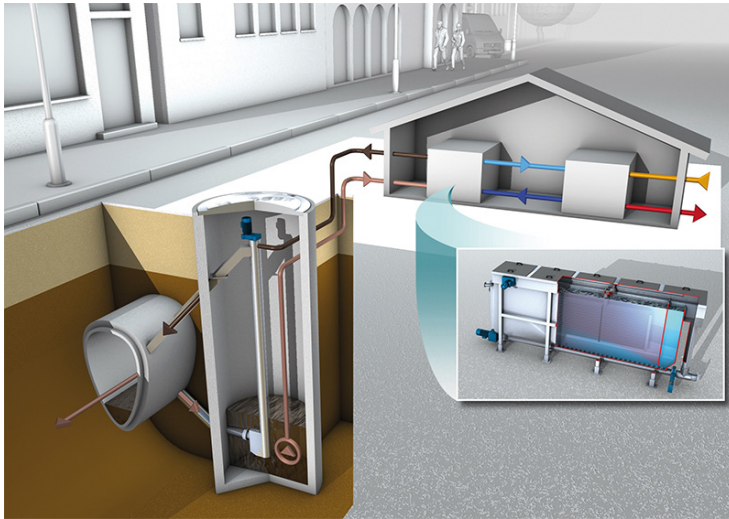
The water source heat pumps (WSHP) utilized in many heat recovery systems discussed below is typically a single or double stage centrifugal chiller operating with a synthetic refrigerant like R514A or common in Europe R-1233zd. In some situations, screw compressors are instead used in the heat pump design. The WSHP will either absorb heat from the sewage water during the winter and heat the water to about 70°C. During the summer operation the WSHP will reverse the direction in instead release heat into the sewage water.

6.1 External sewer heat exchanger

6.1.1 Noventa-Huber Thermwin²

In this system a portion of the raw sewage flows is fed via gravity into a wet well. The solids are retained by the screen and transported vertically up and returned to the trunk sewer. The screened wastewater is pumped up the heat exchanger and heat is transferred to the cooling water loop. The water loop is then transferring the heat to the heat pump and the wastewater flows back to the sewer with the solids to the trunk sewer.

Please see below the configuration of the sewer heat recovery system

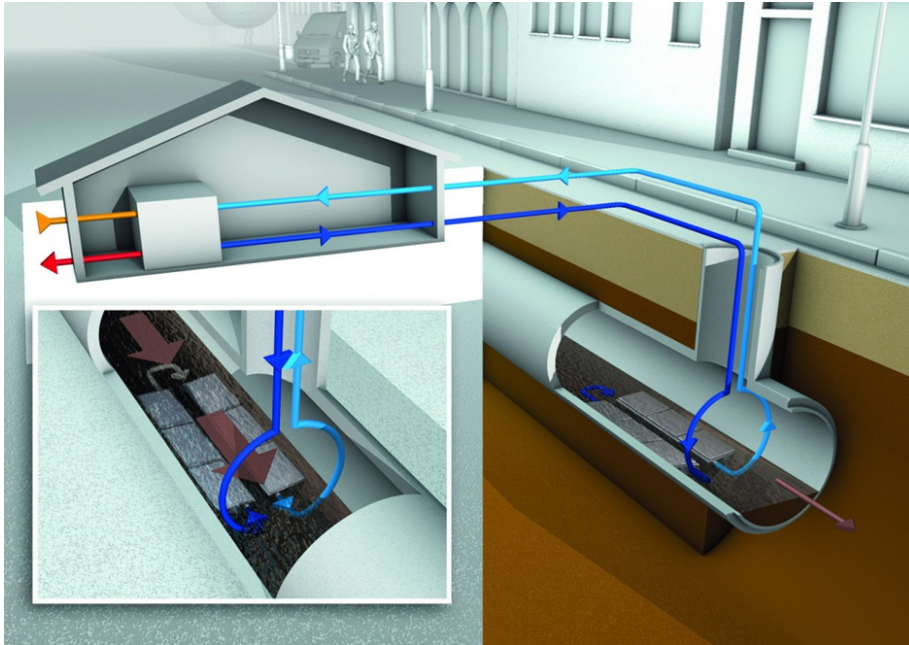


² Noventa Energy Partners, Toronto, ON

6.2 In-sewer heat exchanger

6.2.1 TubeWin by Huber Technology

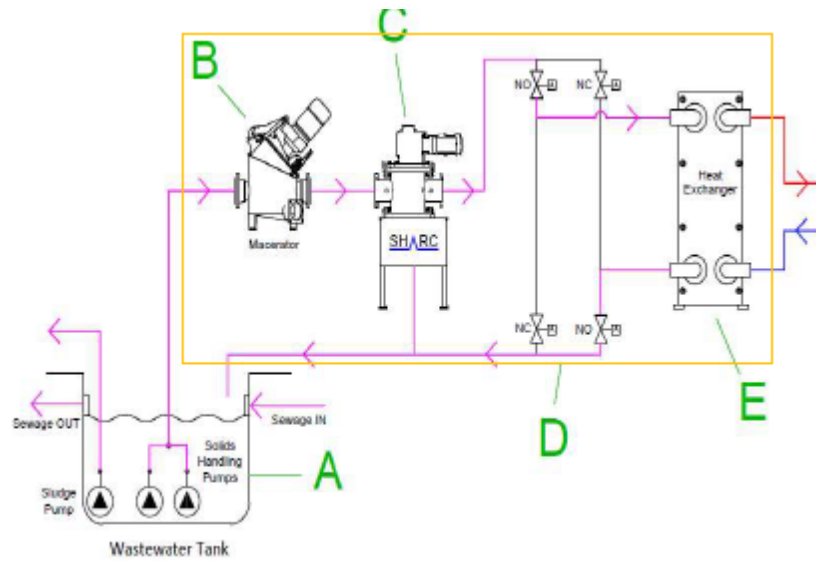
This system uses a heat exchanger element installed directly in the trunk sewer bottom. The heat exchanger elements are made of stainless steel connected in serial or parallel with a pump circulating the clean water to the heat exchanger.



6.2.2 Sharc Energy System³

In this system the raw sewage is pumped to the macerator allowing the particles sizes to break up and then filtered before entering a plate and frame heat exchanger for heat recovery. The secondary flow through the heat exchanger is water that will then in turn transfer the recovered heat to a heat pump to allow the temperature to increase to a useful temperature.

³ Sharc Energy Systems, Vancouver BC



The heat pump is not shown in the flow diagram above but would typically be connected to centrifugal chiller with heat pump capabilities. This will allow the heat pump to provide heating and cooling depending on the season.

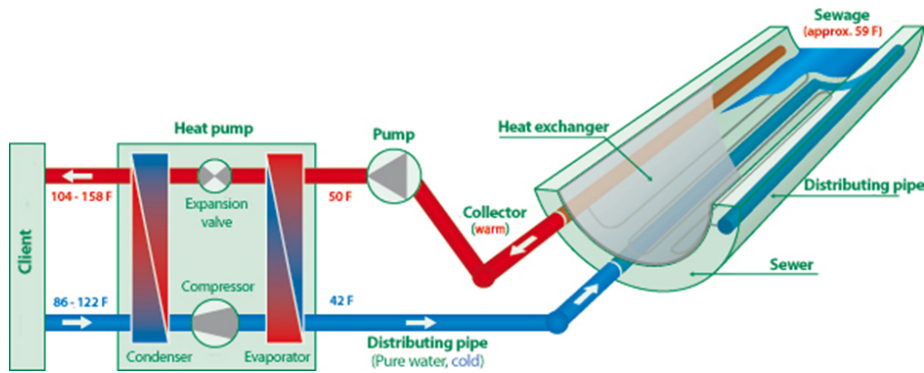


6.2.3 Rabtherm Energy System

This system was developed based on an integrated heat exchanger inside the sewer pipe, which results in the trunk sewer lines will have to be replaced with this integrated new sewer.



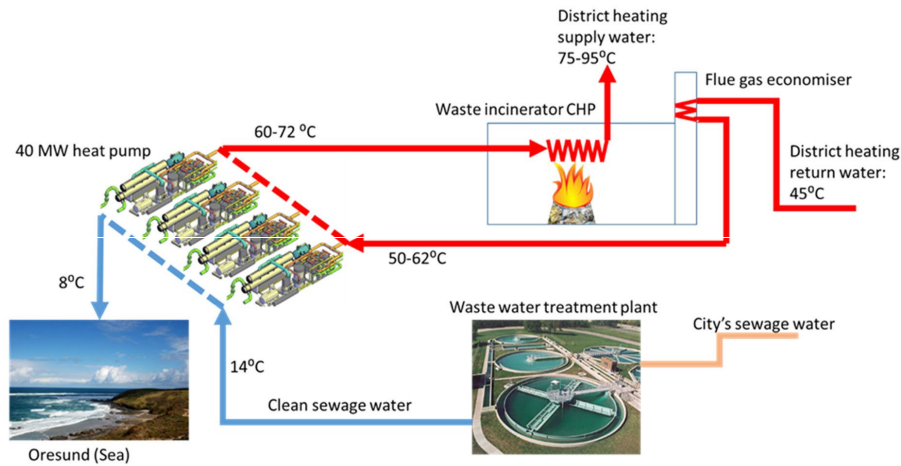
Below, the connection between the new integrated sewer pipe and the heat pump is shown. A circulation pump will circulate the clean water between the embedded pipes in the floor of the sewer pipes and the heat pump adjacent to the trunk sewer. The heat pump will again elevate the heat recovery to a useful temperature for the heating system or for the district energy network.



6.3 WWTP and District Energy

There are several large scale examples of WWTP being used in district energy projects. In Richmond, British Columbia, an effluent sewage heat recovery at the Lulu Island WWTP to service the District Energy Utility in the Richmond city centre area is being developed.

There are several large heat pump installations in Europe connected to district heating systems. One such sewage heat recovery systems is connected to the discharge side of the WWTP and waste incineration plant in Malmö Sweden. This plant has four GEA ammonia heat pumps removing 30 MW_{th} from the sewage water. The wastewater is chilled from 14°C to 8°C, the energy harvested is upgraded to a useful heat for the district heating network through the heat pumps. For each 1 kWh of electricity used by the heat pump, 3.5 kWh of heat is produced for the city.



⁴ Large scale heat pumps for high efficiency district heating projects by Kenneth Hoffman

6.4 Case Studies

There are many examples of heat recovery from sewer systems around the world. Below are a few examples in North America and Europe.

North America

- False Creek Neighbourhood Energy Utility. Vancouver, BC.
- Toronto Western Hospital. Toronto, Ont.
- King County Wastewater Treatment Division. Seattle, Washington

Europe

- London Underground. Islington, England
- E.ON. Malmo, Sweden
- HOFOR. Copenhagen, Denmark
- CO1. Cologne, Germany

7.0 POLICY RECOMMENDATIONS

1. Increase Operator Awareness & Knowledge
 - a. Planners and wastewater operators should become informed of the energy potential of this technology and encourage its adoption for new developments. Developments near high flow areas over 65,000ft² should consider WWHR
2. Municipal Database Development
 - a. Develop a data base of temperatures in the trunk sewer system. The cities of Kitchener and Waterloo expressed an interest to set up an automatic monitoring system capable of collecting data. If combined with ongoing maintenance and planning, this should be a valuable addition.
3. Transition from Energy Map to Energy Model
 - a. In addition to temperature, real-time data can be collected with water flows. Combining the two data sets would move this from an energy map to an energy model and follow leading municipalities such as Seattle and Toronto. It could be used to proactively identify energy development opportunities
4. System Regulation & Coordination
 - a. Area and regional municipalities should coordinate to regulate the withdrawal of thermal energy from wastewater distribution systems. Currently wastewater heat recovery (WWHR) systems seem to follow a first-come-first-serve rule. This is not optimal for reducing GHGs or encouraging the long-term sustainability of these technologies.
 1. Clear processes for establishing WWHR systems will encourage its development, offer securing for the developer, optimize the resource, and avoid confusion and reputational damage to the technology.
 2. Worst-case scenarios for this technology would be:
 - A) if a second system was built upstream from the first and removes so much heat that it renders the first system inefficient

- B) If a system removes so much heat that it cools the pipes below the WWTP designed temperature.
5. Consider heat recovery when designing wastewater distribution systems. In particular:
- a. Designing the sewage system to increase flows of over 100l/s close to source. The closer this threshold is met to the source, the hotter the water and therefore the greater the heat recovery potential.
 - b. Consider the size of the pipe in the context of the user. Food and Beverage and health service users typically have higher sewage discharge temperature and therefore optimal for heat recovery;
 - c. Encourage high flows near high-density developments;
 - d. Evaluate WWHR opportunities (internal vs. external) on all future wastewater systems by layering growth expectations over existing and future sewage and flow maps.

8.0 NEXT STEPS

The accompanying WWHR thermal map identifies where trunk sewers can effectively be utilized by planning staff in these decisions. This map is a start, but more work will need to be done to encourage the industry locally. WR Community Energy and area and municipal governments can play a critical role in supporting this opportunity. WR Community Energy will engage with key stakeholders to discuss interest in this technology and ways to foster the development of this industry locally. Please reach out to m.day@wrcommunityenergy.ca if you or your organization are interested in the following:

- **Discussing the above policy recommendations.**
- **Educating property and energy developers.**
- **Educating city planners.**
- **Developing a site-specific pre-feasibility studies.**
- **Organizing tours of successful systems.**

ⁱ designed to Ontario Building Code energy standards for the majority of heating and cooling loads.

ⁱⁱ Assuming a size of 185 meters square (2,000ft)

ⁱⁱⁱ In cooling mode, wastewater heat recovery will remove the additional power and water required for operating a cooling tower. Details were not explored in this study.



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