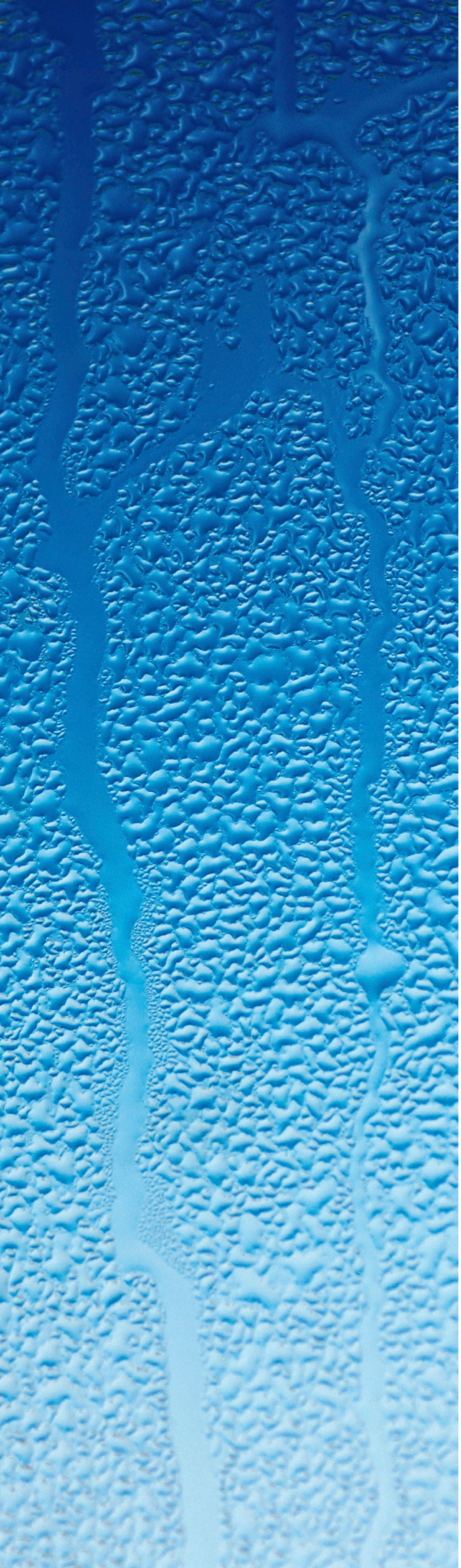

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Ontario's Water-Energy Nexus:

Will We Find Ourselves in Hot Water… or Tap into Opportunity?

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POLIS Project on Ecological Governance
watersustainabilityproject

Ontario's Water-Energy Nexus

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Preface

This research and report was inspired by an emerging interest worldwide in the water-energy nexus and, in particular, an interest in identifying opportunities for water conservation to reduce energy use. A comprehensive understanding of the water-energy nexus in Ontario has been hampered by the lack of a synthesized dataset that describes the energy used for water-related services. In recent years it became clear that a comprehensive provincial review of the energy embedded in water across all major water-using sectors was needed to provide a strong foundation for future work in this area.

The report is highly quantitative in nature and was therefore written with a technical audience in mind. The study has been structured in three pieces – an executive summary, a main report and a technical appendix. Given the importance and wide reaching implications of the water-energy nexus both the executive summary and the main report body have excluded many of the technical details and assumptions in the interest of providing a concise, accessible report and summary. The appendices have been drafted with the intention of providing a clear statement of the methodological approach, including equations used and assumptions made, for the benefit of readers looking for specific technical details or to replicate this study elsewhere for other contexts. To avoid excessive length, the narrative and graphic representation in the Appendices has intentionally been kept short and direct, with summary tables included in Appendix A.

Prior water-energy studies have typically focused on the energy used for pumping and heating water as these are prime targets of municipal water conservation programs. However, this report also includes an analysis of the energy for steam used both for manufacturing processes and space heating and the waste heat from power generation. A soft path approach to water and energy demands holistic thinking; quantifying this energy lost in cooling water or through boiler inefficiencies is a first step in understanding how innovative processes and ideas may reveal the water and energy saving opportunities that these sectors have to offer. Analyses of the energy used to pump, treat and heat water are also provided separately from the energy used to generate steam and produce power (Figure 6 for example) with the intention of offering the information required by different types of practitioners.

It is the sincere hope of the author that this report will not only help to fill this research gap, but also stimulate future dialogue on this important topic.

Introduction

What is the water-energy nexus?

Water used to produce energy and the energy used to provide water-related services together have been coined the "water-energy nexus" in recent times. Water is essential for generating energy - to power the turbines in hydro-electric facilities, for cooling in thermal or nuclear energy plants, and to extract oil from tar sands. Indeed, collectively, the energy sector is the single largest user (though not the largest consumer) of water in Canada (Environment Canada, 2007). At the same time, energy is required to pump, treat and heat water and to generate steam for urban, industrial and agricultural use and to deal with the resulting wastes. Together, the two sides of this nexus (depicted in Figure 1) are generating new research, policy proposals and public dialogue that will be critical as societies struggle to address the intersecting challenges of climate change, energy security and water scarcity.

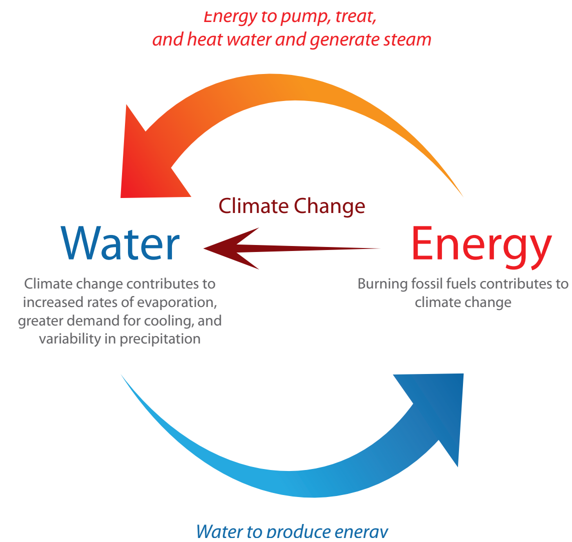

Figure 1 - The water-energy nexus in the context of climate change.

Climate Change and the Water-Energy Nexus

The water-energy nexus is deeply embedded within the context of climate change, a concern that is front and centre for many Canadians and that the Ontario Government has identified as a priority (Pembina, 2008; Office of the Premier, 2004). Burning fossil fuels to generate electricity and heat for provision of water services creates greenhouse gas emissions, heat-trapping gases that contribute to global warming and ultimately to climate change. Climate change will in turn impact water availability, increase water temperature and alter the frequency and duration of rainfall.

> *"Climate change may have been created by energy use, but it will be felt through water."*
>
> —Oliver Brandes, POLIS' Water Sustainability Project Leader

Indeed, this changing "waterscape" is likely to impact all aspects of our relationship with water and energy, as described by Thirwell *et al.* (2007) in a discussion of the water-energy nexus in Canada:

> *"It is anticipated that as climate changes, water resources will be altered; potentially reducing their quality, quantity, and accessibility. This in turn will require increased energy inputs to purify water of lower quality or pump water from greater depths or distances. Increased energy use will potentially lead to greater greenhouse gas emissions. Additionally, Canada's hydroelectricity sector could be affected forcing Canada to turn to other energy sources with higher emissions. All of this would ultimately reinforce climate change and create a vicious circle."*
>
> —Thirwell *et al*. (2007)

Warmer water temperatures will furthermore reduce the efficiency of cooling in thermal and nuclear power generating stations, and industrial settings, necessitating increased water withdrawals. A discussion of the energy associated with water use is therefore also necessarily a discussion of climate change and power generation.

Integration of Water-Energy Policy & Research

New research reveals strong linkages between water and energy consumption. A study by the Energy Policy Research Institute (EPRI) in 2002 provided a first estimate of the total energy associated with water in North America (EPRI, 2002). The report estimated that 4% of the electricity consumed in the United States is used to move and treat water and wastewater. Other studies in the U.S. have since built on EPRI's work and have suggested that energy consumption for water use is even greater. Most recently, an updated examination of the energy to pump, treat and heat water suggested that total water-related energy use is equivalent to 13% of all electricity produced in the U.S.[1] (Griffiths-Sattenspiel & Wilson, 2009). This nationwide survey reflected results from prior studies of individual states including California, where water-related services account for 19% of electricity consumption and 30% of the state's natural gas demand (Cohen *et al*., 2004). A study in the United Kingdom revealed that 6% of the UK's annual greenhouse gas emissions are related to water, 90% of which are associated with hot water use in the home (Environment Agency, 2009).

As we elucidate the implications of the water-energy nexus, new opportunities for more integrated approaches emerge. The United States has included minimum water efficiency standards for fixtures and appliances in its Energy Policy Act since 1992 (Energy Policy Act, 1992). In October 2006, the California Public Utilities Commission (CPUC) issued a ruling which directed each energy utility to develop a one year pilot program, together with a water provider, to "implement a jointly-funded program designed to maximize embedded energy savings per dollar of program cost" (CPUC, 2006). The University of Delaware conducted a jurisdictional review of water-energy programs in other states to inform the Delaware General Assembly of how water-energy initiatives may be applied in the state (Young-Doo Wang *et al.*, 2008).

The U.S. passed the Energy and Water Research Integration Act to "ensure consideration of water intensity in the Department of Energy's energy research, development, and demonstration programs to help guarantee efficient, reliable, and sustainable delivery of energy and water resources" (Bill H.R. 3598, 2009). Most recently, the Great Lakes Commission launched a Great Lakes Energy-Water Nexus initiative that aims to better integrate water and energy decision making processes, including a new project that will develop tools to better understand the impacts of power generation on water resources (Great Lakes Commission, 2010).

Relevance of the Water-Energy Nexus to Ontario

Ontario's energy use for water services is likely to rise on a steep trajectory in coming years. A rapidly growing population means increased demands for water. Declining water quality and availability in our watersheds could require more energy intensive treatment processes, and pumping from greater distances and depths, to maintain a reliable water supply while protecting public health and the environment. In fact, the Electric Power Research Institute estimates that the energy to pump and treat a litre of water in the U.S. will increase by 5-10% over 10 years (EPRI, 2002) and the energy consumption of municipal water utilities is predicted to double within the next 40 years (Alliance to Save Energy, 2002). The anticipated rise of energy intensive treatment processes, the need to pump water greater distances and depths and population growth together suggest an exponential increase in the energy used to provide water services. Future energy use for water could conceivably outstrip our ability to provide renewable energy if wasteful water practices continue to go unchecked.

1 this estimate includes hot water uses but excludes steam

Our previous report, *The Greenhouse Gas and Energy Co-benefits of Water Conservation*, highlighted water and wastewater services as the single-largest consumer of electricity in Ontario municipalities, comprising between one to two thirds of electricity costs (Maas, 2009). The rising cost of electricity, combined with Ontario's commitment to eliminate coal-fired power and a $30-40 billion water and wastewater infrastructure deficit, suggest that communities across the province will seek to minimize their use of both electricity and water to save money and to promote environmental sustainability (RCCAO, 2006).

Higher fuel costs coupled with an increased need for cooling and irrigation could also mean steep increases in operating costs for manufacturers, farmers and homeowners. TD Canada Trust (2008) found fuel prices were a top concern of small business owners. However, a recent report by the Canadian Business for Social Responsibility revealed that businesses often fail to recognize the water-related risks within their supply chain (CBSR, 2009). Declining water quality, for example, could mean significant increases in capital and energy costs if advanced treatment or importing of water were required to manufacture materials.

The anticipated rise of energy intensive treatment processes, the need to pump water greater distances and depths and population growth together suggest an exponential increase in the energy used to provide water services.

The agricultural sector is similarly prone to water and energy related risks. Drought conditions and high fuel prices could put irrigators at increased financial risk and North America has recently seen an increasing prevalence of both. Farm fuel prices in Canada increased by 66% between 2004 and 2008 (Agriculture and Agri-Food Canada, 2009) and drought conditions plagued prairie farmers in 2001 / 2002 in what was called one of the most expensive natural disasters in Canadian history (CBC News, 2009). In seven short years these same farmers were faced with yet another year of drought in 2009. Shortt *et al*. (2004) suggest that Ontario's farmers are facing mounting pressure to irrigate, stemming from an increased frequency of low rainfall during the growing season and demands for consistent quality products. Although irrigation offers a reduced risk of crop losses, irrigators are not immune to other risks. For example, high fuel prices coupled with a drought in 2004 left cotton farmers in West Texas facing an additional $10,000 per pivot irrigator in a single growing season; this could be illustrative of times ahead in Ontario given the uncertainty of climate change impacts (Associated Press, 2004).

Rising energy costs, the imperative to reduce greenhouse gas emissions and a changing waterscape implies that water and energy conservation are fundamental to creating sustainable communities, farms and businesses in Ontario.

Opportunities for Water and Energy Savings

Encouragingly, researchers and practitioners around the globe are recognizing the potential for efficient use of water and energy to mitigate greenhouse gas emissions, work towards adapting to climate change and reduce the environmental, social and economic costs of our water use (Maas, 2009; Cohen *et al*., 2004; Griffiths-Sattenspiel & Wilson, 2009). The water-energy nexus is leading to new opportunities to save water, energy and costs. Griffiths-Sattenspiel & Wilson (2009) revealed that if every household in the U.S. installed water efficient fixtures and appliances, 38.3 million tonnes of carbon dioxide emissions could be avoided. Tellinghuisen (2009) estimated that retrofitting half of Denver's households with water efficient faucets, showerheads, dishwashers and clotheswashers could prevent 274,000 tonnes of CO_2 being released each year.

Water recycling has also been found to be highly energy efficient in places like California, where recycling wastewater is typically half of the energy consumption of new surface or ground water supplies (Cohen *et al*., 2004). In Ontario, A recent report identified water saving opportunities that could reduce water use by 46% for the residential sector, 36% for the commercial and institutional sector, 41% for municipal water loss and 16% for the manufacturing sector (RMSi, 2009). And these estimates exclude water savings from process integration, water recycling and low impact development.

California's story of leadership on the water-energy nexus, outlined in Box 1, has led other States to follow suit and devote resources towards better understanding and acting on the conservation opportunities that lie at the nexus of energy and water.

Box 1: California - Leading the Way to New Energy Savings

Bob Wilkinson, at the University of California, Santa Barbara, first published a methodology for quantifying the energy used for water services and applied the method to California water systems in 2000 (Wilkinson, 2000). Dr. Wilkinson's report inspired the Natural Resources Defense Council and Pacific Institute to generate a joint report entitled Energy Down the Drain (Cohen *et al*., 2004). This report in turn generated sufficient interest to launch a seminal report, California's Water-Energy Relationship, by the California Energy Commission in 2005 (Klein *et al*., 2005). During this study, the CEC found that "the energy savings [from water conservation programs] would achieve 95 percent of the savings expected from the 2006-2008 energy efficiency programs, at 58 percent of the cost."

Energy efficiency programs have historically been funded to a much greater extent than water efficiency programs in North America. In recognizing this inequity, the CEC was able to direct funds to energy saving, economical water conservation projects and reduce costs. Water-energy studies and reports are increasing in number, reinforcing the notion that energy used for water services, and the potential for conservation of both, is significant beyond California (Young-Doo Wang, 2008; Tellinghuisen, 2009; Griffiths-Sattenspiel & Wilson, 2009; Pourkarimi, 2007; Young and Koopman, 1991; Iowa Association of Municipal Utilities, 2002; Cheng, 2002).

Purpose & Overview of Methodology

This study provides a first estimate of the total energy required for water-related services in Ontario. Specifically, it aims to quantify the energy to heat, treat, deliver, and remove water from communities, farms, businesses, institutions and power plants. The purpose of this research was to illuminate the energy inputs to water in Ontario, Canada, and to provide a platform for future research into opportunities for water and energy conservation.

Five broad sectors were examined in this study: residential, commercial/institutional (CI), manufacturing, agriculture and power generation. The municipal sector was also examined in terms of the energy used to pump and treat water. A detailed technical description of the methodology employed for calculating energy demands for water is presented in Appendices B through J. The base year for the analysis was 2006.

Water Use

Annual water and wastewater volumes for each sector were determined using the analysis completed by Resource Management Strategies Inc. for the Province of Ontario (RMSi, 2009: Table 36). Water withdrawals for each sector were then further disaggregated to assess the volume of water that was heated and the volume of water that was discharged as wastewater. Water withdrawal volumes reported by RMSi (2009) were cross-checked with the Great Lakes Data Regional Water Use Database and found to vary considerably in certain sectors; however the Great Lakes data have not been updated since 2000 (Great Lakes Commission, 2009). Since 2008, actual water takings in Ontario must be reported through the provincial permit to take water system and so it is likely that a more accurate re-assessment of the energy demands for water can be conducted when these data become available. A summary of estimated water takings by sector in 2006 is presented in Table 1.

Table 1 - Water withdrawals by sector in Ontario, 2006

	Sector	Water Withdrawals in 2006 (m^3/yr)
Municipal Supply	Residential	966,600,000
	Commercial/Institutional	132,300,000
	Manufacturing	1,647,188,790
	Municipal Water Loss	374,466,653
Private Supply	Power Generation	26,687,000,000
	Agriculture - Irrigation	108,210,000
	Agriculture - Livestock	61,500,000
	Agriculture - Aquaculture	39,192,000
	Residential	171,700,000
	Manufacturing	1,622,811,210
	TOTALS	**31,810,968,653**

Energy Use

The energy intensity, i.e., the energy applied (in kWh) to 1 m^3 of water, was determined for each of pumping, treating and heating water within each of the given sectors. Total energy demand was estimated for each sector by multiplying the energy intensity by the applicable volume of water. For example, the energy intensity to heat water from 12°C to 60 °C was estimated using basic heat calculations and then multiplied by the volume of water heated.

Where either the energy intensity or the respective volume of water used was unavailable, a combination of assumptions and alternative methodologies were employed. In particular, the energy estimates for hot water use and steam were primarily extracted from the Comprehensive Energy Use Database published by the Office of Energy Efficiency within Natural Resources Canada (NRCan, 2007).

The energy used to drive turbines in nuclear and thermal electric power plants is first applied to water to generate steam and then released as waste heat into cooling water and into the atmosphere. The waste heat energy from generating steam in power plants was estimated using an assumed thermal efficiency and the annual power output and crosschecked using the known differential between the ambient lake temperature and the cooling water discharge.

Given the heavy reliance on a national database of energy use, and conservative estimates for the majority of remaining assumptions, the energy estimates presented herein are anticipated to represent a reasonably accurate first estimate of energy used for water-related services in Ontario and should be considered a mid-range approximation at this time.

Total Energy Used for Water Services in Ontario

The total energy consumed in Ontario for water-related services, including pumping, treating and heating water and generating steam (including steam used to generate electricity) was estimated to be 976 Petajoules per year (PJ/yr or 271,600,000 MWh/yr).[2]

What does 976 PJ/yr of Energy Input to Water Look Like?

Figure 2 disaggregates the 976 PJ/yr of energy that is applied to water in Ontario annually into energy used for steam, hot water and pumping and treatment. The energy used to pump treat and heat water and to generate steam could heat every home in Canada.[3] The waste heat from generating steam in nuclear and fossil-fuel fired power plants accounts for approximately half of this energy.

The energy used to pump treat and heat water and to generate steam could heat every home in Canada.[3]

However, as discussed in later sections, the energy for heating water, pumping and treating water and wastewater and generating steam in other sectors should not be overlooked. Consider the energy demand used to provide hot water, cold water and steam services in all sectors except power generation (460 PJ/yr); if this energy were provided by electricity alone, water-related services would consume all power produced by every hydro-

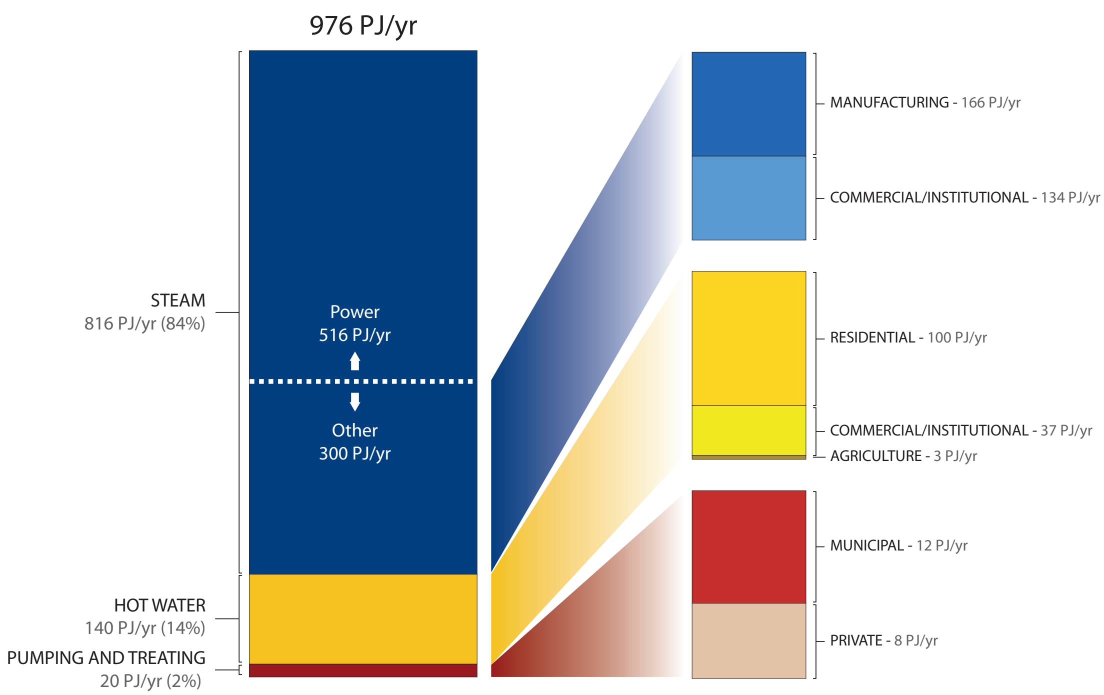

Figure 2 – Summary of energy inputs to water, including (left) and excluding (right) the power sector.

2 Note that for clarity, reported energy numbers excluded line and production losses, estimated at 6% for electricity and as much as 10% for other fuels.

3 Space heating in the residential sector consumed 805 PJ/yr in Canada in 2006 (NRCan, 2006)

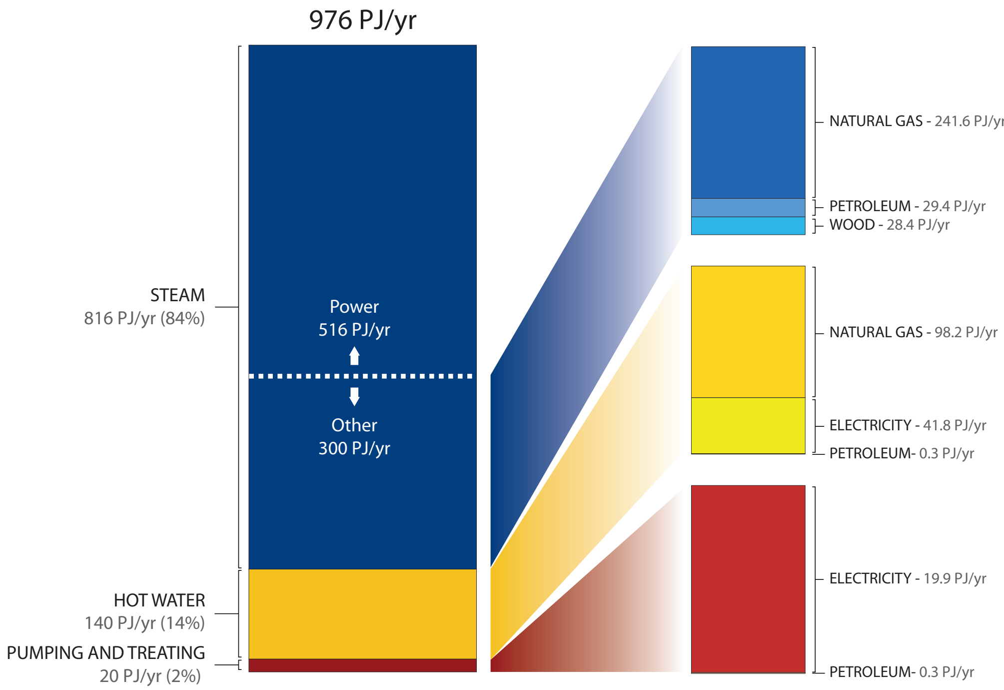

Figure 3 – Fuel type for each use of water.

electric, coal and nuclear power plant in Ontario.[4] Importantly, 80% of this energy is actually provided by fossil fuels largely as a result of Ontario's heavy reliance on natural gas for firing boilers to produce steam and hot water as illustrated in Figure 3 (refer to Table A.2 in Appendix A for further details of energy use by fuel type).

When steam was excluded entirely, the energy for pumping, treating and heating water alone was estimated at 161 PJ/yr. In fact, pumping, treating and heating water in Ontario's homes businesses, institutions and farms consumes significantly more energy than the power produced by the largest coal-fired power plant in North America.[5]

How Does Energy Used for Water Services Compare with Other Sectors?

Powering pumps, treatment plants, hot water heaters and boilers was found to consume 12% of Ontario's total demand for electricity and 40% of the natural gas demand.[6] This corresponds well with California's use of energy for water services, estimated at 19% of electricity and 30% of natural gas use (Cohen *et al.*, 2004).

Economic sectors such as agriculture, commercial/institutional, industry and transportation individually represent between 3% and 47% of the total demand for natural gas and between 1% and 37% of the electricity demand in Ontario. Energy consumption for water

Pumping, treating and heating water in Ontario's homes businesses, institutions and farms consumes significantly more energy than the power produced by the largest coal-fired power plant in North America.[5]

4 490 PJ/yr of electricity were produced in Ontario in 2008 (OPG, 2008)
5 Nanticoke power generating station in operating at full capacity produces 115 PJ/yr (OPG, 2010a)
6 Note that these values exclude the energy for steam in the power sector. 840 PJ/yr of natural gas energy is used in Ontario by all sectors (NRCan, 2007); 339 PJ/yr is used for water

intersects each of these economic sectors; however it is interesting to note that on a percentage basis water-related energy usage is comparable in magnitude to the energy consumed by individual economic sectors. For example, Figure 4 illustrates the breakdown of natural gas use in Ontario by economic sector. Clearly, the relative volume of natural gas used for water-related services, 40% of total demand, is comparable to the individual residential, commercial, institutional and manufacturing sector's fraction of natural gas demand in Ontario. Arguably, the energy used for water services is sufficiently large to warrant consideration of water as a "sector" of sorts. Investigation of opportunities to conserve water across traditional economic sectors could elicit innovative ideas and programs with new opportunities for reduction of energy use.

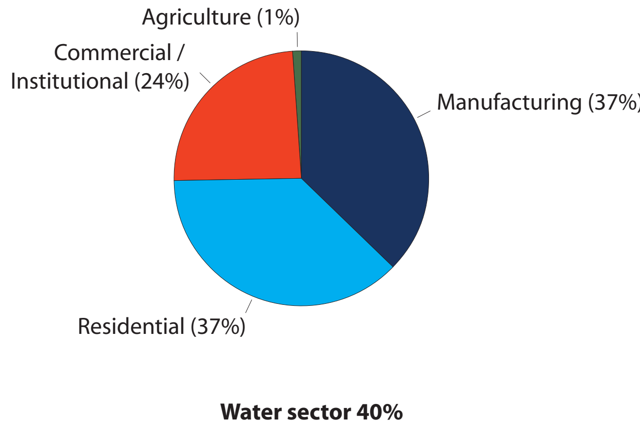

Figure 4 – Ontario's natural gas demand by sector, contrasted with the natural gas demand for water-related services.

Embedded vs. End-use Energy

The energy input upstream of the end-use, primarily the energy for pumping and treatment[7], is commonly referred to as the embedded or embodied energy of water. Energy input at the point of use is defined as end-use energy and for the purpose of this report is generally the energy to heat water and generate steam. End-use energy may also be applied for water cooled chillers and on-site treatment systems such as water softeners and UV disinfection.

End-use energy is often under private control, whereas embedded energy inputs tend to be publicly managed – at least in the case of municipally supplied water services. For example, a homeowner can install a water efficient clothes washer (hot water / end-use energy), while only a municipality can reduce leakage in the water distribution system (pumping / embedded energy). Energy inputs for hot water and steam also tend to employ a wider variety of fuels such as natural gas and petroleum products in comparison to pumping and treatment, which generally rely on electricity. In addition, though the embedded energy may appear small in comparison to end-use energy, the energy consumption for water-related uses relative to other activities may still be significant to an individual or sector. For these reasons, a separate examination of embedded and end-use energy is warranted. As illustrated in Figure 2, steam (including waste heat from power generation) accounts for 84%, hot water use 14%, and pumping and treatment 2% of total energy inputs to water in Ontario.

Hot Water & Steam (End-Use Energy)

The energy for heating water and generating steam together was estimated to be 440 PJ/yr in the residential, CI and manufacturing sectors, with an additional 516 PJ/yr of energy stemming from nuclear and fossil-fuel inputs to generate steam in the power sector, as previously illustrated in Figure 2. The energy

The energy for heating water alone, 141 PJ/yr, could keep close to half of all Ontarians warm in the winter.[8]

7 energy for manufacturing of chemicals may also be considered, but a study by Maas (2009) suggested that this energy was negligible in comparison to pumping and treatment.

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Pumping & Treatment (Embedded-Use Energy)

The 20 PJ/yr required for pumping and treating Ontario's water could light every home in the province.[10]

Despite the predominance of energy for heating water and generating steam in the water-energy nexus, as depicted in Figure 2, the electrical energy[9] required for pumping and treatment is not inconsequential. In fact, the 20 PJ/yr required for pumping and treating Ontario's water could light every home in the province.[10] About half of this embedded (electrical) energy for water in Ontario is used to power municipally operated water and wastewater systems across the province.

Box 2: Hot!!! Water Savings

The second largest consumer of energy - and producer of GHG emissions - in both the residential and commercial sectors, is hot water (NRCan, 2007). Importantly, with a payback period of 0-3 years for a number of measures, hot water savings are readily available for residential and commercial end-uses such as showering/bathing, clothes-, dish- and vehicle-washing (SeeLine Group Inc., 2005).

The economic rationale for including hot water conservation is seen in programs such as Manitoba Hydro's provincial commercial clothes-washer rebate (Manitoba Hydro, 2010), the U.S. Energy Policy Act (1992) that establishes minimum standards for pre-rinse spray valves and the free showerhead retrofits and boiler audits offered by gas companies.

New opportunities to save hot water are continually emerging such as hot water recirculation within homes and recycling and reuse of hot washwater in farms, car-washes and industry (Ally *et al*., 2002; Vickers, 2001). Washwater reuse and recycling in milking operations, for example, have been demonstrated to save 65% of water, 60% chemicals and 40% of energy (Havard, 2002).

Energy Used for Water Services by Sector

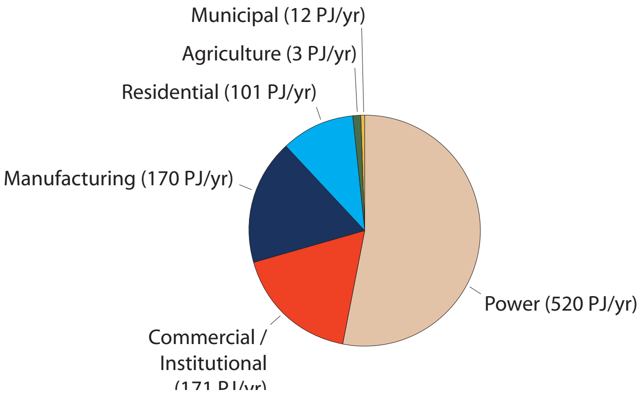
The total energy and water use in the province of Ontario was disaggregated by sector in Figures 5a and 5b respectively and Table A.1 in Appendix A includes additional details. The power generation, residential, commercial/ institutional and manufacturing sectors clearly dominate the energy demand for water because of the large amounts of energy required to heat water and generate steam. The municipal sector represents the energy for pumping and treatment of public water supplies, including water losses.

Given the large amounts of energy used for steam in the manufacturing, commercial / institutional and power generation sectors - and the general exclusion of steam from traditional water conservation programming - it can be helpful to separate steam from other end-uses of water to better illustrate the energy required for heating, pumping and treating water. Figure 6 excludes steam and disaggregates the energy required for pumping, treating

8 Hot water heating includes both residential and commercial sectors. Residential space heating in Ontario used 310 PJ/yr in 2006 (NRCan, 2006)

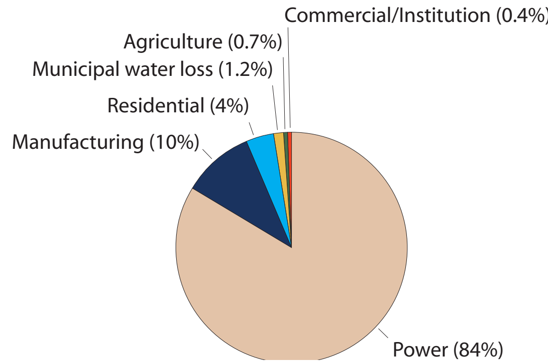
9 For the purpose of this report, all water and wastewater pumping is considered embedded energy, even if the water is being pumped from a well on the property.

10 Residential lighting in Ontario consumes 20.8 PJ/yr (NRCan, 2007)



Total energy - 976 PJ/yr

Figure 5a – Energy used for water services in Ontario, 2006, PJ/yr.



Total withdrawals - 31.8 billion m³/yr

Figure 5b – Water withdrawals in Ontario, 2006, m³/yr.

and heating water by sector.

Residential

The residential sector in Ontario uses an estimated 1,138,300,000 m³/yr of water (RMSi, 2009). Water-related energy consumption in the residential sector is predominantly used to heat water for clotheswashers, showers and faucets (101 PJ/yr), with the remaining energy (0.25 PJ/yr) used for pumping from private wells, which supply 15% of Ontario's homes with water (RMSi, 2009).

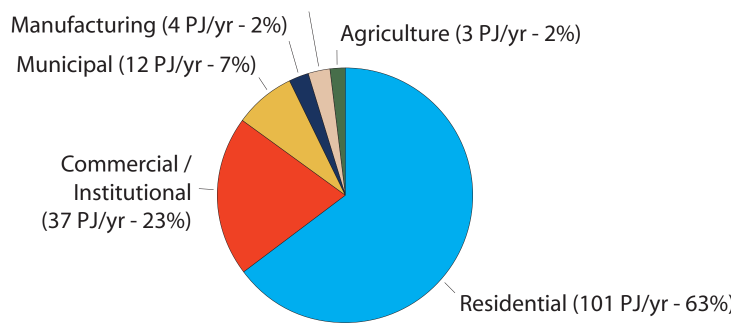


Figure 6 – Energy used for water services, by sector, excluding steam.

The residential sector was estimated to heat approximately 30% of its total water use. Residential water heating consumes more energy than appliances, lighting and space cooling combined, 70% of which is provided using natural gas (NR Can, 2007; NR Can, 2003). Not surprisingly then, greenhouse gas emissions for water heating in the residential sector are second only to space heating.[11]

Commercial / Institutional

The commercial sector in Ontario includes businesses, hotels, golf courses and restaurants while the institutional sector includes hospitals, schools, universities and government buildings among others. Together, commercial and institutional facilities use an estimated 132,300,000 m³/yr of water (RMSi, 2009). Energy for water within the commercial institutional (CI) sector fuels the hot water required for kitchens, laundry, car washing, showering,

11 A portion of space heating energy is assumed to be provided by boilers in the residential sector. However, no information about boiler use in residences was available for Ontario, so this energy for water was excluded at tthis time. 4.6 million tonnesCO_2/yr emitted from residential hot water heating (NRCan, 2006)

cleaning and steam generated in boilers in addition to cold water services such as process cooling, toilets and irrigation (Vickers, 2001).[12]

Energy for hot water heating in the CI sector was estimated at 36.9 PJ/yr based on NRCan (2006) estimates. Approximately 47% of hot water energy is fueled by natural gas, making it the second largest source of GHG emissions in the CI sector (NR Can, 2006). Steam generation for space heating was estimated to consume 133.7 PJ/yr based on an assumed 56% of heating energy supplied by boilers (CIBEUS, 2003). The heavy dependence on boilers in Ontario can be explained by Ontario's relatively large number of universities, large corporations and other institutions that rely on steam for both space and water heating.

Manufacturing

Manufacturing consumes an estimated 3,270,000,000 m^3/yr in Ontario, 20% of which is used for generating steam (RMSi, 2009). Water is used to replace steam lost through leakage, blowdown[13] and other losses in applications where steam is not fully condensed and returned to the boiler. Griffin and Johnson (2006) identified the automotive, pulp-and -paper, petrochemical, food and beverage and steel industries as particularly large steam users in Ontario. In the United States, major industrial energy users such as food processing and pulp and paper devote 20-80% of their fossil fuel consumption to steam production (Einstein *et al*., 2001).

Steam generation in Ontario was estimated to consume 20% of the total energy demand of the manufacturing sector.[14]

In fact, generating steam to provide process heat, hot water for process reactions and space heating, consumes between 20-45% of industrial energy use in the United States, the Netherlands and by extension other industrialized countries (ETSAP, 2009; Blok and Worrell, 1992; Ellis *et al*., 2009; US DOE, 2009). Ontario's manufacturing sector is anticipated to have similar energy use patterns, and a recent study reported that steam and hot water use

Box 3: Steaming Hot Opportunities

97 Ontario Steam Saver audits were completed between 1997 and 2005 by Enbridge Gas, which identified natural gas savings of 156 million m^3/yr with an average project payback period of only 1.2 years (Griffin & Johnson, 2006). Significant reductions of both water and energy can be achieved by increasing the rate of condensate return in boiler systems, however these improvements may, in some cases, be more expensive than other measures (payback period of 5.9 years) (Marbek, 2009). Lower cost measures that save both water and energy include optimizing and automating blowdown rates and improving feedwater treatment to reduce the frequency of blowdown (North Carolina, 2010). The Hamilton, Ontario based company Day and Campbell provides an excellent example of the water and energy savings potential of steam audits:

> Day and Campbell have been producing autoclaved concrete for over 60 years. An energy audit by Union Gas revealed an opportunity to re-circulate steam condensate from the autoclaves to the boiler. The wastewater from the auto-clave was too contaminated for the storm sewers and too hot to discharge to sewer. Re-circulating the steam therefore seemed an ideal solution, except the water was too contaminated to return directly to the boiler without treatment. Union Gas then engaged water specialists, who proposed a cost effective treatment solution, with a total retrofit payback period of only 2.5 years. The energy cost savings were $103,000 annually, water and sewer charges were reduced 70%, and water treatment costs were reduced by 25%. Greenhouse gas savings from the project were equivalent to removing 568 cars from the road.
>
> ***Excerpted from Enercase: Condensate and Flue Gas Heat Recovery (Union Gas, 2010)***

12 CIBEUS (2003) estimated that 47% of CI buildings utilized central chillers, but no additional information was available on the type of chillers employed. Water cooled chillers are known to be energy intensive, but were excluded at this time because of a lack of information about their use in Ontario.

13 blowdown refers to the discharge of water from a boiler to remove built up contaminants that reduce boiler efficiency

Box 4: Brewing Up Savings

The Energy Guide for the Brewers Association of Canada suggest that inefficiently operated breweries could reduce their water consumption from a ratio of 20 L of water purchased per L of beer produced down to a ratio of less than 4.5:1 with efficient practices. "Breweries usually pay for water twice: in purchase costs and in sewer chargers. A large brewery with a water-to-beer ratio of 9:1 had an incoming water temperature of 9 °C, but the combined effluent temperature averaged 28 °C. The use of water in a brewery has a strong energy consumption connotation. It makes sense to save these costs through conservation measures that can normally be accomplished more easily than direct energy-saving activities."

Excerpted from the Brewers Association of Canada's Energy Guide (1998: pp40)

consume 34% of the natural gas used in Ontario's industrial sector (Marbek, 2009). Steam generation in Ontario was estimated to consume 20% of the total energy demand of the manufacturing sector.[14]

Approximately 50% of manufacturing water in Ontario is obtained by private withdrawals of nearby groundwater, lakes and rivers. Annual electrical energy demands of 4.28 PJ/yr are required for industries such as paper, coal and petroleum and primary metals manufacturing that rely on privately-supplied sources of water.

Agriculture - Irrigation

An estimated average of 108,210,000 m^3/yr is used for irrigating crops, greenhouses, sod and nurseries (RMSi, 2009). In Ontario, irrigated crops primarily include field fruits and vegetables, tobacco, and greenhouse floriculture and vegetables (RMSi, 2009; Shortt, 2010: PC). Irrigation of crops is highly dependent on weather patterns and can vary greatly year to year. Irrigated water for non-greenhouse crops is primarily delivered using overhead (60%) and drip (40%) irrigation powered

Although the energy for irrigation is only 5% of the total energy use in the agricultural sector[16], the impact of wasted energy and water for individual farmers can be significant given the rising costs of fuel.

Box 5: Saving Energy by Managing Irrigation

The state of Idaho is paying farmers to not irrigate crops during hot afternoons when peak energy demand is highest. This measure has been estimated to shave 5% of peak electricity demands, with the potential to save water by reducing evaporative losses by irrigating when temperatures are cooler (Galbraith, 2009). Other examples corroborate the agricultural water-energy link illustrated in Idaho:

> "A Kansas study found that irrigation scheduling reduced water use by 20% while also reducing energy, fertilizer, and labor costs. The study found that the benefits of irrigation scheduling exceeded the costs, with a net return of nearly $13 per acre (Buchleiter *et al*. 1996). Kranz *et al*. (1992) found that irrigation scheduling reduced the applied water by 11% and energy use by 17% while improving yields by 3.5%."

Excerpted from Cooley, H., J. Christian-Smith and P. Gleik (2009) Sustaining California Agriculture in an Uncertain Future, Pacific Institute pg. 46.

14 166 PJ/yr for steam generation; 844 PJ/yr for all end-uses in manufacturing sector (NRCan, 2006)

Box 6: "Hot"house Savings

Over half of Canada's greenhouses are located in Ontario, making the province North America's largest greenhouse sector (Enbridge Gas, 2010). Fuel for heating, primarily delivered using steam or hot water, comprises more than 15-35% of a growers operating budget. Enbridge Gas has a dedicated greenhouse program offering to cover 50% of energy audits and a $0.05-0.10/m3 of gas saved as an implementation incentive (Enbridge Gas, 2010). Growers, such as Albert Grimm- the head grower at Jeffery's Greenhouses in St. Catharines, Ontario – are recognizing the relevance of water conservation to their bottom line:

> "In some very arid climates, the cost of irrigation water is beginning to exceed the cost of fuel, and I would speculate that water efficiency is going to be one of the keywords in the future of crop production. I believe that major trends for the future of greenhouse technology are going to be revolving around water conservation technology, especially because this is going to be a very profitable business".
>
> ***Excerpted from Grimm (2010) Irrigation Water Quality Challenges. Greenhouse Canada.***

by diesel fuel, whereas electricity is generally used to power irrigation systems in greenhouses (Shortt, 2009: PC).[15] Energy use for crop irrigation in Ontario was estimated at 0.18 PJ/yr. Although the energy for irrigation is only 5% of the total energy use in the agricultural sector[16], the impact of wasted energy and water for individual farmers can be significant given the rising costs of fuel.

Heating water in greenhouse operations is likely the most significant energy input related to agricultural irrigation. The energy used for heating water in greenhouses, 1.75 PJ/yr, was estimated by assuming all water withdrawals for irrigation were heated to 20 °C. This particular estimate is preliminary in nature, and should be refined when improved water use estimates and additional information on boiler use in the greenhouse sector become available.

Agriculture - Livestock

Livestock operations in Ontario include beef, dairy, swine and poultry with smaller operations of goat and sheep (OMAFRA, 2009). Water use requirements for livestock operations were estimated at 62,031,000 m^3/yr, and are generally used for drinking (80%), sanitary and equipment washing (10%) and animal cooling (1%) (RMSI, 2009: Table 60). Spillage and losses are reported to account for another 9.5% of total water use. An annual electricity demand of 0.03 PJ/yr was required to pump water given livestock operations were assumed to be privately supplied.

Energy requirements for heating water have been recognized as significant in livestock operations such as milking. Half of the water used for sanitary washing and cleaning was assumed to be heated based on a study of dairy farms, resulting in an estimated energy demand of 1.0 PJ/yr (OMAFRA, 2006).

15 Greenhouses, sod and nursery were assumed to be irrigated using the same energy intensity as drip irrigation in the absence of sector specific data. Land-based aquaculture was excluded because of both low energy inputs and lack of data on pumping energy.

16 Total agricultural energy consumption is 48 PJ/yr (NRCan, 2007)

Aquaculture

Water withdrawals for land-based aquaculture of rainbow trout, tilapia and other fish species in Ontario were estimated to be 39,192,000 m^3/yr in the Water Taking Reporting System (Ministry of the Environment, 2009).[17] The vast majority of land-based aquaculture relies on gravity flow surface water sources or artesian wells to minimize the energy costs of pumping (Naylor, 2010:PC). A first estimate of the energy use for aquaculture was obtained by estimating the water pumped from groundwater sources, assuming all surface water takings required negligible energy inputs. Estimates of actual groundwater takings for land-based aquaculture were 13,925,000 m^3/yr in 2008.

The electrical energy demand for water pumping in aquaculture was then estimated to be 0.01 PJ/yr. However, the water and energy demands reported herein provide only a first estimate given the known inaccuracies in both water use estimates and energy assumptions (refer to Appendix I for details).

Power Generation

Ontario Power Generation supplies approximately 70% of Ontario's electricity needs. Forty-five percent of this energy is supplied by nuclear, 34% by hydroelectric and 22% by fossil fuelled generating stations (OPG, 2008). Both thermal and nuclear power generation require large volumes of water for cooling, an estimated 86% of the total withdrawals in Ontario today (RMSi, 2009). Cooling water is withdrawn with large, highly efficient, axial flow (propeller) pumps that have lower energy intensities than, for example, municipal pumps where a higher lift

Box 7: Powering into the Future

Kalundborg, Denmark is considered the gold standard of industrial ecology practices internationally. Over a period of 20 years, this community increased synergistic linkages between power generation, industry, greenhouses and heating of homes and businesses. Since 1987, cooling water has been piped from an oil refinery to the coal-fired power plant to be used as boiler make-up water. Steam from the power plant was piped to both the oil refinery and a pharmaceutical manufacturing plant in 1982, a 2 mile pipeline that paid for itself in two years. Reuse of the steam reduced thermal pollution from the power plant in a nearby fjord. In 1991 the same oil refinery began treating wastewater to a sufficient quality that the power plant could utilize this water for cleaning purposes. Overall this innovative approach has been estimated to save 1,200,000 m^3 of water every year, and avoided 130,000 tonnes of carbon dioxide emissions (Ehrenfeld & Gertler, 1997).

Closer to home, the Bruce Energy Centre in Tiverton, Ontario, has been applying the concept of industrial ecology since 1998. Steam from the Bruce Nuclear Power plant is used within local industries such as an ethanol and biodiesel plant, a food processor and a biodegradable plastics manufacturer. Bruce Tropical Produce Inc. uses low grade steam for space heating of an 8-acre greenhouse, after which the cold water condensate is recycled to the power plant (Canadian Eco Industrial Network, 2010). Greenhouses have been identified by a number of studies as an ideal user of waste heat from cooling water, which could utilize the energy for space heating (Connecticut Academy of Science and Engineering, 2009; Lawrence National Centre for Policy and Management, 2009). Depending on the configuration, using greenhouses or other industries to "cool" the cooling water could simultaneously reduce the volume of raw water withdrawn from local ecosystems.

(pressure) is required (OPG, 2010b: PC). The energy associated with pumping cooling water in power plants in Ontario was estimated to be 3.6 PJ/yr.

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17 RMSi (2009) estimated aquaculture water withdrawals at 96,200,000 m^3/yr based on an Ecologistics (1993) study. However, Steve Naylor (2010:PC) suggested that both the volume of water withdrawn for land-based aquaculture may have decreased since 1993.

An estimated 35-48% of energy inputs in nuclear and fossil-fuel fired power plants are converted to electricity, the remaining energy is converted to waste heat that is lost to the atmosphere and cooling water (Roth, 2005). The energy associated with steam generation in the power sector was difficult to ascertain. However, the energy for steam was approximated by estimating the energy lost as waste heat in Ontario's nuclear and thermal power generation facilities (refer to Appendix J for methodology). The energy associated with generating steam was found to be approximately 516 PJ/yr. This energy cannot necessarily be directly reduced through efficiency, however many places in the world have demonstrated innovative ways to capture this waste heat for use in district heating of homes and businesses, greenhouses and in other industrial processes while simultaneously reducing water use (refer to Box 7).

The energy associated with water loss in municipal infrastructure incurs an estimated $15,000,000 every year in electricity expenditures.[19]

Municipalities

Municipalities supply water to the CI sector and a portion of the residential and manufacturing sectors. The energy for pumping and treatment of water and wastewater is typically provided by electricity, and the associated energy intensity for water treatment and distribution and for wastewater treatment and collection was assessed in detail in a prior study (Maas, 2009). Municipally provided water was estimated at 3,120,555,443 m^3/yr with a total electrical energy use estimated at 11.6 PJ/yr.

Box 8: Municipal Dollars in the Bank

The existing water conservation programs in Ontario, involving a wide range of measures ranging from toilet rebate programs to industrial capacity buy-back programs, saved approximately 6,500,000 m^3 of water each year in 2006 (RMSi, 2009: Table 130). If investment in conservation continues at the current rate, in 10 years these municipalities will reduce electricity use by 44,000,000 kWh and save $2.6 million municipal dollars in energy costs each year across the province for pumping and treatment alone (see assumptions below); a cumulative savings over ten years of 243,000,000 kWh and $15 million in energy costs. Importantly, the residents of these communities also benefit by decreasing their home and business energy costs (if hot water or steam use is reduced), keeping water rates low by avoiding new water infrastructure and reducing their carbon footprint.

The opportunities for reduction of water losses in the municipal distribution system were estimated at 40% (RMSi, 2009). Water loss management techniques in municipalities can include water audits, leak detection and repair and pressure management. At only a fraction of the cost per litre saved of typical toilet rebate programs, water loss management is known to be a highly cost effective water conservation measure for municipalities (RMSi, 2009). Energy savings from infrastructure upgrades may be further amplified by the reduced friction losses as corroded pipes are replaced and the lower pressure requirements as leaks are minimized (Lahlou, 2001).

Assumptions: 0.68 kWh/m^3 water saved from (Maas, 2009); today's electricity prices $0.06/kWh

Municipal water providers have to contend with water loss through treatment plants and distribution piping estimated at 12% of municipal water takings in Ontario (Environment Canada, 2007) representing an average annual volume of 374,500,000 m^3.[18] The energy associated with water loss in municipal infrastructure incurs an estimated $15,000,000 every year in electricity expenditures.[19]

18 Note that this estimate differs from RMSi (2009) due to a difference in assumed total municipal volume. See Appendix for details

19 0.91 PJ/yr of electricity lost (252,000,000 kWh/yr) and assumes an electricity rate of $0.06 / kWh

Recommendations & Conclusion

This study offers the first provincial estimate of the total energy used for water-related services in Canada. In Ontario, an estimated 976 PJ/yr of energy was used for all water-related services in 2006. Excluding the power generation sector, water-related services were found to consume 40% of our natural gas usage and 12% of our electricity use in the province. And the energy for pumping, treating and heating water alone would require North America's largest coal-fired generating station running all day, every day to supply an equivalent amount of energy.[20] Clearly, the energy used for water-related services is both significant and worthy of future investigation into synergistic opportunities to save water and energy simultaneously.

Consideration of a "water sector" could offer a new lens with which to integrate energy reporting, research and conservation strategies across traditional economic sectors.

Natural Resources Canada already evaluates the energy consumed in residential and commercial/institutional sectors for water heating. Expanding the measurement and reporting of energy consuming activities to include water-related activities such as generating steam, heating water and pumping and treatment for all sectors including manufacturing, agriculture and power generation would help to build the capacity to investigate solutions that benefit both water and energy resources. The energy use for water was found to be comparable in magnitude to the energy used by individual economic sectors[21]. This suggests that consideration of a "water sector" might offer a new lens with which to integrate energy reporting, research and conservation strategies across traditional economic sectors.

An encouraging number of studies have revealed how water conservation and efficiency can reduce energy demands and provide a myriad of co-benefits including reduced infrastructure costs, maintenance costs and greenhouse gas emissions (Maas, 2009; Cohen *et al*., 2004; Griffiths-Sattenspiel & Wilson, 2009; Tellinghuisen, 2009). By seizing water conservation and efficiency opportunities, Ontario could reduce energy consumption, free up funds for struggling municipalities and greatly contribute to Ontario's fight against climate change. While many of these opportunities are available at minimal cost and with payback periods of less than two years, barriers

Box 9: Opportunities for Integrated Thinking and Action on Water and Energy

1. **CHOOSE THE WATER AND ENERGY SOFT PATH** by prioritizing conservation of water and energy over new infrastructure. Recognize the impacts of new water infrastructure on energy use, and new energy infrastructure on water.
2. **BETTER INTEGRATE** water and energy monitoring, reporting, management and efficiency programs. Examine energy use and efficiency opportunities across economic sectors through a "water sector" lens that includes cold water, hot water & steam.
3. **COLLABORATE** by bringing together water and energy expertise together to encourage development of innovative, synergistic solutions.
4. **INFORM** the public, policy makers and practitioners of the mutual benefits of reducing water and energy use.

20 actual energy used for water services is provided by a variety of sources including natural gas and electricity

21 sectors are defined as residential, manufacturing, commercial/institutional, agricultural and power generation

remain for homeowners, business owners and municipalities alike. New thinking and action is therefore required to increase participation in conservation programs and thereby build a more resilient future for Ontarians.

Linking water and energy conservation efforts offers one such new way of thinking. Box 9 highlights several opportunities to encourage a more integrated approach to water and energy.

This research offers a comprehensive depiction of the energy inputs to water in Ontario, offering a basis for future work to identify measures, policies and programs that offer both water and energy savings. The energy inputs to water in Ontario suggests that water conservation and efficiency is likely to be the next frontier of energy saving opportunities in Ontario. Furthermore, the simultaneous water and energy impacts that stem from development of new water treatment plants and new power plants emphasize that energy conservation remains the best fuel and water conservation the best source of new water.

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The POLIS Project

Created in 2000, the POLIS Project on Ecological Governance is a research-based organization housed at the University of Victoria in British Columbia. Researchers who are also community activists work together at POLIS to dismantle the notion of the environment as merely another sector, and to make ecological thinking and practice a core value in all aspects of society. Among the many research centres investigating and promoting sustainability worldwide, POLIS represents a unique blend of multidisciplinary academic research and community action.

Visit www.polisproject.org to learn more.

Water Sustainability Project

The Water Sustainability Project (WSP) is an action-based research group that recognizes that water scarcity is a social dilemma that cannot be addressed by technical solutions alone. The project focuses on three themes crucial to a sustainable water future:

- Water Conservation and the Soft Path
- Water-Energy Nexus
- Water Law, Policy and Governance

WSP works with industry, government, civil society and individuals to develop and embed water conservation strategies to benefit the economy, communities and the environment. WSP is an initiative of the POLIS Project on Ecological Governance at the University of Victoria.

Visit www.poliswaterproject.org to learn more.

POLIS Project on Ecological Governance
watersustainabilityproject