POSTERITY GROUP

Study Report

Market Characterization & Conservation Potential for Ontario's Drinking Water & Wastewater Treatment Plants

December 21, 2018

Independent Electricity System Operator
120 Adelaide Street West, Suite 1600
Toronto, ON M5H 1T1

Posterity Group
43 Eccles St, 2nd Floor, Unit 2
Ottawa, ON K1R 6S3

Due to technical limitations, not all of the content in this document may be captured by a screen-reading device. This study, titled Market Characterization & Conservation Potential for Ontario's Drinking Water & Wastewater Treatment Plants, assesses provincial water treatment in four sectors: wastewater treatment plants, drinking water treatment plants, wastewater pumping stations and drinking water pumping stations. It provides best-available information to reduce energy consumption, electric peak demand and greenhouse gas emissions to support decision makers, operations staff and other industry stakeholders. If you require additional assistance, please contact saveonenergy@ieso.ca

POSTERITY GROUP

Contents

1 Executive Summary

Water treatment represents the largest energy use for most municipal governments and over a third of municipal energy consumption in Ontario [1]. This study assesses provincial water treatment across four sectors, including wastewater treatment plants (WWTP), drinking water treatment plants (DWTP), wastewater pumping stations (WW Pumping) and drinking water pumping stations (DW Pumping).

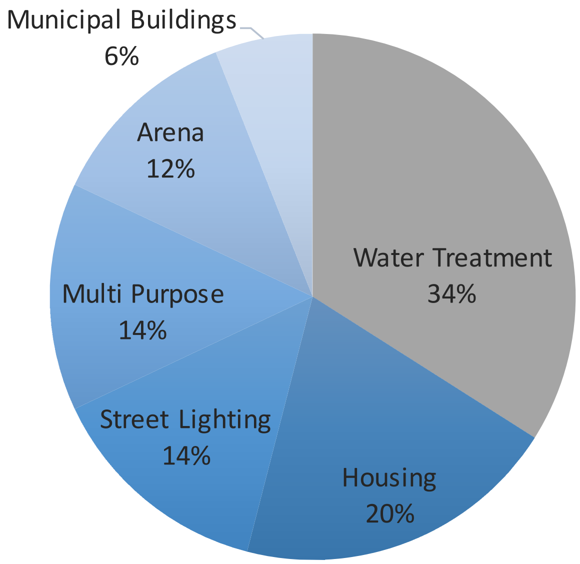
There are numerous opportunities to reduce energy consumption, lower electric peak demand, and abate GHG emissions in Ontario's municipal water treatment sectors. This study provides best-available energy and GHG information to support decision makers, operations staff, and other industry stakeholders including the Independent Electricity System Operator (IESO) and other provincial organizations.

Ontario municipalities and WWTP/DWTP facility operators can use this report to:

- Compare energy use at their facility to others in the province; and
- Understand the key opportunities applicable to their specific infrastructure, including energy savings measures (processes and technologies), biogas recovery using combined heat and power, load shifting strategies, and market participation.

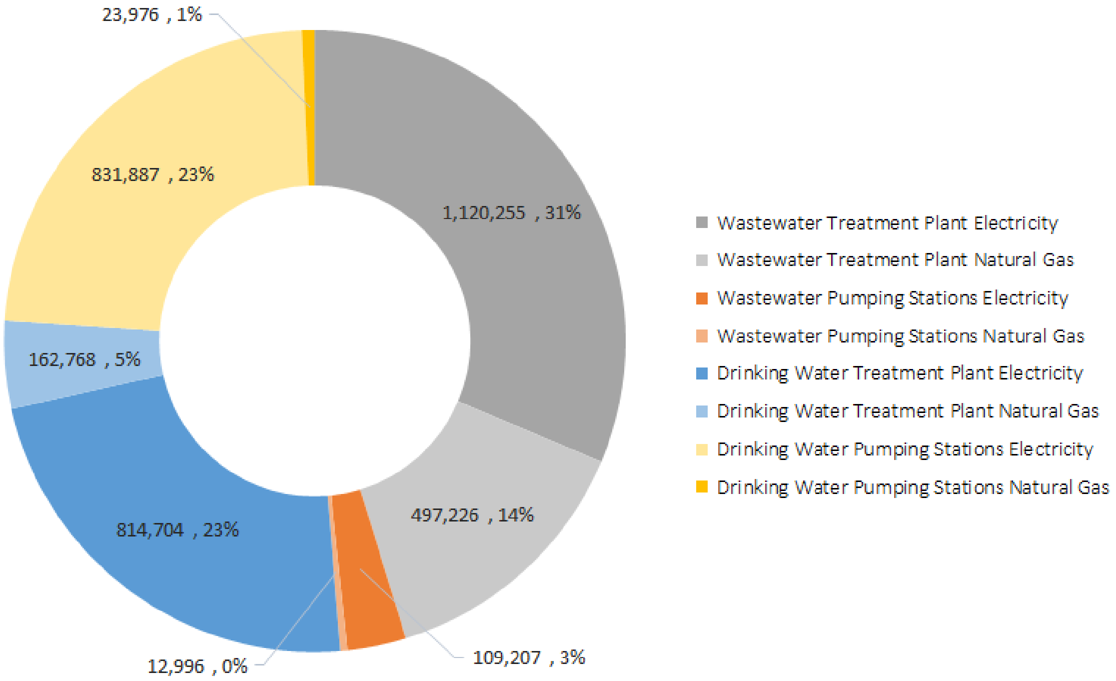
What do the Ontario Water Treatment Sectors Look Like Today?

The Ontario water treatment sectors are the largest municipal electricity consumers, representing more than a third of annual electricity consumption [2]. In Ontario, this electricity is being consumed by 423 drinking water treatment plants, 340 wastewater treatment plants and over 2,000 pumping stations.



Sector	Number of Facilities
Wastewater Treatment Plant	340
Drinking Water Treatment Plant	423
Wastewater Pumping Stations	1,246
Drinking Water Pumping Stations	990

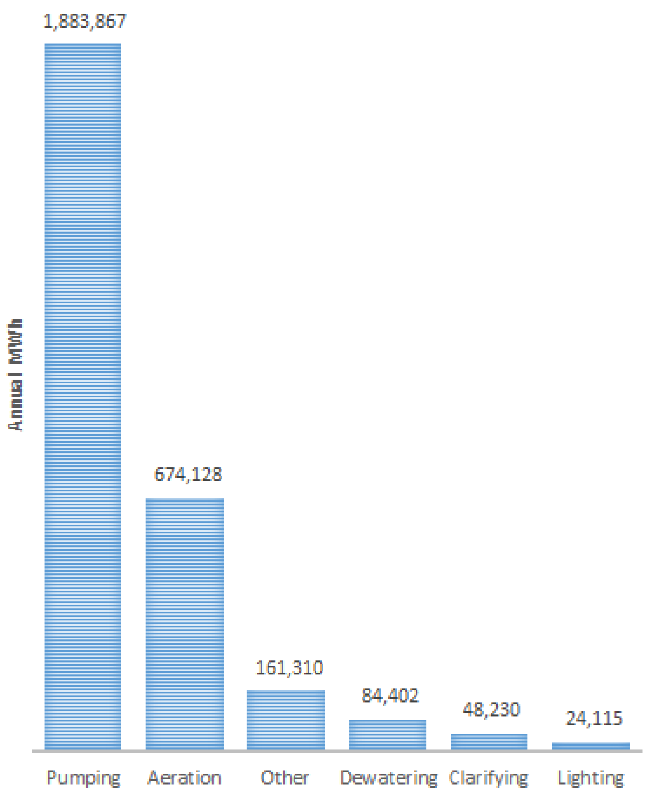
Annual electricity and natural gas consumption across all water treatment sectors in Ontario is approximately 3.57 eTWh (with annual electricity consumption representing 2.88 TWh). WWTPs consume most of this energy (45%).



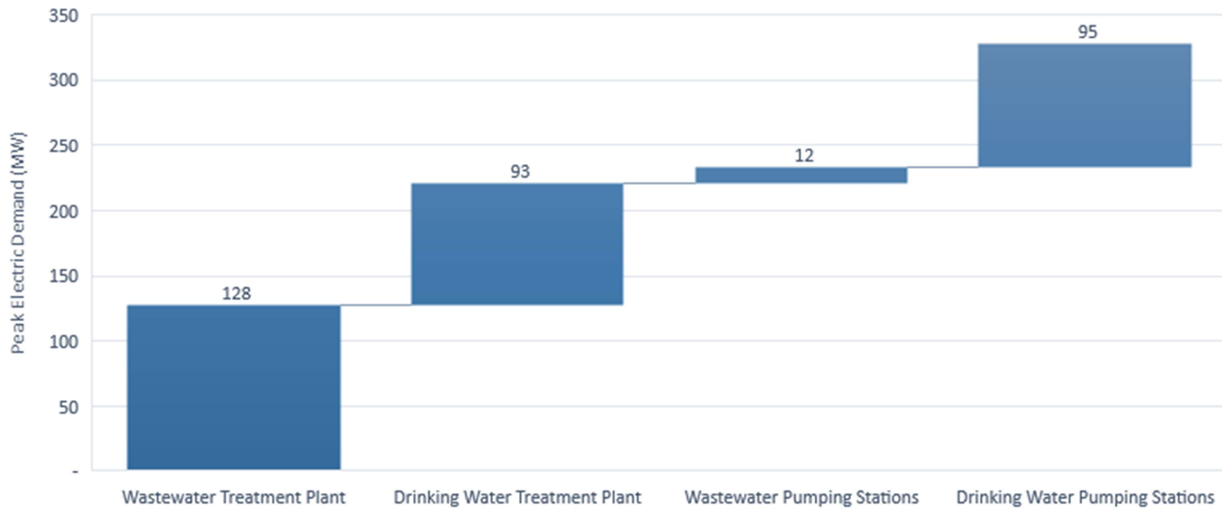
Annual GHG emissions in the water treatment sectors are approximately 0.58 Mt CO2e. Again, WWTPs represent most of these emissions (46%), with a footprint of 0.27 Mt CO2e.

A breakdown of electric energy consumption shows the biggest energy end-use in the water treatment sectors is pumping, representing 1.9 TWh (65% of all energy use), followed by aeration with 0.7 TWh (23%).

Pumping consists of many different pumping end-uses across different sectors (e.g., high-lift pumping in DWTPs, low-lift pumping in DWTPs, influent pumping in WWTPs).



Aggregate peak electric demand of all water treatment facilities in Ontario is approximately 0.33 GW. WWTPs represent most of this demand (39%), with an aggregate peak demand of 0.13 GW.



What Can Be Done?

Opportunities to improve performance and reduce costs exist. To maximize impact, decision-makers should start by focusing on these four areas:

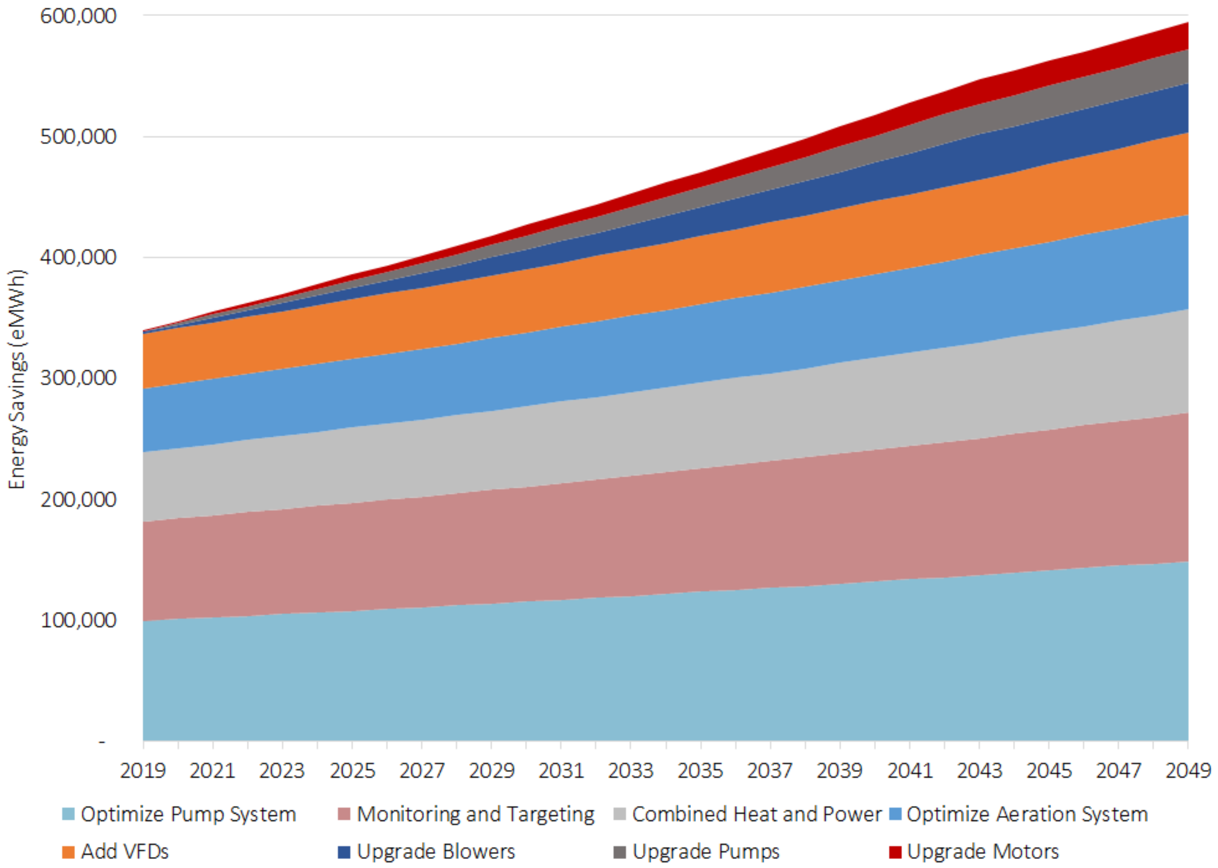
1. **Key Energy Savings Opportunities**: There are numerous energy consumption savings opportunities that pay for themselves in savings over their lifetime. In addition to equipment replacement, consider high-impact measures including monitoring and targeting, and system optimization.
2. **Key Electric Peak Demand Savings Opportunities**: In addition to energy-saving opportunities, electric peak demand can be reduced through load shifting and self-generation. Reducing peak demand can have a meaningful impact on your electricity costs and helps maintain the reliability of Ontario's power grid.
3. **Biogas Recovery** at WWTPs represents an opportunity to make productive use of a valuable energy source produced by your plant's existing process.
4. **Electricity Market Participation**: Taking control of your facility's electric peak demand unlocks the ability to pursue additional financial benefits.

These four areas are described further below.

Key Energy Savings Opportunities

A breakdown of potential energy consumption savings by measure shows that a systems approach is the most effective way to achieve significant savings in the water treatment sectors.

The biggest opportunity for energy savings is in **optimizing pumping systems**, followed by **monitoring and targeting**, **combined heat and power (CHP)** and **optimizing aeration systems**. Secondary to system optimization, but also notable are equipment replacement measures such as **pump**, **motor** and **blower upgrades.**



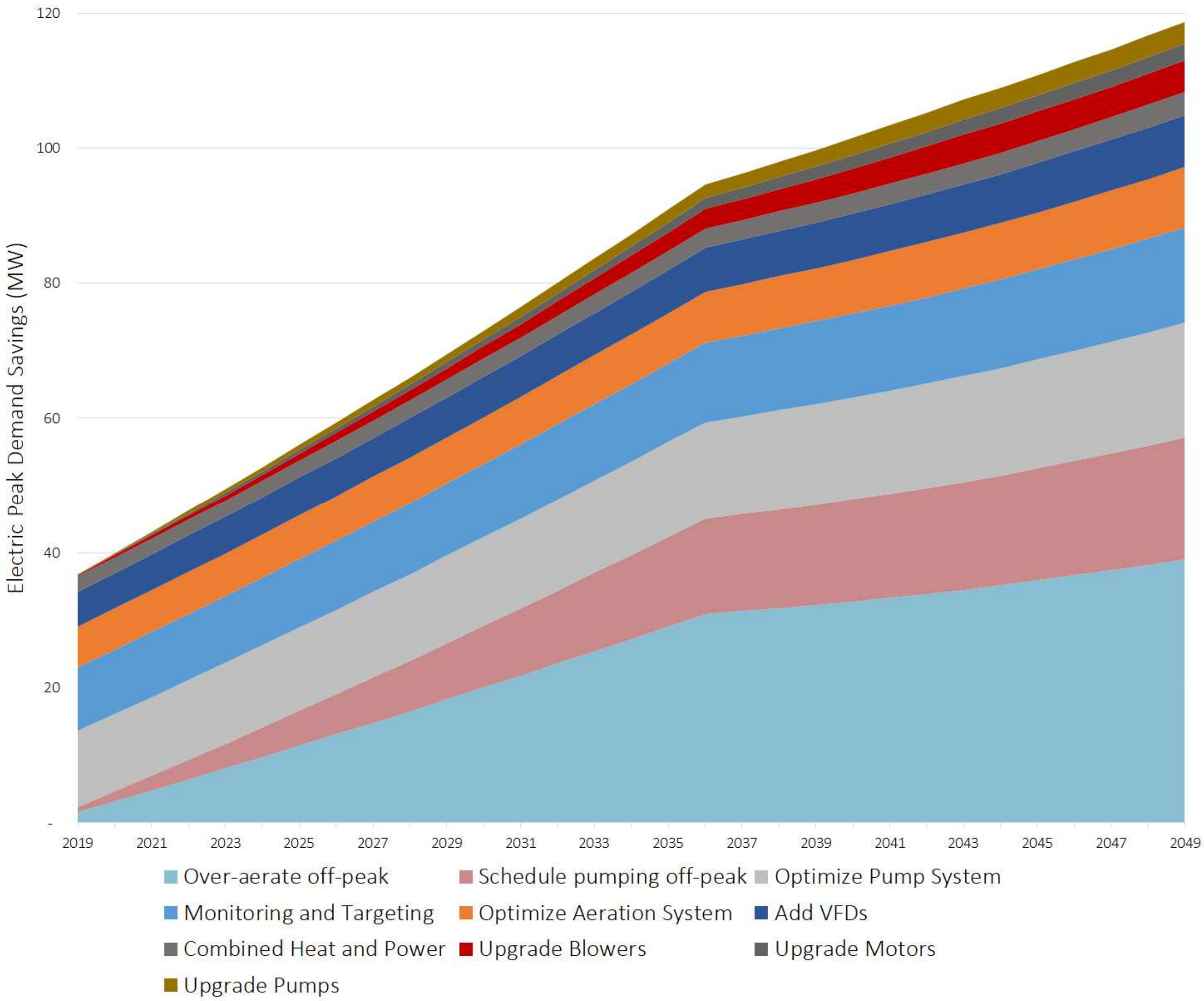
The total opportunity for energy consumption savings, for all study measures, across all sectors is 0.30 TWh in 2019, the first year of the study period. This is a 10% improvement over the base year (2018).

The total opportunity for energy consumption savings, for all study measures, across all sectors is 0.54 TWh in 2049, the final year of the study period. This is a 12% improvement over the reference case.

Key Electric Peak Demand Savings Opportunities

A breakdown of potential electric peak demand savings by measure shows the top five demand savings measures are systems-based measures.

In addition to the energy consumption savings measures, which also reduce electric peak demand, there are two key load-shifting measures (i.e., measures that move energy use from on-peak to off-peak times): **high-lift pump system storage** and **aeration system over-oxygenation**.



The total opportunity for electric peak demand savings, for all study measures, across all sectors is 37 MW in 2019, the first year of the study period. This is a 11% improvement over the base year.

The total opportunity for electric peak demand savings, for all study measures, across all sectors is 119 MW in 2049, the final year of the study period. This is a 24% improvement over the reference case.

- For **WWTPs**, the biggest energy consumption saving measure is combined heat and power (26%) closely followed by optimizing the aeration system (24%). The biggest electric peak demand savings measure is over-aerating off-peak (56%).
- For **DWTPs**, the biggest energy consumption saving measure is optimizing pumping systems (43%) followed by monitoring and targeting (23%). The biggest electric peak demand savings measure is scheduling pumping off-peak (60%).

- For **WW Pumping and DW Pumping**, the biggest energy consumption saving measure and electric peak demand savings measure is optimizing pumping systems (53%) followed by monitoring and targeting (18%).

Biogas Recovery at WWTPs

Biogas (i.e., methane) recovery represents a meaningful opportunity for medium and large WWTPs with anaerobic digestors. The embedded energy in recovered biogas can be used in one of four applications: 1) Heat production in gas heater systems; 2) Gas engine and gas turbine CHP systems; 3) Upgrading biogas to vehicle fuel quality; and 4) Upgrading biogas to renewable natural gas (RNG).

This report focuses on using biogas in a CHP system, the biggest electricity savings opportunity:

- Approximately 51 of the 340 WWTPs in Ontario currently have anaerobic digestors and are large enough to be good candidates for CHP systems;
- 15 of these plants already operate, or will soon be operating, CHP systems;
- Installation of CHP at the remaining plants represents **more than a quarter of the energy consumption savings** opportunity in the WWTP sector and **5% of the electric peak demand savings** potential for the sector.
- The total opportunity for savings from CHP is 86,000 eMWh and 3.4 MW in 2049, the final year of the study period.

Electricity Market Participation Opportunity

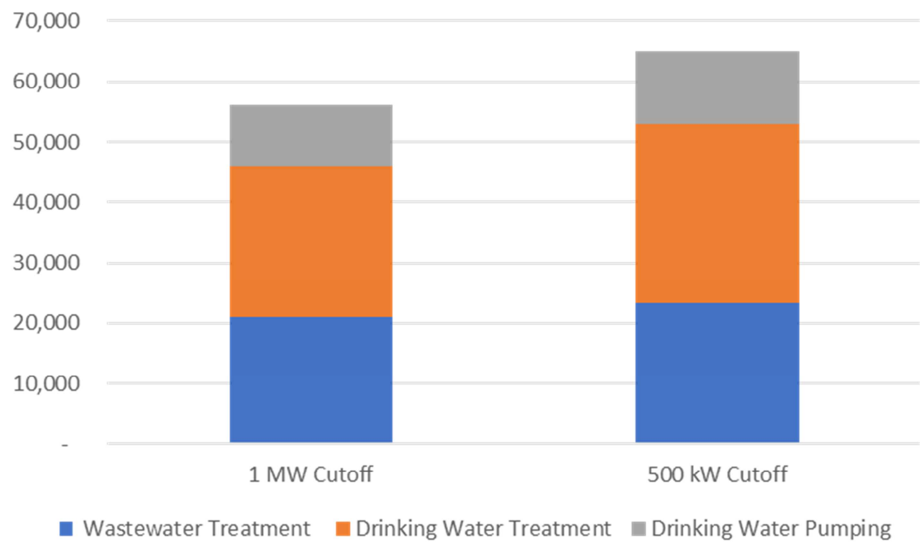
Electric peak demand savings potential represents an opportunity within the water treatment sectors. Through active market participation, facilities may pursue financial benefits beyond the value of savings that result from reduced electricity consumption and distribution charges.

As an illustrative example, we have assessed the potential for Industrial Conservation Initiative (ICI) participation and undertaken a high-level quantification of financial benefits applicable to the water treatment sectors.

WWTP, DWTP, WW Pumping and DW Pumping facilities with average peak demand above 1 megawatt (MW) are currently eligible to participate. Although the ICI eligibility threshold was reduced from 1MW to 500 kilowatt (kW) in 2017 for specific sectors, the water treatment sectors were not included [3]. The report analysis explores sector potential and benefits under two different scenarios:

1) WWTP, DWTP, WW Pumping and DW Pumping facilities currently eligible to participate in ICI; and
2) A broader group of facilities that could be eligible if the 500 kW threshold eligibility criteria were adjusted to include the water treatment sectors.

A comparison of electric peak demand savings potential by sector shows the difference between the 1MW and 500 kW cutoffs.



An electric peak demand savings potential of 56,300 MW for the 1MW cutoff represents Global Adjustment (GA) savings on the order of **$30 million/year** for the water treatment sectors, with a portion of these financial benefits already being realized by current ICI participants.

Electric peak demand savings potential of 65,100 MW for the hypothetical 500 kW cutoff translates into additional financial benefits, with a total benefit on the order of **$35 million/year**.

Call to Action

Information in this report will help Ontario municipalities and WWTP/DWTP facility operators make informed decisions to effectively:

- Lower their energy use and energy costs;
- Reduce their peak demand and do their part to improve reliability of the Ontario power grid; and
- Minimize GHG emissions.

By engaging with the IESO, municipal staff and facility operators can find out how to take advantage of programs and training offerings to capitalize on the full range of potential opportunities.

2 Acronyms

AD	Anaerobic Digestion
BPS	Broader Public Sector
BOD	Biological Oxygen Demand
CEPT	Chemically Enhanced Primary Treatment
CHP	Combined Heat and Power
DW	Drinking Water
DWTP	Drinking Water Treatment Plant
eMWh	Equivalent Megawatt-Hour
EUI	Energy Use Intensity
GA	Global Adjustment
GHG	Greenhouse Gas
GJ	Gigajoule
HHV	Higher Heating Value
ICI	Industrial Conservation Initiative
IESO	Independent Electricity System Operator
LDC	Local Distribution Company
LHV	Lower Heating Value
MWh	Megawatt-Hour
ML	Megalitre
NYSERDA	New York State Energy Research and Development Authority
OCWA	Ontario Clean Water Agency
PDF	Peak Demand Factor
PS	Pumping Stations
PSUP	Process & Systems Upgrade Program
RBC	Rotating Biological Contactor
RNG	Renewable Natural Gas
UV	Ultraviolet
VFD	Variable Frequency Drive
WW	Wastewater
WWTP	Wastewater Treatment Plant

3 Introduction

Water treatment represents the largest energy use for most municipal governments and over a third of municipal energy consumption in Ontario [1]. This study assesses provincial water treatment across four sectors, including wastewater treatment plants (WWTP), drinking water treatment plants (DWTP), wastewater pumping stations (WW Pumping) and drinking water pumping stations (DW Pumping).

Posterity Group worked with the Independent Electricity System Operator (IESO) to:

- Characterize the current and projected energy consumption, electric peak demand and GHG emissions for the water treatment sectors;
- Identify energy savings opportunities; and
- Quantify potential for conservation, electric peak demand reduction, load shifting, and GHG mitigation over the next 30 years.

There are numerous opportunities for the municipal water treatment sectors in Ontario to reduce energy consumption, lower electric peak demand, and minimize GHG emissions. The findings included in this study provide best-available energy and GHG data for decision makers, operations staff, and other industry stakeholders like the IESO and other provincial organizations. This information will help the organizations and individuals capitalize on the available opportunities.

This report has two intended audiences:

1) Primary audience - Ontario municipalities and WWTP/DWTP facility operators; and a
2) Secondary audience - key Ontario organizations that can influence change in the water treatment sectors.

The primary audience will be able to use this report to:

- Compare energy use at their facility to others in the province (Section 7);
- Understand the key opportunities applicable to their specific infrastructure, including energy savings measures (processes and technologies), biogas recovery using combined heat and power, load-shifting strategies, and market participation (Sections 9, 10 and 11); and
- Make informed decisions based on the energy efficiency and GHG mitigation potential associated with these opportunities (Section 11).

The IESO and other Ontario organizations will be able to use this report to:

- Understand the regulatory environment and processes associated with the Ontario water treatment sectors, as well as its energy profile and GHG footprint (Sections 4, 5, 6, and 7);
- Understand the unique barriers preventing these sectors from implementing the changes required to realize its energy savings potential (Sections 9 and 10);
- Understand the size of the opportunity in the province for energy savings from measures used in WWTP, DWTP, WW Pumping and DW Pumping (Section 11); and
- Support the sectors and facilitate the required changes (Section 12).

3.1 Data Sources

To estimate the baseline energy use for this study (see Section 6) and benchmark energy performance of facilities (see Section 7), Posterity Group used the following data sources:

- *Data reported by municipalities as part of the Broader Public Sector* (BPS) requirement under O.Reg. 397/11 [4].
- *Data provided directly by the Ontario Clean Water Agency* (OCWA). These data were more detailed than the BPS reported data and gives information on the plant process type in addition to flow and energy use.
- *Data provided directly by energy managers and plant operators* on the facilities they manage through telephone interviews and email correspondence with Posterity Group. These data were more detailed than the BPS reported data and gives information on the plant process type in addition to flow and energy use.

The BPS dataset was used to determine the total energy and the total flow in the WWTP, DWTP, WW Pumping and DW Pumping sectors in the province, however the dataset required cleaning and was supplemented using the other sources noted. Additional information regarding the use of these data sources and actions taken to improve data quality and usefulness are included in Appendix F.

3.2 Report Structure

The remainder of this report is organized as follows:

General Sector Information

4 Key Regulations and Processes for the Sectors

5 Biogas Recovery in WWTPs

Reference Case Information

6 Description of Ontario Facilities and Current Energy Use

7 Energy Benchmarking

8 Incentive Programs and Training Offerings

Energy Savings Opportunities and Potential

9 Energy Savings and GHG Mitigation Measures

10 Load-Shifting Measures

11 Potential for Energy and GHG Savings

The report finishes with Key Findings and Recommendations. Appendices include additional reference information.

4 Key Regulations and Processes for the Sector

This section describes the applicable regulations and key processes used to treat drinking water and wastewater in Ontario. The information provided below is meant to be a high-level introduction. Please see the referenced sources for a more information on each topic.

4.1 Applicable Regulations

The following are some of the key provincial acts and regulations that specifically apply to DWTP and WWTP:

- Clean Water Act – help protect drinking water by stopping contaminates from entering drinking water sources.
- Municipal Water and Sewage Transfer Act – transferred ownership of provincially-owned and operated DWTP and WWTP from OCWA to municipalities; some municipalities chose to continue having OCWA operate their facilities.
- Ontario Water Resources Act – to provide for the conservation, protection and management of Ontario's waters; applies to water, wells and sewage works.
  - O.Reg 129/04: Licensing of sewage works operators
- Safe Drinking Water Act – Regulates drinking water systems and drinking water testing.
  - O.Reg. 128/04: Certification of drinking water system operators and water quality analysts
- Water Opportunities Act – purpose is to foster innovative DW and WW technologies, services and practices, and to conserve and sustain water resources.

Aspects of the following regulations may apply to DWTP and WWTP in Ontario:

- Environmental Assessment Act – public sector projects are subject to this Act, including municipal water and sewage projects; applicable projects must identify ecological, social, cultural and economic impacts that may arise from the project.
- Environmental Protection Act – main pollution control regulation for the province; includes provisions to protect surface water and groundwater from contamination.
- Green Energy Act[1] – fosters renewable energy projects, ensures public sector organizations conserve energy and use it efficiently, and promote energy efficiency.
  - O.Reg 20/17: Reporting of Energy Consumption and Water Use
  - O.Reg. 397/11: Energy Conservation and Demand Management Plans

4.2 Key Processes to Treat Drinking Water

Drinking water must be treated to meet provincial regulations. Water is treated to remove particles, bacteria and viruses to make it safe for people to consume. Treatment usually involves a combination of

[1] On December 6th, the Green Energy Repeal Act received royal assent. Discussion of the Green Energy Act is included in here as its impact is relevant to the study.

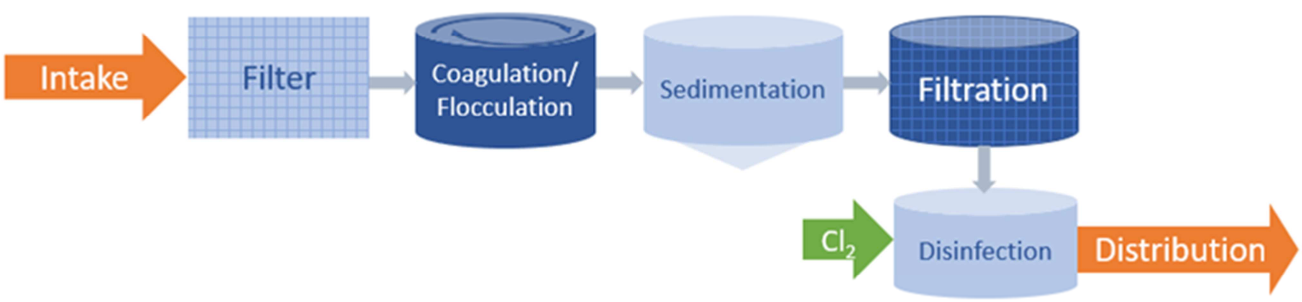
physical (i.e., filtering) and chemical processes. The processes used to treat drinking water vary by municipality and depend on the source of the water (ground or surface). According to Environment Canada's 2011 Municipal Water Use Report, about 90% of Ontario's water comes from surface water sources [5].

Given the variability in drinking water treatment processes, two examples are provided to illustrate the treatment of surface water and groundwater. Section 6 discusses the energy requirements of the major processes and the associated equipment.

The City of Ottawa's process is used as an example of *surface water treatment* [6]:

1. **Intake & Screening:** Low-lift pumps are used to bring water into the DWTP. Screens filter out solid objects.
2. **Coagulation & Flocculation**: Smaller solids such as bacteria and algae are captured.
3. **Sedimentation:** Water is held in a settling tank so heavy particles sink to the bottom and clear water is collected.
4. **Filtration:** Pumps are used to pass the water through many filters to capture fine particles, and to back-wash the filter media periodically.
5. **Primary Disinfection & pH Correction**: Chlorine is used to disinfect the water and the pH is adjusted.
6. **Secondary Disinfection & Fluoride:** Chloramine is added to the water as a mild disinfectant and fluoride is added.
7. **Testing:** Water quality is tested.
8. **Distribution**: High-lift pumps pump water into reservoirs and through water mains.

Exhibit 1 – Drinking Water Treatment Process: Example for Surface Water



The City of Barrie's process is used as an example of *groundwater treatment* [7]:

1. **Pumping:** Water is pumped from the groundwater source via small drilled wells.
2. **Disinfection:** The water is disinfected using chlorine.
3. **Iron Removal:** Iron is removed from the water using sodium silicate.
4. **Storage:** The water is now ready to be used. It is pumped into water towers and reservoirs for storage.

4.3 Key Processes to Treat Wastewater

Municipal wastewater systems collect wastewater through the sewer system, which sends wastewater to a WWTP for treatment. This section discusses the process to treat wastewater in a WWTP prior to releasing it into a body of water. Section 6 discusses the energy requirements of the major processes and the associated equipment.

The majority of wastewater is water, with solids being a small portion [8]. Wastewater is treated to create an 'effluent' that is clean enough to discharge back into the natural environment. Wastewater must be treated according to provincial regulations in order to protect the health of people and the natural environment [9].

There are five key stages of treatment for wastewater [10] [9] [8] [11]:

1. *Pre-treatment* (sometimes called preliminary treatment): Wastewater is sent to the treatment plant where large objects are removed using screens. The wastewater is put in tanks to then separate out more solids such as rocks and sand. Energy use in this stage comes mainly from the influent pumps.

2. *Primary treatment*: Wastewater is pumped into a tank where smaller solids can settle and be removed. Materials that float are also removed during primary treatment. Primary treatment employs the following energy-using equipment [12]:
    - Sludge and skimmer collection drives and pumps,
    - Skimming pumps and grinders,
    - Channel aeration blowers, and
    - Exhaust and supply fans.

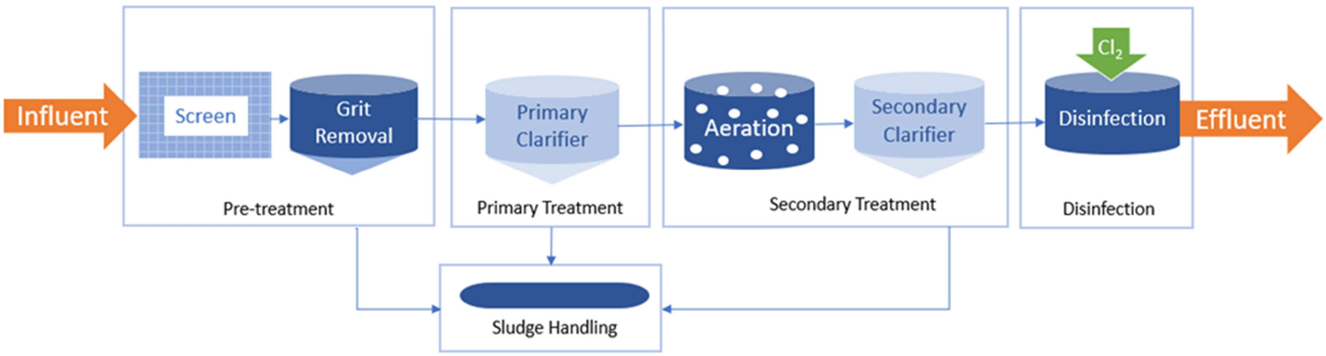
3. *Secondary treatment:* Bacteria that naturally occur in the wastewater are used to help treat organic pollutants when wastewater is mixed with bacteria and oxygen. Aeration systems are required to add oxygen to the effluent. Energy use in this stage comes mainly from sludge aeration and secondary clarifiers. Two processing methods that can be used during secondary treatment that are discussed in subsequent sections of the report are:

- *Lagoons (or ponds):* Lagoons are often used during secondary treatment as a place for biological treatment of wastewater to occur. There are two main types of lagoons:
    - Stabilization or Anaerobic Lagoons: A pond about three metres deep where wastewater digests anaerobically.
    - Facultative Lagoons: A pond, normally about two metres deep, where wastewater digests anaerobically (at the bottom of the pond) and aerobically (near the top of the pond) [13] [14].
- *Rotating Biological Contractor* (RBC): An RBC is an "array of discs" that is placed inside of a wastewater treatment tank for use during secondary treatment. The discs slowly rotate through the wastewater so that bacteria attach to the discs, creating a film of biomass. When the discs rotate out of the wastewater and pass through air, the biomass will conduct biological degradation of the organic pollutants in the wastewater [15].

4. *Tertiary treatment:* Any remaining dissolved solids (e.g., metals) and chemicals are removed.

5. *Disinfection:* Some WW is disinfected prior to being released into a body of water, typically using chlorine or ultraviolet irradiation.

Exhibit 2 – Wastewater Treatment Process Illustration



The level of treatment applied to WW depends on the municipality [16].

4.3.1 Treatment of Wastewater Solids (sludge)

The solids that are removed during the treatment of wastewater (called 'sludge') must also be handled. The following processes are used to treat and manage sludge [12]:

- *Solids Dewatering*: Removing liquid from the sludge.
- *Sludge Digestion*: Sludge is 'stabilized' through digestion in order to reduce the volume of sludge. There are two forms of digestion: anaerobic or aerobic [17].
- *Anaerobic digestion*: Bacteria consume organic matter and turn it into water, carbon dioxide and methane. Anaerobic digestion occurs without oxygen, in an enclosed space. The mixture of methane and carbon dioxide – called biogas – can be used as an energy source. If sludge is treated anaerobically, additional energy use for process heating is required.
- *Aerobic digestion*: Bacteria consume organic matter and turn it into water, carbon dioxide and other gases. Aerobic digestion occurs in the presence of oxygen.
- *Drying or incineration*: Sludge is either dried or incinerated.

Section 5 discusses biogas recovery in WWTPs with anaerobic digestion in more detail.

5 Biogas Recovery in WWTPs

Biogas recovery (i.e., methane recovery) represents a meaningful opportunity for those WWTPs with a large enough treatment volume to make biogas recovery measures economically attractive. The big opportunity is leveraging the embedded energy in the recovered biogas. As described below, the GHG reductions are mainly related to offsetting electricity and natural gas consumption, rather than a reduction in on-site methane emissions.

Plants that digest sludge with anaerobic digestors are the best candidates for methane capture. Plants that currently have aerobic digestors are also potential candidates, however their process must be modified to include an anaerobic digestor.

Plants that do not recover biogas are required to flare it for safety reasons [18]; effectively converting methane to carbon dioxide through combustion.

Therefore, for this study we:

- Focus on understanding the potential to leverage methane at plants that already have anaerobic digestors;
- Assume recovered biogas would have been flared if it were not recovered for productive use[2] [19], [20]; and
- Assume the difference is GHG emissions between flaring and combustion post-recovery is negligible.

This section describes how biogas is produced and recovered at WWTPs and presents four key ways biogas can be used productively by municipalities:

1) Heat production in gas heater systems
2) Gas engine and gas turbine combined heat and power (CHP) systems
3) Upgrading biogas to vehicle fuel quality
4) Upgrading biogas to renewable natural gas (RNG)

This study focuses on the opportunity for municipalities to recover biogas and use it in an on-site CHP system. As outlined in more detail in Section 6.2 - Wastewater Treatment Plants and Section 9.9 - CHP from Methane Capture, we estimate that approximately 51 of the 340 WWTPs in Ontario currently have anaerobic digestors and are large enough to be good candidates for CHP systems. Details on potential for energy consumption, electric peak demand and emission savings are presented in Section 11.

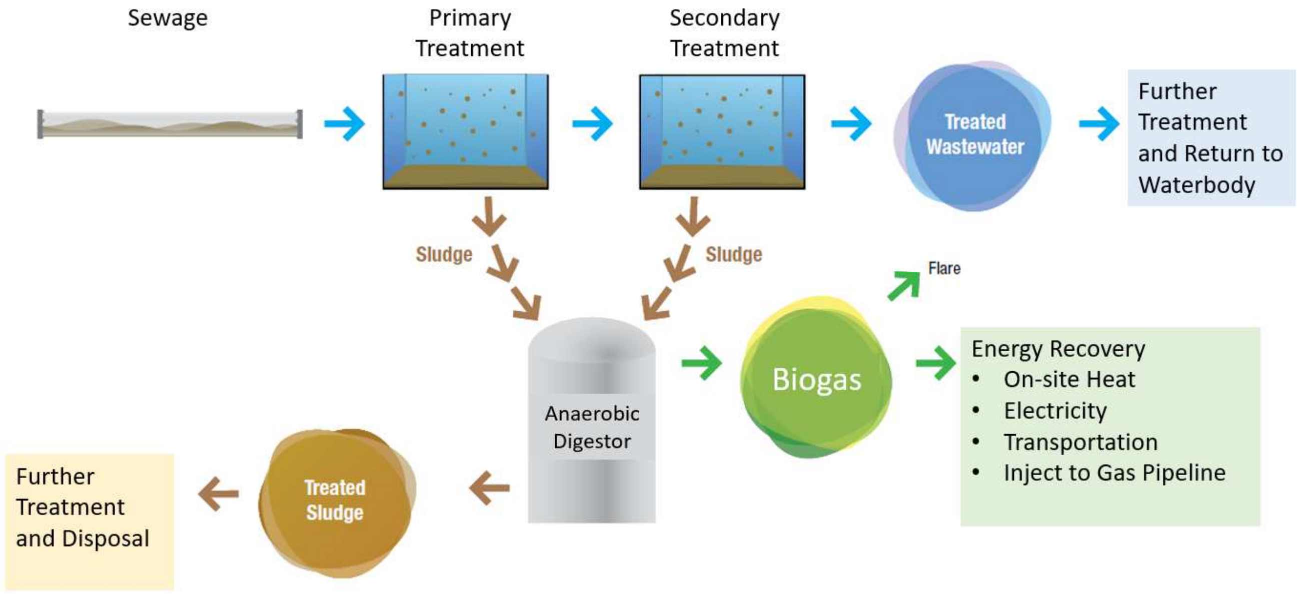
5.1 Biogas Production

Wastewater includes organic material that can be broken down by bacteria into the two most common greenhouse gases: methane and/or carbon dioxide. As shown in Exhibit 3, organic matter that is filtered from the wastewater stream can be further treated through a stage known as anaerobic digestion (AD). AD occurs in a closed vessel that excludes oxygen. It converts 50-60% of the biodegradable organic material to biogas and creates a smaller volume of residual treated sludge. AD is primarily used to

[2] Based on discussions with Ontario market actors and consistent with the EPA's assumptions for WWTP in the United States, we assume that biogas is either utilized or flared. IPCC guidelines regarding wastewater treatment state that "emissions from flaring are not significant, as the CO2 are of biogenic origin, and the CH4 and N20 emissions are very small."

reduce solid waste and the cost of its disposal. It also presents an opportunity to recover energy through the capture of biogas. The biogas produced typically contains 55-75% methane, and 24-44% carbon dioxide [1].

Exhibit 3 – Anaerobic Digestion and Energy Recovery from Wastewater Treatment [1]



5.2 Biogas Applications

Biogas produced by AD has several applications:

- **Heat production in gas heater systems –** Gas heater/boiler systems do not necessarily require high-quality gas. However, it is recommended to reduce the hydrogen sulfide (H_2S) content to below 1,000 ppm to prevent corrosion and to condense the water vapour in the gas to prevent interference with the gas nozzles [17] [21].
- **Gas engine and gas turbine CHP systems –** Using biogas in internal combustion engines is a well-established and reliable technology. Gas engines also do not necessarily require high-quality gas, however, like boilers, lower H_2S levels facilitate longer engine life. Large scale applications typically use diesel engines rebuilt into a spark ignited gas engine or a dual fuel engine with 8-10% diesel injection [17] [21].
- **Upgrading biogas to vehicle fuel quality –** Biogas can be upgraded for use in existing engines and vehicles suitable for natural gas. Sulfur, water, and particles must be removed to prevent corrosion and mechanical engine damage. Carbon dioxide should also be removed to reach a required methane content of 96-97 vol% [17] [21].
- **Upgrading biogas to renewable natural gas (RNG) –** Biogas can be upgraded and injected into the natural gas distribution network. Extensive dewatering, removal of sulfur, and removal of halogens are required to reach the necessary quality for natural gas injection. It is necessary to remove carbon dioxide to attain a calorific value and 'Wobbe index' similar to natural gas [17] [21].

Exhibit 4 summarizes gas quality requirements for these four applications.

Exhibit 4 – Gas Quality Requirements for Various Applications [17]

	H_2S	CO_2	Halogens (Cl, F)	Dust Particles	H_2O
Gas Boiler	< 1000 ppm	-	-	-	Removal Advisable
Gas Engine	<700-1200 mg/m^3	LHV 13-21 MJ/m^3	60-80 mg/m^3	<30 mg/m^3	Humidity <70-80%
Vehicle Fuel	Max. 23 mg/m^3	Max 3 vol%	Removal Required	-	Max 32 mg/m^3
RNG	<5 mg/m^3	Max 3 vol%	Cl <5 mg/m^3	Removal Required	Dew point at -10 ^oC

5.3 Ontario Plants with CHP

Exhibit 5 on the next page presents details of current CHP systems at Ontario WWTPs. The table is based on information provided by the Canadian Biogas Association and the ECO survey [1] [22]. Flow information is estimated from Broader Public Sector data reported by municipalities [23].

Barrie's CHP System

Barrie's wastewater treatment plant generates electricity from biogas produced on-site. A 250 kW CHP engine supplies about 20-30% of the plant's electricity which saves the facility about $150,000 each year in energy costs [106].

The City is currently examining how to optimize biogas through new or modified facilities to utilize surplus biogas and generate additional electricity [98] [102].

Exhibit 5 – Ontario Wastewater Treatment Plants with CHP

Municipality	Electrical Co-generation Capacity (kW)	Annual Flow of Wastewater Treated (ML)
Barrie	500	17,700
Chatham-Kent	250	Unknown
Collingwood	65	4,999
Guelph	500	18,537
Hamilton	1,600	105,464
Kingston (Ravensview)	370	19,373
Mississauga – Clarkson (in development)	1,400	69,026
Ottawa	2,400	143,080
Peterborough	380	14,383
Thunder Bay	600	29,396
Toronto – Humber	4,700	98,174
Waterloo Region (to be completed in 2020)	1,200 (3 plants combined)	291,333

6 Description of Ontario Facilities and Current Energy Use

This section describes how energy is currently used in the water treatment sectors in Ontario. Energy use estimates are presented for a base year of 2018. The section is organized into four sub-sections:

- Section 6.1 presents base year energy use for all sectors (WWTP, DWTP, WW Pumping and DW Pumping).
- Section 6.2 presents base year energy use in WWTPs.
- Section 6.3 presents base year energy use in DWTPs.
- Section 6.4 presents base year energy use in pumping stations for both wastewater and drinking water.

As discussed in Section 3.1, Posterity Group used the following data sources to estimate the base year energy use:

- Data reported by municipalities as part of the Broader Public Sector (BPS) requirement under O.Reg. 397/11 [4].
- Data provided directly by the Ontario Clean Water Agency (OCWA).
- Data provided directly by energy managers and facility operators on the plants they operate.

In each section, an estimate of total annual energy use (MWh/year) and total volume of water treated (ML/year) for a base year of 2018 was made. For WWTPs and DWTPs, energy use was further broken down based on end uses present within typical plants. Base year energy use and flow are presented by IESO zone in Appendix C.[3]

[3] In contrast, the sector dataset did not allow energy savings potential analysis outputs, presented in section 11, to be segmented by IESO zone; this is because energy savings potential analysis relied on the OCWA data to estimate savings by plant type, and this anonymized OCWA data does not enabled segmentation by IESO zone.

6.1 Summary of Base Year Energy Use

Exhibit 6 presents the total GHG emissions, electric peak demand, and energy consumption for both electricity and natural gas in each sector in Ontario, for the base year 2018. Exhibit 7 presents the total flow for the baseline year of 2018.

Exhibit 6 – Base Year Emissions and Energy Use by Sector (2018)

Sector	Number of Facilities	Total Emissions (tonnes CO2e)	Aggregate Electric Peak Demand (MW)	Total Electricity Use in Ontario (eMWh/year)	Total Natural Gas Use in Ontario (eMWh/year)	**Total Energy Use (eMWh/year)**
Wastewater Treatment Plant	340	267,397	128	1,120,255	497,226	1,617,481
Drinking Water Treatment Plant	423	158,673	93	814,704	162,768	977,472
Wastewater Pumping Stations	1,246	19,681	12	109,207	12,996	122,202
Drinking Water Pumping Stations	990	136,419	95	831,887	23,976	855,863
All Sectors	**2,999**	**582,171**	**328**	**2,876,053**	**696,965**	**3,573,018**

Exhibit 7 – Base Year Flow by Sector (2018)

Sector	Number of Facilities	Flow (ML/year)
Wastewater Treatment Plant	340	2,056,908
Drinking Water Treatment Plant	423	3,098,136
Wastewater Pumping Stations	1,246	620,235
Drinking Water Pumping Stations	990	3,500,516

Exhibit 8 presents a visual representation of the breakdown of energy consumption in the WWTP, DWTP, WW Pumping and DW Pumping sectors in Ontario, for the base year 2018, for all fuel types. Exhibit 9 shows energy use broken-down by sector and fuel type.

Exhibit 8 – Breakdown of Energy Consumption (eMWh/year) by Sector (2018)

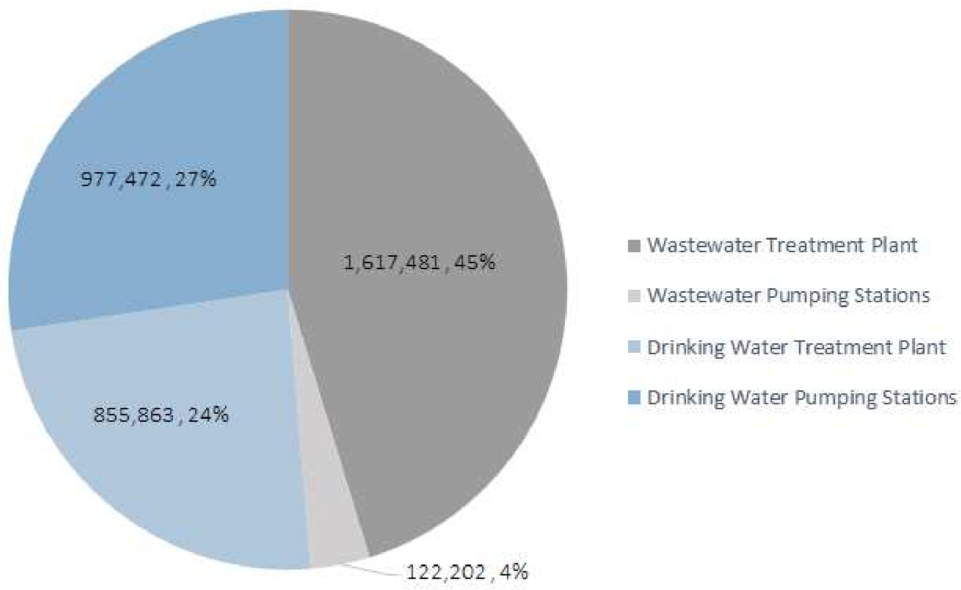


Exhibit 9 – Breakdown of Energy Consumption (eMWh/year) by Sector and Fuel (2018)

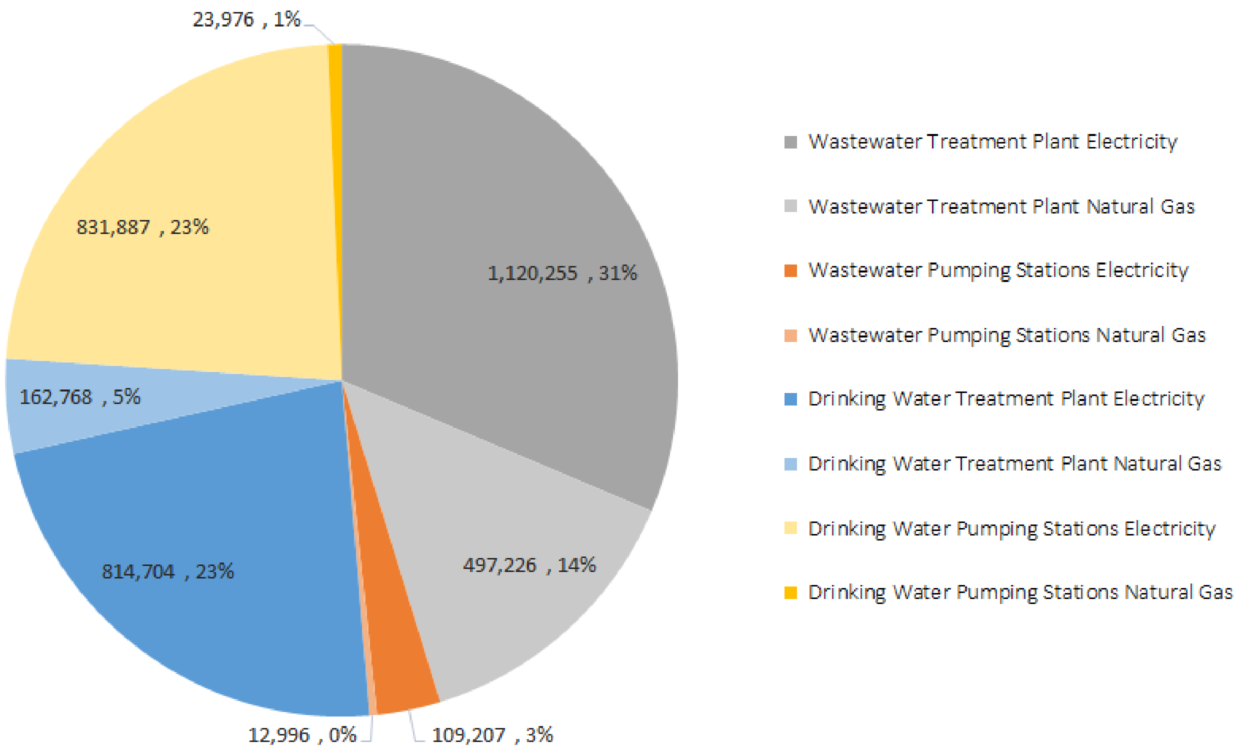


Exhibit 10 is a visual representation of the breakdown of base year *electric* energy consumption in Ontario's WWTP, DWTP, WW Pumping and DW Pumping sectors, by end-use category. The biggest end-use is pumping (~65%) followed by aeration (23%). Note that pumping is an end-use category and consists of many different pumping end-uses across different sectors (e.g., high-lift pumping in DWTPs, low-lift pumping in DWTPs, influent pumping in WWTPs).

Exhibit 10 – Breakdown of Electricity Consumption (MWh/year) by End-Use Category (2018)

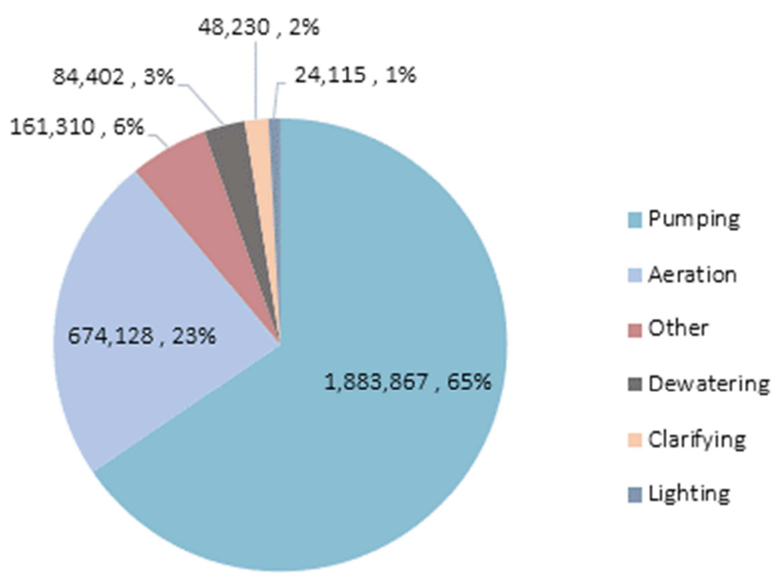
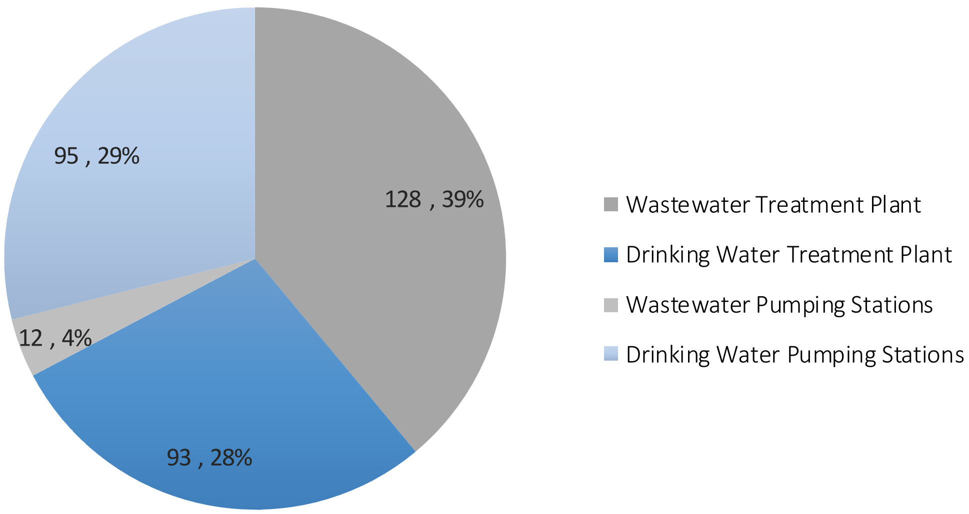


Exhibit 11 presents a visual representation of the breakdown of electric peak demand by sector for the base year.

Exhibit 11 – Breakdown of Electric Peak Demand (MW) by Sector in Ontario (2018)



6.2 Wastewater Treatment Plants

This section describes the energy use in Ontario's wastewater treatment plants, including a description of the major energy using processes in WWTPs, and how this sector was broken into segments to model potential energy and GHG savings.

6.2.1 Description of Major Energy Using Processes

Exhibit 12 presents the nine major energy end uses in Ontario's WWTPs and their associated equipment [24].

Exhibit 12 – WWTP Major Energy End Uses

End Use	Description	Associated Equipment
Influent Pump Station	Water is pumped into the pre-treatment process.	Pumps, Motors
Primary Clarifier and Sludge Pump	Primary treatment process. After the effluent is screened it is sent to the primary clarifier where sludge settles at the bottom of the tank. Sludge is sent to solids handling and water is pumped to secondary treatment.	Pumps, Motors
Activated Sludge Aeration	Adding air to wastewater to facilitate biological decomposition of organic matter.	Blowers, Motors
Secondary Clarifier	Secondary treatment process. After aeration, water is sent to the secondary settling tank, where sludge is removed from the bottom of the tank.	Motors, Pumps
Solids Dewatering	Sludge treatment, removing excess water through a centrifuge, rotary drum, or belt press.	Motors
Anaerobic Digestion Process Heating	Sludge is heating in a reactor until organic material has broken down into methane and carbon dioxide. Only present in plants that treat sludge through anaerobic digestion.	Boilers
Space Heating	Provides space heating in the plant	Boilers
Lighting	Provides lighting in the plant	Lighting
Other	Includes: chlorine mixing, thickener and sludge pump, headworks and effluent filters, UV disinfection. There are also buildings associated with the end uses above that would require supply and exhaust fans and space cooling.	N/A

6.2.2 WWTP Segments

For the purposes of analysis, WWTPs in Ontario were broken into segments based on characteristics of the plant that affect energy use and applicable upgrade measures.

WWTPs were separated into segments using three criteria: Plant size, sludge digestion method and presence/absence of aeration. These criteria and the divisions used are described in Exhibit 13.

Exhibit 13 – Criteria for Defining WWTP Segments

Criteria	Classification	Description
Plant Size	Small	Average daily flow of sewage treated is < 5,000 m^3/day. Plants of this size are not candidates for energy recovery from methane capture [1].
	Medium/Large	Average daily flow of sewage treated is ≥ 5,000 m^3/day. Plants of this size are candidates for energy recovery from methane capture, including cogeneration of heat and electricity, as discussed in section 5. [1]
Sludge Digestion	No Digestion	These plants do not process sludge through aerobic or anaerobic digestion and are not candidates for energy recovery through methane capture.
	Aerobic Digestion	These plants process sludge through aerobic digestion. These plants are candidates for methane capture if the aerobic digestion system is modified to an anaerobic system that produces methane.
	Anaerobic Digestion	These plants are candidates for methane capture. About 65% of wastewater in Ontario is processed through anaerobic digestion.[4]
Aeration System	Aeration	WWTPs that have an aeration system. Almost all wastewater in Ontario (99.9%) is processed in a plant that has an aeration system[4].
	No Aeration	WWTPs that do not have an aeration system. Very few plants in Ontario fall into this category, only lagoons and RBC treatment processes [24].

Plant Size: Plants were divided by size, based on whether they are candidates for energy recovery from methane capture. Small plants (<5,000 m^3 of sewage treated per day) are generally not good candidates for cogeneration without additional organic inputs from offsite [1]. For the energy savings analysis, the CHP measure is only applied to plants in the Medium/Large size category.

Sludge Digestion: Plants are divided based on how they process sludge. Plants with anaerobic digestors are potential candidates for methane capture. Plants that have aerobic digestors are also potential candidates, however their process must be modified to include an anaerobic digestor, which is not typically economically attractive [24]. Plants with no digestion are not candidates for methane capture [24]. For the energy savings analysis, the CHP measure is only applied to plants that currently have anaerobic digestion.

Aeration System: Aeration is the largest energy end use in most of Ontario's WWTPs. However, there are a small number of plants (lagoon and RBC type) that are not mechanically aerated. For the energy potential savings analysis, it is important to separate these plants, since the aeration system measures cannot be applied.

[4] See Section 6.2.3 for data sources

6.2.3 Breakdown of Base Year Energy Use

As previously explained, data from OCWA and the BPS reporting requirement were used to estimate which WWTP types are present in Ontario and how much energy each segment consumes.

Using the criteria and classification divisions in Exhibit 13 yields 12 possible WWTP segments. In practice some combinations do not, or rarely, exist. This analysis retains eight different WWTP categories. These segments are listed in Exhibit 14 below, along with the number of facilities classified under each category and estimates of total volume of wastewater treated per year. Energy consumption includes energy from both electricity and natural gas.

Exhibit 14 – Base Year Energy Use by WWTP Segment (2018)

Plant Size	Aeration	Sludge Digestion	Number of Facilities	Volume of Wastewater Treated (ML/year)	Total Energy Use in Ontario (eMWh/year)	% Total Energy Use
Small	No Aeration	Aerobic	3	559	842	<1%
		No Digestion	6	699	200	<1%
	Aeration	Aerobic	162	64,300	91,166	5.6%
		Anaerobic	24	21,483	25,261	1.6%
		No Digestion	44	27,561	21,239	1.3%
Medium/ Large	Aeration	Aerobic	45	595,365	337,714	21%
		Anaerobic	51	1,340,605	1,140,382	71%
		No Digestion	6	6,337	677	<1%
		Total	**340**	**2,056,908**	**1,617,481**	**100%**

Exhibit 15 shows how much energy use is attributed to each of the end-uses and plant types. It is assumed that all non-natural gas end uses are purely electric. These numbers were calculated using the numbers in Exhibit 14 above, and then disaggregating based on end use. The percentage of energy allocated to each end use was determined by taking the values given in *Wastewater Engineering: Treatment and Resource Recovery* [25] and through conversations with industry experts [24]. There are some exceptions to the typical energy use breakdown. For example, plants with anaerobic digestors have an end-use for process heating, and plants without aeration do not have activated sludge aeration as an end-use.

Exhibit 15 – Base Year Energy Breakdown by WWTP Segment and End Use (2018)

WWTP Segment			Typical Energy Consumption by End Use (MWh/year)								
Plant Size	Aeration	Sludge Digestion	Influent Pump Station	Primary Clarifier and Sludge Pump	Activated Sludge Aeration	Secondary Clarifier	Solids Dewatering	Lighting	Natural Gas	Other Electricity	Grand Total
Small	No Aeration	Aerobic	63	158	-	63	110	32	259	158	842
		No Digestion	15	37	-	15	26	7	61	37	200
	Aeration	Aerobic	2,716	6,789	38,020	2,716	4,753	1,358	28,025	6,789	91,166
		Anaerobic	753	1,881	10,535	753	1,317	376	7,765	1,881	25,261
		No Digestion	633	1,582	8,858	633	1,107	316	6,529	1,582	21,239
Medium/ Large	Aeration	Aerobic	10,060	25,150	140,842	10,060	17,605	5,030	103,816	25,150	337,714
		Anaerobic	33,971	84,927	475,591	33,971	59,449	16,985	350,562	84,927	1,140,382
		No Digestion	20	50	283	20	35	10	208	50	677
Total			**48,230**	**120,575**	**674,128**	**48,230**	**84,402**	**24,115**	**497,226**	**120,575**	**1,617,481**

Exhibit 16 gives a visual representation of the breakdown of electricity consumption by end use in all WWTPs in Ontario. Activated sludge aeration accounts for the majority of total sector electricity use (~60%).

Exhibit 16 – Base Year Electricity Use in WWTPs (MWh/year) in Ontario by End Use [1], [24]

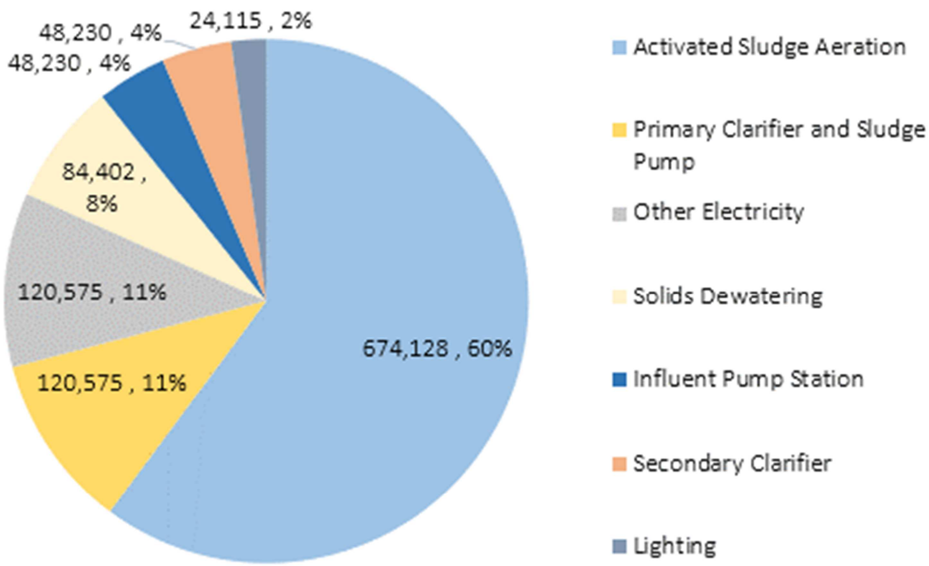
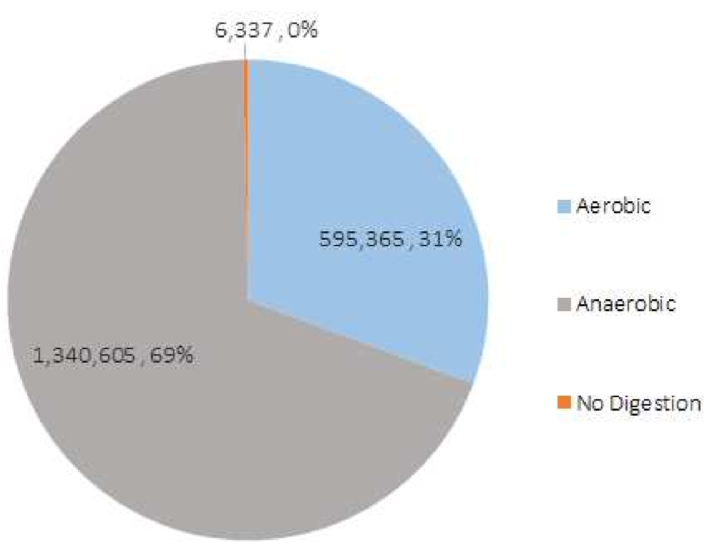


Exhibit 17 shows the volume of wastewater in Ontario that is currently treated by sludge digestion process for plants in the medium/large size category. This is significant because it shows that plants representing 69% of treated volume are currently using anaerobic digestion, making them candidates for methane capture and installation of CHP equipment.

Exhibit 17 – Base Year Volume of Wastewater Treated (ML/year) in Medium/Large WWTPs in Ontario by Sludge Digestion Process



6.3 Drinking Water Treatment Plants

This section describes the current energy use in Ontario's DWTPs. This includes a description of the major energy using processes in DWTPs, and how this sector was broken into segments for the purposes of modelling potential energy and GHG savings.

6.3.1 Description of Major Energy Using Processes

Exhibit 18 presents the six major energy end uses in DWTPs in Ontario and their associated equipment.

Exhibit 18 – DWTP Major Energy End Uses

End Use	Description	Associated Equipment
Low-Lift Pumping	Low-lift pumps draw the water from its source into the treatment plant	Pumps, Motors
Backwash Pumping	Backwash pumps are used to clean the filters	Pumps, Motors
High-Lift Pumping	High-lift pumps move treated water into the water distribution system and reservoirs	Pumps, Motors
Space Heating	Provides space heating in the plant	Boilers
Lighting	Provides lighting in the plant	Lighting
Other	Includes: chlorine mixing, UV disinfection	Various

6.3.2 DWTP Segments

For the purposes of analysis, DWTPs in Ontario were separated into segments using two criteria affecting energy use: Plant Size and Water Source. These criteria and the divisions used are described in Exhibit 19.

Exhibit 19 – Criteria for Defining DWTP Segments

Criteria	Classification	Description
Plant Size	Small	Average daily flow treated is < 500 m^3/day.
	Medium/Large	Average daily flow treated is ≥ 500 m^3/day.
Water Source	Surface Water	Water source is surface water. Surface water inflow is typically gravity driven but can become very energy intensive if pumped long distances [26].
	Wells	Water source is groundwater. These facilities are generally more energy intensive because of pumping required to raise water from the subsurface [26].
	Surface Water & Wells	A combination of surface water and wells.

6.3.3 Breakdown of Base Year Energy Use

As previously discussed, data provided by OCWA and data reported by municipalities as part of mandatory BPS reporting were used to estimate which DWTP types are present in Ontario and how much energy each plant type typically consumes.

Using the criteria and classifications in Exhibit 19 yields five possible DWTP segments. These segments are listed in Exhibit 20 below, along with the number of facilities classified under each category and estimates of total volume of water treated per year. Energy consumption includes energy from both electricity and natural gas.

Exhibit 20 – Base Year Energy Use by DWTP Segment (2018)

Plant Size	Water Source	Number of Facilities	Volume Water Treated (ML/year)	Total Energy Use (MWh/year)	% Total Energy Use
Small	Surface Water	95	4,355	17,061	2%
	Wells	64	1,793	2,957	<1%
Medium/ Large	Surface Water	173	3,059,360	939,268	96%
	Wells	81	29,063	16,127	2%
	Surface Water & Wells	10	3,565	2,059	<1%
Total		**423**	**3,098,136**	**977,472**	**100%**

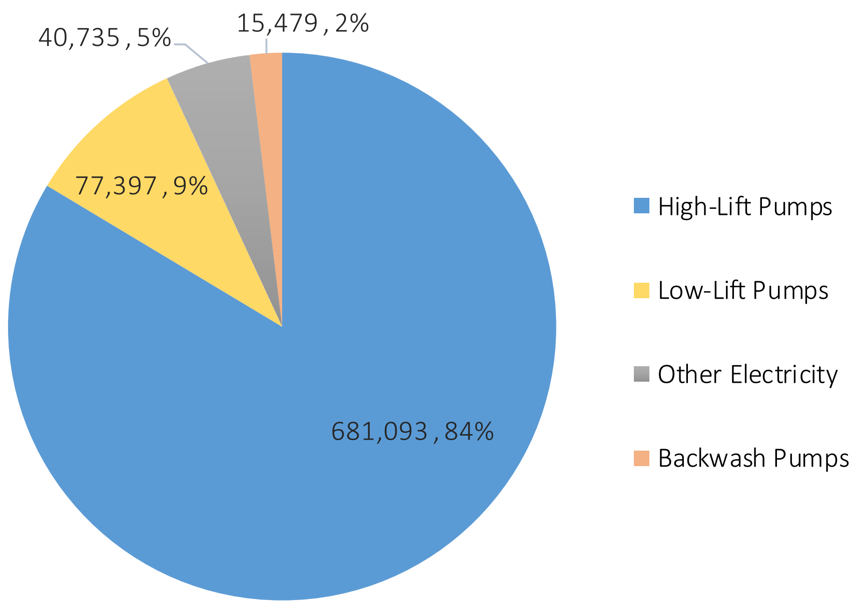
Exhibit 21 provides an estimate of energy use attributed to each of the end-uses and plant types. These numbers were calculated by taking the energy use in DWTP segments in Exhibit 20 and breaking them down by end-use. The end-use breakdown was developed through conversations with industry experts [24]. Unlike with WWTPs, there is no significant change in the end-use breakdown for different plant types.

Exhibit 21 – Base Year Energy Breakdown by DWTP Segment and End Use (2018)

DWTP Segment		**Typical Energy Consumption by End Use (MWh/year)**					
Plant Size	Water Source	High-Lift Pumping	Low-Lift Pumping	Backwash Pumping	Natural Gas	Other Electricity	Total
Small	Surface Water	11,888	1,351	270	2,841	711	17,061
	Wells	2,061	234	47	492	123	2,957
Medium/ Large	Surface Water	654,472	74,372	14,874	156,406	39,143	939,268
	Wells	11,237	1,277	255	2,686	672	16,127
	Surface Water & Wells	1,434	163	33	343	86	2,059
Total		**681,093**	**77,397**	**15,479**	**162,768**	**40,735**	**977,472**

Exhibit 22 shows the electricity consumption breakdown by end use for a typical DWTP. Most of the electricity use in this sector (~84%) is attributed to high-lift pumping which thus presents the biggest opportunity for energy savings.

Exhibit 22 – Base Year Electricity End-Use Breakdown of a Typical DWTP



6.4 Pumping Stations

The breakdown of energy use in Sections 6.2 and 6.3 does not include energy consumed by stand-alone drinking water or wastewater pumping stations.

This section provides separate estimates of drinking water and wastewater pumping station energy consumption based on data reported by municipalities through the BPS reporting requirements [23].

Municipalities were required to report energy consumption from pumping stations in 2012, but not in subsequent years. However, some municipalities voluntarily continue to report pumping energy use.

For the purposes of this analysis, we estimate energy use for those pumping stations that did not report 2015 data (the most recent submission) using their 2012 reported data. We make the simplifying assumption that all electricity use is attributable to pumping. Pumping stations are not segmented by size.

Exhibit 23 and Exhibit 24 provide estimated pumping station numbers, electricity consumption and flow for wastewater and drinking water respectively in the base year. Details on how the BPS data were cleaned to arrive at these numbers are provided in Appendix F.

Exhibit 23 – Base Year Wastewater Pumping Stations Estimates

Metric	Value
Number of Wastewater Pumping Stations [27]	1246
2018 Estimated Electrical Consumption of Wastewater Pumping Stations [28]	109,207 MWh
2018 Estimated Natural Gas Consumption of Wastewater Pumping Stations [28]	12,996 MWh
2018 Estimated Flow of Sewage Pumped [28]	620,235 ML

Exhibit 24 – Base Year Drinking Water Pumping Stations Estimates

Metric	Value
Number of Drinking Water Pumping Stations [27]	990
2018 Estimated Electrical Consumption of Drinking Water Pumping Stations [28]	831,887 MWh
2018 Estimated Natural Gas Consumption of Drinking Water Pumping Stations [28]	23,976 MWh
2018 Estimated Flow of Drinking Water Pumped [28]	3,500,516 ML

7 Energy Benchmarking

Energy benchmarking is intended to provide a relative assessment of the energy efficiency of similar facilities or processes. For WWTPs, DWTPs and pumping stations (PS) in Ontario, an ideal benchmarking analysis would provide a fair assessment of a facility's energy consumption relative to a peer comparison group of facilities that provide similar water treatment/pumping services in similar climates.

Any benchmarking model intended to account for the unique operations of a WWTP, DWTP or PS must be based on a granular, reliable and statistically representative sample of data quantifying the treatment processes and the properties of influent and effluent flows for WWTPs and DWTPs, and the characteristics of the water distribution network (e.g., flow, elevation, distribution main length) for PSs. Such data could be used to create benchmarking models that ensure facilities are only compared to similar facilities (e.g., WWTPs with similar biological oxygen demand treatment requirements, or pumping stations with similar flow/head requirements). A comprehensive, high-quality dataset like this does not exist for Ontario facilities; therefore, statistically representative benchmarking cannot be performed.

In the sections that follow we discuss several key resources that can be used as points of reference when assessing the energy performance of WWTPs, DWTPs, and PSs in Ontario:

- OCWA data;
- BPS data; and
- ENERGY STAR Scores for WWTPs in the U.S.

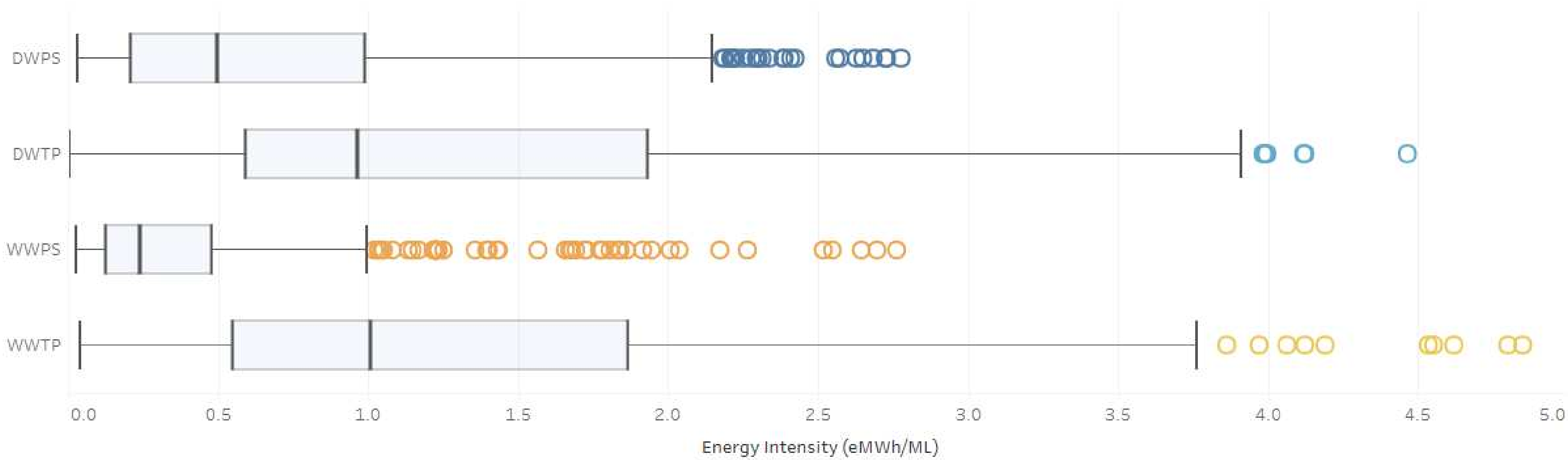
Leveraging the BPS data, Exhibit 25 presents a box plot that shows the distribution of Ontario treatment plant and pumping station energy performance by sector. Energy performance is expressed as an energy use intensity (i.e., energy per unit of water flow):

- The edges of the box represent the 25th percentile (right edge of box) and 75th percentile (left edge of box) of energy performance. This is also known as the inter-quartile range;
- The centre line (the line that divides the box) represents the median performance;
- The whiskers (the lines extending to the left and right of the boxes) represent the outlier boundaries. Facilities with energy intensities that are 50% lower or higher than inter-quartile range are considered outliers; and
- Individual data points outside the whiskers show some of the outliers.

Using WWTPs as an example, Exhibit 25 shows:

- 75% of Ontario WWTPs have energy intensities that are better (lower) than 1.87 eMWh/ML (right edge of the box);
- 25% of Ontario WWTPs have energy intensities that are better (lower) than 0.55 eMWh/ML (left edge of the box);
- The median energy use intensity for WWTPs is 1.01 eMWh/ML (the line that divides the box);
- Outlier facilities have energy intensities greater than 3.76 eMWh/ML (the right whisker) or lower than 0.04 eMWh/ML (the left whisker).

Exhibit 25 – Facility Energy Performance by Sector, All Fuels



7.1 Treatment Plants (DWTP and WWTP)

A review of the best available datasets for WWTPs and DWTPs in Ontario found that no individual dataset has a statistically representative sample upon which to base a benchmarking model that approaches the rigour of the ENERGY STAR® Score model for WWTPs in the US. However, three key resources were reviewed for potential benchmarking use in Ontario and the following sections present the merits of each resource.

7.1.1 OCWA

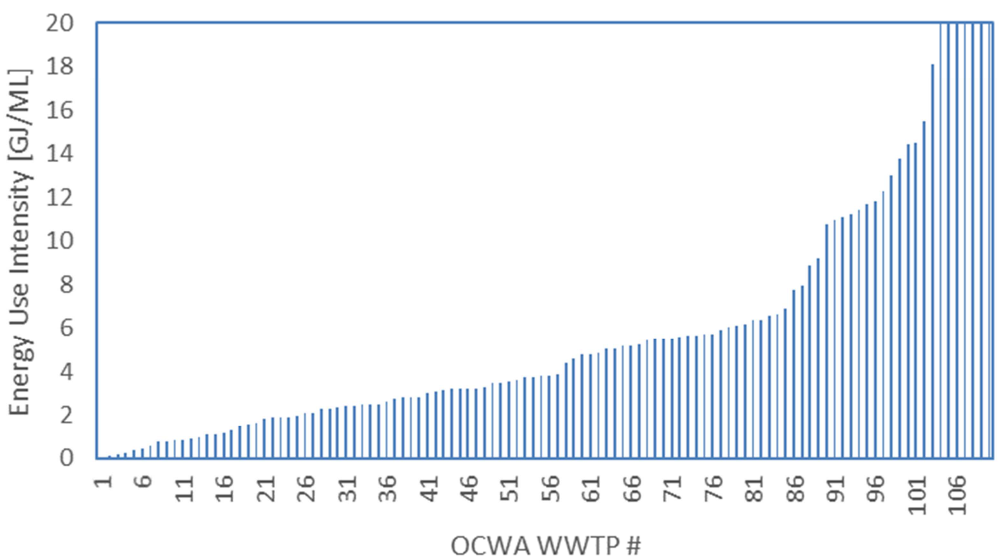
OCWA monitors energy consumption and key performance indicators (KPIs) for 214 DWTP and WWTPs. OCWA tracks several energy use intensity metrics, including energy use per unit of treated water, and per-unit values for biological oxygen demand treatment (BOD), phosphorus (TP), and nitrogen (TKN) removal for the wastewater facilities. OCWA compares the per-unit intensities of similar plants under their management, as defined by the size, major process, and location of the facility.

The most significant limitation of the OCWA data is the small sample size. Although the dataset contains a description of over 200 treatment plants, only 18 WWTP and 26 DWTPs have both energy and flow data reported. Of these 18 WWTPs, only 16 have data reported for BOD, TP and TKN treatment volumes (2 of which appeared to be EUI outliers). In addition, regression analyses performed on the small sample of facilities showed no statistically reliable predictors of EUI for WWTPs or DWTPs (regression models had low R-squared values). For this reason, we could not create a statistically consistent benchmarking model suitable for scoring the remaining 300+ WWTPs and 400+ DWTPs in Ontario from the OCWA dataset. However, the OCWA EUI data are summarized below and may be used as reference points for comparing other WWTP and DWTP facilities in Ontario.

WWTP

The chart below shows a ranking of the OCWA WWTP energy use intensities for records that had at least one year of non-zero EUI data between 2012-2017. Some of the facilities listed in the OCWA data had year-over-year data available – in these cases, the average EUI between 2012-2017 for each record was used to avoid over-representing individual facilities. The OCWA sample of WWTPs with EUI data contains 110 records, with a median EUI of 3.79 GJ/ML (or 1.06 kWh/m^3), up to a maximum of 52 GJ/ML (14.6 kWh/ m^3). Note that the range of the y-axis has been limited to 20 GJ/ML to ensure the relative rankings of EUIs below this limit are clearly visible in the chart below.

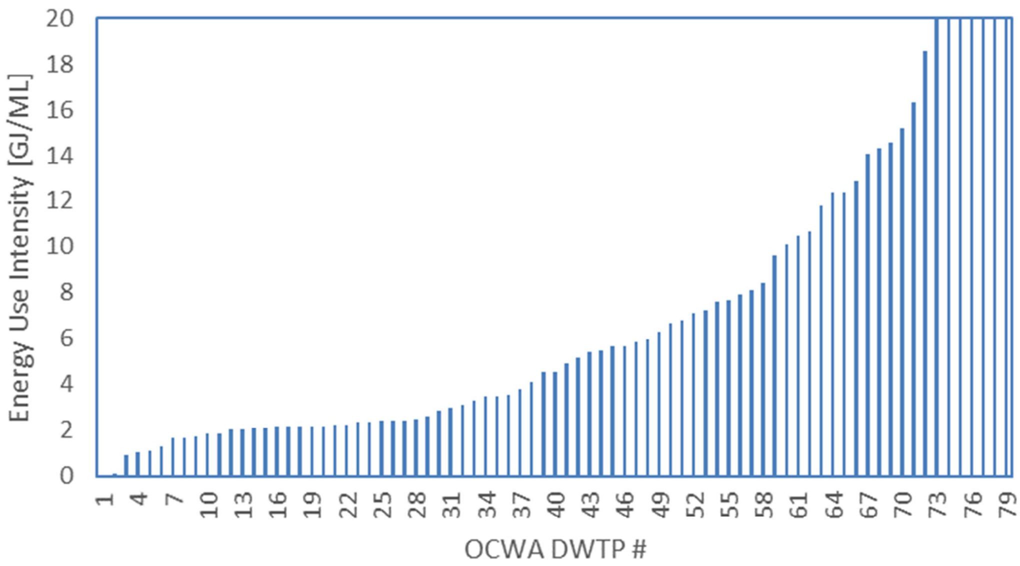
Exhibit 26 – Energy Use Intensity Ranking: OCWA WWTPs



DWTP

The chart below shows a ranking of the OCWA DWTP energy use intensities for records that had at least one year of non-zero EUI data between 2012-2017. The sample contains 79 records with EUI data, with a median of 4.57 GJ/ML (or 1.27 kWh/m^3), up to a maximum of 124 GJ/ML (34 kWh/m^3). Note that the range of the y-axis has been limited to 20 GJ/ML to ensure the relative rankings of EUIs below this limit are clearly visible in the chart below.

Exhibit 27 – Energy Use Intensity Ranking: OCWA DWTPs



Conclusion

Though the OCWA data contained fields describing the major processes and operations of the properties, the data were sparse and inconsistent – 23 unique Major Processes and nine unique Operational Descriptions were reported in the data for the 135 WWTPs, though more than 90% of the data had no operational description. Of the 79 DWTPs, only six had any Major Process or Operational Descriptions. Were the data more granular and more easily classified, the EUI rankings shown above could potentially have been segmented by process and operation to provide more specific benchmarks.

7.1.2 BPS

The raw BPS data contains 349 records for WWTPs, and 480 records for DWTP. As discussed in Appendix F, the BPS dataset contains significant over-reporting of flow, and thus required cleaning to establish more reliable estimates for overall energy consumption, flow, and energy use intensity distributions. After applying conservative flow and EUI filters, only 263 WWTP and 301 DWTP records remain, which are thought to be a more reliable representation of the actual aggregate performance of plants in Ontario than the raw BPS data.

The percentile distributions of EUI within the cleaned BPS dataset are shown in the table and charts below. Note that the median EUI for WWTPs in the BPS compares closely to the average from the OCWA data, at 3.62 GJ/ML and 3.79 GJ/ML respectively. For DWTPs, the BPS median of 3.36 GJ/ML is lower than the OCWA median of 4.57 GJ/ML.

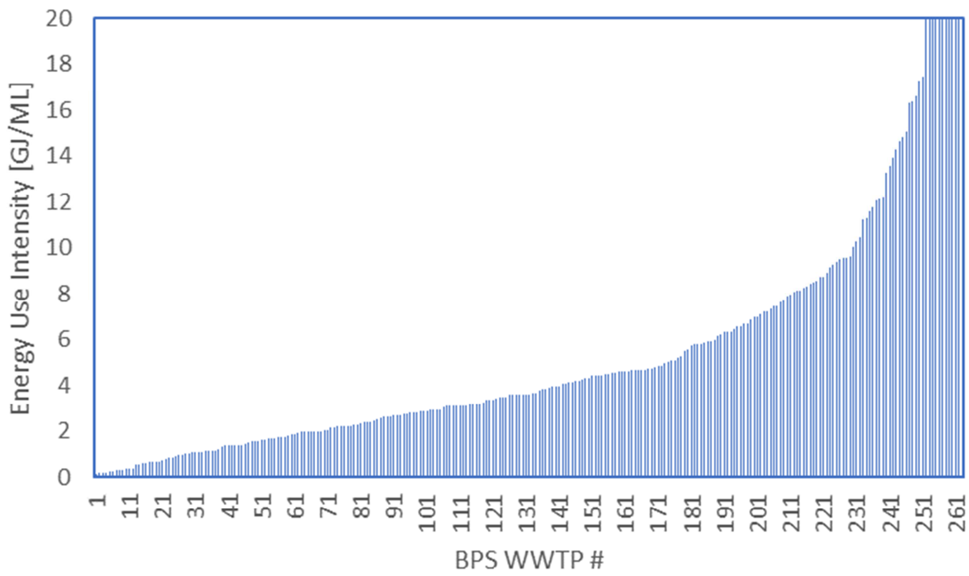
Exhibit 28 – Energy Use Intensity Percentile Rankings: BPS Facilities

EUI [GJ/ML]	WWTPs	DWTPs
#	263	341
Minimum	0.14	0.01
5th Percentile	0.58	0.13
25th Percentile	1.96	2.07
Median	3.62	3.36
75th Percentile	6.72	6.23
95th Percentile	16.63	14.82
Maximum	82.54	94.38

WWTP

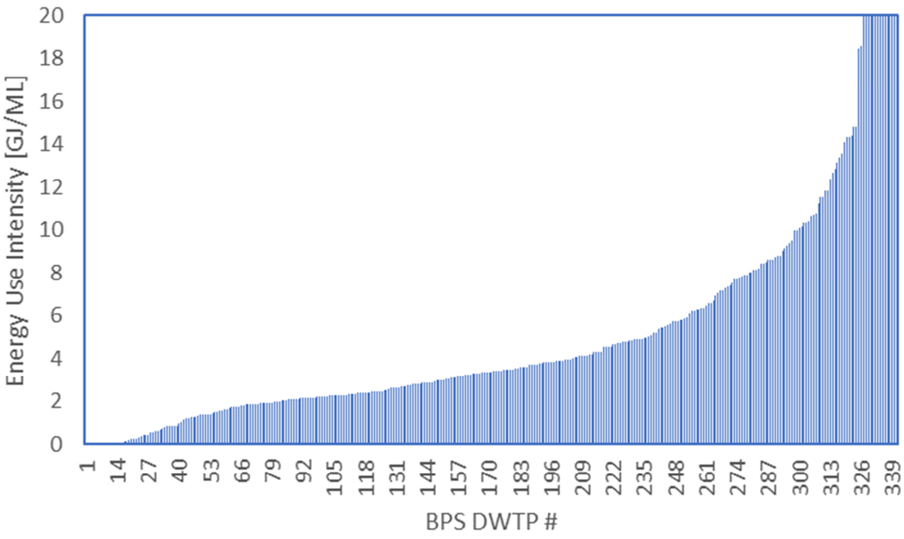
Note that the range of the y-axis has been limited to 20 GJ/ML to ensure the relative rankings of EUIs below this limit are clearly visible in the charts below.

Exhibit 29 – Energy Use Intensity Ranking: BPS WWTPs



DWTP

Exhibit 30 – Energy Use Intensity Ranking: BPS DWTPs



Conclusion

The BPS data do not contain information to describe and quantify the treatment activity at each plant (e.g., BOD treatment in mg/L, TP treatment in mg/L etc.). For this reason, we cannot establish a regression model that normalizes for the treatment activities at the plant (as is done for the ENERGY STAR Score) from the BPS data. The only independent variable available for regression in the BPS dataset is plant flow, however it is not a statistically reliable predictor of EUI for WWTPs or DWTPs, with R-squared values of less than 0.02.

Though the BPS data cover a significant number of facilities, the significant over-reporting of flows coupled with the limited number of fields collected prevents the creation of a statistically representative model that normalizes for the processes within each facility. However, after cleaning, the distribution of EUIs as summarized in the table and charts above can provide plant managers an indication of how the energy performance of their facility compares to the general population in Ontario.

7.1.3 ENERGY STAR Scores for WWTPs in the US

At the time of writing, the US EPA's Portfolio Manager ENERGY STAR Score for WWTPs cannot officially be used to score WWTPs in Canada, as the source data contain only data points from within the US. This score was developed based on more than 250 observations from the American Waterworks Association Research Foundation (AwwaRF) [29], which were deemed to have reliable data on the energy consumption, flow, water treatment metrics, and climate. The final regression equation that was used to determine the ENERGY STAR Score considers the following variables:

- Source Energy Use (kBtu/average gallons per day)
- Average Influent Flow (MGD)
- Average Influent BOD (mg/L)
- Average Effluent BOD (mg/L)
- Plant Load Factor
- Presence of trickle filtration

- Presence of nutrient removal
- Heating Degree Days
- Cooling Degree Days

The ENERGY STAR Technical Reference[5] document for the US WWTPs indicates that the dataset used to create the regression equation includes plants with heating degree days as high as 6,224 (in °C). Many of the plants in Ontario have heating degree days between 4,000-6,000, similar to the climate experienced by plants in upstate New York, Ohio, and Michigan, which were presumably represented in the AwwaRF's US dataset. However, the AwwaRF dataset contains records ranging in size from roughly 900 ML to 450,000 ML per year in flow, much larger than many of the plants contained in the BPS dataset, where the median flow is only 650 ML.

Under the assumption that Canadian and US plants are not substantially different in function, the US scoring model may be applied to Canadian facilities to provide a directional benchmark in the absence of a specific ENERGY STAR Score for WWTPs in Canada. However, given the sample population used to develop the US Score had flows larger than 900 ML per year, only Canadian facilities larger than 900 ML per year should consider using the US Scoring model as a benchmark.

The procedure for estimating the ENERGY STAR Score for a Canadian WWTP is as follows:

1. Create an ENERGY STAR Portfolio Manager account and login at the link below: https://portfoliomanager.energystar.gov/pm/login.html
2. Add a "Wastewater Treatment Plant" to your Portfolio
3. When entering the country and address of your facility, select "United States", and enter the zip code of the closest US city to your facility (the zip code is used to assign climatic and weather data to your property).
    - e.g. Buffalo, NY – 14201, Watertown, NY – 13601, Detroit, 48127
4. Enter the characteristics (i.e., Property Use Details) of your WWTP, including average influent/effluent BOD, presence of nutrient removal plant flow rate, etc.
5. Create energy meters and enter your electricity, natural gas, and any other utility bill applicable to your facility, ensuring that the appropriate energy units are selected (e.g. kWh, cu-m NG etc.)

If Portfolio Manager detects no data entry errors, the estimated ENERGY STAR Score for your facility should be available. Any Score obtained by applying the US WWTP to Canadian facilities should never be publicly presented as a recognized performance metric or be construed as an ENERGY STAR certification provided by the US EPA or NRCan. Informed by the discussion above, plant managers should use these unofficial results with caution and in conjunction with other performance assessment approaches.

Note that Portfolio Manager does not have ENERGY STAR scores for DWTPs.

---

[5] For a more detailed description of the ENERY STAR scoring procedure and data collection please see: https://www.energystar.gov/sites/default/files/tools/Wastewater_Trtmnt_Aug_2018_EN_508.pdf

7.2 Pumping Stations

A review of the best available datasets for PSs in Ontario indicates that data are even more sparse than in the treatment plant sectors. No OCWA data are available for these facilities, and there is no ENERGY STAR Score available within Canada or the US. However, the BPS data can provide insight to facility managers on the range of expected energy intensity for pumping stations.

7.2.1 BPS

The raw BPS data from 2015 contains 747 records for sewage pumping stations, and 670 records for drinking water pumping stations. As with the treatment plants (and as discussed in Appendix F), the BPS dataset contains significant suspected over-reporting of flow for pumping stations, and thus required cleaning to establish more reliable estimates for overall energy consumption, flow, and energy use intensity distributions. After applying conservative EUI filters (based on a study of municipal pumping energy by the Electric Power Research Institute (EPRI)[6]) [30], only 501 WWPS and 448 DWPS records remain, but are thought to be a more reliable representation of the actual aggregate performance of PSs in Ontario than the raw BPS data.

The percentile distributions of EUI within the cleaned BPS dataset are shown in the table and charts below. Note that the range of the y-axis has been limited to 10 GJ/ML to ensure the relative rankings of EUIs below this limit are clearly visible in the charts.

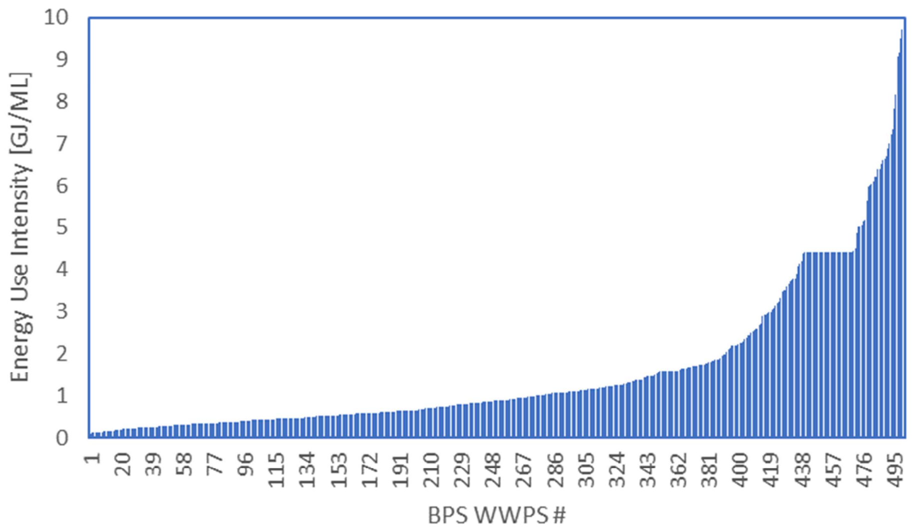
Exhibit 31 – Energy Use Intensity Percentile Ranking: BPS PSs

EUI [GJ/ML]	WWPS	DWPS
#	501	448
Minimum	0.10	0.10
5th Percentile	0.22	0.18
25th Percentile	0.46	0.75
Median	0.87	1.78
75th Percentile	1.72	3.55
95th Percentile	5.05	7.95
Maximum	9.94	9.99

[6] The EPRI study used to establish analytical filters for the BPS suggested that average water distribution intensity ranges from roughly 0.7 to 1.3 GJ/ML. To be conservative, EUI filters were set at 0.1 GJ/ML at a minimum, and 10 GJ/ML at a maximum.

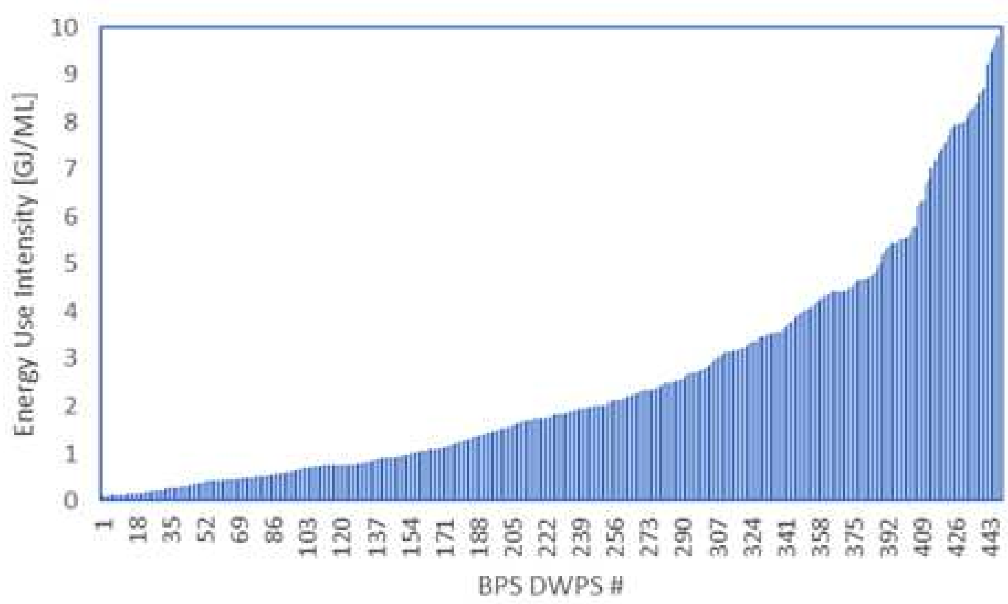
WWTP Pumping Stations

Exhibit 32 – Energy Use Intensity Ranking: BPS WWPSs



DWTP Pumping Stations

Exhibit 33 - Energy Use Intensity Ranking: BPS DWPSs



Conclusion

The BPS data do not contain information to describe and quantify the pumping requirements at each plant (e.g., distribution main length/elevation or head). For this reason, we cannot establish a regression model that normalizes for the pumping activities from the BPS data. The only independent variable available for regression in the BPS dataset is plant flow, however it is not a statistically reliable predictor of EUI for WWPSs or DWPSs, with R-squared values of less than 0.04.

Though the BPS data cover a significant number of pumping stations, the significant over-reporting of flows coupled with the limited number of fields collected prevents the creation of a statistically representative model that normalizes for the processes within each facility. However, after cleaning, the distribution of EUIs as summarized in the table and charts above can provide plant managers an indication of how the energy performance of their facility compares to the general population.

8 Incentive Programs and Training Offerings

This section presents the energy saving incentive programs, and training offerings, available to WWTP, DWTP, WW Pumping and DW Pumping sectors in Ontario and a brief analysis of the participation by the sector.

8.1 Existing Incentive Programs

DWTP and WWTP may be eligible to receive incentives for energy efficiency and conservation projects from several programs. Incentives are available for specific projects, and to fund the salary of an Energy Manager to help a facility identify opportunities for energy savings and implement projects. Exhibit 34 summarizes some of the key existing incentive programs relevant to the water treatment sectors:

Exhibit 34 – Incentive Programs Relevant to WWTP and DWTP

Program Name & Description	Administered (Funded) by	Program Type & Incentives	Eligible Sectors	Eligible Projects
Process & Systems Upgrade Program (PSUP) The PSUP is designed to help organizations with complex systems and processes identify, implement, and validate energy efficiency projects from start to finish.	Save on Energy (IESO or LDC)	▪ Project incentive: the lesser of up to 70% of project costs, or; $200 per MWh of annual electricity savings	Industrial and Commercial	▪ Must be a single facility connected to a local hydro company distribution network. ▪ The project must be in service before December 31, 2020 and provide annualized electricity savings of greater than 300 MWh
Retrofit Program Incentives available for energy saving equipment.	Save on Energy (IESO or LDC)	▪ Retrofit program: up to 50% of project costs for customer projects, or; fixed incentive levels for prescriptive projects ▪ Prescriptive track: per unit incentives ▪ Custom track: Incentives are based on energy savings over pre-project baselines.	Commercial, Industrial, Agricultural, or Institutional Facilities	▪ Must provide sustainable, measurable and verifiable reductions in electric peak demand and/or electricity consumption. ▪ Prescriptive track: projects must be pre-approved. Small projects must be worth a minimum incentive of a $100. ▪ Custom track: projects must have an estimated electric peak demand reduction of 1 kW or

Program Name & Description	Administered (Funded) by	Program Type & Incentives	Eligible Sectors	Eligible Projects
				first-year annual energy savings of 2,000 kWh. ▪ Projects must deliver energy savings for at least 48 months.
Industrial Conservation Initiative (ICI) The ICI is a demand response program that allows participating customers to manage their global adjustment (GA) costs by reducing electric peak demand during peak periods.	IESO	Customers who participate pay GA based on their percentage contribution to the top five peak Ontario demand hours over a 12-month base period.	Customers must have an average monthly peak demand greater than 500 kW during an annual base period from May 1 to April 30	NA
Energy Manager Program Incentives to help bring an energy manager onto a team.	Save on Energy (IESO or LDC)	Incentive depends on the eligible organization	Industrial and Commercial	Incentive to hire a Certified Energy Manager, and further leverage incentive programs
OCWA Pay for Performance OCWA's pilot program identifies opportunities for energy savings, recommends the best available technologies to do the job, and then pays an incentive on the savings once retrofits or upgrades are completed.	OCWA (IESO)	▪ Pay-for-performance incentive paid to the municipality for every kilowatt-hour of verified annual energy savings from the project ▪ Financial support up to 50% of eligible project costs	Water and wastewater treatment plants operated by OCWA	▪ Equipment Retrofit (pumps, blowers, motors, compressors) ▪ Variable Frequency Drive installation ▪ SCADA Upgrades with power monitoring component for facility and major process systems ▪ Aeration Systems Upgrades ▪ Operational Changes

8.1.1 Other Energy Efficiency Support Programs and Project Funding Sources

Opportunity Accelerator

The Opportunity Accelerator program provides a technical advisor to visit a facility to help identify energy-saving projects. The services range from a) a facility site visit to conduct an energy audit; b) focusing on a system and its equipment; c) defining the scope and developing the business case for a capital project; and, d) helping to find low-cost operational changes to save energy at the facility. These services are offered by local hydro companies at no-cost. To be eligible, a facility must:

- "Have an average annual consumption of 3 GWh/year or an average on-bill monthly peak demand greater than 500 kW.
- Be a single facility that is connected to a local hydro company's distribution system or a tenant facility with sub-metered electricity." [31]

Energy Training and Support programs

Industry can receive training and support for energy management through a number of third-party training offerings, including the Dollars to $ense Energy Management Workshop, Energy Efficient Building Operations 101, and Certified Energy Manager training. In some cases, eligible individuals and organizations can apply for funding through Save on Energy to participate in these training and support programs [32].

OCWA provides a variety of training courses on water and wastewater systems [33]. While none of the courses focus specifically on energy management, they do cover various systems and there is a course dedicated to water conservation.

The Canadian Institute for Energy Training (CIET) offers a pump systems optimization training course that is product-neutral [34]. Incentives are available for this training from the IESO, Canada-Ontario Job Grant, Enbridge, and Union Gas [35].

The Walkerton Clean Water Centre provides education and training to DWTP operators and operating authorities. In addition to courses on safety and treatment, the WCWC offers a course on energy management for drinking water operators. This course provides information on ways to conserve energy and reduce energy costs, and how audits and incentive programs can help operators recommend and implement energy saving measures [36].

AgriPump Rebate Program

The AgriPump Rebate Program is currently operating as a pilot for *agricultural customers* of Hydro One and Niagara Peninsula Energy and is being presented here because a similar program structure may be appropriate for the water treatment sectors.

The program provides rebates for qualified high-efficiency submersible, end suction and vertical multistage pumpsets with capacities from 0.5hp to 10hp. It is administered under a "midstream" model, where customers receive instant rebates from participating contractors, who are then refunded by the LDC. Full details are available at the program website [37].

A similar program approach may be appropriate for efficient pumping equipment in the water treatment sectors. Three broad program options for the water treatments sectors are outlined for consideration:

1. *Revise equipment eligibility to include water treatment pumping equipment within the AgriPump program as it currently exists.* This would require current participating contractors to serve water treatment customers.

2. *Expand the current midstream program structure to additional contractors (and/or distributors) that serve the WWTP, DWTP, WW Pumping and DW Pumping sectors*. This would include an associated recruitment effort.

3. *Take a separate programmatic approach*.

The website lists four participating manufacturers and provides information on how to become a participating distributor but does not appear to list participating distributors explicitly. The program website lists 28 current participating contractors [37].

The four manufacturers listed include manufacturers of large industrial/municipal pumps. However, suppliers, distributors, and contractors serving the municipal water treatment sectors do not appear to be included on the contractor list. A cursory examination and web search indicate that perhaps two of the 28 participating contractors focus services toward industrial and/or municipal water treatment customers.

The foregoing indicates that option 1 is not an appropriate program approach.

However, because this is a narrow market with reasonably few contractor/distributors serving it, it is likely that an upstream or mid-stream approach is appropriate.

Incentives to Reduce Natural Gas

Incentives are available from Union Gas and Enbridge to reduce natural gas consumption from space and water heating. Incentives are also available for engineering feasibility and process improvement studies [38]. DWTP and WWTP may use these incentives to lower their natural gas consumption and associated energy costs.

Region of Waterloo Wastewater Treatment Energy Efficiency Upgrades

During a series of upgrades performed between 2011 and 2013, the Kitchener Wastewater Treatment Plant replaced mechanical aerators with more efficient diffused aeration systems and installed new efficient blowers. A new Blower Building was constructed to use less energy, including ensuring that waste heat generated by air blowers is captured to provide heat during the winter.

Besides energy efficiency and conservation improvements, the upgrades and new systems helped to significantly lower the amount of ammonia and phosphorus in the final effluent. The project cost almost $18 million and was supported by the Federation of Canadian Municipalities' Green Municipal Fund Loan and Grant program [104] [39]

Green Municipal Fund

Funds are available to municipalities to support infrastructure projects, including for WWTP and DWTP. Although these funds may not explicitly incent energy efficiency, they often seek to ensure the environmental performance of municipal infrastructure and facilities.

The Green Municipal Fund (GMF) is offered by the Federation of Canadian Municipalities to support "initiatives that demonstrate an innovative solution or approach to a municipal environmental issue…(and) offer significant environmental benefits" [39]. Funds are available to support initiatives that focus on energy efficiency and water quality and conservation [40]. Many Ontario municipalities have used the GMF to support capital projects, feasibility studies, and pilot projects at their WWTP and DWTP [41].

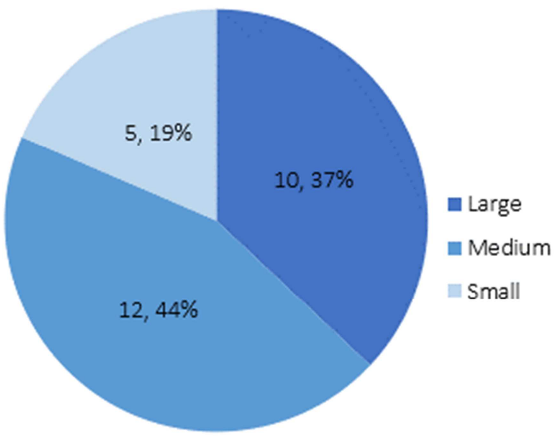
8.2 Program Participation

Based on IESO data, 337 Ontario municipalities participated in at least one IESO incentive program from 2010 to 2017. Data provided by the IESO and from the BPS mandatory reporting requirement were used to determine how many incentives went to projects specifically in DWTP and WWTP. The following subsections provide details of participation in each program listed in Exhibit 34.

8.2.1 PSUP Participation

From 2012 to 2017, 27 municipalities participated in the PSUP program. As displayed in Exhibit 35 below, 44% of the participating municipalities are medium size,[7] while 37% are large and 19% are small. From these municipalities, a total of 77 incentive applications were completed, of which 38 (49%) were for projects in DWTP and WWTP (see Exhibit 36). Of these 38 projects, 25 (66%) were conducted in WWTP and 13 (34%) in DWTP (see Exhibit 37). Applications were mainly for Detailed Engineering Studies or Preliminary Engineering Studies. For WWTPs, projects were conducted on variety of systems and equipment including aeration system upgrades, plant energy optimization, fans and blowers, and cogeneration systems. In DWTP, projects were mainly for pumps, HVAC, and process cooling.

Exhibit 35 – Size Breakdown of Participating Municipalities (PSUP)



[7] Municipalities with populations under 10,000 are considered Small, between 10,000 and 100,000 are considered Medium, and over 100,000 are considered Large.

Exhibit 36 – Sector Breakdown of 77 Completed PSUP Applications

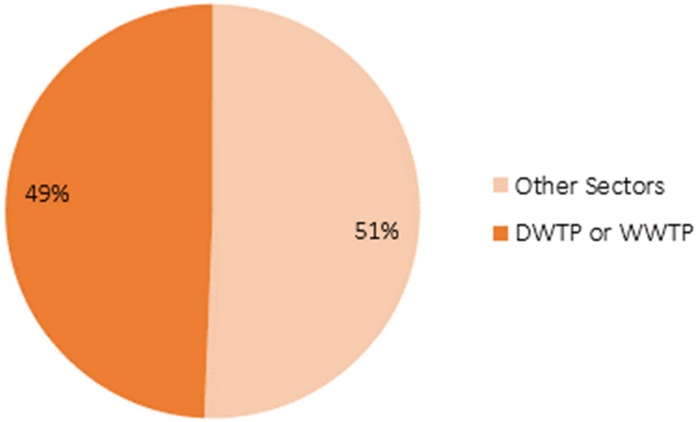
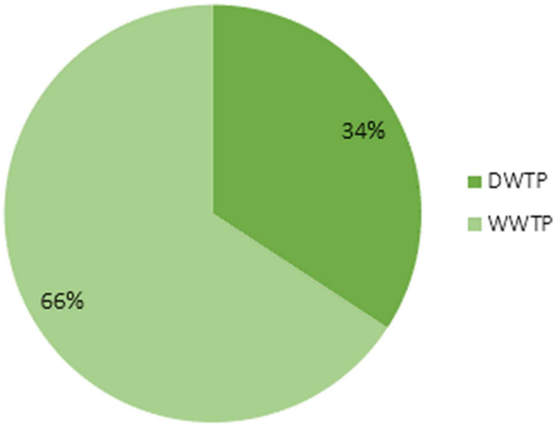


Exhibit 37 – Facility Type Breakdown of 39 PSUP Projects



The PSUP requires that projects provide annualized electricity savings of more than 300 MWh. We assessed the base year data for the DWTP and WWTP sectors to determine if this threshold was too high for some DWTP and WWTP to participate in the program:

- Of the approximately 760 DWTP and WWTP facilities screened into the dataset, approximately half reported annual electricity consumption of less than 300 MWh. These facilities would be unable to participate in the PSUP.
- For illustrative purposes, we then used the example of an aeration system optimization upgrade to estimate if the remaining facilities could meet the savings threshold.
- Using energy savings potential findings later outlined in Section 11, we are approximating that only 20% of all DWTP and WWTP facilities could meet the current savings eligibility threshold.

8.2.2 Retrofit Program

Data on 7,117 applications[8] submitted to the Retrofit Program since 2010 were analyzed. Of the 7,117 applications, 300 were for projects in either WWTP or DWTP; with 158 applications (~2%) for WWTP and 142 (~2%) for DWTP. Fifty-nine municipalities applied for incentives under the retrofit program, with the majority - 24 (~41%) - being medium-sized municipalities.

In both WWTP and DWTP, most projects were for lighting measures. Non-lighting project measures were mainly for VFDs in WWTP and DWTP. In DWTP, non-lighting projects were also for VFDs, controls, HVAC systems and pumps. In total, over $19 million was invested in DWTP and WWTP upgrades and to date, there has been an annual energy savings of over 14 GWh in the sectors.

Exhibit 38 – Size Breakdown of Participating Municipalities (Retrofit)

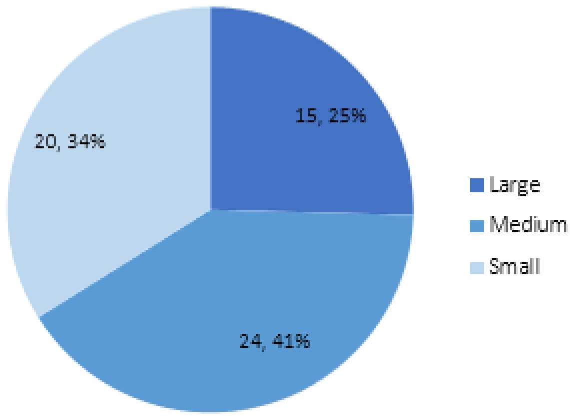
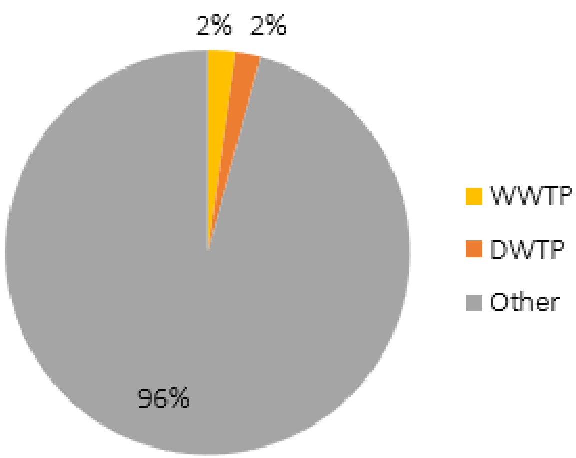


Exhibit 39 – Sector Breakdown of Retrofit Applications



[8] Applications that were labelled "rejected" in the dataset were not included in the analysis.

Exhibit 41 – DWTP Project Measure Breakdown

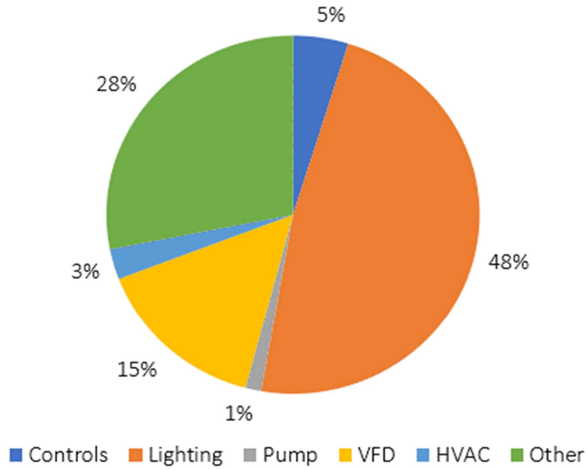
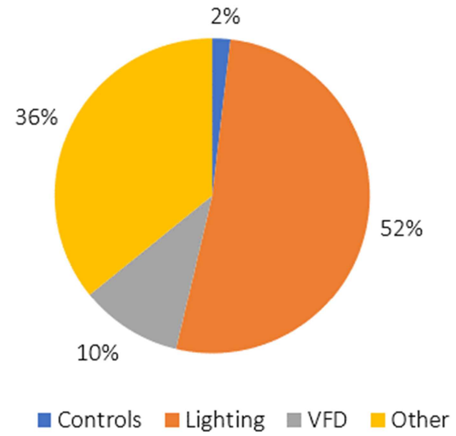


Exhibit 40 – WWTP Project Measure Breakdown



8.2.3 Industrial Conservation Initiative

Based on 2017 data, 47 DWTPs and WWTPs participated in the ICI program: 33 were water treatment and pumping facilities, while 14 were sewage treatment. For comparison, these same municipalities also participated in the ICI program with 54 facilities of other building types including multi-purpose facilities, arenas and municipal buildings.

8.2.4 Energy Manager

The IESO currently funds 10 Energy Managers in seven municipalities. The expertise and scope of practice of these individuals varies widely. Some Energy Managers are primarily concerned with water/wastewater infrastructure, some have water/wastewater infrastructure included within a broader facility energy management mandate, and some focus only on buildings and do not have responsibility for water treatment infrastructure.

8.2.5 OCWA Pay-for-Performance

OCWA supports its municipal clients to identify, assess, recommend, and implement energy conservation measures. Through the program, OCWA also provides education and training to operators to raise awareness for energy conservation in their DWTP and WWTP.

As of 2017, over 150 municipalities have participated in OCWA's Pay-for-Performance program. The pilot funding of $1 million is expected to help realize 4,762 MWh in savings by the end of 2019. As of the third quarter of 2018, 90 projects have enrolled in the program. [24]

Common measures funded by the program are:

- VFD on High-Lift and Low-Lift Pumps, Aeration and Digester Blowers

Kirkland Lake DWTP High-Lift Pump & Motor Upgrades

OCWA's Energy Team helped identify energy savings opportunities in Kirkland Lake's DWTP and prepared a business case for the measures. The project involved replacing two pumps with new pumps accompanied by VFDs that are operated as a base pump with variable flow and pressure based on demand. These retrofits resulted in 200,000 kWh annual energy savings. The project cost of $80,000 was 100% funded by the IESO and Hydro One Networks. OCWA implemented the project, conducted the M&V and incentive application process on behalf of Kirkland Lake. [22]

- Automated DO controls, flow controls and level controls
- UV retrofits
- Operational changes combined with retrofits
- HVAC upgrades [24]

As of November 2018, the P4P program had the following projects in each stage of the program:

Exhibit 42 – OCWA P4P Projects by Status

Status	Measure (number of projects)
Incentive paid	▪ Aeration blower upgrades (4) ▪ High-lift pump (HLP) upgrade (2) ▪ HLP Upgrade + VFD (1) ▪ Low-lift pump retrofit (3) ▪ Motor/pump upgrades (2) ▪ Motor/pump replacement + VFD (1) ▪ Blower motor retrofit (1) ▪ VFDs (3)
Post Implementation Complete	▪ VFDs (4) ▪ Blower motor upgrade (2) ▪ New pump + VFD (1) ▪ Pump upgrades (1) ▪ HLP + VFD (1)
Post Submission to IESO	▪ HLP pump + VFD (1) ▪ Pump upgrade (2) ▪ Pump motor + VFD (1) ▪ Pump retrofit (1) ▪ UV system replacement (1) ▪ Compressor retrofit (1) ▪ VFDs (1)
Pre-submission to IESO	▪ VFDs (3) ▪ Pump upgrade (4) ▪ Motors + VFD upgrade (1) ▪ Blower + VFD (1) ▪ Surface aerator (2) ▪ UV retrofit (1)

9 Energy Saving and GHG Mitigation Measures

This section summarizes measures that can be implemented to reduce energy consumption and electric peak demand in the WWTP, DWTP, WW Pumping and DW Pumping sectors. Section 9.1 explains the process of determining which measures to investigate in this study, and Sections 9.2-9.9 provide details on the energy savings measures that were ultimately decided on.

Eight core measures were investigated:

Process Improvement Measures:

- Section 9.2 - Pumping System Optimization
- Section 9.3 - Aeration System Optimization
- Section 9.4 - VFDs with Controls
- Section 9.5 - Monitoring and Targeting

Equipment Replacement Measures:

- Section 9.6 - Pump Upgrades
- Section 9.7 - Blower Upgrades
- Section 9.8 - Motor Upgrades

Fuel-switching Measures:

- Section 9.9 - CHP from Methane Capture

Each section includes:

- A description of the measure,
- Details on applicability,
- The current level of market penetration in Ontario,
- Typical energy savings (reported on a percentage basis),
- Typical costs (reported on a $/Lifetime MWh savings basis), and payback periods, and
- Key barriers for implementation.

Several market actors indicated that a systems approach is the most effective way to achieve significant savings at water and wastewater treatment plants [24], [42]. Plants utilize systems and processes that are complex, and changes to one piece of equipment can interact in complex ways with the rest of the system.

The final list of measures includes both equipment replacement measures (pump, motor and blower upgrades) and process improvement measures (pump system optimization, aeration system optimization, VFDs with controls and general operational improvements).

Process improvement measures and equipment replacement measures only reduce the need for electricity; no other fuels are impacted. The only measure that impacts natural gas use is the fuel-switching measure, CHP. In addition to reducing the need for electricity, CHP reduces the amount of natural gas required for space and process heating.

9.1 Measure Screening

One of the first steps of this study was to determine which energy savings measures to investigate in detail and include in the energy potential savings analysis. This was done by coming up with a comprehensive list of potential energy savings measures available in the water treatment sectors and then paring it down, based on our research, to focus on measures that offer the greatest potential for energy and GHG savings.

Measures Initially Considered

Before deciding on the final measures, Posterity Group did a scan of literature available on energy savings measures in water and wastewater treatment plants to come up with a comprehensive list of potential measures. This list is presented in Appendix B.

We looked at measures that applied to all end uses in water and wastewater treatment plants. Our sources for this initial list include *NYSERDA's Water and Wastewater Energy Management Best Practices Handbook* [43], *Water & Wastewater Infrastructure Energy Efficiency and Sustainability* by Frank R. Spellman [44], and conversations with the study contributors listed in Appendix A.

Deciding on Final Measures

The following steps were completed to decide on the final measure list:

1. Once the initial list was established, Posterity Group conducted interviews with several market actors and industry experts, including OCWA, to determine which measures should ultimately be included in this study. The study objective was to focus on measures with the highest province-wide energy and GHG savings potential.
2. Most market actors indicated that a systems approach is the most effective way to achieve significant savings at water and wastewater treatment plants and that some of the top measures we should be looking at include pumping system optimization, aeration system optimization adding VFDs with controls, and monitoring and targeting. Secondary to system optimization, but also notable, were equipment replacement measures such as pump, motor and blower upgrades.
3. Finally, several market actors and study stakeholders flagged the need to assess methane capture and the large opportunity for energy and GHG savings through power generation and heat recovery.

As a result of this screening exercise, there are several measures from the initial list that were not ultimately subject to analysis. These including UV disinfection, filter backwash control, compressed air measures, as well as measures that focus on reducing water use (e.g., leak detection, system repair). Although province-wide potential energy and GHG savings did not support full analysis under the scope of this study, it is possible other measures may be attractive in specific plants on a case-by-case basis.

9.2 Pumping System Optimization

9.2.1 Description

This measure is applicable to both DWTP and WWTP. It is a system improvement measure that involves a system analysis of the pumping system to identify the optimum operating conditions for each pump. Right-sizing pumps and re-designing the system to reduce pump head and flow are included in this measure. A systems approach is required for these measures since pumping flows and head are inter-related and cannot be easily dissociated. A reduction of flow will result in an increase in head and vice versa [16].

Right sizing pumps is an important aspect of pump system optimization. Pumps are often not properly matched to the system in which they operate. This can occur for several reasons. Most commonly, pumping systems are specified for design-flow rates that do not match in-service conditions. Systems are typically required to supply a range of flows over their lifetime, particularly in the case of new development areas where the design flow may take decades to become reality. Conversely, at full build-out, design flows are often more conservative than actual flows. Other reasons for mis-sized pumping systems include assumptions relating to friction factors, which may also vary over time [42].

Transmission Operations Optimizer (TOO) for the City of Toronto and York Region

The water supply system serving the City of Toronto and York Region is the largest in Canada, serving 3.4 million people. The Toronto system includes 4 water filtration plants, 18 pumping stations, 11 reservoirs, 126 pumps, and ~500 km of transmission mains. Due to the size and complexity of the system, a new automation system was commissioned in November 2015. The Transmission Operations Optimizer (TOO) ensures water quality and quantity are met while minimizing energy use and electricity costs. A smart, real-time system determines control strategies that account for variations caused by seasons, daily demand patterns, energy prices, and ad-hoc events (e.g., equipment out of service) [107] [108].

The system saved $1 million in energy costs in 2016, and 16 million kWh in one year [109]. The TOO project received a $1.6 million incentive from Toronto Hydro [110, p. 14] [108].

Variable frequency drives are not considered under this measure. Instead, they are captured under the VFDs with controls measure in Section 9.4.

9.2.2 Applicability

Exhibit 43 shows the sectors and end-uses that this measure applies to, as well as the current implementation rate of this measure.

Exhibit 43 – Applicable Sectors and End-Uses for Pumping System Optimization

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Influent Pump Station	60%
	Primary Clarifier and Sludge Pump	20%
	Secondary Clarifier	60%
Drinking Water Treatment	Low-Lift Pumps	60%
	Backwash Pumps	60%
	High-Lift Pumps	60%
Pumping Stations	Drinking Water Pumping Stations	60%
	Wastewater Pumping Stations	60%

9.2.3 Energy Savings

Energy savings vary widely and are dependent on the design of the baseline system. Energy savings of 15-30% are typical, with savings up to 70% possible in retrofit scenarios where a service area has not grown as forecasted [43].

Conversations with market actors and industry experts indicated that an energy savings value of 15-30% was too high in practice. In reality, an energy savings value of 10% is more realistic. Therefore, a value of 10% savings was used to model energy and GHG savings. [45], [24].

9.2.4 Costs and Payback

NYSERDA's Water and Wastewater Energy Management Best Practices Handbook states that in retrofit applications, optimizing pumping stations has typical payback periods ranging from three months to three years. For new facilities, the payback period is typically less than two years [43].

The lifetime of a pumping system is estimated to be 25 years [46]. Assuming a percentage energy savings (10%) and cost of electricity ($140/MWh [47]) and assuming a payback period of two years, we estimated that the levelized cost of energy savings for this measure is $11/MWh.

9.2.5 Barriers to implementation

Exhibit 44 – Barriers to Implementing Pumping System Optimization Measure

Category	Barriers
Technical	▪ Pumping flows and head are inter-related and cannot be easily dissociated. A reduction of flow will result in an increase in head and vice versa [42]. ▪ Physical system constraints and complexity of implementation and operation [42].
Financial	▪ Capital costs to adjust and redesign these systems are a barrier [42].
Market	▪ To correctly implement this measure, it is essential to hire someone who has a deep understanding of all the systems in water and water wastewater treatment plants, including how these systems interact. There are many experts on equipment replacement in Ontario, but fewer experts who would be able to implement this measure effectively [42].
Training/ Education	▪ Since this is a process improvement measure instead of an equipment upgrade measure, there is a lack of qualified system-level practitioners. Therefore, training and education are key [42]. ▪ Maintenance and operational staff are sometimes averse to change and influence decisions without full awareness of financial impact [48].
Other	▪ It is difficult to establish the baseline for avoided costs/savings when there are major upgrades going on [48]. ▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24]. ▪ System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24]. ▪ System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].

9.3 Aeration System Optimization

9.3.1 Description

This measure involves analyzing the aeration system to determine whether it is operating as efficiently as possible for the required level of treatment. It applies to WWTP only. This measure includes the consideration of sub-measures [49], [43] such as:

- Assessing the feasibility of implementing fine-bubble aeration. This technology usually improves operations and increases the organic treatment capability of a wastewater treatment facility.
- Dissolved oxygen monitoring and control and optimization of air-wastewater mixture. This sub-measure will maintain the dissolved oxygen level of the aeration tank at a pre-set control point by varying the air flow rate to the aeration system.
- Adequate equipment selection, equipment characteristics (i.e., turndown ratio) and right-sizing equipment.

- Monitoring of pressure drop across membrane diffusers to detect fouled diffusers.

Variable air flow rate is not considered under this measure. Instead, it would be captured under VFDs with controls in section 9.4.

9.3.2 Applicability

Exhibit 45 shows that this measure is only applicable in one sector and end-use. Market research indicates that this measure has already been implemented in about 80% of wastewater treatment plants in Ontario [49].

Exhibit 45 – Applicable Sectors and End Uses for Aeration System Optimization

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Activated Sludge Aeration	80%

9.3.3 Energy Savings

Savings for this measure vary widely depending on the baseline system performance. NYSERDA's Water and Wastewater Energy Management Best Practices Handbook estimates that potential energy savings that can be achieved through optimizing aeration system design range from 30-70% [43]. Market actor interviews confirmed that savings may fall within this range, however one market actor believed that 10-50% is a more realistic range [45]. Implementing dissolved oxygen controls and upgrading to fine-bubble aeration as stand-alone measures may each independently yield savings of up to 50% [50], [51].

An energy savings value of 40% was used for the modelling of energy and GHG savings for this measure [45].

Town of Kingsville WWTP Aeration Upgrade Project

OCWA identified energy conservation measures at the Lakeshore WWTP in the Town of Kingsville after they conducted an energy and process walkthrough which was funded by the IESO's Energy Efficiency Service Provider Program. OCWA submitted a proposal to the Town to spend $256,850 to update three existing 75hp centrifugal blowers with one high-efficiency turbo blower with continuous DO control. In 2014, OCWA implemented the project and secured $41,970 in incentives from Hydro One to help cover the project costs.

The retrofit has resulted in 419,703 kWh in energy savings and $58,758 in energy cost savings. The project has a simple payback period of three years [120].

9.3.4 Costs and Payback

The cost of implementing an aeration system optimization was estimated by reviewing four aeration system upgrade replacement projects: two that were completed by the District of Muskoka and two submitted through the IESO's Save on Energy PSUP [52]. The cost of energy savings for the four projects ranged from $18/MWh to $36/MWh[9]. For the purposes of modelling, the average value of all the projects was taken, and it was assumed that the cost of energy savings for this measure is $25/MWh.

The lifetime of an aeration system at a wastewater treatment plant is estimated to be 25 years [53].

Assuming the retail rate of electricity is $140/MWh, these project examples suggest that this measure has a simple payback period ranging from three to six years. This aligns with the estimate in the NYSERDA Water and Wastewater Energy Management Best Practices Handbook that estimates that the payback period for optimizing the aeration system ranges from three to seven years [43].

9.3.5 Barriers to implementation

Exhibit 46 – Barriers to Implementing Aeration System Optimization Measure

Category	Barriers
Technical	▪ No technical barriers have been identified.
Financial	▪ Capital costs to adjust and redesign these systems are a barrier [42].
Market	▪ To correctly implement this measure, it is essential to hire someone who has a deep understanding on all the systems in water and water wastewater treatment plants, including how these systems interact. There are many experts on equipment replacement in Ontario, but fewer experts who would be able to implement this measure effectively [42].
Training/ Education	▪ Since this is a process improvement measure instead of an equipment upgrade measure, there is a lack of qualified system-level practitioners. Therefore, training and education are key [42]. ▪ There is a lack of technical expertise and maintenance and operational staff are often averse to change [48]. ▪ Maintenance and operational staff influence decisions without full awareness of financial impact. Equipment that is easy to maintain is not always the best financial decision [48].
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24]. ▪ System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24]. ▪ System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].

[9] See Appendix D for details on how costs were calculated.

Stratford Wastewater Treatment Plant Aeration Blower Upgrade

The City of Stratford's wastewater treatment plant accounted for over 20% of the municipality's total energy consumption. To reduce its energy use, the City focused on the aeration system as it accounted for 60% of the plant's total energy use. With support from OCWA and Festival Hydro, the City obtained incentives through Save on Energy [105].

The City replaced two fixed-speed 200hp centrifugal blowers with a single 350hp turbo air blower. A VFD was also added to the system to adjust the flow of air into the aeration basins based on dissolved oxygen levels in the basins. [105].

This new system uses 30% less energy, has improve the operational performance of the secondary clarifiers, and saved approximately $68,000 in energy costs in the first 9 months of operation [105].

9.4 VFDs with Controls

9.4.1 Description

Variable frequency drives (VFDs) match motor output speeds to the load requirement and avoid running at constant full power unnecessarily. Equipment must be designed to operate at peak load, and is significantly less efficient at part-load, which may represent typical operating conditions. This measure involves assessing variations in motor loads and installing VFDs, particularly where peak load is significantly higher than the average load, and where the motor can run at partial loads [43]. It is applicable to DWTPs, WWTPs and PSs.

Many of the benefits of VFDs can also be obtained by replacing Permanent Split Capacitor (PSC) motors serving variable loads with Electrically Commutated Motors (ECM). ECMs allow for variable speeds, which offer efficiencies of approximately 80% (compared to about 60% for PSC) [49].

9.4.2 Applicability

Exhibit 47 shows the sectors and end-uses to which this measure applies as well as the current implementation rate of this measure.

Given that there are many instances where adding VFDs would not achieve energy savings (as discussed below in Section 9.4.5), an additional applicability factor of 50% was added. This means that in the modelling, VFDs were only added to 50% of the remaining opportunities.

Exhibit 47 – Applicable Sectors and End Uses for VFDs with Controls

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Influent Pump Station	20%
	Primary Clarifier and Sludge Pump	50%
	Activated Sludge Aeration	90%
	Secondary Clarifier	85%
	Solids Dewatering	40%
Drinking Water Treatment	Low-Lift Pumps	85%
	Backwash Pumps	85%
	High-Lift Pumps	85%
Pumping Stations	Wastewater Pumping Stations	85%
	Drinking Water Pumping Stations	85%

9.4.3 Energy Savings

Savings vary widely with application and technology. In some installations, particularly where throttling has previously been used to control flow, savings of 10% to 40% are typical [46]. Applied to a wastewater secondary treatment process, a VFD can save more than 50% of that process's energy use [43]. In general, if a VFD is the only energy savings measure applied attributable savings will be higher. However, if a VFD is installed along with other energy savings measures, specific savings attributable to the VFD will be reduced.

Based on conversations with market actors and industry experts, an energy savings value of 10% was used for the modelling of energy and GHG savings [42], [24]. In the energy modelling for this project, VFDs are not examined at as a stand-alone measure, but rather applied alongside many other energy savings measures, therefore a lower savings value was deemed appropriate.

9.4.4 Costs and Payback

Costs

The cost of adding a VFD with controls was estimated by reviewing 16 VFD projects: one completed by the City of Windsor and 15 submitted through the IESO's Save on Energy Retrofit Program [54]. The cost of energy savings for the 16 projects ranged from $19/MWh to $330/MWh, though the more expensive projects (>$100/MWh) appear to be outliers.[10] For the purposes of modelling, the median value of the 16 projects, $32/MWh, was taken.

Payback

The lifetime of a VFD in drinking or wastewater treatment plants is estimated to be 15 years. Assuming the retail rate of electricity is $140/MWh [47], these examples suggest that this measure has a simple payback period ranging from 2-31 years. The median payback period for the projects analysed is three years.

Ailsa Craig Wastewater Treatment Plant

In 2015, OCWA implemented a retrofit in the Ailsa Craig WWTP on behalf of the Municipality of North Middlesex. The retrofit included installation of VFDs for the aeration blower and aerobic digester. The project cost $52,787 and received $16,209 in incentives from Hydro One. The project has resulted in 162,094 kWh in annual energy savings and $25,935 in electricity cost savings. The project has a simple payback of 1.4 years [118].

[10] See Appendix D for details on how costs were calculated.

9.4.5 Barriers to implementation

Exhibit 48 – Barriers to Implementing VFDs with Controls Measure

Category	Barriers
Technical	▪ VFDs are not a universal energy savings measure. They only save energy in systems in specific circumstances related to flow variability. In many systems, VFDs can actually consume more energy than if they weren't installed at all, being counter-productive. As well, VFDs that are operated at low speeds can be rather energy consumptive, thereby negating any efficiency improvements [42]. ▪ For applications where 100% flow is needed, installing VFDs will not result in energy savings [48].
Financial	▪ Capital cost is one of the biggest barriers to implementing VFDs [45], [48]. ▪ VFDs are additional equipment that entail maintenance costs and will fail prior to the pump failing, a cost that is often not included in lifecycle analysis [48].
Market	▪ To correctly implement this measure, it is essential to hire someone who has a deep understanding of all the systems in water and water wastewater treatment plants, including how these systems interact. There are many experts on equipment replacement in Ontario, but fewer experts who would be able to implement this measure effectively [42].
Training/ Education	▪ Since this is a process improvement measure instead of an equipment upgrade measure, there is a lack of qualified system-level practitioners. Therefore, training and education are key [42]. ▪ There is a lack of knowledge in the market on selecting appropriate VFDs and applications, selecting control parameters, setpoints, installation and repairs [49].
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24]. ▪ System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24]. ▪ System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].

9.5 Monitoring and Targeting

9.5.1 Description

Market actors have indicated that operational improvements through monitoring and targeting are the cheapest, easiest and most effective way of achieving energy savings at WWTPs and DWTPs [24].

This measure is applicable to DWTPs, WWTPs and PSs. Sub-measures that are included under this measure are:

- Real-time energy monitoring. This involves collection and analysis of energy data at regular intervals. This enables facility staff and management to set reduction goals and monitor consumption closely [43].

- Education for facility personnel. Ensuring that all staff understand the relationship between energy efficiency and facility operations leads to significant energy savings [43].
- Periodic facility energy assessments. Energy assessments at drinking and wastewater treatment plants are used to determine opportunities to improve energy efficiency. The survey should review all energy-consuming processes [43].
- Improved maintenance practices. A proper preventive maintenance program can extend equipment lifetime and improve equipment efficiency [43].

Walkerton Clean Water Centre - Energy Management for Drinking Water Operators course

The WCWC provides education and training to DWTP operators and operating authorities, including to 133 First Nations communities in Ontario. In addition to courses on safety and treatment, the WCWC offers a course on energy management for drinking water operators. This course provides information on ways to conserve energy and reduce energy costs, and how audits and incentive programs can help operators recommend and implement energy saving measures [34] .

9.5.2 Applicability

Exhibit 49 shows the sectors and end-uses to which this measure applies as well as the current implementation rate of this measure.

Exhibit 49 – Applicable Sectors and End Uses for Monitoring and Targeting

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Influent Pump Station	80%
	Primary Clarifier and Sludge Pump	20%
	Activated Sludge Aeration	60%
	Secondary Clarifier	80%
	Solids Dewatering	40%
	Other	80%
Drinking Water Treatment	High-Lift Pumps	80%
	Low-Lift Pumps	80%
	Backwash Pumps	80%
	Other	80%
Pumping Stations	Wastewater Pumping Stations	80%
	Drinking Water Pumping Stations	80%

9.5.3 Energy Savings

NYSERDA's Water and Wastewater Energy Management Best Practices Handbook estimates that energy savings from facility energy assessments range from 10% to 50% and savings from real-time energy monitoring range from 5-20% [43].

Market actor interviews indicated that overall, operational Improvements give 10-15% energy savings [24]. For the purposes of modelling, a conservative value of 10% was used.

9.5.4 Costs and Payback

Given the broad nature of this measure, costs are highly variable, and it is difficult to accurately estimate the cost of implementation. Market actors interviewed stated that implementing this measure paid back quickly [24].

Knowing the percentage energy savings (15%) and cost of electricity ($140/MWh [47]) and assuming a payback period of two years, we estimated that the cost of energy savings for this measure is $11/MWh.

9.5.5 Barriers to implementation

Exhibit 50 – Barriers to Implementing Monitoring & Targeting Measure

Category	Barriers
Technical	▪ No technical barriers have been identified.
Financial	▪ Capital cost is a barrier for this measure. Funding is often tied to having a resident energy manager as part of the agreement [24].
Market	▪ To correctly implement this measure, it is essential to hire someone who has a deep understanding on all the systems in water and water wastewater treatment plants, including how these systems interact. There are many experts on equipment replacement in Ontario, but fewer experts who would be able to implement this measure effectively [42].
Training/ Education	▪ Since this is a process improvement measure instead of an equipment upgrade measure, there is a lack of qualified system-level practitioners. Therefore, training and education are key [42].
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].

Sudbury Wastewater Treatment Plant Upgrades

Sudbury's Wastewater Treatment Plant was built in 1971. The plant is a conventional type but due to the technology available at the time of construction, the raw wastewater had to be pumped twice: once from the lower section/wet well area of the lift station 33 meters to surface and then, after the headworks, the wastewater was pumped again to the aeration cells.

The City was faced with a potential $30 million investment when the plant began to experience operational and maintenance issues that included a new pump station and headworks.

After careful analysis, the City decided to overhaul the existing facilities. In 2010 the City embarked on a series of capital upgrades over five years. The work cost approximately $15 million and included installing new lift station pumps and coarse mechanical bar screens, an overhaul of the headworks facility (including fine bar screens), and the install of a new high-speed blower.

Once the high-speed blower was installed, it was recognized that the aeration cell membrane diffusers (15+ years old) would limit the expected energy gains from the newly installed blower. A combination of efforts by both internal staff and contractors led to the complete overhaul of the diffusers which provided real time savings aligned with estimates from engineering studies.

Fine bubble diffusers improve aeration efficiency by providing smaller bubbles with more surface area to deliver oxygen to the wastewater column. With improved aeration efficiency, older, less efficient equipment could be shut down [111].

The retrofit, which also included installing VFDs, was completed in 2015 and is expected to save the City over $100,000 per year in energy costs [112] [113]. Since the retrofit, the City has been able to keep energy costs steady at the WWTP despite increased energy rates [111]. The Sudbury WWTP also participates in the IESO's ICI program.

9.6 Pump Upgrades

9.6.1 Description

This measure involves replacing low-efficiency pumps with higher-efficiency pumps. It is applicable to DWTPs, WWTPs and PSs.

In practice, this measure should only be applied after a pumping system optimization has been completed. In most cases, much greater energy savings can be achieved through right-sizing pumps and correctly designing the system to optimize energy use.

9.6.2 Applicability

Exhibit 51 shows the sectors and end-uses that this measure is applicable to. Market research indicates that this measure has already been implemented in about 60% of water treatment plants in Ontario [42], [24].

Exhibit 51 – Applicable Sectors and End Uses for Pump Replacement

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Influent Pump Station	60%
	Primary Clarifier and Sludge Pump	60%
	Secondary Clarifier	60%
Drinking Water Treatment	Low-Lift Pumps	60%
	Backwash Pumps	60%
	High-Lift Pumps	60%
Pumping Stations	Wastewater Pumping Stations	60%
	Drinking Water Pumping Stations	60%

9.6.3 Energy Savings

The energy savings that can be achieved from replacing a low-efficiency pump with a high-efficiency pump vary widely, from 5-25%. Standard pumps in drinking and wastewater treatment applications have efficiencies ranging from 70-75% and high-efficiency pumps have efficiencies ranging from 83-90% [46].

Based on conversations with market actors and industry experts, an energy savings value of 5% was used for the modelling of energy and GHG savings [42], [45].

9.6.4 Costs and Payback

Costs

The cost of a pump upgrade was estimated by looking at three separate pump replacement projects: one completed by the City of Windsor and two completed by the District of Muskoka [54], [52]. The cost of energy savings for the three projects ranged from $116/MWh to $161/MWh, assuming the pump was replaced before the end of its natural life.[11]

[11] See Appendix D for details on how costs were calculated.

If we assume the pump was replaced at the end of its natural life, we would look at the incremental cost of a high-efficiency pump over a standard-efficiency pump, instead of the full cost.[12] This gives a much lower cost of energy savings, ranging from $23/MWh to $32/MWh. For the purposes of modelling, we assumed that the pump was replaced at the end of its life and the cost of energy savings was $27/MWh.

Windsor's WWTP Energy Efficiency Upgrades

The City of Windsor conducted several upgrades to two WWTP with the following costs, incentives and outcomes:

Little River Pollution Control Plant:

Project	Capital Cost	Incentive	Incentive Program	Annual Demand Savings	Annual Consumption Savings
Replaced two sewage pump motors (250 hp each)	$611,021	$8,877	Save on Energy Retrofit Program	22 kW (2%)	189 MWh (3.3%)
Installation of Air Conditioning Energy Savers in several AC units	$1,997	NA	Non-incented	3 kW (0.3%)	6 MWh (0.1%)
Small LED Retrofit Project	$10,771	NA	Non-incented	2 kW (0.1%)	13 MWh (0.2%)

Lou Romano Water Reclamation Plant:

Project	Capital Cost	Incentive	Incentive Program	Annual Demand Savings	Annual Consumption Savings
Installed turbo process air blowers	$699,110	$296,096	Save on Energy P&SU Program	169 kW (5%)	1,565 MWh (9.5%)
Installation of two VFDs	$7,160	$4,710	Save on Energy Retrofit Program	6 kW (0.2%)	24 MWh (0.1%)

The City is currently conducting engineering studies on battery storage and a comprehensive LED retrofit project at both plants. [52]

[12] We assume the price premium of a high-efficiency pump over a standard pump is 20%, with no rebate

Payback

The lifetime of a pump in a water treatment plant was assumed to be 25 years [46]. Assuming the retail rate of electricity for is $140/MWh [47] these examples suggest that this measure has a simple payback period ranging from 18-25 years, if the if the pump is replaced at full cost and a simple payback period of 3.6-5 years if replaced at the end of life.

9.6.5 Barriers to implementation

Exhibit 52 – Barriers to Implementing Pump Upgrades Measure

Category	Barriers
Technical	▪ Asset management systems often do not track efficiency, meaning existing pumps could be more efficient than assumed [48]. ▪ Old pumps could be operating outside of their best efficiency point due to poor system design. Improving the design of the system should take priority over equipment upgrades [48], [42].
Financial	▪ Capital cost is a barrier for equipment upgrade measures [45].
Market	▪ There are many experts on equipment replacement but fewer experts who have a deep understanding of all the systems in water and water wastewater treatment plants, including how these systems interact.
Training/ Education	▪ No training/education barriers have been identified.
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].

Hamilton's Woodward Avenue WWTP High-Lift Pumping Station Efficiency Upgrades

When the equipment at Hamilton's Woodward Avenue High-Lift Pumping station reached its end of life energy-efficient pumps with VFDs were installed. To optimize the system, the existing pumps of various sizes and voltages were replaced with six identical pumps: four of which were connected to VFDs and two operating as single-speed pumps. This new system operates more efficiently across a range of flow rates and allows pumping capacity to be varied depending on the cost of electricity and the need for water capacity. The pumps provide operators with real-time electricity consumption to inform their decisions and help control energy costs at the plant [46] [116].

These upgrades have resulted in annual energy savings of 20%, or approximately $400,000 in electricity costs. The project received over $2 million in incentives from Save on Energy's Retrofit and Process & Systems program [116].

9.7 Blower Upgrades

9.7.1 Description

This measure involves replacing low-efficiency blowers with higher-efficiency blowers. It is applicable to WWTPs only. Blowers are one of the higher energy users at WWTPs and considerable energy savings can be achieved by upgrading to more efficient equipment.

In practice, this measure should only be applied after an aeration system optimization discussed in section 9.3 has been completed. Depending on the system, more energy savings may be achieved through measures such as fine bubble aeration or dissolved oxygen control. Since all plants are unique, system options for aeration energy savings should be considered before upgrading any equipment.

9.7.2 Applicability

Exhibit 53 shows that this measure is only applicable in one sector and end use. Market research indicates that this measure has already been implemented in about 80% of wastewater treatment plants in Ontario [49], [24].

Exhibit 53 – Applicable Sectors and End Uses for Blower Upgrades

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Activated Sludge Aeration	80%

9.7.3 Energy Savings

Most standard blowers have efficiencies ranging from 60-80% with older blowers having efficiencies as low as 50% [45], [46], [55]. High-efficiency blowers have efficiencies of up to 82% [55], [45]. Therefore, there is a wide range of possible energy savings for this measure, ranging from 10-40% [24], [50].

An energy savings value of 25% was used for the modelling of energy and GHG savings.

Town of Aylmer Lagoon Aeration Upgrade Project

In 2013, OCWA conducted an energy and process walkthrough at the Aylmer Lagoon. The audit was supported by the IESO's Energy Efficiency Service Provider Program and identified energy savings opportunities with aeration blower upgrades. With support from the town, OCWA implemented the retrofit in 2016. An existing positive displacement 75hp aeration blower was replaced with one 75 hp high-efficiency turbo blower with continuous DO control. The project cost $196,349 which was supposed by $22,770 with incentives from the IESO. The project has realized 259,728 kWh in energy savings and $38,959 in energy costs. The project has a simple payback period of 4 years [122]

9.7.4 Costs and Payback

Costs

The cost of a blower upgrade was estimated by looking at five separate blower replacement projects: two completed by the City of Windsor and three submitted through the IESO's Save on Energy PSUP [54]. The cost of energy savings for the five projects ranged from $12/MWh to $86/MWh, assuming the blower was replaced before the end of its natural life.[13]

If we assume the blower was replaced at the end of its natural life, we would look at the incremental cost of a high-efficiency blower over a standard-efficiency blower, instead of the full cost.[14] This gives a much lower cost of energy savings, ranging from $2/MWh to $17/MWh. For the purposes of modelling, we assumed that the blower was replaced at the end of its life and the cost of energy savings was $6/MWh.

Payback

The lifetime of a blower in a wastewater treatment plant is estimated to be 25 years [46]. Assuming the retail rate of electricity for is $140/MWh [47], these examples suggest that this measure has a simple payback period ranging from 2-14 years if the blower were replaced at full cost and a simple payback period of three months to three years if replaced at the end of life.

9.7.5 Barriers to implementation

Exhibit 54 – Barriers to Implementing Blow Upgrade Measure

Category	Barriers
Technical	▪ No technical barriers have been identified.
Financial	▪ Capital cost is a barrier for equipment upgrade measures [45].
Market	▪ There are many experts on equipment replacement but fewer experts who have a deep understanding of all the systems in water and water wastewater treatment plants, including how these systems interact.
Training/ Education	▪ No training/education barriers have been identified.
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].

[13] See Appendix D for details on how costs were calculated.
[14] We assume the price premium of a high-efficiency blower over a standard blower is 20%, with no rebate

Municipality of Central Elgin WWTP Aeration Blowers Upgrade

The Municipality of Central Elgin used incentives from the Save on Energy Retrofit Program to upgrade the aeration blowers at the WWTP. Two 11-year-old blowers were replaced with one, high-efficiency 100HP VFD turbo blower with dissolved oxygen controls. The retrofit took five days to install and caused minimal disruption to the facility. The new equipment has resulted in about 474,000 kWh annual verified energy savings and $56,850 in annual energy cost savings. With $47,373 in incentives from Hydro One, the project has a simple payback of 1.9 years [117].

9.8 Motor Upgrades

9.8.1 Description

This measure involves replacing standard-efficiency motors with high-efficiency motors. It is applicable to DWTP, WWTP and pumping stations.

In practice, this measure should only be applied after the process improvement measures have been completed. In most cases, much greater energy savings can be achieved through improving operations and optimizing systems. Only then does upgrading to more efficient motors make sense.

9.8.2 Applicability

Exhibit 55 shows the sectors and end-uses to which this measure applies. Market research indicates that this measure has already been implemented in about 80% of drinking and wastewater treatment plants in Ontario [42].

Exhibit 55 – Applicable Sectors and End Uses for Motor Upgrades

Sector	End Use	Current Market Penetration in Ontario **[24]**
Wastewater Treatment	Influent Pump Station	20%
	Primary Clarifier and Sludge Pump	20%
	Activated Sludge Aeration	80%
	Secondary Clarifier	80%
	Solids Dewatering	40%
Drinking Water Treatment	High-Lift Pumps	80%
	Low-Lift Pumps	80%
	Backwash Pumps	80%
Pumping Stations	Wastewater Pumping Stations	80%
	Drinking Water Pumping Stations	80%

9.8.3 Energy Savings

NYSERDA’s Water and Wastewater Energy Management Best Practices Handbook estimates that energy savings from installing high-efficiency motors range from 5-10% [43]. Some market actor interviews agreed that 5-10% was a reasonable range but others suggested that it is unlikely that savings would exceed 5% [42], [45]. For energy and GHG modelling, an energy savings value of 3% was used to be conservative.

9.8.4 Costs and Payback

Costs

The cost of a motor upgrade was estimated by looking at a motor replacement project completed by the City of Windsor [54]. The cost of energy savings for this project was $129/MWh, assuming the motor was replaced before the end of its natural life. If we assume the motor was replaced at the end of its natural life, we would look at the incremental cost of a high-efficiency motor over a standard-efficiency motor, instead of the full cost.[15] This gives a much lower cost of energy savings of $26/MWh.

The capital cost of upgrading motors can be prohibitive for many municipalities. The capital cost of replacing a 250 hp (0.186 MW) motor is approximately $ 300,000 [54].

Payback

The lifetime of a motor in a water treatment plant is estimated to be 25 years [46]. Based on the project example given above, the payback period for a motor replacement is 20 years, if the motor replaced at full cost and four years if replaced at the end of life.

9.8.5 Barriers to Implementation

Exhibit 56 – Barriers to Implementing Motor Upgrades Measure

Category	Barriers
Technical	▪ No technical barriers have been identified.
Financial	▪ Capital cost is a barrier for equipment upgrade measures [45].
Market	▪ There are many experts on equipment replacement but fewer experts who have a deep understanding of all the systems in water and water wastewater treatment plants, including how these systems interact.
Training/ Education	▪ No training/education barriers have been identified.
Other	▪ The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].

9.9 CHP from Methane Capture

9.9.1 Description

This measure is applicable to WWTPs. Combined Heat and Power (CHP) equipment can be used in wastewater treatment facilities to recover energy from biogas produced via anaerobic digesters.

In addition to reduced energy costs, CHP offers additional benefits including:

[15] We assume the price premium of a high-efficiency motor over a standard motor is 20%, with no rebate [115]

- Resilience against electrical grid failures. CHPs can provide high-quality electricity and thermal energy to a site regardless of what might occur on the power grid, thereby decreasing the impact of outages and improving power quality for sensitive equipment [56] [57].
- Environmental benefits including reduced GHG emissions and reduction in other air pollutants as less fossil fuel is burned to produce each unit of energy output (both thermal and electrical)[16] [56] [57].
- Provision of a hedge against unstable grid energy costs, and opportunities for electrical load shifting [56] [57].

9.9.2 Applicability

Opportunity for CHP in Ontario

Only medium and large WWTPs (daily volume of sewage treated is >5000 m^3) are candidates for energy recovery from methane capture [1]. Smaller plants do not produce enough methane for a CHP unit to be economically feasible, though they can be candidates if they receive additional organic material from other sources [1], [48], [58]. Plants that currently have anaerobic digestors are the most obvious candidates for adding CHP to their plants, although plants with aerobic digestion are also candidates if the plant undergoes additional upgrades to convert to an anaerobic digestor [24].

Exhibit 57 shows the WWTP segments in Ontario that are candidates for CHP based on size and method of sludge digestion.

Exhibit 57 shows that approximately 51 of the 340 WWTPs in Ontario meet the size threshold and currently have anaerobic digestors, meaning that they are good candidates for CHP systems. About 45 WWTPs in Ontario meet the size threshold and have aerobic digestion, meaning that they are also candidates for CHP, but the upfront cost would be higher and there would be additional technical barriers to installing a CHP system [24].

Exhibit 57 – WWTP Segments that are Candidates for CHP in Ontario

Plant Size	Sludge Digestion	Number of Plants in Ontario	Total Flow (ML/year)
Medium/Large	Anaerobic	51	1,287,744
Medium/Large	Aerobic	45	571,889

Current Implementation of CHP in Ontario

Exhibit 58 shows the current implementation of CHP at WWTPs in Ontario, based on information provided by the Canadian Biogas Association, and the ECO survey [1], [22]. This information is summarized in Exhibit 58. This exhibit indicates that a large percentage of wastewater in Ontario is already being treated at a facility with a CHP on site. It should be noted that four of these CHPs are currently still under development and may not be completed by the time this study is completed.

[16] CHPs only reduce GHGs if fuelled 100% by biogas.

Exhibit 58 – Current Implementation of CHP at WWTPs in Ontario (2018)

Number of Plants in Ontario	Total Flow (ML/year)
15	1,058,023

9.9.3 Energy Savings

Hamilton's Woodward Avenue Wastewater Treatment facility has a 1.6 MW CHP unit installed. Assuming the unit runs 7,466 hours out of the year (85% run time is recommended to allow time for regular scheduled maintenance [59]), the unit would be able to generate approximately 11,946 MWh of electricity annually, representing 18% of the plant's total annual electricity consumption of 65,523 MWh. This aligns with market actor interviews that state that a CHP unit at a WWTP can meet up to 20% of the electric load [48].

Another example is the CHP Unit at Toronto's Humber WWTP where electricity bills decreased by 21% once the CHP unit was installed [60]. For the purposes of modelling it was assumed that 18% of the electric load could be met by a CHP unit.

It is assumed that 100% of the natural gas load (space heating and anaerobic process heating) can be met with the CHP unit, since space and process heating together only represent about 10% of a WWTPs total energy use [24] and the thermal efficiency of a CHP system is generally higher than the electric efficiency. [61]

Hamilton's Woodward Avenue Wastewater Treatment Combined Heat and Power Plant

Since 2006 the Woodward Avenue Wastewater Treatment Plant has used anaerobic digestors to generate biogas for use in a Combined Heat and Power (CHP) unit. The facility also has a biogas purification unit to upgrade captured methane into renewable natural gas (RNG). [106, p. 19] This RNG is injected into the local gas distribution system operated by Union Gas. [20]

The 1,600 kW CHP system was originally constructed at a cost of $4.4 million (paid through a power purchase agreement contract) and generates over $900,000 in revenue annually. The digestors were upgraded in 2017 to improve resource recovery and biogas generation. [20]

Tom Chessman, Manager of Energy Initiatives for the City of Hamilton, notes that successful production and sales of RNG required a knowledge of the natural gas industry [114]. The City of Hamilton has developed this expertise in-house. [46]

9.9.4 Costs and Payback

Costs

The capital cost (equipment and installation) of Hamilton's 1.6 MW unit was about $5 million [48]. In addition to the capital cost, CHP units have ongoing operating costs, including additional maintenance. Collingwood's WWTP Cogeneration Plant Feasibility Study estimates that the operating costs of a CHP unit would be $75/MWh [59].

Assuming the lifetime of a cogeneration facility a wastewater treatment plant is 20 years [62], the example above shows that the capital cost of generating on-site energy (gas and electric) is $7/MWh.[17] There are also ongoing operating costs of $75/MWh [48].

Payback Period

Using the example and assumptions listed above, the simple payback period of a CHP unit is 17 years. Although the CHP is expected to pay for itself over its lifetime, the payback period is very long, and the capital cost may be prohibitive for many municipalities.

This is just one example, and it should be noted that each site is unique and there is a lot of variability in the potential payback period.

9.9.5 Barriers to Implementation

Exhibit 59 – Barriers to Implementing CHP from Methane Capture

Category	Barriers
Technical	▪ There is often limited space on-site to install a CHP unit. ▪ The heat load may not be high enough in the summer months, and the CHP may create waste heat.
Financial	▪ There is uncertainty about cost savings. Priority is often not given to biogas generation projects and, therefore, it must compete with other funding demands that are linked to the facility's core business. The economic case is unattractive when a simple payback analysis is conducted compared to a deeper economic analysis. Also, there is currently uncertainty about the financial value of biogas in Ontario [13] [25]. ▪ Cost of converting old systems to new systems [1]. The capital cost of implementing this measure is high [54]. Although the payback period of this measure is less than its lifetime, it is still long and, therefore, less attractive.
Market	▪ No market barriers have been identified.
Training/ Education	▪ There is a lack of human resources and technical knowledge within municipalities.
Other	▪ Environmental approvals are a barrier for CHP systems. For a municipality to install or alter an anaerobic digestor at its WWTP, it must apply for an amendment to the WWTP's Environmental Compliance Approval (ECA) under section 53 of the *Ontario Water Resources Act*. In addition, a

[17] See Appendix D for details on how costs are calculated.

municipality will either need to apply for or amend its section 9 ECA for air emissions under the *Environmental Protection Act*. The approval process is even more challenging if the municipality wants to use the biogas to generate electricity (often through a combined heat and power unit). No matter how small, this requires a Renewable Energy Approval (REA) under O. Reg. 359/09 of the *Environmental Protection Act*, irrespective of whether the electricity is to be sold into the grid.24 [1]

- **Economies of Scale:** The United States Environmental Protection Agency estimates that energy recovery (at least for cogeneration) is only feasible at plants that treat at least 4,000-19,000 m^3 of wastewater per day, roughly the amount generated by 10,000-50,000 households. The International Energy Agency estimates a minimum of about 5,000 m^3 of wastewater per day, representing about 12,500 households. Many Ontario WWTPs do not receive this amount of wastewater. However, Ontario can facilitate its proposed diversion of organics from landfill, while making energy recovery cost-effective at more WWTPs, by enabling WWTPs to digest appropriate local food/organic wastes [1] [17].
- The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].
- System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24].
- System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].

The Environmental Commissioner of Ontario provided several recommendations for the Ontario government to help WWTPs overcome some of the barriers highlighted above [1]:

- The Ministry of Infrastructure should make anaerobic digestion and biogas generation technology eligible for water/wastewater infrastructure funding.
- The Ministry of the Environment, Conservation and Parks should, without reducing environmental protection, simplify the regulatory approvals process for energy recovery systems associated with anaerobic digestion at wastewater treatment plants, including systems that co-digest off-site organics.
- The Ontario Energy Board should set a renewable natural gas content requirement and cost recovery criteria for gas utilities.
- Co-digestion at WWTPs can play a substantial role in Ontario's plan to increase the organics diversion rate through the Strategy for a Waste-Free Ontario.

Co-digestion is defined as the digestion of wastewater sludge in combination with other organics transported to the WWTP. The Township of Georgian Bluffs in Ontario used the "BIOGRID" digestor when needed to process sewage and process domestic solid waste [100]. The viability of the site going forward is unknown as provincial funding was recently cancelled [101].

There are several examples of successful co-digestors in other jurisdictions: A WWTP in Gresham, Oregon achieved net-zero energy status, by producing 92% of its power from on-site biogas, made possible by to co-digestion.

In Quebec, the city of Saint-Hyacinthe acts as an organic waste hub that capitalizes on waste from 23 participating municipalities and recovers energy for running municipal vehicles, heating and cooling municipal buildings, and injecting excess into the local gas grid [1].

10 Load-Shifting Measures

All measures previously outlined in Section 9 reduce energy consumption and electric peak demand, while this section focuses on measures that move energy use from on-peak to off-peak times. In the subsections below, we outline two measures that can be implemented to shift electric loads in the water treatment sectors: high-lift pump system storage and aeration system over-oxygenation.

By implementing both energy consumption savings and load-shifting measures, some customers will have an opportunity to reduce their costs. Section 11.3 presents electric peak demand potential details and discusses the potential for the WWTP, DWTP, WW Pumping and DW Pumping sectors to become market participants. As an illustrative example, potential for Industrial Conservation Initiative participation is explored in some detail, including a high-level quantification of financial benefits applicable to the water treatment sectors.

10.1 High-Lift Pump System Storage

10.1.1 Description

This measure shifts the energy requirements associated with pumping to off-peak times by making use of water storage. For this measure it is important to make sure there is sufficient storage capacity in reservoirs to accommodate the required water [63].

10.1.2 Applicability

High-lift pumps in DWTPs provide the biggest opportunity for load shifting, since they have sufficient water storage [63], [24]. About 10-20% of drinking water in Ontario is already treated at a plant that uses this measure [24] and about 50% of all DWTPs are eligible for this measure [24].

To model electric peak demand savings, the following assumptions were made [24]:

- This measure only applies to the DWTP sector (in practice we know that some high-lift pumps are being operated in DW pumping stations separate from the DWTP facilities, making our modelled electric peak demand savings conservatively low),
- This measure only applies to the high-lift pumping end-use,
- 15% of DWTPs have already implemented this measure, and
- This measure can apply to 50% of DWTPs in Ontario.

10.1.3 Barriers

The following barriers have been identified for this measure:

- Only about 30% of DWTPs in Ontario are subject to time-of-use pricing, which means that they don’t have a financial incentive to move their pumping to off-peak times [24].
- The water treatment sectors typically have long decision-making cycles, making it difficult for projects to advance quickly [24].
- System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24].

- System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].
- Water treatment facilities with average electric peak demand between 500 kW and 1 MW are not currently eligible to participate in the Industrial Conservation Initiative.

10.1.4 Demand Savings

This measure can reduce the electric peak demand by high-lift pumps by 50% [24]. The lifetime of this measure is estimated at 18 years, consistent with pump lifetimes.

10.2 Aeration System Over-Oxygenation

10.2.1 Description

This measure involves over-oxygenating wastewater during off-peak hours, so operators can reduce aeration energy use during on-peak hours [1]. The measure is limited by minimum required oxygen levels. In general, if only 50% of the required oxygen is supplied during peak hours, dissolved oxygen levels will still meet required specifications [24].

10.2.2 Applicability

To model electric peak demand savings, the following assumptions were made [24]:

- This measure only applies to the WWTP sector;
- This measure only applies to the aeration end use;
- 15% of WWTPs have already implemented this measure; and
- This measure can apply to 100% of WWTPs in Ontario.

10.2.3 Barriers

The following barriers have been identified for this measure:

- Only about 30% of WWTPs in Ontario are subject to time-of-use pricing, which means that they don't have a financial incentive to move their aeration to off-peak times [24].
- This measure can be complex to implement, especially in larger plants where more sophisticated control systems are required [24].
- The water treatment sectors typically have long decision-making cycles making it difficult for projects to advance quickly [24].
- System-based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations [24].
- System-based changes expose municipalities to the risk of re-classification or a change in operating requirements under their licensing category framework [24].
- Water treatment facilities with average electric peak demand between 500 kW and 1 MW are not currently eligible to participate in the Industrial Conservation Initiative.

10.2.4 Demand Savings

This measure can reduce the electric peak demand for aeration by 50% [24]. The lifetime of this measure is estimated as 18 years, consistent with blower system lifetimes.

11 Potential for Energy and GHG Savings

This section estimates the potential energy and greenhouse gas (GHG) savings that can be achieved from implementing the measures described in Section 7 and Section 10. It is organized into three subsections:

- Section 11.1 presents the modelling approach.
- Section 11.2 summarizes consumption and GHG savings potential for all sectors (WWTP, DWTP, WW Pumping Stations and DW Pumping Stations).
- Section 11.3 summarizes electric peak demand savings potential for all sectors.
- Sections 11.4 - 11.7 present detailed results for each sector.

11.1 Modelling Approach

Potential modelling was completed using the Posterity Group Navigator Energy and Emissions Simulations Suite. Base year energy use and emissions was developed using the information presented in section 6 of this report, for a base year of 2018. For future years, a reference case was developed by assuming that energy consumption would increase 1.35% each year to 2049, to scale with population growth.[18] Emissions factors used to calculate GHG emissions are provided in Appendix E.

The four sectors are presented as follows:

- Wastewater Treatment Plants (Section 11.3)
- Drinking Water Treatment Plants (Section 11.5)
- Wastewater Pumping Stations (Section 11.6)
- Drinking Water Pumping Stations (Section 11.7)

The economic potential of energy and GHG savings was calculated for each sector. For electric peak demand savings, the technical potential was calculated. Technical and economic potential are defined as:

- **Technical Potential -** The theoretical maximum amount of energy use that could be displaced by the measures, only considering technical constraints. Non-technical constraints such as cost-effectiveness and the willingness of end-users to adopt the efficiency measures are not considered [64].
- **Economic Potential -** The subset of the technical potential that is economically cost-effective to the end-user [64].

Economic Tests

To calculate the economic potential of the measures, a benefit cost ratio test was applied. To pass the benefit cost ratio test, the ratio of the total benefits of the measure over its lifetime to its total lifetime costs must be greater than one. The benefits in this test are the energy cost savings, from the facility's perspective. The costs are the total costs of implementing the measure.

---

[18] Population growth rate is expected to fall from 1.8% to 0.9% between 2017 and 2041, according to the Ontario Ministry of Finance [97]. We took the midpoint between these two numbers, 1.35%.

For this study, the only economic screen is one from the end-user perspective, not the utility's perspective. Because the main audience for this study is Ontario municipalities and facility operators, it was important to present energy and GHG savings potential from a municipal perspective.

In this analysis a flat rate of electricity was used ($140/MWh) and it was assumed the cost does not differ based on time of use. In practice, an end-user may see different energy savings depending on what time of day they reduce their load. For example, class A (ICI) customers will see much lower electricity cost savings from reductions in electricity consumption outside their peak 5 hours [65].

Adding Measures to the Model

Most measures were introduced to the model on a full cost basis, at the beginning of the study period. Because this study only focuses on technical and economic potential, it makes sense theoretically to introduce most measures at the beginning of the study period; however, in real life there would likely be constraints that prevent all the measures from being introduced at one. The purpose of this analysis is to show the potential for energy savings opportunities, while recognizing that it would likely take several years to achieve this level of market penetration.

The equipment replacement measures are unique (blowers, motors and pump upgrades) because they are only introduced to the model at the end of their useful life. They need to be modelled this way to reflect that equipment upgrades are only economically attractive when equipment is being replaced on burn-out.

Demand Savings Assumptions

A detailed dataset with sectoral plant-level and end-use load shape data in Ontario does not currently exist, nor is it readily available from other North American jurisdictions. For our analysis, we have assumed plant-level and end-use load shapes are flat in the water treatment sectors, which aligns with the assumption being made by other leading industry organizations such as the Northwest Power and Conservation Council [66]. Electric peak demand potential outputs using this assumption will be conservative (i.e., electric peak demand savings will likely be underestimated).

Electric peak demand savings from energy conservation measures are modelled by applying load shape assumptions to baseline sector consumption, as well as measure-level conservation potential. More accurate electric peak demand savings assumptions could be determined at some point in the future if plant-specific load shapes were developed.

As presented in Section 10, two load-shifting measures were investigated in this study in addition to the energy conservation measures. Like the equipment replacement measures, the load-shifting measures are introduced to the potential model on an incremental basis over the study period. This is a conservative assumption, which acknowledges that this study has not assessed the economic attractiveness of implementing the measures.

Other Assumptions

Electricity was assumed to have a 100% fuel share for all end-uses, except the natural gas end-use which consists of space and process heating. The costs of implementing these measures were not discounted.[19]

[19] It was assumed that the discount rate was close to zero, since municipalities can borrow at a rate that is close to the rate of inflation.

11.2 Summary of Energy and GHG Results

Provincial energy and GHG savings potential has been assessed for each sector:

- Wastewater Treatment Plants (WWTP)
- Drinking Water Treatment Plants (DWTP)
- Wastewater Pumping Stations (WW Pumping)
- Drinking Water Pumping Stations (DW Pumping)

Exhibit 60 shows the reference case energy consumption in all sectors from 2019 to 2049, as well as the economic potential consumption. All measures pass the economic test, so the technical and the economic potential are the same.

Exhibit 61 shows the breakdown of potential energy consumption savings by sector, over the entire study period. This chart shows that most energy savings are attributed to wastewater treatment plants. This is in part because WWTPs represent the largest portion of the reference case energy use (see section 6.1). WWTPs also can implement CHP for significant additional energy savings, while the other sectors do not have this option.

Exhibit 60 – Energy Savings (MWh) All Sectors, All Fuels

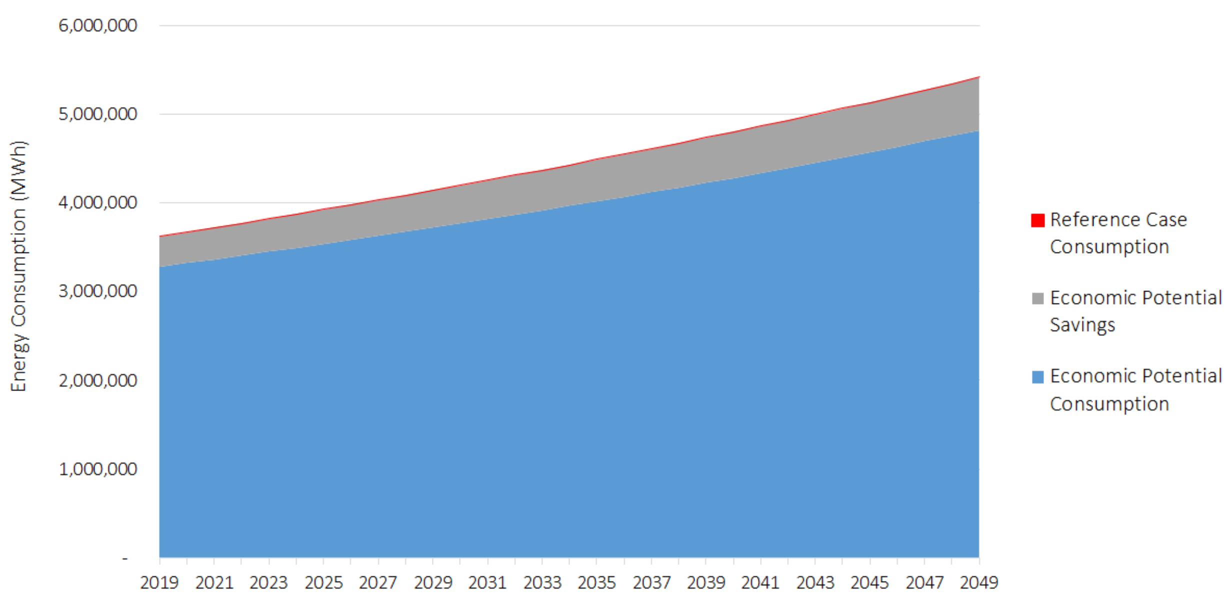


Exhibit 61 – Potential Energy Savings (MWh) by Sector, All Fuels

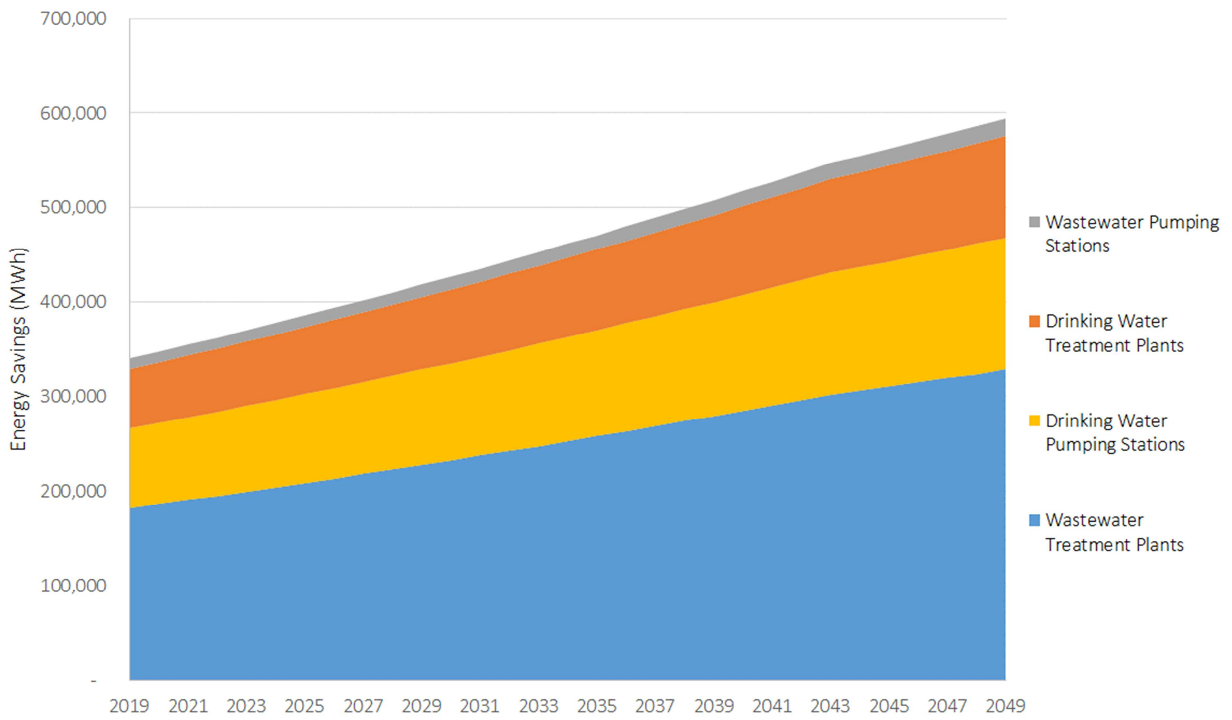


Exhibit 62 presents the potential for energy consumption savings in all four sectors for the first year the measures could be implemented: 2019. Exhibit 63 presents the same results for the final year of the study: 2049. These tables show that most electricity savings come from the WWTP sector and this is also the only sector that sees natural gas savings (because the CHP measure is the only measure that reduces natural gas in this study). Exhibit 64 shows the emissions by sector for 2019 and 2049. This table shows that that most of the emissions savings are from the WWTP sector.

Exhibit 62 – Energy Savings by Fuel and Sector, 2019

Sector	Total Economic Potential Electricity Savings (MWh/year)	% Electricity Savings vs. Reference Case	Total Economic Potential Natural Gas Savings (MWh/year)	% Natural Gas Savings vs. Reference Case
Wastewater Treatment Plants	145,243	12.8%	37,221	7.4%
Drinking Water Treatment Plants	62,788	7.6%	-	-
Wastewater Pumping Stations	10,997	9.9%	-	-
Drinking Water Pumping Stations	83,773	9.9%	-	-
All Sectors	**302,802**	**10.4%**	**37,221**	**5.3%**

Exhibit 63 – Total Energy Savings by Fuel and Sector, 2049

Sector	Total Economic Potential Electricity Savings (MWh)	% Electricity Savings vs. Reference Case	Total Economic Potential Natural Gas Savings (MWh)	% Natural Gas Savings vs. Reference Case
Wastewater Treatment Plants	272,960	16.1%	55,655	7.4%
Drinking Water Treatment Plants	107,863	8.7%	-	-
Wastewater Pumping Stations	18,365	11.1%	-	-
Drinking Water Pumping Stations	139,893	11.1%	-	-
Total	**539,081**	**12.4%**	**55,655**	**5.3%**

Exhibit 64 – Total Emissions Savings by Sector, All Fuels 2019 and 2049

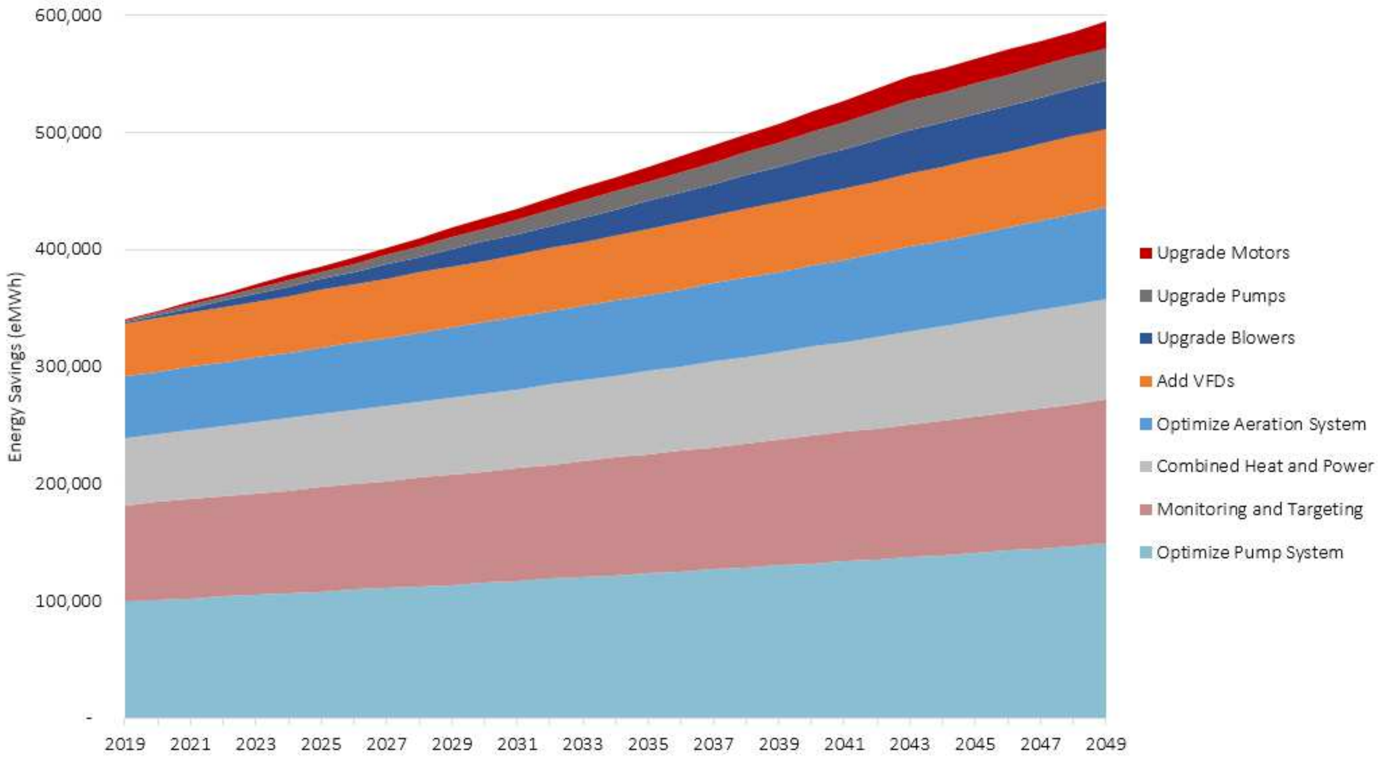
Sector	Emissions Savings 2019 (tonnes CO_2e)	% Emissions Savings vs. Reference Case	Emissions Savings 2049 (tonnes CO_2e)	% Emissions Savings vs. Reference Case
Wastewater Treatment Plants	29,764	11.0%	53,364	13.2%
Drinking Water Treatment Plants	9,971	6.2%	17,129	7.1%
Wastewater Pumping Stations	1,746	8.8%	2,916	9.8%
Drinking Water Pumping Stations	13,303	9.6%	22,215	10.7%
All Sectors	**54,785**	**9.3%**	**95,624**	**10.8%**

Exhibit 65 presents the total potential energy savings in all sectors over the study period, by measure. Exhibit 66 gives a visual representation of the breakdown of potential energy savings by measure. These results show that in Ontario, the biggest opportunity for energy savings is in optimizing pumping systems, followed by monitoring and targeting and CHP. These exhibits also show that while equipment replacement measures do not contribute significantly to energy savings in 2019, they contribute more as the study period progresses.

Exhibit 65 – Energy Savings by Measure, All Sectors, All Fuels 2019 and 2049

Measure	Total Economic Potential Energy Savings 2019 (eMWh)	% Energy Savings from this Measure vs. Reference Case	Total Economic Potential Energy Savings 2049 (eMWh)	% Energy Savings from this Measure vs. Reference Case
Optimize Pump System	99,659	29%	149,015	25%
Monitoring and Targeting	82,227	24%	122,950	21%
Combined Heat and Power	57,355	17%	85,516	14%
Optimize Aeration System	52,472	15%	78,458	13%
Add VFDs	45,494	13%	67,581	11%
Upgrade Blowers	1,260	0.4%	40,991	7%
Upgrade Pumps	870	0.3%	28,125	5%
Upgrade Motors	686	0.2%	22,100	4%
Total	**340,023**	**100%**	**594,736**	**100%**

Exhibit 66 – Energy Savings by Measure, All Sectors, All Fuels



11.3 Summary of Demand Savings

Exhibit 67 shows the reference case electric peak demand and the peak demand if all the energy and load-shifting measures are implemented. Exhibit 68 shows the breakdown of potential electric peak demand savings by sector between 2019 and 2049.

Exhibit 67 – Reference Case and Upgrade Electric Peak Demand, All Sectors

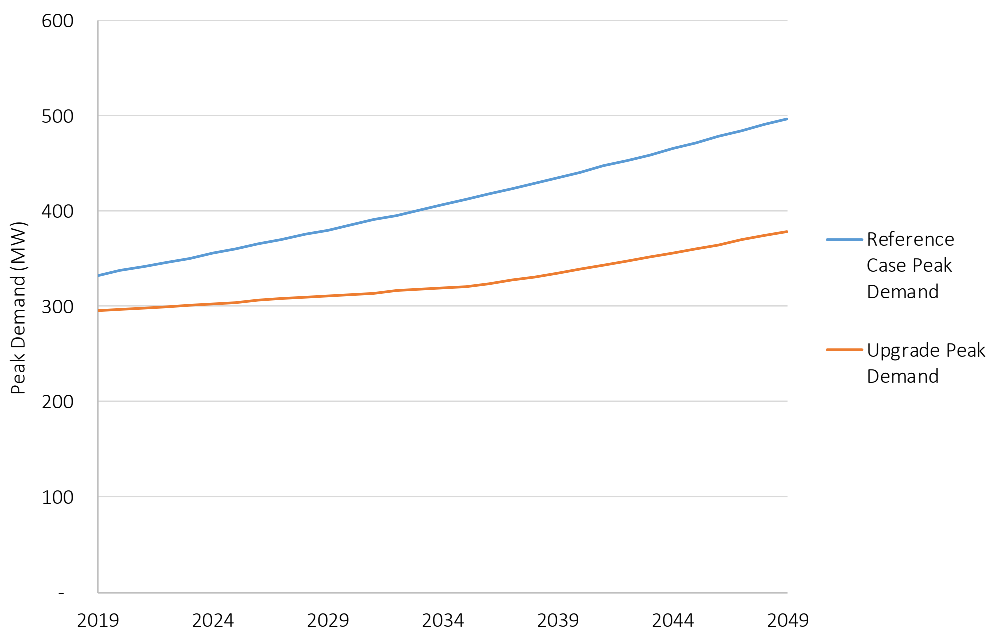


Exhibit 68 – Potential Electric Peak Demand Savings (MW) by Sector

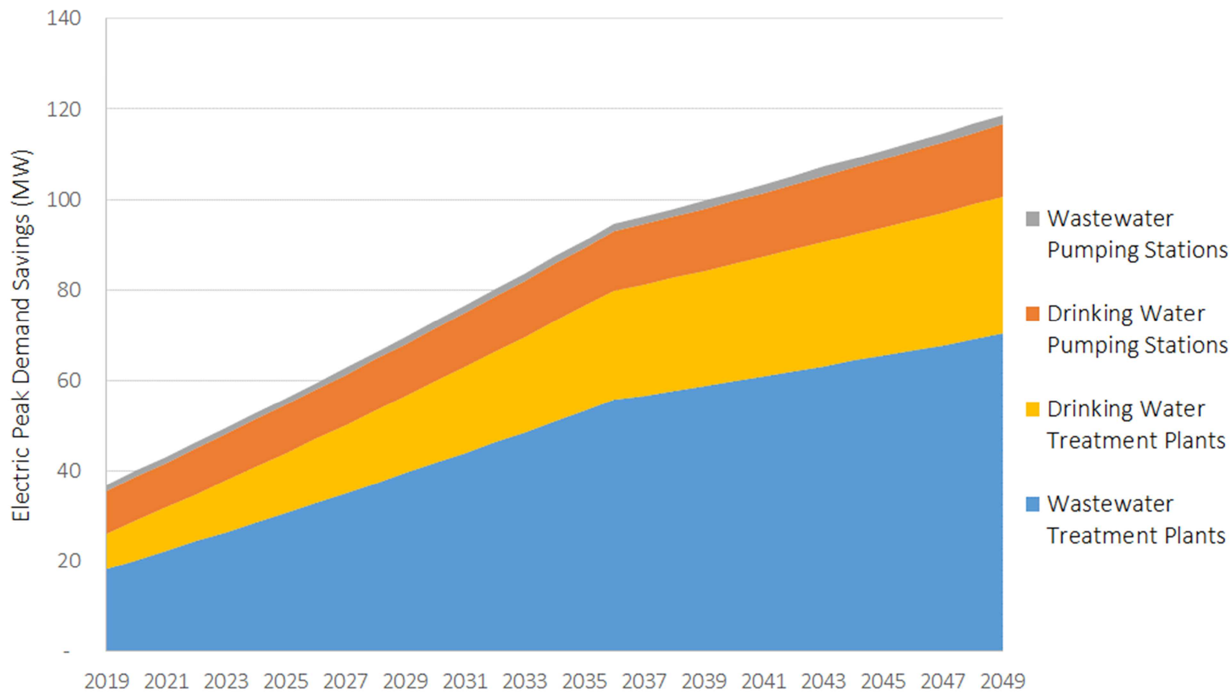
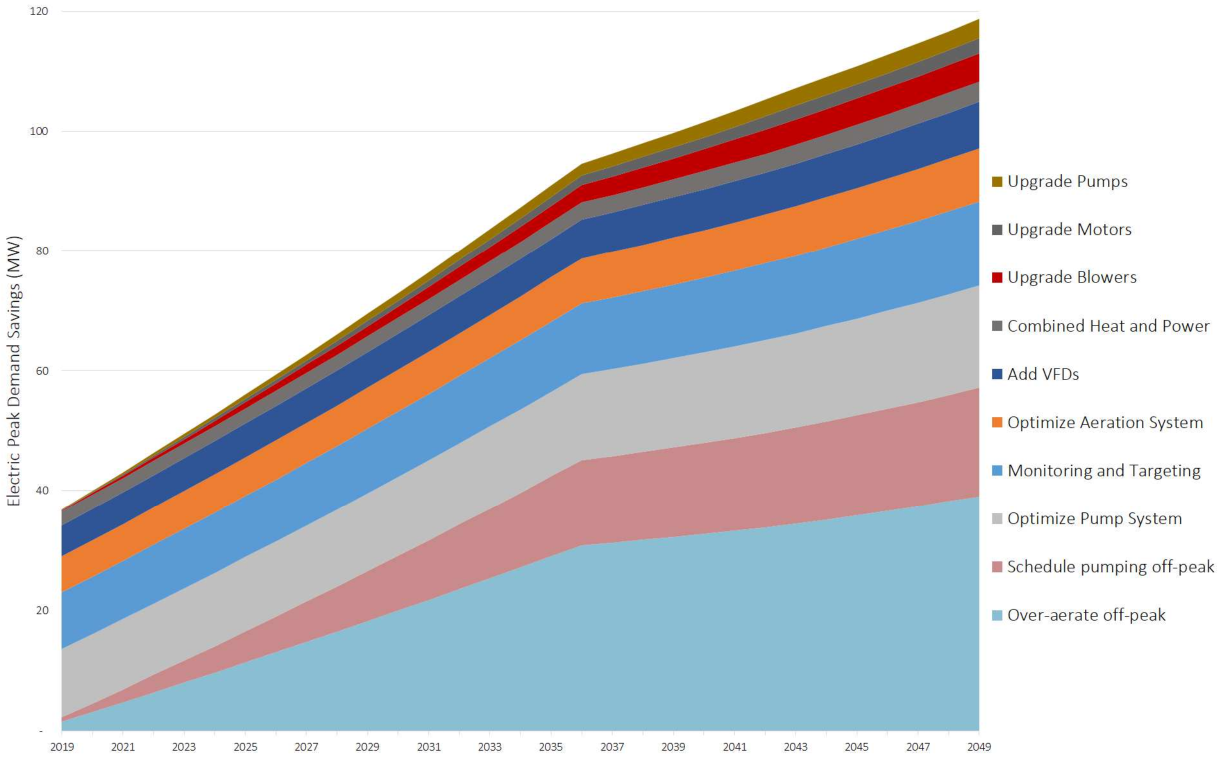


Exhibit 69 shows the electric peak demand technical potential savings by measure. Exhibit 70 gives a visual representation of the breakdown of potential electric peak demand savings by measure.

Exhibit 69 – Electric Peak Demand Savings by Measure, All Sectors, 2019 and 2049

Measure	Aggregate Potential Electric Peak Demand Savings 2019 (MW)	% Savings from this Measure vs. Reference case	Aggregate Potential Electric Peak Demand Savings 2049 (MW)	% Savings from this Measure vs. Reference case
Over-Aerate Off-Peak	1.6	4.3%	39.0	32.9%
Schedule Pumping Off-Peak	0.7	1.9%	18.1	15.3%
Optimize Pump System	11.4	30.9%	17.0	14.3%
Monitoring and Targeting	9.4	25.5%	14.0	11.8%
Optimize Aeration System	6.0	16.2%	9.0	7.5%
Add VFDs	5.2	14.1%	7.7	6.5%
Combined Heat and Power	2.3	6.2%	3.4	2.9%
Upgrade Blowers	0.1	0.4%	4.7	3.9%
Upgrade Motors	0.1	0.2%	2.5	2.1%
Upgrade Pumps	0.1	0.3%	3.2	2.7%
Total	**36.9**	**100%**	**118.7**	**100%**

Exhibit 70 – Electric Peak Demand Savings by Measure, All Sectors



11.3.1 Market Participation Potential

Electric peak demand savings potential provides the water treatment sectors with an opportunity to participate in the electricity marketplace by curtailing their electric demand during peak periods. For example, this could be through participation in the Demand Response Auction [67] , the Industrial Conservation Initiative (ICI) [65], or by taking advantage of zonal pricing under the anticipated Single Schedule Market design [68]. This potentially enables plants to pursue additional financial benefits, beyond electricity cost savings resulting from reduced electricity consumption and distribution charges.

As an illustrative example, we have assessed the potential for ICI participation and undertaken a high-level quantification of financial benefits applicable to the water treatment sectors.

The ICI is a form of demand response that allows participating Class A customers to lower their global adjustment (GA) costs by curtailing electric demand during Ontario's peak periods. Customers are assessed their portion of GA costs based on the percentage that their demand contributes to the top five Ontario system peaks. The Peak Demand Factor (PDF) set during the base period (May through April) is used to calculate the customer's monthly GA charge during the annual adjustment period (July through June) [65].

WWTP, DWTP, WW Pumping and DW Pumping facilities with average electric peak demand above 1MW are currently eligible to participate. Although the ICI eligibility threshold was reduced from 1MW to 500kW in 2017 for specific sectors, the water treatment sectors were not included [3]. The following analysis explores sector potential and benefits under two different scenarios:

1. WWTP, DWTP, WW Pumping and DW Pumping facilities currently eligible to participate in ICI; and

2. A broader group of facilities that could be eligible if the 500 kW threshold eligibility criteria were adjusted to include the water treatment sectors.

Several WWTP, DWTP and DW Pumping facilities are currently eligible for ICI, many of which currently participate. Several more facilities could participate if ICI eligibility for the water treatment sectors were expanded to an average monthly demand of at least 500 kW.

This section provides bounded-range estimates by sector of the number potential participants, their aggregate electric peak demand, and peak demand savings potential. A summary of current ICI participation is also included.

Because facility-level electricity data are limited to annual consumption, a range of load-shape estimates has been made:

- The ***Minimum Estimate*** assumes a flat load shape, consistent with energy savings potential estimates presented in Section 11. In this case, kW peak is estimated as: (Annual kWh consumption)/8760. This is the theoretical lower bound estimate, as it assumes all facilities have a perfectly flat annual load.
- The ***Mid-point Estimate*** assumes a load shape such that average monthly peak demand is 50% higher than average annual peak. In this case, kW peak is estimated as: (Annual kWh consumption)/8760*1.5. Based on a cursory review of available data, this estimate represents a notional annual electric peak demand range for many WWTP, DWTP and DW Pumping facilities.
- The ***Maximum Estimate*** assumes a load shape such that average monthly peak demand is 100% higher than average annual peak. In this case, kW peak is estimated as: (Annual kWh consumption)/8760*2. Based on a cursory review of available data, this estimate also represents a notional annual electric peak demand range for many WWTP, DWTP and DW Pumping facilities.

Exhibit 71 provides a summary of estimated total number of facilities eligible under these three approaches that meet both the current 1 MW cutoff and the potential 500 kW cutoff. A summary of current participation is also provided.[20]

Exhibit 72 provides the estimated aggregate electric peak demand of eligible facilities, using the same load-shape estimates described above.

As shown, by moving the cutoff threshold to 500 kW, an additional 51 facilities would notionally qualify under the mid-point estimate scenario (~ 90% increase), resulting in an additional 35,300 kW of electric peak demand that would qualify (~16% increase).

Exhibit 71 – Estimated Number of Facilities Eligible for the ICI Program, All Sectors

	1 MW Cutoff	500 kW Cutoff
Minimum Estimate	35	72
Mid-point Estimate	56	107
Maximum Estimate	72	123

[20] Based on analysis of IESO ICI participation data for the Broader Public Service.

Current Participation	47	-

Exhibit 72 – Estimated Aggregate Electric Peak Demand (kW): Facilities Eligible for the ICI Program, All Sectors

	1 MW Cutoff	500 kW Cutoff
Minimum Estimate	132,100	158,700
Mid-point Estimate	225,000	260,300
Maximum Estimate	317,500	355,300

Exhibit 73 provides an estimate of program potential for these facilities assuming 25% of the aggregate electric peak demand is curtailable. This estimate is consistent with both the electric peak demand technical potential savings estimates outlined in Section 11.3 and experience of current program participants (see case study below, for example).

Exhibit 73 – Estimated Aggregate Electric Peak Demand Savings Potential (kW): Facilities Eligible for the ICI Program, All Sectors

	1 MW Cutoff	500 kW Cutoff
Minimum Estimate	33,000	39,700
Mid-point Estimate	56,300	65,100
Maximum Estimate	79,400	88,800

Exhibit 74 and Exhibit 75 disaggregate estimates of potential ICI participants by sector for the 1MW and 500 kW cutoff respectively.

Exhibit 74 – Estimated Number of Facilities Eligible for the ICI Program by Sector: 1 MW cutoff

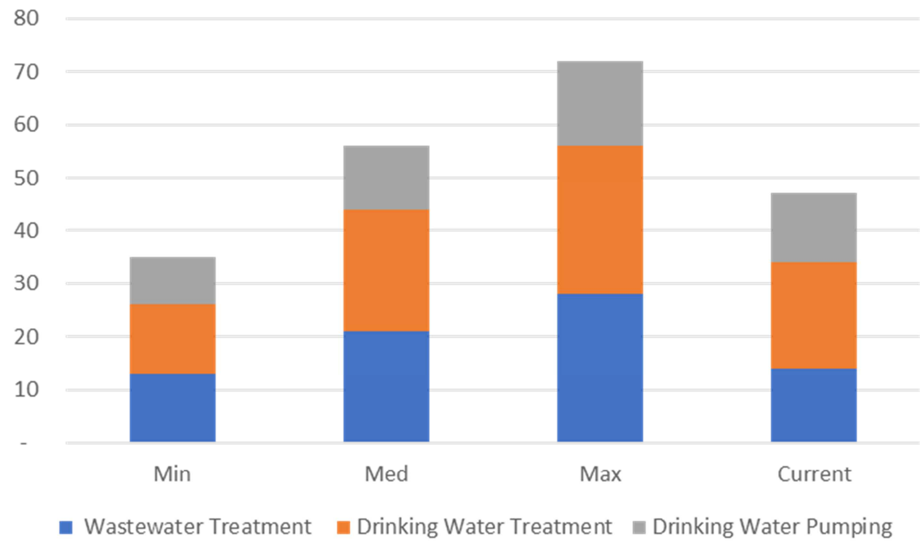


Exhibit 75 – Estimated Number of Facilities Eligible for the ICI Program by Sector: 500 kW cutoff

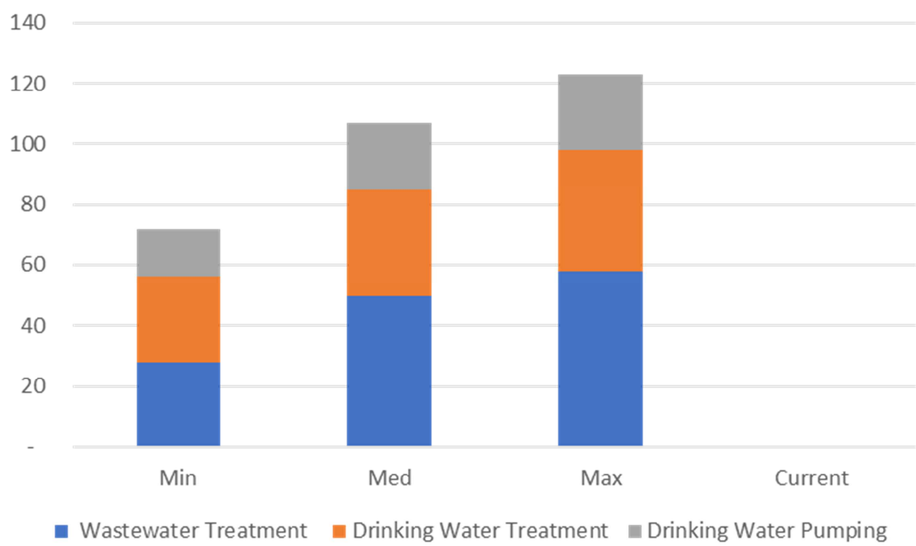
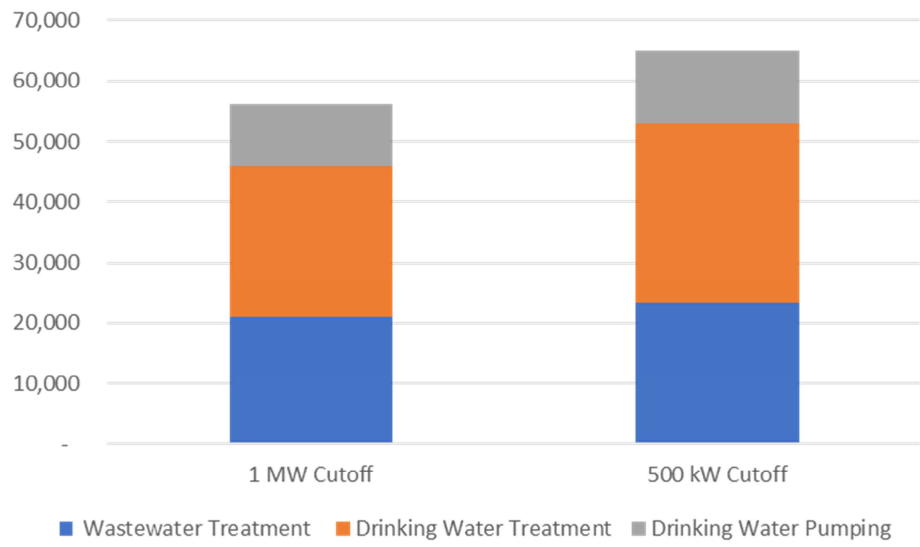


Exhibit 76 provides a comparison of electric peak demand savings potential for the 1MW and 500 kW cutoff under the Mid-Point estimate.

Exhibit 76 – Estimated Electric Peak Demand Savings Potential (MW) for Facilities Eligible for the ICI Program by Sector under the 1 MW and 500 kW Cutoffs, Mid-Point Estimate



Using the electric peak demand saving potential numbers for the 1MW and 500 kW cutoff under the Mid-Point estimate, we developed a high-level estimate for GA savings:

- For the 1 MW cutoff, total financial benefits for the water treatment sectors are GA savings in the order of $29.7million/year. Some of this is already being realized by the current participants.
- For the hypothetical 500 kW cutoff, total financial benefits for the water treatment sectors are GA savings in the order of $34.4 million/year; just over $4.5 million more than the 1MW cutoff.

Region of Peel: G.E. Booth WWTP and the ICI Program [121]

The G.E. Booth Wastewater Treatment Plant is operated by OCWA on behalf of the Region of Peel. The plant includes seven 1000-hp blowers and aeration accounts for approximately 60% of the plant's electricity consumption. During the summer of 2016, staff conducted peak shaving and load reduction activities as part of a six-week pilot to determine the viability of reducing GA charges. Provincial peak periods tend to happen on hot days, which typically coincide with highest oxygen demand (and requirement for blower use) in wastewater treatment plants.

Demand Response Activities

Overall optimization of the aeration system in the G.E. Booth WWTP had been ongoing prior to the GA pilot, so overall optimization was not available as a load reduction strategy. Staff employed two similar strategies to reduce demand during potential peak periods:

a) *"Inhibition" of blower start-up (i.e., do not allow blower to start based on normal sensor signal)*
b) *Blower shut-down (i.e., shut off operating blower for a specified period).*

Although staff did not apparently use the strategy of over-oxygenation prior to curtailment events, additional oxygen was typically added to the system following events.

Results

Four of the year's five provincial peak periods occurred during the pilot. The plant's load immediately prior to the peak reduction period ranged from 7,500 – 8,700 kW, and from 6,900 – 7,900 kW during the peak reduction period. The actual load removed or curtailed during the period ranged between 1,600 - 2,800 kW indicating that in some cases, the "natural" peak would have been higher than the load immediately prior.

This load reduction resulted a lower GA rate for the following period, July 2017 to June 2018, leading to and an estimated $1M in avoided GA costs in that period. Minimal impact to the WWTP process was reported, and at no time was the plant's effluent outside of compliance parameters.

Key Learnings

Staff noted that it is difficult to predict peak periods, even with notifications received the morning of anticipated events. This difficulty was exacerbated by the tendency for system peaks to be relatively "flat" on high load days as a result of large industrial customers curtailing load in response to ICI program.

The execution of load reduction activities required close coordination between staff, as events typically began during the day shift and ended during the night shift.

Staff recommended exploring automating peak shaving activities via the plant's aeration control system and exploring the feasibility of reducing the output of all blowers rather than shutting down individual blowers.

11.4 Wastewater Treatment Plant Savings Analysis

11.4.1 Approach

Seven energy efficiency measures were implemented in the WWTP sector in Ontario, in the following order:

- Monitoring and Targeting
- Pumping System Optimization
- Aeration System Optimization
- Blower Upgrades
- Motor Upgrades
- Pump Upgrades
- VFDs with Controls

CHP was also applied to WWTPs that meet the following criteria:

- Daily flow of water treated exceeds 5,000 m^3/day (i.e., in the medium/large size category),
- Already have anaerobic digestors present at their facility, and
- Do not already have a CHP unit on site.

Barrie's Wastewater Treatment Facility Expansion and Upgrades

The City of Barrie received support from the Federation of Canadian Municipalities Green Municipal Fund grants and loans program to upgrade and expand their wastewater treatment facility. The 9-year project cost almost $9 million was necessary to support population growth while also ensuring effluent would meet standards for ammonia and phosphorus loading. [14] [3]

The deployment of VFDs on larger pumps combined with the implementation of pumping optimization strategies has reduced electricity consumption within the WWTF. Further, optimization efforts have reduced potable water usage by 60%, (50,000m3 annually) ultimately reducing the volume of wastewater processed within the facility and saving energy. [98]

11.4.2 Economic Potential Energy and GHG Savings

Exhibit 77 and Exhibit 78 show consumption and GHG savings in the first year that the measures are introduced (2019) and the savings in 2049, at the end of the study period. The equipment upgrade measures are introduced to the model as old equipment reached the end of its lifetime. Since the maximum lifetime of the equipment considered in this study is 25 years, by 2049 we can assume that all equipment will be high-efficiency.

Exhibit 77 – WWTP Energy Savings by Fuel, 2019 and 2049

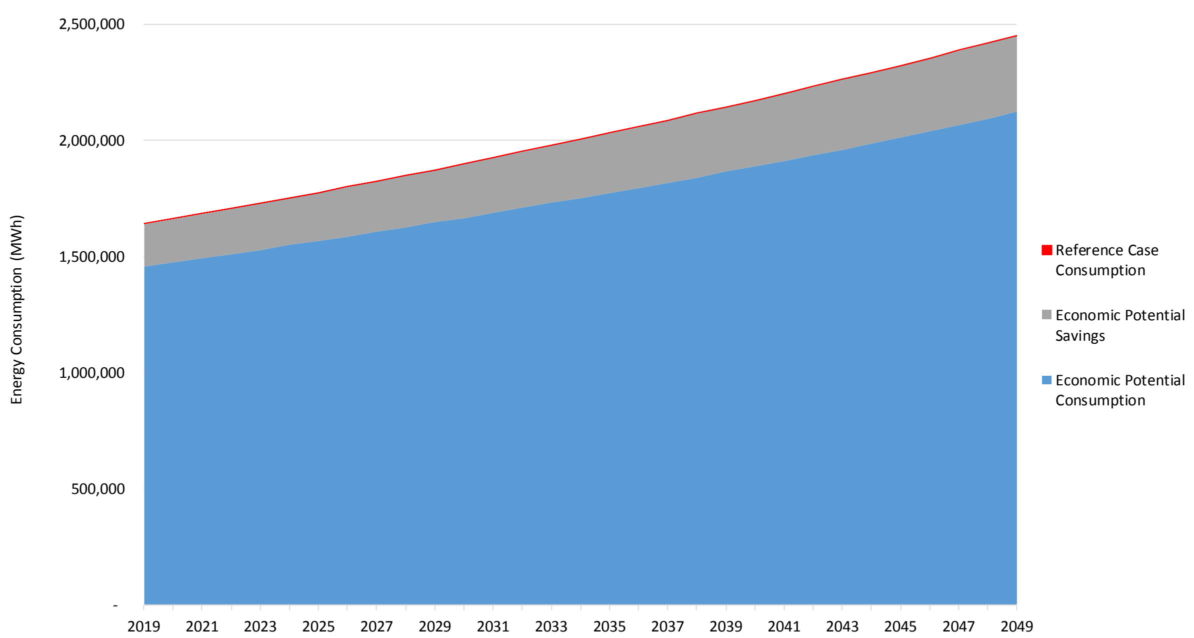
Year	Total Economic Potential Electricity Savings (MWh/year)	% Electricity Savings vs. Reference Case	Total Economic Potential Natural Gas Savings (MWh/year)	% Natural Gas Savings vs. Reference Case	**Total (MWh/year)**	**Total % Savings**
2019	145,243	12.8%	37,221	7.4%	**182,464**	**11.1%**
2049	272,960	16.1%	55,655	7.4%	**328,615**	**13.4%**

Exhibit 78 – WWTP Emissions Savings by Fuel, 2019 and 2049

Year	Emissions Savings from Electricity (tonnes CO2e/year)	% Electricity Savings vs. Reference Case	Emissions Savings from Natural Gas (tonnes CO2e/year)	% Natural Gas Savings vs. Reference Case	**Total (tonnes CO2e/year)**	**Total % Savings**
2019	23,065	12.8%	6,700	7.4%	29,764	**11.0%**
2049	43,346	16.1%	10,018	7.4%	53,364	**13.2%**

Exhibit 79 shows the results of the potential modelling over a 30-year period.

Exhibit 79 – WWTP Energy Savings (MWh), All Fuels



11.4.3 Savings by Measure

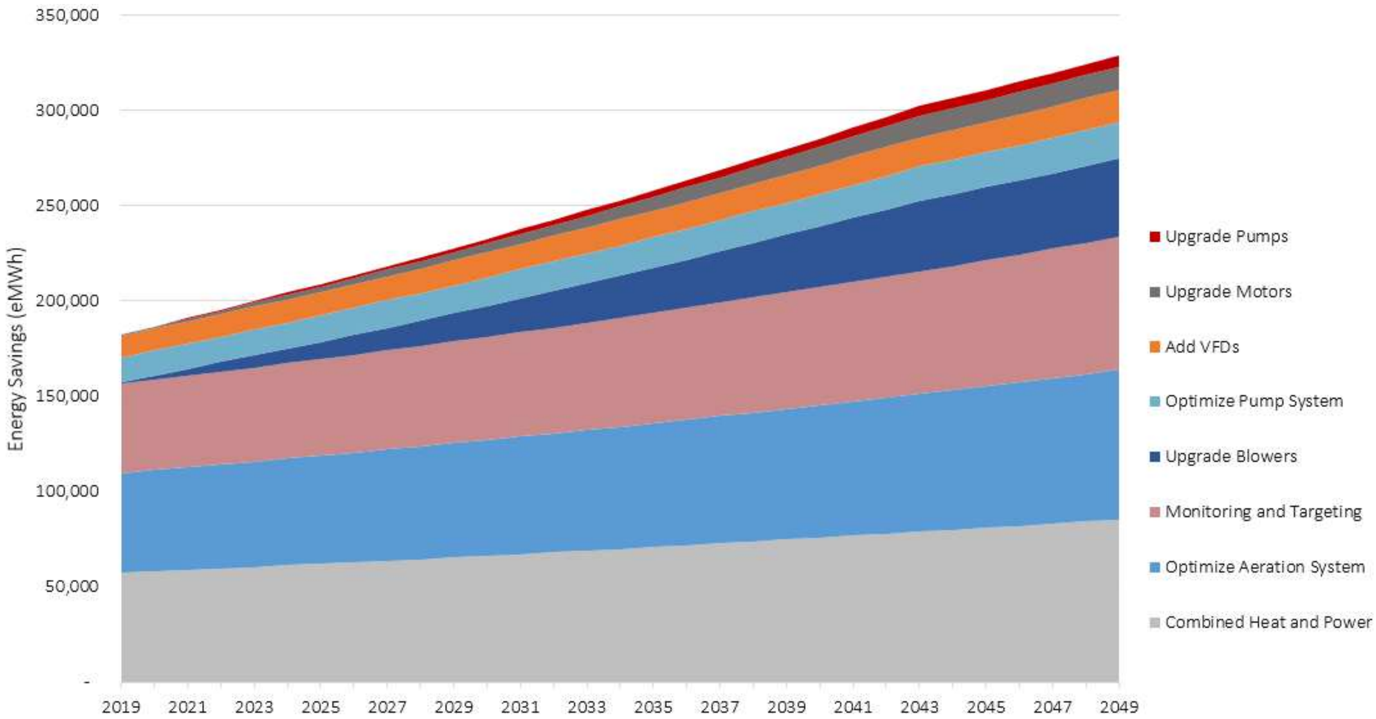
Exhibit 80 shows the total economic potential for energy consumption savings in the WWTP sector by measure in Ontario.

Exhibit 81 shows the percentage of energy savings that can be attributed to each measure. In this scenario, most energy consumption savings (26%) can be attributed to combined heat and power, closely followed by optimizing the aeration system (24%) and monitoring and targeting (21%).

Exhibit 80 – Energy Savings by Measure WWTPs, All Fuels

Measure	Total Economic Potential Energy Savings 2019 (MWh)	% Energy Savings from this Measure vs. Reference Case	Total Economic Potential Energy Savings 2049 (MWh)	% Energy Savings from this Measure vs. Reference Case
Combined Heat and Power	57,355	31%	85,516	26%
Optimize Aeration System	52,472	29%	78,458	24%
Monitoring and Targeting	46,637	26%	69,734	21%
Upgrade Blowers	1,260	1%	40,991	12%
Optimize Pump System	12,826	7%	19,179	6%
Add VFDs	11,352	6%	16,766	5%
Upgrade Motors	386	0.2%	12,350	4%
Upgrade Pumps	176	0.1%	5,621	2%
Total	**182,464**	**100%**	**328,615**	**100%**

Exhibit 81 – WWTP Energy Savings by Measure, All Fuels



11.4.4 Demand Savings

Exhibit 82 shows the reference case electric peak demand and the peak demand if all the energy and load shifting measures are implemented.

Exhibit 82 – Reference Case and Upgrade Electric Peak Demand, WWTP

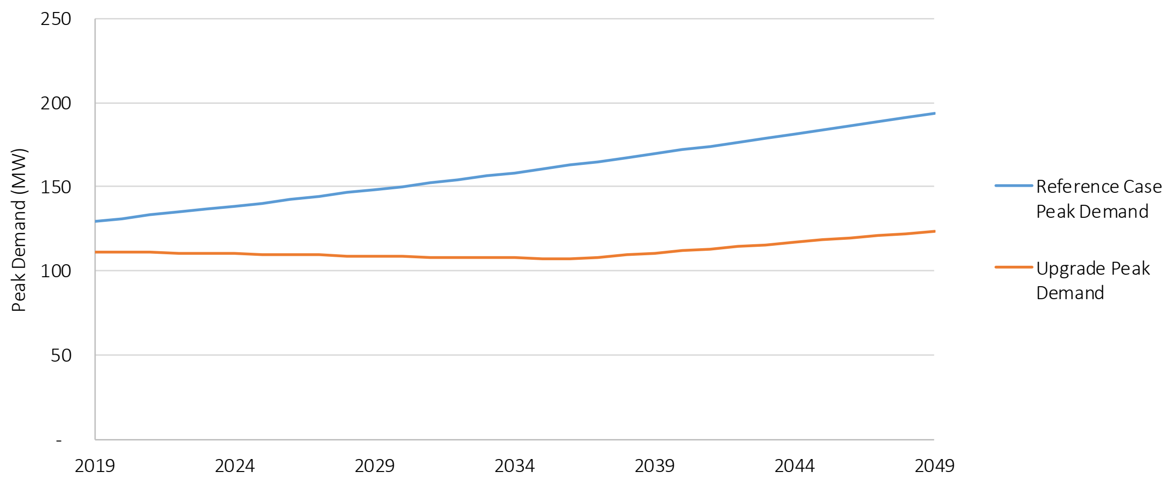


Exhibit 83 shows the electric peak demand technical potential savings by measure.

Exhibit 83 – Electric Peak Demand Savings by Measure, WWTP, 2019 and 2049

Measure	Aggregate Potential Electric Peak Demand Savings 2019 (MW)	% Savings from this Measure vs. Reference Case	Aggregate Potential Electric Peak Demand Savings 2049 (MW)	% Savings from this Measure vs. Reference Case
Over-Aerate Off-Peak	1.6	8.8%	39.0	55.6%
Optimize Pump System	1.5	8.1%	2.2	3.1%
Monitoring and Targeting	5.3	29.3%	8.0	11.3%
Optimize Aeration System	6.0	33.0%	9.0	12.8%
Add VFDs	1.3	7.1%	1.9	2.7%
Combined Heat and Power	2.3	12.6%	3.4	4.9%
Upgrade Blowers	0.1	0.8%	4.7	6.7%
Upgrade Motors	0.04	0.2%	1.4	2.0%
Upgrade Pumps	0.02	0.1%	0.6	0.9%
Total	**18.2**	**100%**	**70.2**	**100%**

11.5 Drinking Water Treatment Plant Savings Analysis

11.5.1 Approach

Five energy efficiency measures were implemented in the DWTP sector in Ontario, in the following order:

- Monitoring and targeting
- Pumping System Optimization
- Motor Upgrades
- Pump Upgrades
- VFDs with Controls

11.5.2 Economic Potential Energy and GHG Savings

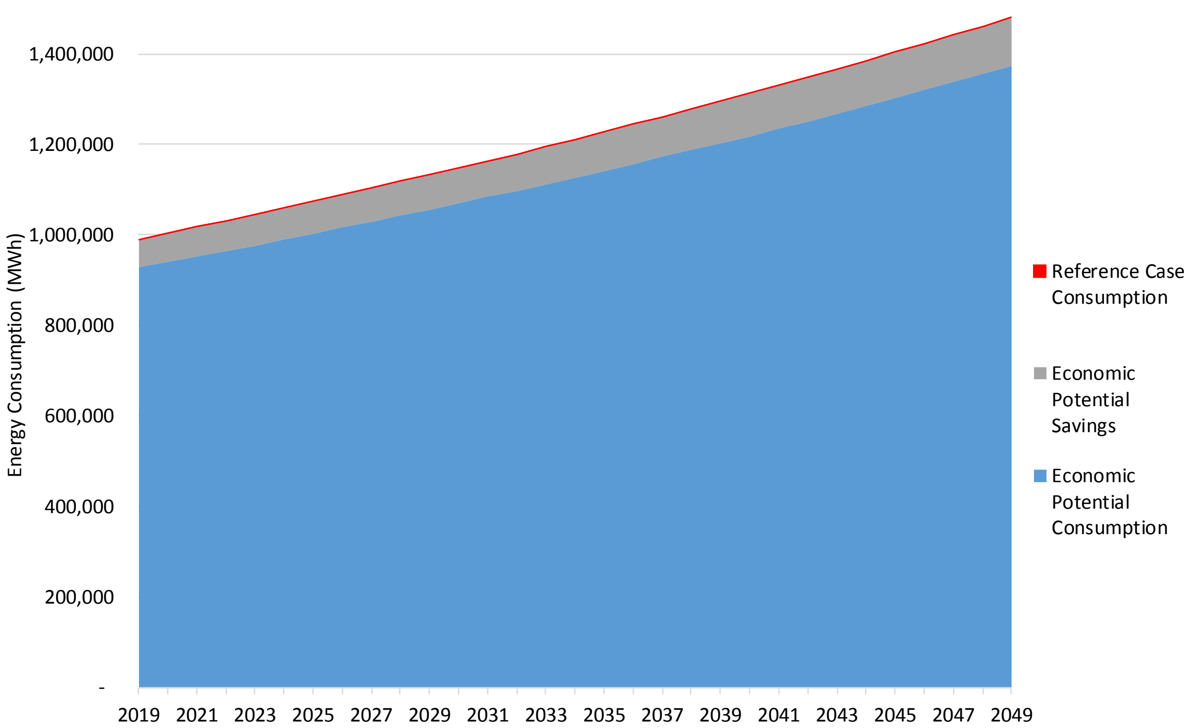
Exhibit 84 shows electricity consumption and GHG savings in the first year that the measures are introduced (2019) and the savings in 2049 at the end of the study period. The equipment upgrade measures are introduced to the model as old equipment reached the end of its lifetime. Since the maximum lifetime of the equipment considered in this study is 25 years, by 2049 we can assume that all equipment will be high-efficiency.

Exhibit 84 – DWTP Electricity and Emissions Savings, 2019 and 2049

Year	Total Economic Potential Electricity Savings (MWh/year)	% Electricity Savings vs. Reference Case	Emissions Savings (tonne CO2e/year)	% Emissions Savings vs. Reference Case
2019	62,788	7.6%	9,971	7.6%
2049	107,863	8.7%	17,129	8.7%

Exhibit 85 shows the results of the modelling over a 30-year period. For this sector, all measures pass the economic test, so the technical and the economic potential are the same.

Exhibit 85 – DWTP Energy Savings (MWh)



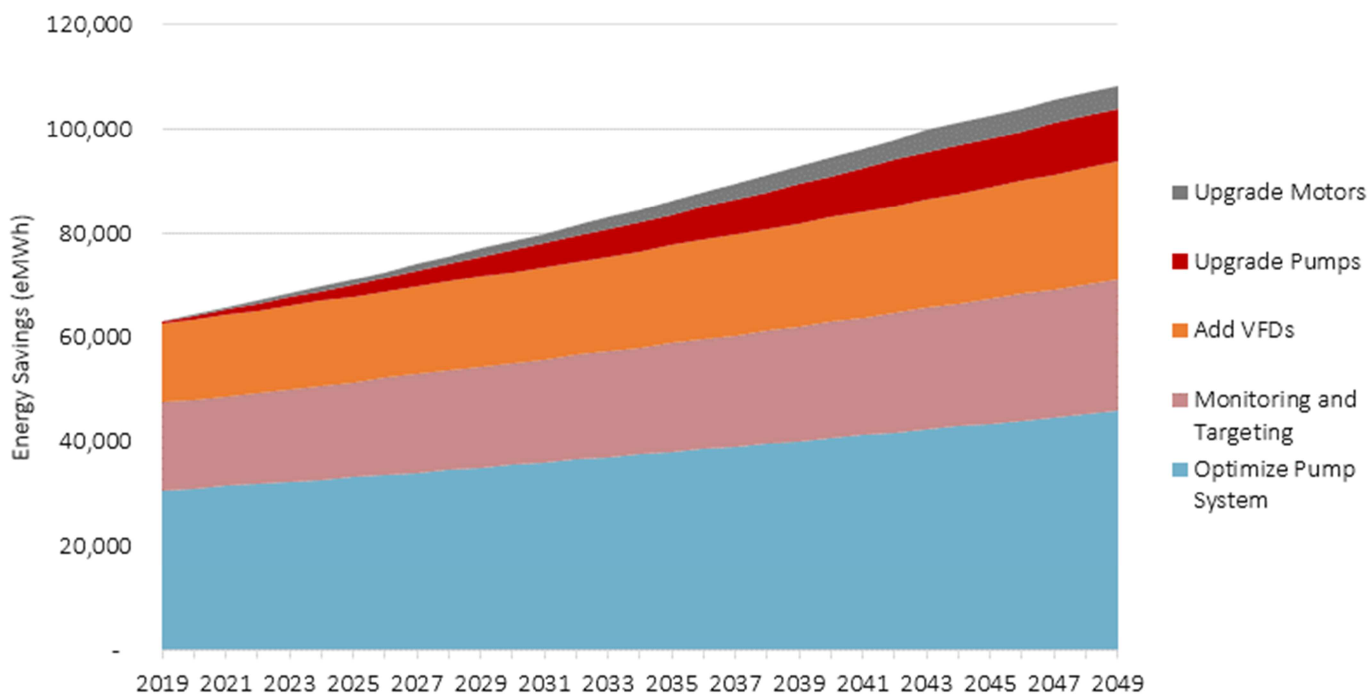
11.5.3 Savings by Measure

Exhibit 86 shows the total economic potential for energy saving in the DWTP sector by measure in Ontario. Exhibit 87 gives a visual representation of the breakdown of energy savings that can be attributed to each measure. In this scenario, most energy savings (approximately 41%) can be attributed to optimization of pumping systems.

Exhibit 86 – Energy Savings by Measure DWTPs

Measure	Total Economic Potential Energy Savings 2019 (MWh)	% Energy Savings from this Measure vs. Reference Case	Total Economic Potential Energy Savings 2049 (MWh)	% Energy Savings from this Measure vs. Reference Case
Optimize Pump System	30,749	49%	45,978	43%
Monitoring and Targeting	16,514	26%	24,693	23%
Add VFDs	15,073	24%	22,538	21%
Upgrade Pumps	313	0.5%	10,155	9%
Upgrade Motors	138	0.2%	4,500	4%
Total	**62,788**	**100%**	**107,863**	**100%**

Exhibit 87 – DWTP Energy Savings by Measure



11.5.4 Demand Savings

Exhibit 88 shows the reference case electric peak demand and the peak demand if all the energy and load shifting measures are implemented.

Exhibit 88 – Reference Case and Upgrade Electric Peak Demand, DWTP

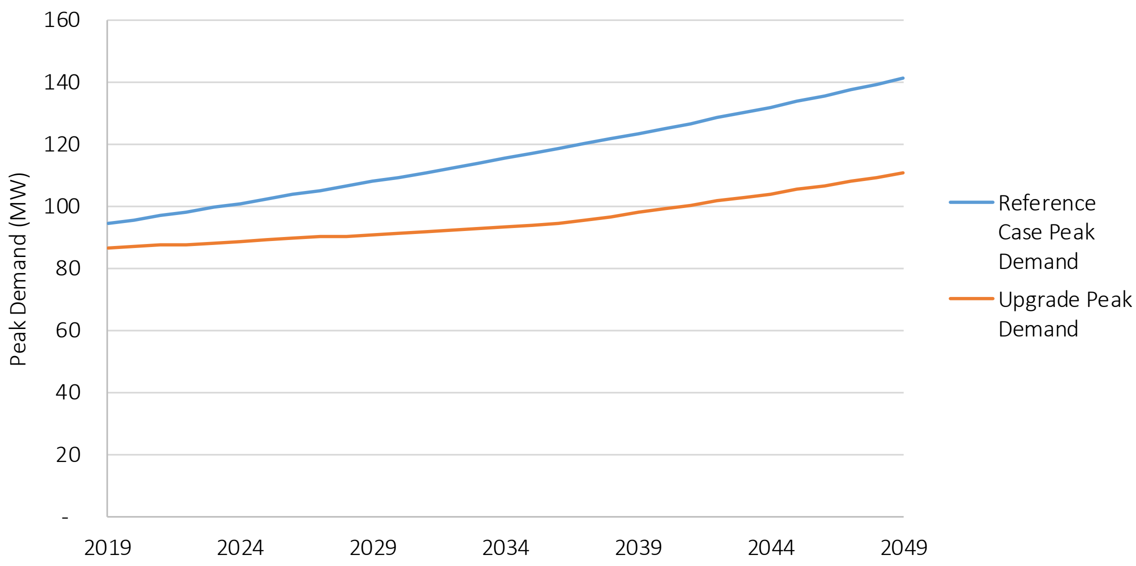


Exhibit 89 shows the electric peak demand technical potential savings by measure.

Exhibit 89 – Electric Peak Demand Savings by Measure, DWTP, 2019 and 2049

Measure	Aggregate Potential Electric Peak Demand Savings 2019 (MW)	% Savings from this Measure vs. Reference Case	Aggregate Potential Electric Peak Demand Savings 2049 (MW)	% Savings from this Measure vs. Reference Case
Schedule Pumping Off-Peak	0.7	9.0%	18.1	59.5%
Optimize Pump System	3.5	44.6%	5.2	17.3%
Monitoring and Targeting	1.9	23.9%	2.8	9.3%
Add VFDs	1.7	21.8%	2.6	8.5%
Upgrade Motors	0.02	0.2%	0.5	1.7%
Upgrade Pumps	0.04	0.5%	1.2	3.8%
Total	**7.9**	**100%**	**30.4**	**100%**

11.6 Wastewater Pumping Stations Savings Analysis

11.6.1 Approach

Five energy efficiency measures were implemented in wastewater pumping stations in Ontario, in the following order:

- Monitoring and Targeting
- Pumping System Optimization
- VFDs with Controls
- Motor Upgrades
- Pump Upgrades

11.6.2 Economic Potential Energy and GHG Savings

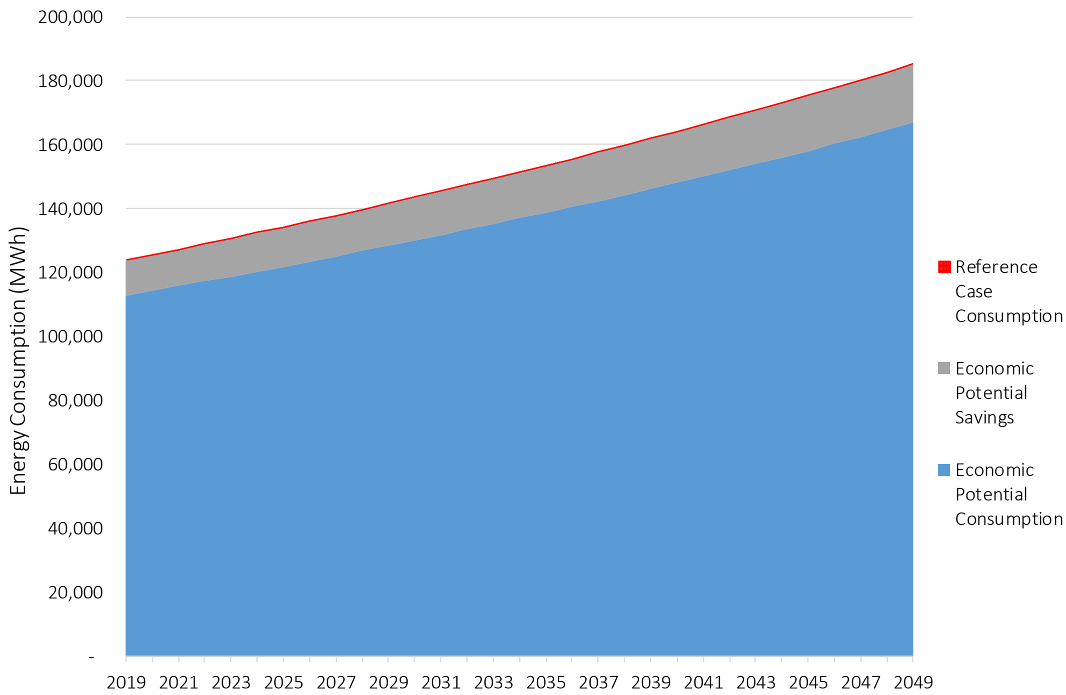
Exhibit 90 shows electricity consumption and GHG savings in the first year that the measures are introduced, 2019, and the savings in 2049 at the end of the study period. The equipment upgrade measures are introduced to the model as old equipment reached the end of its lifetime. Since the maximum lifetime of the equipment considered in this study is 25 years, by 2049 we can assume that all equipment will be high-efficiency.

Exhibit 90 – WW Pumping Electricity and Emissions Savings, 2019 and 2049

Year	Total Economic Potential Electricity Savings (MWh/year)	% Electricity Savings vs. Reference Case	Emissions Savings (tonne CO2e/year)	% Emissions Savings vs. Reference Case
2019	10,997	9.9%	1,746	9.9%
2049	18,365	11.1%	2,916	11.1%

Exhibit 91 shows the results of the modelling over a 30-year period. For this sector, all measures pass the economic test, so the technical and the economic potential are the same.

Exhibit 91 – Reference Case and Technical Potential Energy Consumption in WW Pumping Stations in Ontario



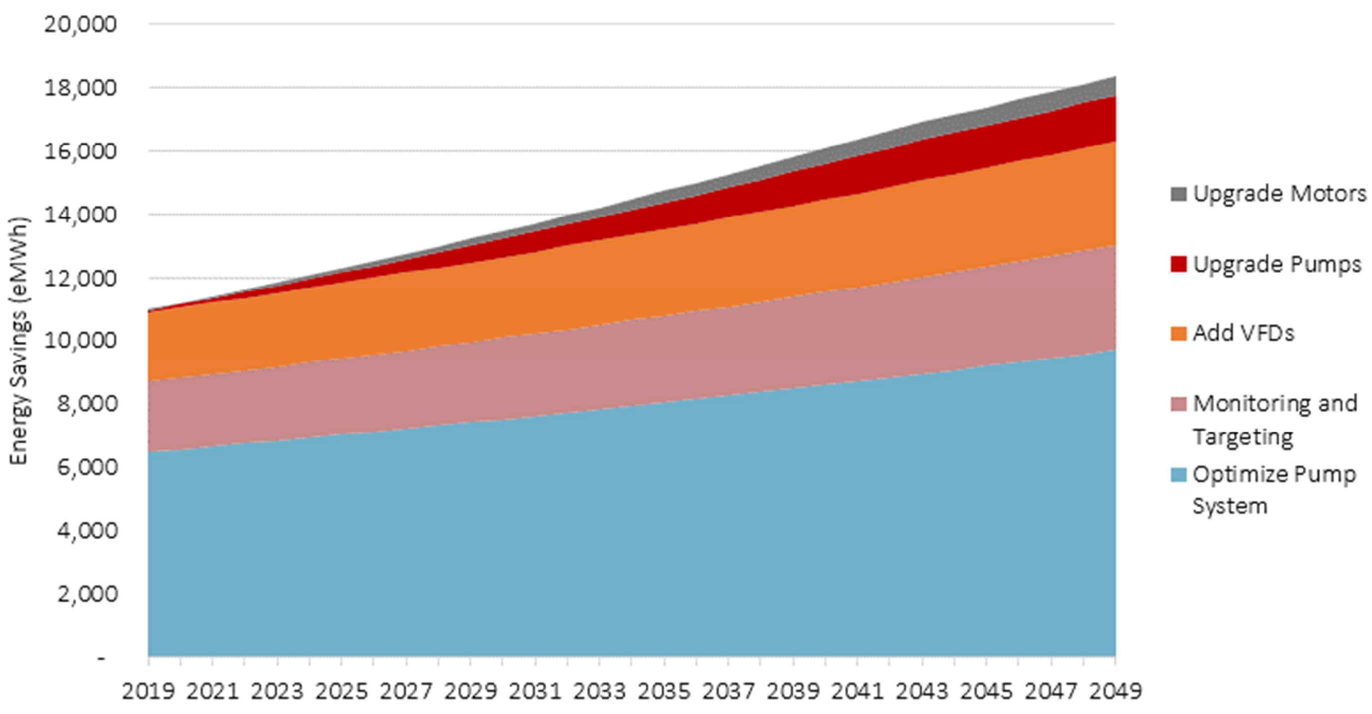
11.6.3 Savings by Measure

Exhibit 92 shows the total economic potential for energy saving in WW pumping stations by measure in Ontario. Exhibit 93 gives a visual representation of the breakdown of energy savings that can be attributed to each measure. In this scenario, most energy savings (approximately 53%) can be attributed to optimization of pumping systems.

Exhibit 92 – Energy Savings by Measure WW Pumping Stations

Measure	Total Economic Potential Energy Savings 2019 (MWh)	% Energy Savings from this Measure vs. Reference Case	Total Economic Potential Energy Savings 2049 (MWh)	% Energy Savings from this Measure vs. Reference Case
Optimize Pump System	6,508	59%	9,731	53%
Monitoring and Targeting	2,214	20%	3,310	18%
Add VFDs	2,213	20%	3,281	18%
Upgrade Pumps	44	0.4%	1,433	8%
Upgrade Motors	19	0.2%	609	3%
Total	**10,997**	**100%**	**18,365**	**100%**

Exhibit 93 – WW Pumping Stations Energy Savings by Measure



11.6.4 Demand Savings

Exhibit 35 shows the reference case electric peak demand and the peak demand if all the energy and load shifting measures are implemented.

Exhibit 94 – Reference Case and Upgrade Electric Peak Demand, WW Pump Stations

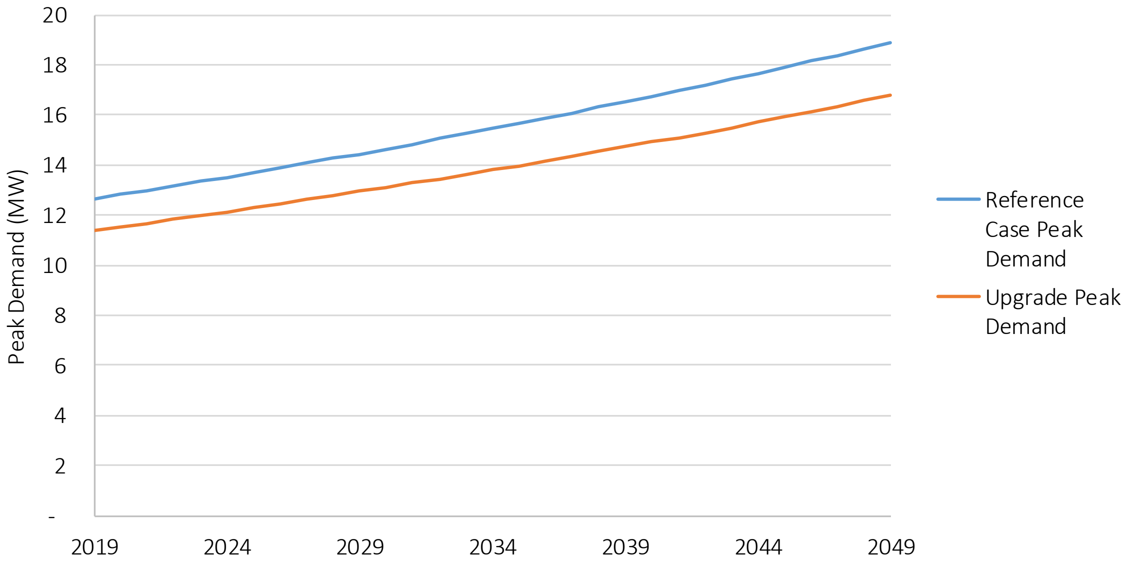


Exhibit 95 shows the electric peak demand technical potential savings by measure.

Exhibit 95 – Electric Peak Demand Savings by Measure, WW Pump Stations, 2019 and 2049

Measure	Aggregate Potential Electric Peak Demand Savings 2019 (MW)	% Savings from this Measure vs. Reference Case	Aggregate Potential Electric Peak Demand Savings 2049 (MW)	% Savings from this Measure vs. Reference Case
Optimize Pump System	0.74	59.2%	1.1	53.0%
Monitoring and Targeting	0.25	20.1%	0.4	18.0%
Add VFDs	0.25	20.1%	0.4	17.9%
Upgrade Motors	0.002	0.2%	0.1	3.3%
Upgrade Pumps	0.005	0.4%	0.2	7.8%
Total	**1.3**	**100%**	**2.1**	**100%**

11.7 Drinking Water Pumping Stations Savings Analysis

11.7.1 Approach

Five energy efficiency measures were implemented in Drinking Water Pumping Stations in Ontario, in the following order:

- Monitoring and Targeting
- Pumping System Optimization
- VFDs with Controls
- Motor Upgrades
- Pump Upgrades

11.7.2 Economic Potential Energy and GHG Savings

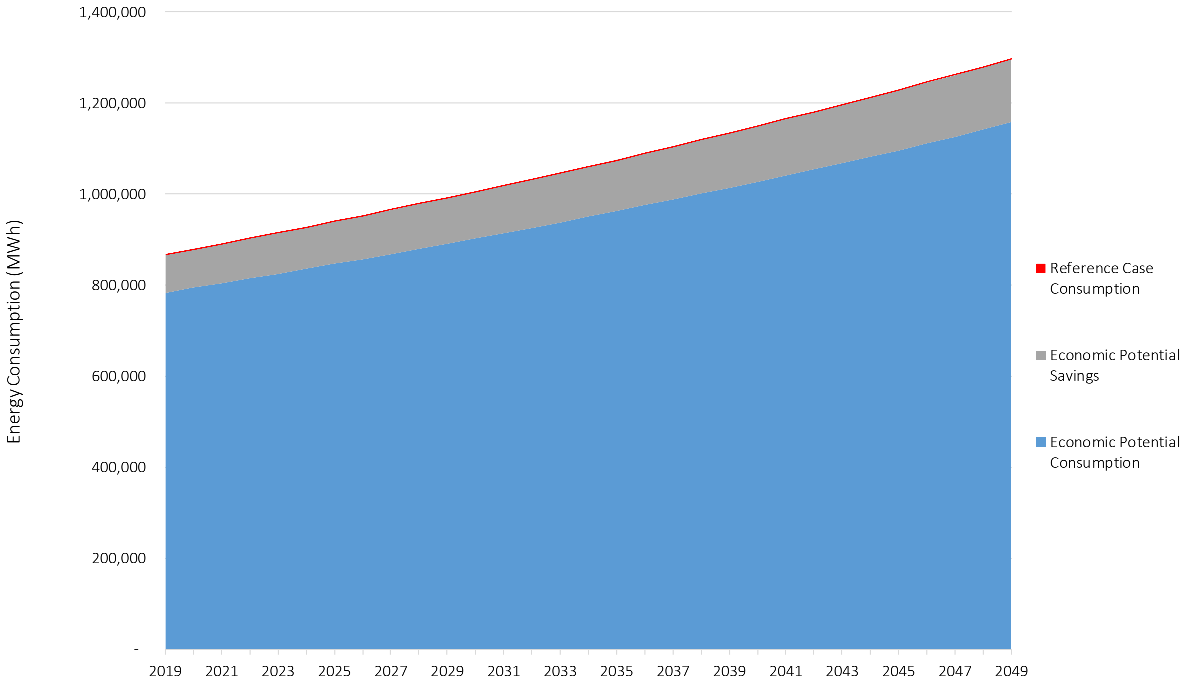
Exhibit 96 shows electricity consumption and GHG savings in the first year that the measures are introduced, 2019, and the savings in 2049 at the end of the study period once all the equipment upgrade measures have been implemented. The equipment upgrade measures are introduced to the model as old equipment reached the end of its lifetime. Since the maximum lifetime of the equipment considered in this study is 25 years, by 2049 we can assume that all equipment will be high-efficiency.

Exhibit 96 – DW Pumps Electricity and Emissions Savings, 2019 and 2049

Year	Total Economic Potential Electricity Savings (MWh/year)	% Electricity Savings vs. Reference Case	Emissions Savings (tonne CO_2e/year)	% Emissions Savings vs. Reference Case
2019	83,773	9.9%	13,303	9.9%
2049	139,893	11.1%	22,215	11.1%

Exhibit 97 shows the results of the modelling over a 30-year period. For this sector, all measures pass the economic test, so the technical and the economic potential are the same.

Exhibit 97 – Reference Case and Technical Potential Energy Consumption in DW Pumping Stations in Ontario



11.7.3 Savings by Measure

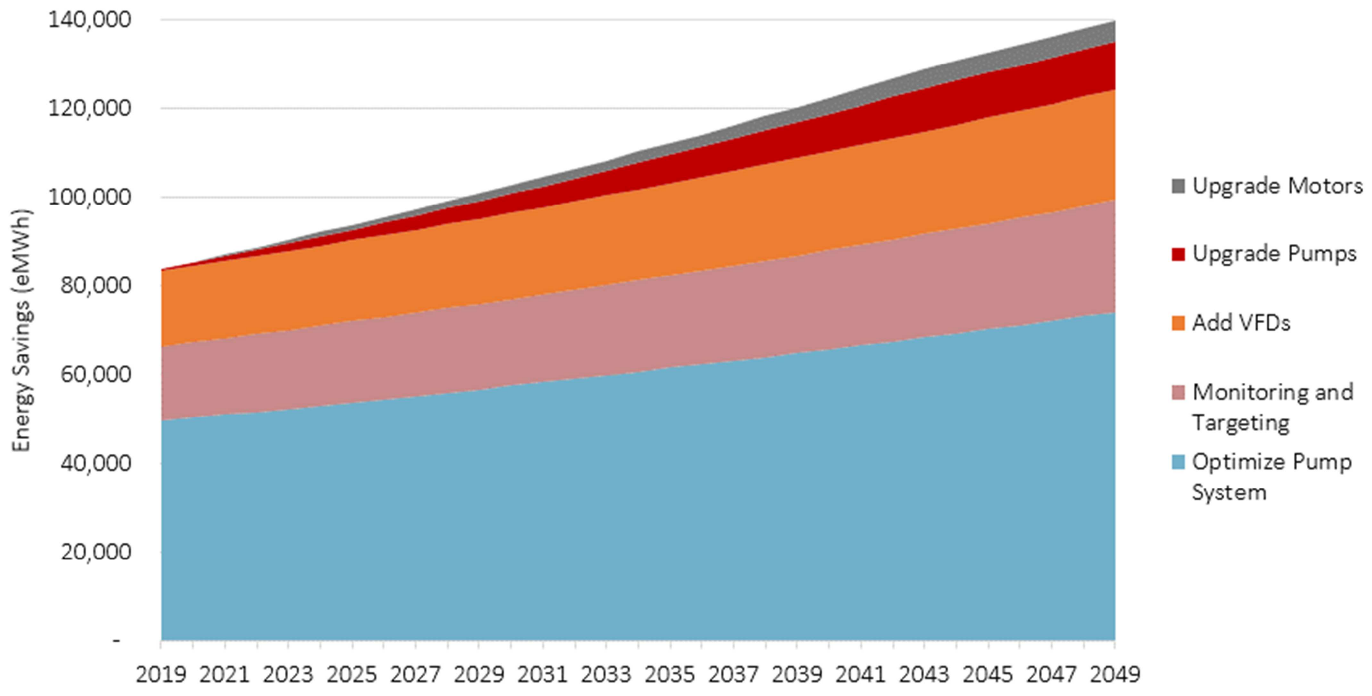
Exhibit 98 shows the total economic potential for energy saving in DW pumping stations by measure in Ontario.

Exhibit 99 shows the percentage of energy savings that can be attributed to each measure. In this scenario, the majority of energy savings (approximately 53%) can be attributed to optimization of the pumping system.

Exhibit 98 – Energy Savings by Measure DW Pumping Stations

Measure	Total Economic Potential Energy Savings 2019 (MWh)	% Energy Savings from this Measure vs. Reference Case	Total Economic Potential Energy Savings 2049 (MWh)	% Energy Savings from this Measure vs. Reference Case
Optimize Pump System	49,575	59%	74,127	53%
Monitoring and Targeting	16,862	20%	25,213	18%
Add VFDs	16,856	20%	24,995	18%
Upgrade Pumps	337	0.4%	10,916	8%
Upgrade Motors	143	0.2%	4,641	3%
Total	**83,773**	**100%**	**139,893**	**100%**

Exhibit 99 – DW Pumping Stations Energy Savings by Measure



District of Muskoka DWTP and WWTP Energy Saving Opportunities

The District of Muskoka hired GHD Consultants to conduct an energy audit on a selection of their water and wastewater facilities. The audit identified many opportunities to save energy, of which: 17 are operational, 8 require a capital investment, and 3 recommendations require further investigation. Some of the suggested measures include:

		Estimated				
Measure Name	Measure Description	Annual Energy Savings (kWh)	Annual Costs Savings	Retrofit Cost	Incentives	Payback (years)
Dissolved Oxygen Overshoot in SBRs	Change the dissolved oxygen sensors to ensure aeration blowers are used only when necessary	17,885	$2,045	$7,500	$3,500	2
Retrofitting of UV Disinfection Systems	Replace the UV disinfection system that enables modulation of power in response to real-time flow and water quality	3,854	$440	$290,000	~$1,000	>600
Elevated dissolved oxygen in Plant Aeration Basins	Retrofit the control of air flow to the aeration basis and consistently operate at a lower DO set point	131,400	$16,425	$190,000	$26,000	10
Retrofit of Low-Lift Pump Systems	Integrate VFDs to align pump energy consumption with pump output	3,832	$500	$25,000	$3,000	44
Retrofitting of Plant Jet Aeration	Switch to a fine bubble diffuser system to minimize blower demand and improve the efficiency of the biological treatment process	291,270 + 332, 880	$78,000	$305,000	$125,000	2-3

GHD noted that the greatest opportunity for operational energy efficiencies at the plants were to retrofit the jet aeration system. The audit report states: "It is likely that such a retrofit would alleviate most operational challenges associated with maintaining aeration basin DO levels during peak flow/loading conditions."

Staff of the District recommended that the Engineering and Public Works Committee phase in a selection of the recommendations. [56]

11.7.4 Demand Savings

Exhibit 100 shows the reference case electric peak demand savings and the peak demand if all the energy and load shifting measures are implemented.

Exhibit 100 – Reference Case and Upgrade Electric Peak Demand, DW Pump Stations

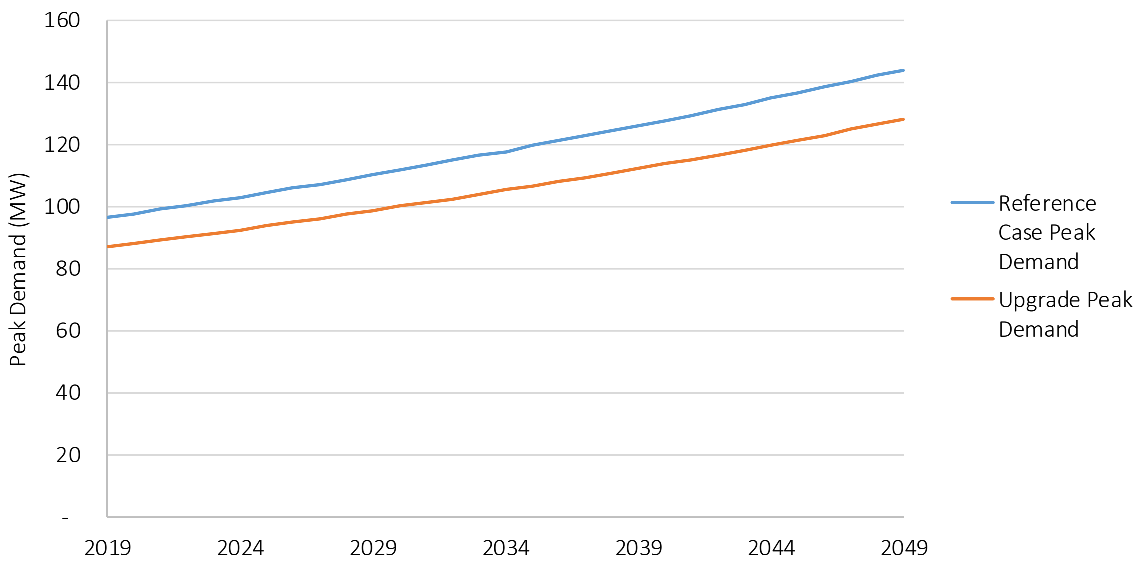


Exhibit 101 shows the electric peak demand technical potential savings by measure.

Exhibit 101 – Electric Peak Demand Savings by Measure, DW Pump Stations, 2019 and 2049

Measure	Aggregate Potential Electric Peak Demand Savings 2019 (MW)	% Savings from this Measure vs. Reference Case	Aggregate Potential Electric Peak Demand Savings 2049 (MW)	% Savings from this Measure vs. Reference Case
Optimize Pump System	5.7	59.2%	8.5	53.0%
Monitoring and Targeting	1.9	20.1%	2.9	18.0%
Add VFDs	1.9	20.1%	2.9	17.9%
Upgrade Motors	0.02	0.2%	0.5	3.3%
Upgrade Pumps	0.04	0.4%	1.2	7.8%
Total	**9.6**	**100%**	**16.0**	**100%**

12 Key Findings and Recommendations

This section highlights key findings from the study and provide recommendations to help further identify and realize energy savings in the provincial water treatment sectors: WWTP, DWTP, WW Pumping and DW Pumping.

As a reminder, this report has two intended audiences: Ontario municipalities and WWTP/DWTP facility operators (primary audience); and key Ontario organizations that have a role to play to influence change in these sectors (secondary audience). Findings and recommendations are tagged to identify the relevant audience categories [Municipal and/or Ontario Orgs].

12.1 Key Findings

There are numerous opportunities for the municipal water treatment sectors in Ontario to reduce energy consumption, lower electric peak demand, and abate GHG emissions. Study findings provide best-available energy and GHG data for decision makers, operations staff, and other industry stakeholders like the IESO and other provincial organizations, to help the water treatment sectors capitalize on the opportunity they are facing.

Through conducting the project, we made several discoveries and developed insights on each key component of the study. This section presents the key findings and takeaways under three topic areas:

- Reference case Information
- Energy Savings Opportunities and Potential
- Key Market Barriers

12.1.1 Reference Case Information

- [Municipal, Ontario Orgs.] There were several aspects related to the three main data sources that introduced analysis limitations and, on their own, each of the data sources did not credibly characterize the provincial water treatment energy footprint. *A valuable output of this study is a master dataset that now represents best-available energy and GHG data for the water treatment sectors*.
- [Ontario Orgs.] *Total **energy consumption** in the water treatment sectors in Ontario in 2018 is estimated to be approximately 3.57 eTWh. WWTPs represent most of this energy* use (45%), consuming 1.62 eTWh. This includes energy from electricity and natural gas.
- [Ontario Orgs.] *Aggregate **peak electric demand** in the water treatment sectors in Ontario in 2018 is estimated to be approximately 0.33 GW*. WWTPs represent most of this demand (39%), with a peak demand of 0.13 GW.
- [Ontario Orgs.] ***GHG emissions** in the water treatment sectors in Ontario in 2018 is estimated to be approximately 0.58 Mt CO_2e*. WWTPs represent most of these emissions (46%), with a footprint of 0.27 Mt CO_2e.
- [Municipal, Ontario Orgs.] *The biggest energy end-use in the water treatment sectors is pumping*, representing 1.9 TWh (65% of all energy use), *followed by aeration* with 0.7 TWh (23%).
- [Municipal, Ontario Orgs.] Available data do not allow for statistically representative benchmarking of the water treatment sectors, but the *WWTP, DWTP, WW Pumping and DW Pumping sectors can compare their energy performance to their peers using the energy intensity*

percentile rankings developed through this study. The WWTP sector also has the option to use the US ENERGY STAR Scoring model.

- [Ontario Orgs.] *Municipalities are using incentives through existing programs to implement energy savings projects*. For Save on Energy Programs, participation from the sectors was higher in the PSUP compared to the Retrofit program relative to other sectors. For the ICI program, almost half of participating municipal facilities are DWTP, WWTP and pumping stations combined.

12.1.2 Energy Savings Opportunities and Potential

- [Ontario Orgs.] *The total opportunity for **energy consumption savings**, for all study measures, across all sectors is 0.30 TWh in 2019*, the first year that measures are implemented in the model. This is a 10% improvement over the base year (2018). *The total opportunity for energy consumption savings, for all study measures, across all sectors is 0.54 TWh in 2049*, the final year of the study period. This is a 12% improvement over the reference case.
- [Ontario Orgs.] *The total opportunity for electric **peak demand savings**, for all study measures, across all sectors is 37 MW in 2019*, the first year that measures are implemented in the model. This is a 11% improvement over the base year. *The total opportunity for electric peak demand savings, for all study measures, across all sectors is 119 MW in 2049*, the final year of the study period. This is a 24% improvement over the reference case.
- [Ontario Orgs.] *The total opportunity for **GHG savings**, for all study measures, across all sectors is 0.055 Mt CO_2e in 2019*, the first year that measures are implemented in the model. This is a 9% improvement over the base year. *The total opportunity for GHG savings, for all study measures, across all sectors is 0.096 Mt CO_2e in 2049*, the final year of the study period. This is an 11% improvement over the reference case.
- [Municipal, Ontario Orgs.] *All energy consumption savings measures examined pay for themselves in savings over their lifetime* (the lifetime of the measures ranges from 15-25 years).
- [Municipal, Ontario Orgs.] *For **WWTPs**, the biggest **energy consumption saving measure** is combined heat and power* (26%) closely followed by optimizing the aeration system (24%). The biggest electric **peak demand savings measure** is over-aerating off-peak (56%).
- [Municipal, Ontario Orgs.] *For **DWTPs**, the biggest **energy consumption saving measure** is optimizing pumping systems* (43%) followed by monitoring and targeting (23%). The biggest electric **peak demand savings measure** is scheduling pumping off-peak (60%).
- [Municipal, Ontario Orgs.] *For **WW Pumping** and **DW Pumping**, the biggest **energy consumption saving measure** and electric peak **demand savings measure** is optimizing pumping systems* (53%) followed by monitoring and targeting (18%).
- [Municipal, Ontario Orgs.] ***Biogas recovery** represents a meaningful opportunity for medium and large WWTPs with anaerobic digestors*. This study focuses on the big opportunity to leverage embedded energy in the recovered biogas using CHP. *The total opportunity for savings from CHP is 86,000 eMWh and 3.4 MW in 2049,* the final year of the study period.
- [Municipal, Ontario Orgs.] Electric peak demand savings potential provides the water treatment sectors with an opportunity to **participate in the electricity marketplace**. As an illustrative example, we have assessed the potential for ICI participation and undertaken a high-level quantification of financial benefits applicable to the water treatment sectors. For facilities

already eligible to participate in ICI, *GA savings in the order of $29.7million/year* are possible. If the eligibility cutoff was changed to 500 kW for the water treatment sectors, total financial benefits would be in the order of *$34.4 million/year*.

- [Municipal, Ontario Orgs.] *Numerous existing programs and training offerings are available to support energy and GHG savings in the DWTP, WWTP, DW Pumping and WW Pumping sectors*.

12.1.3 Key Barriers

- [Municipal, Ontario Orgs.] **Systems-Based Industry Expertise:** *To correctly implement process improvement measures (pump system optimization, aeration system optimization, monitoring and targeting, VFDs) and load-shifting measures (high-lift pump storage and aeration system over-oxygenation), a deep understanding of all water treatment related systems is required*. Conversations with market actors indicated that there is room for improvement in developing industry expertise on how to implement these more complex measures.
- [Municipal, Ontario Orgs.] **Capital Cost:** *Capital cost was mentioned repeatedly as one of the biggest barriers to implement all measures in the water treatment sectors*. Although all energy consumption savings measures investigated in this study have a payback period shorter than the life of the measure, allowing them to pass our economic screen, municipalities often have trouble finding the capital to implement these projects. One specific measure, CHP, has notable uncertainty associated with its estimated capital costs, which further magnifies its associated capital cost barrier.
- [Municipal, Ontario Orgs.] **Regulatory and Other:** System based changes expose municipalities to potential non-compliance risks associated with provincial acts and regulations, as well as the risk of re-classification or a change in operating requirements under their licensing category framework. *System changes need to be approached carefully and under the direction of industry experts.*
- [Municipal, Ontario Orgs.] **Payback Period (CHP):** Some measures have a short payback period. For example, pump optimization and monitoring and targeting both have a payback period of about 2 years. *For CHP however, the payback period is much longer and there is more uncertainty about the cost savings*. The example from section 9.9 shows that the payback period of this CHP is 17 years, and we assume that the lifetime of a cogeneration system at a WWTP is 20 years [62]. Therefore, this measure passes our economic test, but we must recognize that a measure with such a long payback period will be less attractive to a municipality than a measure that pays itself off in a few years. The cost estimate for this measure is also less certain than for other measures.

12.2 Recommendations

Recommendations stem from the key findings and barriers presented above. The recommendations seek to support the realization of energy saving opportunities identified in this study, both by focusing support on the measures with the largest energy saving potential and by reducing the barriers the water treatment sectors currently experience when trying to identify and achieve energy savings. The recommendations also seek to encourage and support innovative opportunities, especially for biogas recovery using CHP. When possible, the recommendations are targeted at the organization(s) that should act on the findings and suggestions.

The water treatment sectors would benefit from a single-point source for current, accurate and comprehensive energy and GHG data moving forward. The Ministry of Energy should consider its opportunity to improve on current BPS data collection process (e.g., by improving data cleaning, collecting pumping station data, and requiring municipalities to report on key variables that characterize treatment activity).

Detailed recommendations are organized into three key themes:

1. Three of the top four energy consumption savings measures, and the top five electric peak demand savings measures are **systems-based measures**.
2. The importance of **systems-based industry expertise** to take advantage of these opportunities, and the need to further develop this expertise in the market.
3. **Biogas recovery** represents a meaningful opportunity for the WWTP sector but requires further research.

12.2.1 Capitalizing on Systems-Based Measures

Intervening in the market by providing incentives may help the water treatment sectors identify and assess energy saving opportunities, develop and implement projects, and assess the results. The following recommendations focus on where and how to intervene in the market and are targeted at the IESO.

1. [Ontario Orgs.: IESO] *Consider offering a province-wide pay-for-performance incentive program to support energy saving projects specifically in the water treatment sectors*. Because of the complex nature of system optimization opportunities, savings achieved through these opportunities will be best captured through a programmatic approach that tracks and pays for energy savings compared to an energy use baseline. The IESO should consider building on the success of the pilot P4P program that OCWA currently runs; early results show a comprehensive list of measures being funded under the program, including many system-based measures.
2. [Ontario Orgs.: IESO] *Consider expanding the eligibility threshold for the PSUP*. Although DWTP and WWTP can and do participate in existing IESO programs including the PSUP, the savings threshold appears to be a barrier to small and medium size facilities wishing to implement system optimization projects. As explained in Section 8, our analysis found that only about 20% of DWTP and WWTP facilities would be large enough to meet the savings threshold (using the example of an aeration system optimization upgrade).
3. [Ontario Orgs.: IESO] *Consider expanding the current midstream program structure used for the AgriPump Rebate Program to include* and *recruit additional contractors and distributors that serve the industrial and municipal water treatment sectors.* Expanding to include equipment distributors is most important for the municipal water treatment sectors, as much of the equipment decision-making influence is likely held by municipal staff (at large plants), or third-parties, rather than contractors under transactional engagements.

12.2.2 Increasing Capacity for Systems-Based Industry Expertise

For incentives to be successful in the market, the water treatment sectors need enough expertise and capacity to identify opportunities within specific facilities and to implement projects. To help build and retain the technical expertise and capacity necessary to realize energy savings opportunities, we recommend the following:

4. [Ontario Orgs.: IESO, OCWA] *Consider supporting the concept of DWTP and WWTP system experts (i.e., a "roving" Energy Manager with specialized process expertise) to work with facilities across the province to help Operators to optimize their pumping and aeration systems*. This study shows how energy savings opportunities are greatest from optimizing systems, rather than just upgrading equipment. Because optimizing a system is more complex than simply replacing equipment, it requires specialized technical knowledge to identify how to optimize a system, and the capacity to implement the project and ensure the system is operating at optimal efficiency. Sector-specific expertise is important not just to identify energy savings opportunities but also to navigate the regulations which may affect which projects are feasible and how they are implemented. These experts would help facilities to identify energy savings opportunities and assess and develop the business case to present to decision makers, including how to secure the necessary funds from municipal budgets and Provincial incentive programs. In addition to identifying specific opportunities, these individuals could deliver basic training to operators specifically on system energy management at DWTPs and WWTPs. Alternately, a separate third-party could provide basic operator training in energy management.
5. [Ontario Orgs.: IESO, OCWA] *Consider delivering training to Operators specifically on system energy management at DWTP and WWTP*. The training should include how to optimize the operation of pumping and/or aeration systems and how to undertake ongoing monitoring and targeting activities. We are aware of several training courses that have previously been delivered or are currently being offered in the market, including the Walkerton Clean Water Centre's course for DW operators, Dollars to $ense workshops, a CIET pump system optimization training course, and training course offered by OCWA. It is likely existing the abundance of existing course material will provide a suitable foundation to build on, but it is also likely additional tools and approaches will be required to strengthen Operator capacity with respect to system-based expertise.

12.2.3 Further Research on Biogas Recovery

Even under a narrow set of economically attractive pre-conditions, biogas recovery using CHP represents a notable opportunity for energy saving and GHG reduction in the province.

6. [Ontario Orgs.: IESO] *Consider further research to improve CHP measure assumptions*. Although this measure can only be applied to certain plant types, it still represents 30% of the total energy savings available in WWTPs in this study. CHP measure analysis outputs are based on input assumptions that are less certain compared to other key measures explored in this study, since there is limited information on costs available and there is a high degree of variability between projects. Measures findings for CHP are more sensitive to assumptions like measures costs given the high costs associated with this emerging sectoral technology.
7. [Ontario Orgs.: IESO*] Consider raising awareness among relevant WWTP decision makers that CHP is still eligible under CDM, provided it uses biogas*. There is confusion in the market about which incentives are still available for CHP. In 2018, behind the meter CHP eligibility under CDM in Ontario was limited to equipment that use only renewable fuels [69], however, incentives are still available for WWTP CHP units that run on biogas.
8. [Ontario Orgs.: IESO] *Consider further research to quantify the even larger CHP opportunity in the province by exploring the potential to convert plant digestion technology from aerobic to anaerobic, and the large-scale opportunity to leverage co-digestion*. Although outside the

bounds of this study, this broader application of CHP will be a significant opportunity in the future for the WWTP sector.

13 Bibliography

[1] Environmental Commissioner of Ontario, " Every Drop Counts: Reducing the Energy and Climate Footprint of Ontario's Water Use," 2017. [Online]. Available: https://eco.on.ca/reports/2017-every-drop-counts/. [Accessed 05 07 2018].

[2] ICF Canada, "Ontario Municipal Energy Profile," Independent Electricity Operator, Toronto, 2018.

[3] Government of Ontario, "O. Reg. 429/04: ADJUSTMENTS UNDER SECTION 25.33 OF THE ACT," 1 7 2018. [Online]. Available: https://www.ontario.ca/laws/regulation/040429#BK6?_cldee=cm91c2VsbGUuZ3JhdGVsYUBpZXNvLmNh&recipientid=contact-ee1513c60f8be6118adc005056ac0057-158bf5ea6cdf4925a50f3c30c078cffa&esid=95b095e4-b8b1-e611-8bcf-005056ac0057&_cldee=cm91c2VsbGUuZ3JhdGVsYUBpZXNvLm. [Accessed 6 12 2018].

[4] Ontario Ministry of Energy, "Energy use and greenhouse gas emissions for the Broader Public Sector," 2018. [Online]. Available: https://www.ontario.ca/data/energy-use-and-greenhouse-gas-emissions-broader-public-sector.

[5] Environment Canada, "2011 Municipal Water Use Report," Environment Canada, Ottawa, 2011.

[6] City of Ottawa, "Water purification, quality and delivery," [Online]. Available: https://ottawa.ca/en/residents/water-and-environment/drinking-water/water-purification-quality-and-delivery. [Accessed 27 11 2018].

[7] City of Barrie, "Water Treatment," [Online]. Available: https://www.barrie.ca/Living/Water/Pages/Water-Treatment.aspx. [Accessed 12 2018].

[8] City of Ottawa, "Wastewater collection and treatment," [Online]. Available: https://ottawa.ca/en/residents/water-and-environment/wastewater-and-sewers/wastewater-collection-and-treatment. [Accessed 27 11 2018].

[9] Environment and Climate Change Canada, "Municipal wastewater treatment," 10 03 2017. [Online]. Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/municipal-wastewater-treatment.html. [Accessed 27 11 2018].

[10] Conference Board of Canada, "Wastewater Treatment," April 2016. [Online]. Available: https://www.conferenceboard.ca/hcp/provincial/environment/waste-water.aspx. [Accessed 27 11 2018].

[11] Safe Drinking Water Foundation, "Wastewater Treatment," 2017. [Online]. Available: https://www.safewater.org/fact-sheets-1/2017/1/23/wastewater-treatment. [Accessed 27 11 2018].

[12] O. M. o. Environment, "Water and Energy Conservation Guidance Manual for Sewage Works," Ontario Ministry of Environment, Ottawa, 2016.

[13] WaterWorld, "Introduction to Wasterwater Treatment Ponds," 1 October 2011. [Online]. Available: https://www.waterworld.com/articles/print/volume-27/issue-10/editorial-features/introduction-to-wastewater-treatment-ponds.html. [Accessed 6 12 2018].

[14] Power and Water Corporation, "Waste Stabilisation Pond Design Manual," PowerWater.

[15] AES, "Rotating Biological Contractor," 2017. [Online]. Available: http://www.aesarabia.com/rotating-biological-contactor/. [Accessed 06 12 2018].

[16] Government of Ontario, "F-5-1 Determination Of Treatment Requirements For Municipal And Private Sewage Treatment Works," 11 10 2016. [Online]. Available: https://www.ontario.ca/page/f-5-1-determination-treatment-requirements-municipal-and-private-sewage-treatment-works. [Accessed 27 11 2018].

[17] T. d. Mes, A. Stams, J. Reith and G. Zeeman, "Methane Production by anaerobic digestion of wastewater and solid wastes," in *Bio-methane & Bio-hydrogen: status and perspectives of biological methane and hydrogen production* , The Hague, The Netherland, Dutch Biological Hydrogen Foundation - NOVEM, 2003, pp. 58-102.

[18] Ontario Ministry of Environment, "Design Guidelines for Sewage Works," Ontario Ministry of Environment, Ottawa, 2008.

[19] U.S Environmental Protection Agency, "Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field," U.S. Environmental Protection Agency CHP Partnership, 2011.

[20] Intergovernmental Panel on Climate Change, "Guidelines for National Greenhouse Gas Inventories - Chapter 6: Wastewater Treatment and Discharge," 2006.

[21] A. Wellinger and A. Lindberg, "Biogas upgrading and utilization," IEA Bioenergy, 1999.

[22] Kelleher Environmental, Robins environmental, "Canadian Biogas Study: Benefits to the Economy, Environment and Energy," Biogas Association, 2013.

[23] Ontario Ministry of Energy, "O. REG. 397/11 Overview of Reporting Requirements," 9 05 2019. [Online]. Available: https://www.las.on.ca/LAS-Docs/EPT/BPS-Reporting-Requirements-May-2016-Webinar.aspx. [Accessed 19 09 2018].

[24] I. 1, Interviewee, *Interview 1.* [Interview]. 30 07 2018.

[25] Metcalfe & Eddy, Wastewater Engineering: Treatment and Resource Recovery Fifth Edition, AECOM, 2013.

[26] R. B. S. Steven C. Jones, "QUANTIFYING ENERGY USE IN THE U.S. PUBLIC WATER," 2014. [Online]. Available: http://www.hansenallenluce.com/wp-content/uploads/2015/11/Energy-Use-Water-Sector.pdf. [Accessed 10 07 2018].

[27] Ministry of Energy, "Energy use and greenhouse gas emissions for the Broader Public Sector," MOE, Ontario, 2012.

[28] Ministry of Energy, "Energy use and greenhouse gas emissions for the Broader Public Sector," MOE, Ontario, 2015.

[29] Awwa Research Foundation, "Energy Index Development for Benchmarking Water and Wastewater Utilities," 2007.

[30] Electric Power Research Institute, "Electricty Use and Management in the Municipal Supply and Wastewater Industries," Palo Alto, 2013.

[31] Save on Energy, "Opportunity Accelerator," 2018. [Online]. Available: https://saveonenergy.ca/en/For-Business-and-Industry/Programs-and-incentives/Opportunity-Accelerator. [Accessed 27 11 2018].

[32] Save on Energy, "Training and Support," 2018. [Online]. Available: https://saveonenergy.ca/en/For-Business-and-Industry/Training-and-support. [Accessed 27 11 2018].

[33] OCWA, "Training Services," [Online]. Available: http://www.ocwa.com/what-we-do/training. [Accessed 12 2018].

[34] CIET, "Pump Systems Optimization," 2018. [Online]. Available: https://cietcanada.com/events/pump-systems-optimization-toronto-winter2019/. [Accessed 12 2018].

[35] CIET, "Incentives," 2018. [Online]. Available: https://cietcanada.com/incentives/#. [Accessed 12 2018].

[36] Walkerton Clean Water Centre, "Energy Management for Drinking Water Operators," 2018. [Online]. Available: https://www.wcwc.ca/en/training/scheduled-courses/. [Accessed October 2018].

[37] Hydro One and Niagara Peninsula Energy Inc, "AgriPump Rebate Program," [Online]. Available: https://agripump.ca/. [Accessed 6 12 2018].

[38] Union Gas, "Save Money & Energy," 2018. [Online]. Available: https://www.uniongas.com/business/save-money-and-energy. [Accessed 12 2018].

[39] Federation of Canadian Municipalities, "Green Municipal Fund," [Online]. Available: https://fcm.ca/home/programs/green-municipal-fund.htm. [Accessed September 2018].

[40] Federation of Canadian Municipalities, "What we fund: Green Municipal Fund," September 2018. [Online]. Available: https://fcm.ca/home/programs/green-municipal-fund/what-we-fund.htm.

[41] Federation of Canadian Municipalities, "Wastewater case studies: Solutions and strategies," September 2018. [Online]. Available: https://fcm.ca/home/programs/green-municipal-fund/resources-and-programs/water-resources/case-studies---wastewater.htm.

[42] I. 3, Interviewee, *Interview 3.* [Interview]. 07 08 2018.

[43] NYSERDA, "Water & Wastewater Energy Management Best Practices Handbook," 2010.

[44] F. R. Spellman, Water & Wastewater Infrastructure Energy Efficiency and Sustainability, Boca Raton: CRC Press, 2013.

[45] I. 4, Interviewee, *Interview 4.* [Interview]. 30 07 2018.

[46] I. 16, Interviewee, *Interview 16.* [Interview]. 2018 10 09.

[47] IESO, "Ontario Planning Outlook," 2016 September 1. [Online]. Available: http://www.ieso.ca/sector-participants/planning-and-forecasting/ontario-planning-outlook.

[48] I. 8, Interviewee, *Interview 8.* [Interview]. 02 08 2018.

[49] I. 17, Interviewee, *Interview 17.* [Interview]. 10 09 2018.

[50] Ontario Power Authority, "Water and Wastewater Treatment," [Online]. Available: https://saveonenergy.ca/images/E-Blast/Channel-Sell-Sheet/Water_Treatment_Brochure.aspx. [Accessed 30 08 2018].

[51] Hach Company, "SAVE MONEY BY CONTROLLING DISSOLVED OXYGEN IN THE AERATION BASIN," 2014. [Online]. Available: https://www.hach.com/asset-get.download.jsa?id=7664029576. [Accessed 30 08 2018].

[52] GHD, "Water and Wastewater Facility Operational Audots," District of Muskoka, Waterloo, Ontario, 2017.

[53] I. 16, Interviewee, *Interview 16.* [Interview]. 2018 10 09.

[54] I. 5, Interviewee, *Interview 5.* [Interview]. 08 08 2018.

[55] J. Loera, "Overview of BLower Technologies and Comparison of High-Speed Turbo Blowers," [Online]. Available: https://www.cwea.org/sarbs/pdfs/Blower%20Technologies%20Loera%20061712.pdf.

[56] SALGA, "Biogas potential in selected waste water treatment plants," Deutsche Gesellschaft für

Internationale Zusammenarbeit (GIZ) GmbH, 2015.

[57] U.S EPA CHP Partnership , "Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field," U.S Environmental Protection Agency, Washignton , 2011.

[58] I. 15, Interviewee, *Interview 15.* [Interview]. 26 08 2018.

[59] Collingwood Public Utilities, "Collingwood Waste Water Treatment Plant Cogeneration Plant Feasibility Study," 10 2013. [Online]. Available: https://glslcities.org/wp-content/uploads/2015/09/Collingwood-Wastewater-Treatment-Cogeneration-Study.pdf. [Accessed 19 09 2018].

[60] Toronto Water, "Humber Wastewater Treatment Plant 2017 Annual Report," Toronto , 2018.

[61] Caterpillar, "G3520C GAS ENGINE TECHNICAL DATA," [Online]. Available: http://toromontpowersystems.com/docs/librariesprovider4/products-documents/2082kw-(g3520c)/performance-data/2082_ekw_g3520c_0-5g_nox_performance_sheet.pdf?sfvrsn=4. [Accessed 30 08 2018].

[62] California Energy Commission, "Cogeneration Optimization," 14 11 2000. [Online]. Available: https://www.energy.ca.gov/process/pubs/cogen.pdf. [Accessed 19 09 2018].

[63] Collingwood Public Utilities, "Energy Conservation & Demand Management Plan 2014-2019," Collingwood, ON.

[64] American Council for an Energy Efficient Economy, "The Technical, Economic, and Achievable Potential for Energy Efficiency in the United States: A Meta-Analysis of Recent Studies," 2004. [Online]. Available: https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel8_Paper19.pdf. [Accessed 25 09 2018].

[65] IESO , "Global Adjustment Class A Eligibility," 2018. [Online]. Available: http://www.ieso.ca/en/Sector-Participants/Settlements/Global-Adjustment-Class-A-Eligibility.

[66] M. Jourabchi, Interviewee, *Manager, Economic Analysis, Northwest Power and Conservation Council.* [Interview]. 12 2018.

[67] IESO, "Demand Response Auction," 2018. [Online]. Available: http://www.ieso.ca/Sector-Participants/Market-Operations/Markets-and-Related-Programs/Demand-Response-Auction. [Accessed 6 12 2018].

[68] IESO, "Single Schedule Market - High-Level Design," 2018. [Online]. Available: http://www.ieso.ca/en/Sector-Participants/Market-Renewal/Single-Schedule-Market-High-Level-Design. [Accessed 6 12 2018].

[69] Ontario Ministry of Energy, Office of the Minister, *re: Amendments to Ministerial Directions Arising from the Long-Term Energy Plan,* 2017.

[70] Environment and Climate Change Canada, "National Inventory Submission 2017," 2017.

[71] The Atmospheric Fund, "A Clearer View on Ontario's Emissions: Practice Guidelines for Electricity Emissions Factors," Toronto, 2017.

[72] H. Monteith, H. Sahely, H. MacLean and D. Bagley, "A Rational Procedure for Estimation of Greenhouse-Gas Emissions from Municipal Wastewater Treatment Plants," *Water Environment Research,* vol. 77, no. 4, pp. 390-403, 2005.

[73] National SMall Flows Clearinghouse, "Small Community Wastewater Issues Explained to the Public," *Pipeline,* vol. 8, no. 2, 1997.

[74] FUCHS Clean Solutions, "Aerated Lagoons for the Treatment of Municipal Wastewater," FUCHS, Mayen, 2011.

[75] Pennsylvania State Association of Township Supervisors, "Wastewater Treatment Plant Operator Certification Training," Penn State Harrisburg Environmental Training Center, Pitsburg, 2016.

[76] Winsconsin Department of Natural Resources, "Introduction to Activated Sludge," Bureau of Science Services, Madison, 2010.

[77] W. E. Federation, Operation of Municipal Wastewater Treatment Plants, Alexandria: McGraw-Hill Education, 1990.

[78] O. W. R. Act, "O. Reg. 129/04: Licensing of Sewage Works Operators," Ontario, Ottawa, 2017.

[79] Ontario Clean Water Agency, "WWTP & WTP Benchmarking Database Energy Program," OCWA, Toronto, 2018.

[80] N. &. Alvarez-Cohen, "Environmental Engineering Science," Wiley, Dartmouth, 2000.

[81] Safe Drinking Water Foundation, "Conventional Water Treatemnt: Coagulation and Filtration," Safe Drinking Water Foundation, Saskatoon, 2017.

[82] D. I. Verrelli, "Drinking Water Treatment Sludge Production and Dewaterability," The University of Melbourne: Department of Chemical & Biomolecular Engineering, Melbourne, 2008.

[83] A. M. Stillwell, D. C. Hoppock and M. E. Webber, "Energy Recovery from Wastewater Treatment Plants in the United States: A Case Study of the Energy-Water Nexus," *Sustainability,* vol. 2, pp. 945-962, 2010.

[84] K. Hamel, "Energy Savings Report Water and Wastewater Treatment Plants: Collingwood, Ontario,"

Collingwood Public Utilities, Collingwood, 2013.

[85] E. Canada, "2011 Municipal Water Use Report," Environment Canada, Ottawa, 2011.

[86] C. Thompson, "Waterloo Region to save millions by using sewer gas to generate electricity," 23 March 2017. [Online]. Available: https://www.therecord.com/news-story/7206169-waterloo-region-to-save-millions-by-using-sewer-gas-to-generate-electricity/.

[87] Fraser Institute, "Ontario electricity rates for industry among highest in North America," 09 11 2017. [Online]. Available: https://www.fraserinstitute.org/article/ontario-electricity-rates-for-industry-among-highest-in-north-america.

[88] Ministry of Environment, "O. Reg 435/93: Water Works and Sewage Works," Ministry of Environment, Ottawa, 2004.

[89] J. A. Nathanson, "Sludge Treatment and Disposal," Encyclopedia Britannica, 22 January 2010. [Online]. Available: https://www.britannica.com/technology/wastewater-treatment/Sludge-treatment-and-disposal#. [Accessed 25 September 2018].

[90] The City of Barrie, "Surface Water Process," The City of Barrie, Barrie, 2011.

[91] The City of Barrie, "Groundwater Process," The City of Barrie, Barrie, 2011.

[92] The British Columbia Ground Water Association, "Hardness in Groundwater," B.C. Mionistry of Environment, Vancouver, 2007.

[93] SNF Floerger, "Drinking Water," SNF Canada, Andrézieux , 2014.

[94] Ontario Ministry of Environment, "O.Reg. 128/04: Certification of Drining Water System Operators and Water Quality Analysts," Ontario Minsitry of Environment, Ottawa, 2017.

[95] The Water Treatments, "Rotating BIological Contactor," 2011. [Online]. Available: http://www.thewatertreatments.com/wastewater-sewage-treatment/rotating-biological-contactor/. [Accessed 25 September 2018].

[96] NPTEL, "Tertiary Wastewater Treatment," Government of India, kharagpur, 2015.

[97] Ontario Ministry of Finance, "Ontario Population Projections Update, 2017–2041," [Online]. Available: https://www.fin.gov.on.ca/en/economy/demographics/projections/#s3a. [Accessed 20 09 2018].

[98] I. 18, Interviewee, *Interview 18.* [Interview]. 23 October 2018.

[99] IESO, "Combined Heat and Power Standard Offer Program (CHPSOP) 2.0," 2018. [Online]. Available: http://www.ieso.ca/en/Sector-Participants/Energy-Procurement-Programs-and-

Contracts/Combined-Heat-and-Power.

[100] Township of Georgian Bluffs, "Biogrid," [Online]. Available: https://www.georgianbluffs.ca/en/business-development/biogrid.aspx. [Accessed 10 Oct 2018].

[101] I. 19, Interviewee, *Interview 19.* [Interview]. 11 October 2018.

[102] The City of Barrie, "Biogas Utilization Upgrades, Wastewater Treatment Facility," 2016. [Online]. Available: https://www.barrie.ca/Living/Environment/Wastewater-And-Sewers/Pages/Biogas-Utilization-Upgrades-WwTF.aspx. [Accessed September 2018].

[103] The City of Barrie, "Project Completion Report" GMF Project 10133 - WPCC expansion to 76 MLD," Barrie, 2013.

[104] The Regional Municipality of Waterloo, "Green Municipal Fund Project: Kitchener WWTP Centrate Management Treatment Upgrades," Federation of Canadian Municipalities, 2013.

[105] Save on Energy, "Stratford Wastewater Treatment Plant," IESO, 2018. [Online]. Available: https://saveonenergy.ca/For-Business-and-Industry/Business-Case-Studies/Sudbury-Waste-Water-Treatment. [Accessed 11 October 2018].

[106] Biogas Association, "Municipal Guide to Biogas," 2015.

[107] Canadian Water and Wastewater Association, Water and Energy Efficiency Committee, "Best Practices of Optimized Operation in Large Scale Pump Systems".

[108] I. 9, Interviewee, *Interview 9.* [Interview]. 21 08 2018.

[109] IBI Group, "Transmission Operations Optimizer," [Online]. Available: https://www.ibigroup.com/ibi-products/transmission-operations-optimizer/. [Accessed September 2018].

[110] City of Toronto, "Water Services - 2016 Performance Measurement and Benchmarking Report," City of Toronto, 2016.

[111] I. 17, Interviewee, *Interview 17.* [Interview]. 16 October 2018.

[112] S. Haddow, "Firm focuses energy on efficiency: opportunities found in inefficient wastewater treatment plants," *Northern Ontario Business,* 1 February 2003.

[113] City of Greater Sudbury, "City of Greater Sudbury Receives Public Works Project of the Year Award," 28 January 2016. [Online]. Available: https://www.greatersudbury.ca/city-hall/news-and-public-notices/2016/city-of-greater-sudbury-receives-public-works-project-of-the-year-award/. [Accessed

September 2018].

[114] Clean Air Parternships, *Clean Air Council Meeting, Renewable Natural Gas,* 2017.

[115] US Department of Energy, "BUYING AN ENERGY-EFFICIENT ELECTRIC MOTOR," 2014. [Online]. Available: https://www.energy.gov/sites/prod/files/2014/04/f15/mc-0382.pdf.

[116] Save On Energy, "Woodward Avenue Water Treatment Plant," IESO, 2018. [Online]. Available: https://www.saveonenergy.ca/Business/Case-Studies/Woodward.aspx?scNodeID=254. [Accessed 11 07 2018].

[117] Hydro One, "How One Town Turbo-Charged Savings with a Blower Upgrade".

[118] E. Nixon, *North Mid rewarded for energy savings,* Hayter-Walden Publications, 2016.

[119] IESO, "Demand Response Auction," 2018. [Online]. Available: http://www.ieso.ca/Sector-Participants/Market-Operations/Markets-and-Related-Programs/Demand-Response-Auction. [Accessed 6 12 2018].

[120] OCWA, "Lakeshore West Wastewater Treatment PLant Aeration Upgrade Project at the Town of Kingsville".

[121] OCWA, South Peel Operations, "GE Booth WWTP's Participation in Class A Global Adjustment Program," in *WEAO 2017 Technical Conference*, Ottawa, 2017.

[122] OCWA, "Aylmer Lagoon Aeration Upgrade Project Town of Aylmer".

Appendix A Study Contributors

The following organizations provided information for this study via telephone interviews and emails:

- Ontario Clean Water Agency
- Environmental Commission of Ontario
- HydraTek
- Regional Municipality of Durham
- City of Windsor
- Lake Huron & Elgin Area Water Systems
- The City of Hamilton
- Toronto Water
- Ontario Municipal Water Association
- Ontario Water Works Association
- Association of Municipalities of Ontario
- Canadian Biogas Association
- District of Muskoka
- Regional Municipality of Peel
- City of Greater Sudbury
- City of Barrie
- Region of Waterloo
- Township of Georgian Bluffs

Appendix B Measures Considered in this Study

Exhibit 102 and Exhibit 103 present all the measures that were initially considered for inclusion in this study. After consultation with industry experts and market actors, this list was pared down to focus on the measures that would have the biggest impact on energy and GHG savings.

Exhibit 102 – Measures Considered for Inclusion in WWTPs

WWTP Measures	
System	Measure
General (Not System Specific)	Annual Energy Assessment / Benchmarking
	Install Variable Frequency Drives (VFDs) with Controls
	Install High-Efficiency Motors & Right Sizing
	Other (Specify)
Operational Improvements	Real-time Energy Monitoring
	Preventative/Proactive Maintenance Program
	Other (Specify)
Building Measures	Install High-Efficiency Lighting
	Other (Specify)
Pumping Systems	Install High-Efficiency Pumps
	Reduce Pumping Flows Where Appropriate
	Reduce Pumping Head Where Appropriate
	Eliminate Throttling Valves

WWTP Measures	
System	Measure
	Other (Specify)
Aeration Systems	Install High-Efficiency Blowers
	Dissolved oxygen control systems
	Other (Specify)
UV Disinfection	Efficient Lamps and Controls
	Other (Specify)
Anaerobic Digestion	Optimize Anaerobic Digester Process: Process temperature, sludge pre-treatment, co-digestion
	Other (Specify)
Sludge	Replace Centrifuge with Screw Press
	Replace Centrifuge with Gravity Belt Thickener
	Other (Specify)

Exhibit 103 – Measures Considered for Inclusion in DWTPs

DWTP Measures	
System	Measure
General (Not System Specific)	Annual Energy Assessment / Benchmarking
	Install Variable Frequency Drives (VFDs) with Controls

DWTP Measures	
System	Measure
	Install High-Efficiency Motors & Right Sizing
	Other (Specify)
Operational Improvements	Real-time Energy Monitoring
	Preventative/Proactive Maintenance Program
	Optimize Well Production/Drawdown/ Sequencing
	Distribution Leak Detection and Repair
	Other (Specify)
Building Measures	Install High-Efficiency Lighting
	Other (Specify)
Pumping Systems	Install High-Efficiency Pumps
	Reduce Pumping Flows Where Appropriate
	Reduce Pumping Head Where Appropriate
	Eliminate Throttling Valves
	Other (Specify)
UV Disinfection	Efficient Lamps and Controls
	Other (Specify)

Appendix C Energy Use and Flow by IESO Zone

Exhibit 104 and Exhibit 105 present the annual energy consumption and flow in Ontario in 2015, by IESO Zone.

Exhibit 104 – Annual Reference Case Energy Use (eMWh/year in 2015) in Ontario by Sector IESO Zone

IESO Zone	WWTP	DWTP	WW Pumping	DW Pumping	All Sectors
Bruce	6,990	2,464	1,146	7,128	17,728
East	118,464	86,568	16,412	40,387	261,830
Essa	142,108	54,145	16,721	96,006	308,980
Niagara	56,972	26,704	915	7,054	91,645
Northeast	96,990	63,319	19,365	44,156	223,829
Northwest	89,996	30,271	2,889	24,824	147,980
Ottawa	58,839	43,820	3,516	17,102	123,277
Southwest	246,372	252,741	22,056	190,066	711,236
Toronto	676,196	308,298	16,568	305,110	1,306,172
Toronto/Southwest	-	-	94	830	925
West	60,775	70,600	17,702	89,452	238,529
Total	**1,553,703**	**938,930**	**117,384**	**822,115**	**3,432,132**

Exhibit 105 – Annual Flow (ML/year in 2015) in Ontario by Sector IESO Zone

IESO Zone	WWTP	DWTP	WW Pumping	DW Pumping	All Sectors
Bruce	10,485	4,355	6,388	28,170	49,398
East	173,948	347,230	106,440	157,109	784,727
Essa	168,748	93,158	74,328	381,728	717,962
Niagara	69,784	60,402	2,288	28,979	161,453
Northeast	148,805	330,830	103,060	175,244	757,939
Northwest	112,665	229,117	13,678	98,716	454,175
Ottawa	159,531	313,433	16,455	72,173	561,592
Southwest	295,836	368,733	107,921	669,607	1,442,096
Toronto	768,767	991,185	70,202	1,312,828	3,142,981
Toronto/Southwest	-	-	478	3,396	3,875
West	67,234	237,533	94,540	434,539	833,845
Total	**1,975,802**	**2,975,975**	**595,778**	**3,362,488**	**8,910,044**

Appendix D Calculating Measure Costs

Measure costs were calculated using the equation below:

For efficiency measures:

$$Cost\ of\ Energy\ Savings\left(\frac{\$}{MWh}\right)=\frac{Measure\ Capital\ Cost(\$)+Annual\ Maintenance\ Costs\left(\frac{\$}{yr}\right)*Measure\ Lifetine\ (yrs)}{Annual\ Savings\ (MWh)*Measure\ Lifetime\ (yrs)}$$

For fuel switching measures:

$$Cost\ of\ Energy\ Generated\left(\frac{\$}{MWh}\right)=\frac{Measure\ Capital\ Cost(\$)+Annual\ Maintenance\ Costs\left(\frac{\$}{yr}\right)*Measure\ Lifetine\ (yrs)}{Annual\ Savings\ (MWh)*Measure\ Lifetime\ (yrs)}$$

Appendix E GHG Emissions Factors

Exhibit 106 presents the emissions factors used in this study to estimate GHG emissions and reductions. The following rational and sources were used to develop each emission factor:

- *Natural Gas*: The emissions factor for natural gas was developed using the Ontario-specific factors in the Environment and Climate Change Canada's 2017 submission to the UNFCC, National Inventory Report 1990-2015. [70] Tables A6-1 & A6-2 in Part 2 of the National Inventory Report provides the GHG-specific emission factors used to calculate the CO2e emission factor.
- *Electricity:* The marginal emission factor was used for electricity to estimate the emission reductions from energy efficiency and load shifting measures. In consultation with the IESO, we selected the marginal emission factor for 2016 that is provided by The Atmospheric Fund in Appendix D of a "A Clearer View on Ontario's Emissions: Practice Guidelines for Electricity Emissions Factors." [71]
- *Natural Gas & Electricity generated from Biogas-fueled CHP:* As biogas from anaerobic digestion is the fuel for CHP in this study, the emissions from the gas and electricity generated is considered carbon neutral (we assume that in the combusted biogas, all CH_4 is converted to CO_2). [72]

Exhibit 106 – Emissions Factors

Fuel	Emissions Factor
Natural Gas (for heating)	0.05 tonnesCO_2e/GJ
Electricity (marginal)	158.8 gCO_2e/kWh
Natural gas generated from biogas-fueled CHP	0.0
Electricity generated from biogas-fueled CHP	0.0

Appendix F Data Sources and BPS Data Cleaning

To estimate the reference case energy use for this study (see Section 6) and benchmark energy performance of facilities (see Section 7), Posterity Group used the following data sources:

- *Data reported by municipalities as part of the Broader Public Sector* (BPS) requirement under O.Reg. 397/11 [4]. The data reported by municipalities include energy use, flow, and sector but do not provide information on the plant process type (340 data points for WWTPs, 423 data points for DWTPs and 2,236 data points for pumping stations).
- *Data provided directly by the Ontario Clean Water Agency* (OCWA). These data were more detailed than the BPS reported data and give information on the plant process type in addition to flow and energy use. This dataset only includes facilities that are operated by OCWA, unlike the BPS dataset which represents all of Ontario (83 data points for WWTPs, 37 data points for DWTPs).
- *Data provided directly by energy managers and plant operators* on the facilities they manage through telephone interviews and email correspondence with Posterity Group. These data were more detailed than the BPS reported data and give information on the plant process type in addition to flow and energy use. This dataset only has a few data points but represents some of the Province's largest facilities in municipalities such as Toronto, Windsor and Durham Region (16 data points for WWTPs, 4 data points for DWTPs).

The BPS dataset was used to determine the total energy and the total flow in the water treatment sectors in the province. Preliminary analysis of the data revealed that a significant number of records contained suspected errors for reported operation type, based on a comparison of the facility name and the selected operation type in the data. Further, the reported annual water flows (and by extension, the calculated EUIs) also appeared to contain errors, with roughly 15% of the raw water treatment/pumping records reporting annual flows of exactly 1 ML/year or less, and with 60 records reporting flows higher than the largest water treatment plant in Ontario (skewing aggregate and average statistics). We "cleaned" the data to remove any data points that did not pass our screening tests to establish more reliable estimates of overall energy consumption, flows, and EUIs. Appendix F details the steps taken to clean the BPS dataset.

The data sources listed above give energy information for 2015. For this study, it was assumed that energy consumption would increase 1.35% every year, to scale with population growth.[21]

Data from the second two data sources – OCWA and facility staff - was used to estimate the breakdown of different plant types in Ontario, since BPS does not provide this information. We combined the two datasets in order to extrapolate for the rest of the province. For example, the assembled data suggest that 65% of the wastewater is treated in a plant with anaerobic digestion. We extrapolated that information to apply to all of Ontario, meaning our assumption for this project is that 65% of all wastewater in Ontario wastewater is treated in a plant that has anaerobic digestion. There are some limitations to this approach. It is possible that the dataset we created from OCWA and energy managers is not representative of all of Ontario, and that extrapolating the results is giving an incorrect picture of the province. However, given the lack of a complete dataset, our approach provides best-available sectoral energy and GHG data.

---

[21] Population growth rate is expected to fall from 1.8% to 0.9% between 2017 and 2041, according to the Ontario Ministry of Finance [97]. We took the midpoint between these two numbers, 1.35%.

BPS Data Cleaning

The BPS data were examined to establish estimates for overall energy consumption, total water treatment/pumping flow, and EUI distributions in Ontario. Preliminary analysis of the data revealed that a significant number of records contained suspected errors for reported operation type, based on a comparison of the facility name and the selected operation type in the data. Further, the reported annual water flows (and by extension, the calculated EUIs) also appeared to contain errors, with roughly 15% of the raw water treatment/pumping records reporting annual flows of exactly 1 ML/year or less, and with 60 records reporting flows higher than the largest water treatment plant in Ontario (skewing aggregate and average statistics). The following cleaning was conducted on the data to establish more reliable estimates of overall energy consumption, flows, and EUIs:

1. Recoding Operation Type

Examination of the operation type data revealed that several records reporting as water treatment facilities (either sewage or drinking water) were actually pumping stations (based on the reported facility name). Records reporting as water treatment facilities were recoded to pumping facilities if the following criteria were met:

- If the reported operation type was:
    - "Facilities related to the treatment of water" or,
    - "Facilities related to the treatment of sewage"
- If the facility name included the word "pump," but not the word "treatment"

Note that the type of water was never adjusted in this cleaning procedure. For example, if a record was incorrectly reported as a sewage treatment plant, it was recoded to a sewage pumping plant, never a drinking water pumping plant.

Overall, 66 water treatment facilities were recoded to pumping stations, as summarized below.

Exhibit 107 – Data Quality Summary: Operation Type Reassignments

# of Records	Raw 2015 BPS	Cleaned 2015-BPS	# Recoded
Facilities related to the treatment of sewage	349	340	-9
Facilities related to the treatment of water	480	423	-57
Facilities related to the pumping of sewage	738	747	+9
Facilities related to the pumping of water	613	670	+57
TOTAL	2180	2180	0

2A. Data Cleaning: DWTP and WWTP

The treatment plants (including both DWTP and WWTP) contained a significant number of suspected errors in reported flow and EUI. Roughly 10% of records reported annual flow less than or equal to 1 ML, and 30 records reported flows larger than the City of Toronto's largest facility (roughly 240,000 ML/yr), accounting for more than 90% of the total flow reported for treatment plants in the 2015 BPS data. Data flags were raised for records with suspected flow errors based on the following criteria:

- Low Flow – Minimum 5 ML
  - Set conservatively lower than smallest WWTP (12 ML) and DWTP (7 ML) observed in the dataset supplied by OCWA
- High-Flow – Maximum 300,000 ML
  - Set slightly higher than flow at largest known plant in Ontario – 240,000 ML

After applying the flow filters listed above, several records with zero EUI remained, indicated missing energy data. Data flags were raised for records with suspected EUI errors based on the following criteria:

- Low EUI – Minimum 0.1 ML for WWTP, 0.01 GJ/ML for DWTP
  - Set conservatively lower than lowest WWTP EUI (0.12 GJ/ML) and DWTP EUI (0.01 ML) observed in the dataset supplied by OCWA

The flags above were applied to the facilities in the BPS, with roughly 80% of records passing both filters.

Exhibit 108 – Data Quality Summary: Flow and EUI Flags

# Flags	WWTP	DWTP	Total
No Flags	263	357	620
Flow or EUI Flag	58	56	114
Flow and EUI Flag	19	10	29
TOTAL	340	423	763

To make an estimate of total energy and flow for all treatment plants in Ontario, the average flow and energy consumption per plant for records with no flags were imputed to records that had at least one flag. The averages used for imputation are were calculated as follows:

Exhibit 109 – Average Per-Plant Energy and Flow for Records with no Data Quality Flags

Average Value Per-Plant	GJ/plant	ML/plant
Facilities related to the treatment of sewage	16,451	5,811
Facilities related to the treatment of water	7,991	7,035

Summing the total energy/flow from records with no flag with the total imputed energy/flow for records with at least one flag results in the following aggregate estimates:

Exhibit 110 – Aggregate Statistics: Cleaned BPS data

Facility Type	Total Energy [GJ]	Total Flow [ML]
Facilities related to the treatment of sewage	5,593,331	1,975,802

Facilities related to the treatment of water	3,380,147	2,975,975
TOTAL	**8,973,477**	**4,951,777**

Comparisons between estimates from the clean dataset with the raw uncleaned BPS dataset reveal that the overall energy estimate increased by roughly 20%, but the flow estimate decreased by more than an order of magnitude. This comparison highlights the difficulty of making accurate energy and flow estimates from the BPS data.

Exhibit 111 – Aggregate Statistics: Raw 2015 BPS

Facility Type	Total Energy [GJ]	Total Flow [ML]
Facilities related to the treatment of sewage	4,532,988	40,625,109
Facilities related to the treatment of water	2,959,502	15,905,875
TOTAL	**7,492,490**	**56,530,983**

Several variations on the data cleaning procedure described above were tested to assess impacts on overall energy and flow estimates. Adjustments to the flow or EUI flag criteria typically affected the energy and flows estimate by +/- 15%, provided the flag criteria remained based on realistic values.

2B. Data Cleaning: Pumping Stations

Similar to water treatment plants, the pumping stations (PS) contained a significant number of suspected errors in reported flow and EUI. Roughly 20% of records reported annual flow less than or equal to 1 ML. No data were available for the largest pumping station in Ontario, but 32 records reported flows larger than the City of Toronto's largest treatment plant (roughly 240,000 ML/yr), accounting for more than 70% of the total flow reported for all PSs in the 2015 BPS data.

Fewer reference points were available for pumping stations upon which to base Data Quality flags. The most directly applicable reference found was taken from a report by the Electric Power Research Institute[22], which indicated that average water distribution pumping EUIs range from roughly 0.7-1.3 GJ/ML. Using this range as a guide, the EUI filter criteria were conservatively set to:

- Low EUI – Minimum 0.1 GJ/ML
- High EUI – Maximum 10 GJ/ML

The flags above were applied to the pumping stations in the BPS, with roughly 67% of records passing both filters.

Exhibit 112 – Data Quality Summary: Flow and EUI Flags

# Flags	WWPS	DWPS	Total
No Flags	501	448	949

[22] EPRI (2013) - Electricity Use and Management in the Municipal Water Supply and Wastewater Industries

EUI Flag	246	222	468
TOTAL	747	670	1417

To make an estimate of total energy and flow for all pumping stations in Ontario, the average flow and energy consumption per pumping station for records with no flags was imputed to records that had an EUI flag. The averages used for imputation are were calculated as follows:

Exhibit 113 – Average Per-PS Energy and Flow for Records with no Data Quality Flags

Average Value Per-Plant	GJ/plant	ML/plant
Facilities related to the pumping of sewage	339	478
Facilities related to the pumping of water	2,990	3,396

An additional step was needed to make a sector-wide estimate of energy and flow. The 2015 BPS reporting was not mandatory for pumping stations – for this reason, there are a significant number of missing records that appeared in 2012, when reporting was mandatory for these facilities. Given the difficulty of precisely matching the records that appear or do not appear between 2012 and 2015, the number of records requiring imputation was estimate using the procedure below.

Exhibit 114 – Summary of Pumping Stations Requiring Imputation

	WWPS	DWPS
PS with no Flags in 2015 BPS (A)	501	448
All records listed in 2012 BPS (B)	1246	990
Records requiring imputation (B – A)	745	542

Summing the total energy/flow from records with no flag with the total imputed energy/flow for records with at least one flag results in the following aggregate estimates:

Exhibit 115 – Aggregate Statistics - Cleaned BPS Data: Pumping Stations

Facility Type	# Records	Total Energy [GJ]	Total Flow [ML]
Facilities related to the treatment of sewage	1,246	422,582	595,778
Facilities related to the treatment of water	990	2,959,615	3,362,488
TOTAL	**2,236**	**3,382,198**	**3,958,267**

3. Mapping Postal Code Areas to IESO Zones

The data summarized above was assigned to specific IESO Zones based on a Zone-to-Postal Code mapping provided by the IESO. The lookup table contained 291,225 unique Zone-to-Postal Code mappings, but several postal codes found in the 2015 BPS data were not found in the lookup table provided by the IESO. The table below lists the assignments that were made for each missing postal code, based on comparison of nearby cities and the IESO Zone Map.[23]

Exhibit 116 – Assigned IESO Zones for Missing Postal Codes

Missing Postal Code	Reported City	Assigned IESO Zone
N0B1G0	Baden	Southwest
N0B1G0	Baden	Southwest
N0N1MO	Mooretown	West
N0B2I0	Wellesley	Southwest
N0B2G0	New Hamburg	Southwest
N8S4L7	Windsor	West
N0H2H0	Lucknow	Bruce
MANUAL1	South-West Oxford	Southwest
MANUAL2	Tavistock	Southwest
MANUAL3	Plattsville	Southwest
MANUAL4	Innisfil	Essa
MANUAL5	Innisfil	Essa
MANUAL6	Innisfil	Essa
MANUAL7	Innisfil	Essa
MANUAL8	Innisfil	Essa
MANUAL9	Innisfil	Essa
L0L2P0	Phelpston	Essa
L0L1Y1	Anten Mills	Essa
K0M1A1	Bobcaygeon	Essa

[23] http://www.ieso.ca/localContent/zonal.map/index.html

NOL1W0	MT. BRYDGES	West
N9J4A4	Amherstburg	West
N0A1H6	Port Dover	Southwest
NOB2H0	Petersburg	Southwest
K0H3G7	Peterborough	East
K0B3K0	Wendover	Ottawa