Issue Brief
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The Energy-Water Nexus: Implications for the Great Lakes

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Overview

Energy and water are inextricably linked (See Figure 1). While this linkage is not unique to the Great Lakes region, the region's vast supply of freshwater make it particularly attractive for water-intensive energy production and potentially competing demands on Great Lakes water resources. Within the Great Lakes basin, the largest source of energy comes from thermoelectric power sources, which have historically required large amounts of water. Projected long term demographic shifts and economic growth coupled with the threat of global climate change and mounting pressure for greater U.S. energy security, will demand additional power generation capacity to meet our energy needs. A large part of that additional power generation is expected to come from electricity. Already, a host of new products, from electric lawnmowers to cars that run on electricity, are gaining a greater foothold in the marketplace. Similarly, biofuels such as ethanol are being refined from corn and cellulosic biomass to fuel flex-fuel vehicles, a process which also requires large amounts of water. Because of the important role of water in energy production, the additional demand for domestic energy has significant potential to put increasing pressure on the Great Lakes and St. Lawrence River, which represent 20 percent of the world's fresh surface water and 90 percent of the U.S. freshwater supply.[1]

This paper describes the interdependence of energy and water—the amount of energy needed to provide water for various uses and, conversely, the amount of water needed to produce different kinds of energy, with a focus on electric power. It also calls attention to the need for greater coordination of institutions and policies to ensure sustainable development of energy and water resources that does not compromise the Great Lakes and St. Lawrence River.

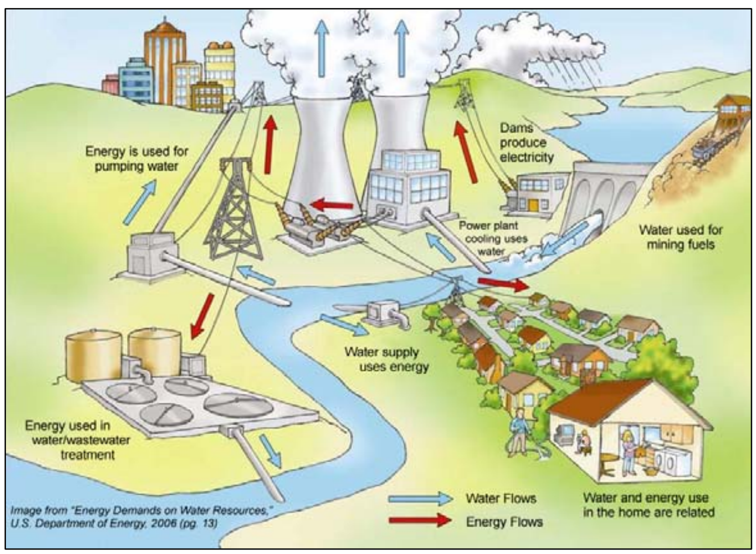

Figure 1: **Examples of Interrelationships Between Water and Energy**

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Water Requires Energy

Hydropower aside, thermoelectric power generation is the largest water user in the Great Lakes basin. In 2004, thermoelectric power accounted for nearly 75% of all water use in the Great Lakes basin.

Satisfying our water needs requires energy to supply, purify, distribute, and treat water and wastewater. Each year, about 4 percent of all U.S. power generation is related to providing and treating water.[2] Public water supplies, for instance, consume between 1,400 and 1,800 kilowatt-hour (kWh) for every million gallons of water distributed. Approximately 80 percent of municipal costs associated with water processing and distribution are for the energy—electricity—alone.[3]

The energy required to pump water can be negligible if users are located close to the source. However, the longer the distance between user and source, the more energy is required for pumping. In addition, surface waters for drinking water supply generally require more treatment, thus more energy, than groundwater.[4] Regardless of the volumes of water that run through a water treatment plant, the predominant use of electricity for delivering surface water for public supply is to pump the water to the distribution system, which represents about 80 to 85 percent of the total electricity consumption for surface water treatment.[5]

Energy requirements for distribution, wastewater collection and treatment vary depending on system size, topography, and age. Older systems, which are prevalent across the Great Lakes region, usually require more energy because of decaying and leaky infrastructure and less energy efficient equipment.

Energy Requires Water

Large amounts of water are withdrawn every day within the Great Lakes and St. Lawrence River basin for a multitude of purposes, from agriculture to industrial activities. In 2004, the latest year for which Great Lakes basin water use data are available, total water withdrawals were slightly over 41 billion gallons a day (bgd). This figure includes public water supply, domestic and industrial uses, irrigation and livestock and thermoelectric power generation (fossil-fuel and nuclear), but excludes hydro-electric power generation. Nearly 75 percent of this 41 bgd was used for thermoelectric power generation alone, making this category the largest water user in the Great Lakes region.[6]

Water Used For Thermoelectric Power Generation

"Thermoelectric power generation" is a broad category of power plants consisting of coal, nuclear, oil, natural gas, and gas-fired combined cycle that relies on a fuel source (fossil, nuclear, or biomass) to heat water to steam that is used to drive a turbine-generator to generate electricity. Thermoelectric generation represents the largest segment of U.S. electricity production, at nearly 90 percent total domestic electricity production. A significant quantity of water is required for thermoelectric power generation. Each kilowatt-hour generated from coal, for example, which accounts for over half of U.S. electricity generation, requires an average of 25 gallons of water. The largest demand for water in thermoelectric plants is cooling water for condensing steam. Other uses by thermoelectric plants also include water for operation of pollution control devices such as flue gas desulfurization (FGD) technology as well as for ash handling, wastewater treatment and wash water.[7]

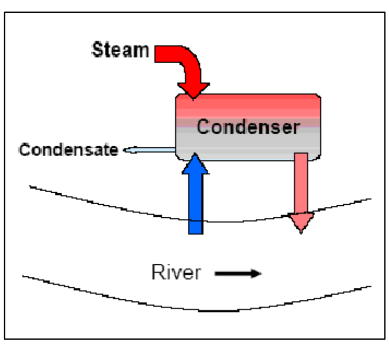


Figure 2: **Open-loop cooling**

Although thermoelectric generation requires water, its *consumptive* use—the amount of water lost in the process—varies depending on the type of technology used for thermoelectric power generation. There are three general types of cooling system designs used for thermoelectric power plants: once-through, wet recirculating, and dry.

Prior to 1970, most thermoelectric power plants were built next to surface water and were commonly using **open-loop cooling** (also called once-through cooling). This system withdraws water for cooling directly from the adjacent water body and discharges the heated water back to the source, as shown in Figure 1. Once-through cooling requires large amounts of water, but evaporation is small (usually less than 3 percent).[8] About 31 percent of current U.S. generating capacity is composed of thermoelectric generating stations using open-loop cooling and some 90 thermoelectric plants use this system in the Great Lakes region.[9, 10]

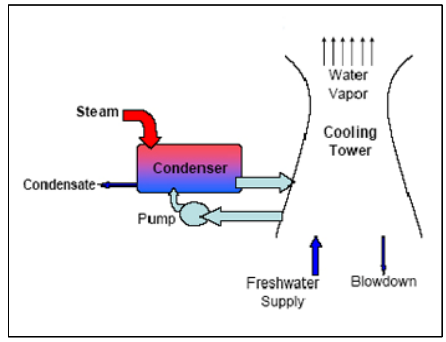
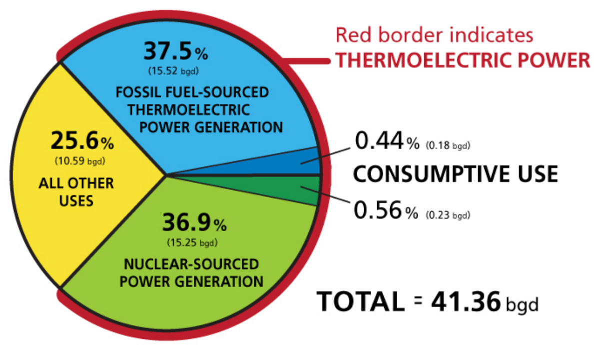


Figure 3: **Closed-loop cooling**

Most thermoelectric plants built since the mid-1970s use **closed-loop cooling** (also called "wet recirculating") systems, which pump water through a cooling tower or a cooling pond (Figure 2). These systems withdraw less than 5 percent of the water withdrawn by open-loop systems, but most of the water withdrawn is lost to evaporation and consumptive use of closed-loop cooling is typically greater than 60 percent.[11, 12] In dry cooling systems, both water withdrawal and consumption are minimal.



Source: Great Lakes Regional Water Use Database Repository 2006 report using 2004 data. *Graphic is not to scale.*

Figure 4: **Water Use in the Great Lakes Basin, excluding hydropower**

The total weighted average water consumption for the Eastern Electric grid (which includes the Great Lakes area) is estimated at 0.49 gal/kWh. For Great Lakes states, the water consumption ranges from 0.41 gal/kWh for Indiana to 1.05 gal/kWh for Illinois.[13] Although over 30 bgd of Great Lakes water was used for power generation in 2004, only 0.41 bgd—slightly over 1 percent—was lost, while the rest was returned to the basin. Figure 4 shows the amount of water used in for thermoelectric power generation in fossil fuel and nuclear plants as compared to total water use in the Great Lakes basin, with total withdrawals and comparative water losses (consumptive uses).

Water Resource and Other Environmental Implications of Thermoelectric Power

Although most Great Lakes thermoelectric power plants use once-through cooling systems so most of the water is returned to the basin, the large quantities of water required for power generation must be continuously available for power utilities to provide reliable service to their customers. This quantity of water is therefore "reserved" for power generation and is not available to other users such as irrigation or public water supply.[14]

Also, once-through cooling can potentially affect fish, shellfish and other aquatic life in several ways, including impingement on intake screens, entrainment in the cooling water systems or warming of return waters. The 90 power plants using open-loop cooling on the Great Lakes are estimated to kill in excess of 40 million fish per year due to impingement alone.[15] Moreover, the discharge of warm water back to the source (between 10° and 20° F warmer)[16] can also adversely affect aquatic life by potentially disturbing local species' growth rates, feeding behavior or other factors.[17] On the U.S. side of the Great Lakes, the U.S. Clean Water Act (CWA, 2002) addresses fish and wildlife impacts associated with thermoelectric power plant discharges and water intake structures. Further, the Clean Water Act requires that thermoelectric facilities constructed after January 17, 2002 use closed-loop cycle cooling.[18, 19]

With a greater reliance on closed-loop cooling systems, water withdrawals are expected to remain relatively constant, while water consumption is expected to increase substantially since closed-loop cooling systems consume more water, due to evaporation, than open-loop systems. With electricity consumption projected to increase by almost 30 percent by 2030,[20] the higher consumptive loss resulting from closed-loop cooling could have adverse impacts on the Great Lakes and St. Lawrence River.

Finally, chemicals added to the water at thermoelectric power plants to extend the useful life of equipment and to ensure efficient operation, such as demineralized regenerants and rinses that prevent biological growth in the towers and prevent corrosion in condensers, can result in the release of degraded water into the Great Lakes and its tributaries. In the United States, these discharges are regulated under the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA).[21]

Water Used For Other Energy Production

The amount of water used for other types of energy production depends on the source of that energy. Unlike thermoelectric power generation, solar photovoltaic and wind power generation uses only minimal water for panel and blade washing and have, therefore, no discernable impact on water supply or water quality.[22] However, the Great Lakes region's predominant reliance on fossil fuel based thermoelectric sources is water intensive. In 2006, nearly 70 percent of the region's electric supply came from coal, petroleum, and gas-fired thermoelectric power plants. More than a quarter of the region's electricity comes from nuclear sources, while energy production from other sources is still comparatively small; hydroelectric makes up 3 percent, while alternatives, such as wind and solar make up only 1 percent. [23]

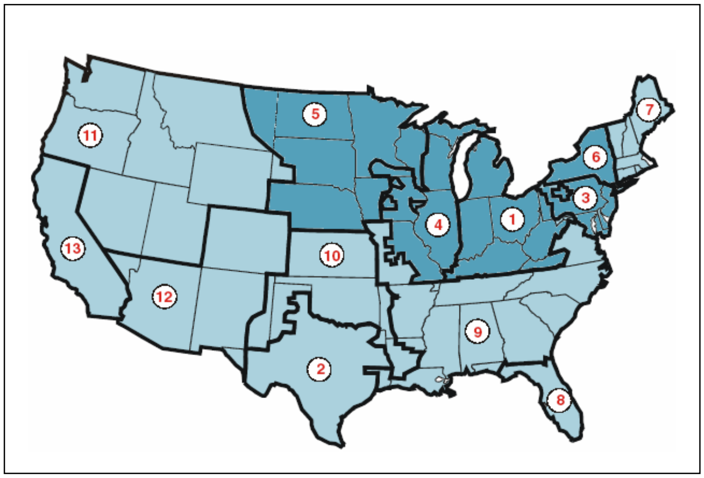
Other energy production activities also use large quantities of water. Consumptive use from hydroelectric is often ignored because all the water is assumed to be returned to the basin. Yet, when hydropower projects involve large storage reservoirs, evaporation can be a significant consumptive use. Nevertheless, since the water storage in hydropower reservoirs usually serves multiple purposes (e.g., irrigation, public water supply and recreation), hydroelectric power is not the sole culprit in these evaporative losses.[24]

Petroleum refining activities use about 1 billion gallons of water per day, nationwide. Crude oil projections for 2008 indicate about 350 billions gallons of water will be consumed to refine 235 billion gallons of oil.[25] The refining capacity in the Great Lakes region is expected to increase by over 2 million barrels a day by 2015, [26] resulting in a concomitant growth in water uses.

The production of biofuels, such as corn-based ethanol, uses vast amounts of water. A 2006 study by the Institute for Agriculture and Trade Policy shows that producing one gallon of ethanol requires an estimated 3.5 to 6 gallons of water. [27, 28] Roughly 90 to 95 percent of that water is lost through cooling towers, wet spent grain shipped locally and exhaust from the spent grain dryers. [29] Based on these estimates, a 2007 Great Lakes Commission study extrapolates that a typical modern ethanol plant with a production capacity of 50 million gallons per year requires on the order of 175 million gallons of water per year: a 3 to 1 ratio. Many of the newer facilities under construction within the Great Lakes-St. Lawrence River region will have larger production capacities of 100 million gallons of ethanol per year or more, requiring 350 to 600 million gallons of water per year (nearly 0.96 to 1.65 million gallons per day). The water-to-ethanol ratio varies seasonally and is largely dependent on the efficiency of a facility's cooling towers and the quality of the water coming into the facility.[30] The previously-referenced studies do not consider the water necessary to actually grow the corn. Agricultural irrigation accounts for roughly 20 percent of all consumptive water use in the Great Lakes-St. Lawrence River basin.[31] When ethanol is produced from corn that requires irrigation, it can use nearly 1,000 gallons of water per gallon of fuel.[32] Public officials are recognizing the wide array of negative environmental and social impacts and there are signs of a public policy shift away from corn-based ethanol as of early 2009. Still, 29 more biorefineries came online in the United States in 2007, with twice as many expanding or under construction[33] so the role of corn-based ethanol and other biofuels could continue to place pressure on Great Lakes water resources well into the future.

The Region's Future Energy and Water Needs

Future demographic and economic growth will necessitate vast amounts of additional energy and water to respond to population needs. Power generation will grow to meet rising electricity demand, especially from the residential and commercial sectors.[34] Nationwide, U.S. electricity demand is expected to rise by about 29 percent by 2030, most of which will be produced by coal-fired power plants.[35] In the five U.S. electricity market regions that cover the Great Lakes area (ECAR, MAAC, MAIN, MAAP and NY) (Figure 5), the Energy Information Agency's 2008 reference case projects over 18 GW of additional power generation capacity by 2030.[36] Moreover, Quebec and Ontario are expected to increase their generating capacity by as much as 43 GW by 2020, most of which (35 GW) will come from Ontario and is expected to be from natural gas fired plants.[37] These projections do not consider potential significant increases in electricity demand from a shift in transportation technology to electric vehicles.



Regions in **Bold** include one or more Great Lakes state(s)

1. **East Central Area Reliability Coordination Agreement (ECAR)**
2. Electric Reliability Council of Texas (ERCOT)
3. **Mid-Atlantic Area Council (MAAC)**
4. **Mid-America Interconnected Network (MAIN)**
5. **Mid-Continent Area Power Pool (MAPP)**
6. **New York (NY)**
7. New England (NE)
8. Florida Reliability Coordinating Council (FL)
9. Southeastern Electric Reliability Council (SER)
10. Southwest Power Pool (SPP)
11. Northwest Power Pool (NWP)
12. Rocky Mountain Power Area, Arizona, New Mexico, and Southern Nevada (RA)
13. California (CA)

Figure 5: **Electricity Market Module Regions**

Water for public water supply by itself will consume a good portion of that energy. In 2005, nationwide total electricity consumption for public water supply was about 32 billion kWh. This is expected to reach about 36 billion kWh by the year 2020 and 46 billion kWh by the year 2050. Table 1 shows projected consumption for different categories of water uses in the East North Central region and the Middle Atlantic region. Combined, these two regions encompass 7 of the 10 states and provinces of the Great Lakes region and can therefore illustrate the scale of the expected growth.[38] As Table 1 shows, an additional 3 billion kWh will be needed just to supply, treat and deliver water across these two regions in 2050.Thermoelectric power generation has been a significant part of the region's energy portfolio. The thermoelectric power generation sector will remain a considerable water consumer for the foreseeable future. In the U.S, thermoelectric generating capacity is expected to increase by nearly 18 percent between 2005 and 2030.[39] During that same period, water withdrawals are projected to decline slightly as new power plants comply with the requirements of the less water-intensive closed-loop technology, although the total amount of water withdrawals will still be huge—on the order of 112 to 154 billion gallons per day. In the face of growing competition for water resources, regional and national efforts to reduce water withdrawal and consumption for thermoelectric power plants are expected to intensify.[40] Freshwater consumption is estimated to increase between 31 to 49 percent between 2005 and 2030 to operate the 124 GW of new U.S. thermoelectric generating capacity projected for 2030.[41]

Table 1: **Water Consumption by Category of Uses**

Million KWh per year per sector	2005	2020	2050
Public supply	8,910	9,360	10,370
Wastewater treatment	8,820	9,280	10,300
Domestic	284	298	329
Commercial	108	114	126
Industrial	140	158	197
Irrigation	241	369	883
Livestock	75	79	86
Total	**18,578**	**19,658**	**22,291**
Source: EPRI			

Implications for the Great Lakes and St. Lawrence River are uncertain. On the one hand, the region's vast amounts of freshwater engender it with an inherent capacity to meet the predicted increase in power generation needs in the Great Lakes region and its associated water use. On the other hand, much will depend on competing uses for these waters and whether climate change predications for the Great Lakes—lower water levels—become a reality. Efficiency gains or losses—the relative rate of decrease in unit of water used per megawatt—will also be an important factor. This will depend on the types of technologies employed to generate future power needs and, in the case of power plants, the types of cooling systems employed as discussed above–compared with the rate of increase in power produced.[42] Furthermore, an increasing population will not only need more electricity but also more food, potentially creating competing interests between public water supply, energy production and agriculture. In the Great Lakes region, where the water resources also serve important functions for recreation, commercial navigation and aquatic habitat the potential for competing uses is noteworthy.[43]

Conclusion

The public policy shift in the United States and Canada away from foreign (primarily Middle Eastern) oil to domestic electricity has particular implications for the Great Lakes. Even with accelerated development of non-water intensive power generation such as wind and solar, the Great Lakes region can still expect a considerable amount of energy to come from thermoelectric sources. While advances are being made to reduce some environmental impacts of thermoelectric power generation, such as the development of clean coal technologies or carbon capture and storage, these efforts are focused on reducing harmful air emissions and greenhouse gases in particular. While the connection between biofuels and water has begun to capture the attention of some policymakers, very little attention is being paid to the potential impacts that a rapid escalation of domestic electricity capacity will have on water resources.

Energy and water are virtually and inextricably linked. Yet, in most regions, including the Great Lakes region, energy and water resource planning are considered separately. The Great Lakes region is endowed with the largest supply of fresh surface water on earth. Future energy and water planning in the Great Lakes region should recognize the interdependence of energy and water. Policies and institutional mechanisms are needed to ensure that potential impacts that each sector has on the other are considered when planning for new power plants and water supply and treatment facilities.

[1] Michael E. Webber, *Energy versus Water: Solving Both Crises Together*, Scientific American, October 2008. Available online at: <http://www.sciam.com/article.cfm?id=the-future-of-fuel>.

[2] U.S. Department of Energy. 2006. *Energy Demands on Water Resources - Report to Congress on the Interdependency of Energy and Water*, at p. 18. Available online at: <http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf>. [Thereafter, *Energy Demands*]

[3] *Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century*, Electric Power Research Institute, Palo Alto, CA: 2000. 1006787. [Thereafter, *Electricity Consumption*]

[4] *Energy Demands*, supra note 2 at p. 26.

[5] *Electricity Consumption*, supra note 3 at p.2-2.

[6] Great Lakes Commission. 2006. *Annual Report of the Great lakes Regional Water Use Data Base Repository - Representing 2004 Water Use Data in Gallons*. GLC: Ann Arbor. Available online at: <http://glc.org/wateruse/database/pdf/2004-gallons.pdf>.

[7] U.S. Department of Energy, *IEP Water-Energy Interface: Power Generation*, National Energy Technology Laboratory. Available online at: <http://www.netl.doe.gov/technologies/coalpower/ewr/water/power-gen.html>.

[8] Kimberly H. Shaffer and Donna L. Runkle. 2007. *Consumptive Water-Use Coefficients for the Great Lakes Basin and Climatically Similar Areas*, National Water Availability and Use Program, U.S. Geological Survey Scientific Investigations Report 2007–5197, at p.46. Available online at: <http://pubs.usgs.gov/sir/2007/5197/>.

[9] *Energy Demands*, supra note 2 at p. 25

[10] PowerScorecard. 2000. *Water Quality Issues of Electricity Production: Consumption of Water Resources*, Pace University, available online at: <http://www.powerscorecard.org/issue_detail.cfm?issue_id=5>.

[11] *Energy Demands*, supra note 9 at p. 19.

[12] Solley, W.B., Pierce, R.R., and Perlman, H.A. 1998. *Estimated use of water in the United States in 1995.* U.S. Geological Survey Circular 1200. For more information on water use variation based on power plant designs and cooling systems, see Ben Dziegielewski and Thomas Bik. 2006. *Water Use Benchmarks for Thermoelectric Power Generation in the United-States*, Southern Illinois University Carbondale; Carbondale (Illinois), especially pp. I-4 and I-5. Available online at: < http://www.geography.siu.edu/geography_info/research/documents/ThermoReport.pdf>.

[13] P. Torcellini, N. Long and R. Judkoff. 2003. *Consumptive Water Use for U.S. Power Production*. National Renewable Energy Laboratory: Golden (Colorado).

[14] *Ibid.*, at p. II-1.

[15] *PowerScorecard, supra* note 16.

[16] Electric Power Research Institute (EPRI). 2006. *Power Plants and Fish Protection (Clean Water Act Section 316).* Available online at: <http://mydocs.epri.com/docs/public/000000000001013162.pdf>.

[17] *Ibid.*

[18] According to the Phase I Rule enacted by the EPA under the Section 316(b) of the Clean Water Act (CWA, 2002). For more information, see EPA, Cooling Water Intake Structure-CWA §316(b) website at: <http://www.epa.gov/waterscience/316b/>.

[19] Rob Runyan. 2008. *Watergy: Faucets and Fuel Battle for Water,* News 21 Project, available online at <http://news21project.org/story/2008/08/27/watergy_faucets_and_fuel_battle>.

[20] Energy Information Agency (EIA). 2008. *Annual Energy Outlook 2008 With Projections to 2030*, DOE/EIA-0383(2008), available online at: <http://www.eia.doe.gov/oiaf/aeo/>.

[21] PowerScorecard. 2000. *Water Quality Issues of Electricity Production: Pollution of Water Bodies,* Pace University, available online at: <http://www.powerscorecard.org/issue_detail.cfm?issue_id=6>.

[22] Betsy Woodhouse. 2007. Energy Demands on Water Resources: The Federal Perspective. Southwest Hydrology: Tucson (Arizona), available at: <http://www.swhydro.arizona.edu/archive/V6_N5/feature2.pdf>.

[23] Energy Information Agency (EIA*). 2008 State Energy Profiles*. Figures reflect 2006 data; available online at http://tonto.eia.doe.gov/state/

[24] *Energy Demands*, *supra* note 11 at p. 20. The average loss for U.S. hydroelectric reservoirs is 4,500 gallons per MWh. With an annual generation of approximately 300 million MWh, total losses are estimated at 3.8 billion gallons per day.

[25] *Rob Runyan, supra* note 19. The Watergy Quiz.

[26] *Energy Demands, supra* note 24 at p. ii.

[27] Dennis Keeney and Mark Muller. 2006. *Water use by ethanol plants: Potential Challenges. Institute for Agriculture and Trade Policy* at p. 4. Available online at: http://www.agobservatory.org/library.cfm?RefID=89449.

[28] Water use records for ethanol plants are not publicly available; however, these figures were obtained from records held by the Minnesota Department of Natural Resources for ethanol plants in that state.

[29] Personal communication: G. Mickelson, Minnesota Department of Natural Resources, November 29, 2007.

[30] Great Lakes Commission. 2007. *The Potential Impacts of Increased Corn Production for Ethanol in the Great Lakes-St. Lawrence River Region*, GLC: Ann Arbor, at p. 21.

[31] *Ibid*., at p. 20.

[32] *Energy Demands, supra* note 26 at p.21.

[33] *Rob Runyan, supra* note 25 at p. 4.

[34] Additional factors, such as the fight against climate change could also create new demands for water and energy. For instance, the process for carbon capture and storage technology is both water intensive and energy intensive. The Department of Energy has said that power plants' consumption of water would nearly double by 2030 if coal-burning power generators had to install this carbon capture technology to combat global warming. Kyle Rabin, The Water Factor, The

New York Times, Letter to the Editor, December 10, 2008. Available online at: <http://www.nytimes.com/2008/12/11/opinion/l11green.html?partner=rssnyt&emc=r>

[35] EIA, Annual Energy Outlook 2008, available online at: <http://www.eia.doe.gov/oiaf/aeo/index.html>.

[36] *Ibid*.

[37] Natural Resources Canada, 2006, Canada's Energy Outlook, The Reference Case 2006, Canada: Ottawa, at p.81 and 86, available online at: <http://www.nrcan-rncan.gc.ca/inter/pdf/outlook2006_e.pdf>.

[38] From a compilation of EPRI *U.S. Electricity Consumption for Water Supply & Treatment* appendixes.

[39] U.S. Department of Energy, National Energy Technology Laboratory, 2008. *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements 2008 Update.* DOE/NETL-400/2008/1339 [Thereafter, *Estimating Freshwater Needs*]

[40] *Estimating Freshwater Needs,* supra note 39, page 67**.**

[41] *Estimating Freshwater Needs,* supra note 40, page 66.

[42] *Ibid*.

[43] *Ibid.*