Watts in a Drop of Water: Savings at the Water-Energy Nexus

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November 2014

An ACEEE White Paper

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Contents

Abstract

Historically, energy and water utilities have had siloed priorities where energy utilities focus on energy use and water utilities focus on water use. Utilities and policymakers have paid little attention to the interactions between energy and water savings. However, saving water saves energy and vice versa. Since available data on these interactions are limited, we recommend that additional data be collected for many geographic areas. Calculations of energy embedded in water based on these empirical data will lead to more comprehensive and cost-effective efficiency programs and greater energy savings.

This paper draws from existing data and methods for calculating savings. We develop national estimates of energy savings associated with water savings including energy used in water conveyance, water heating, and water and sewage treatment. We also estimate energy savings associated with end-use water savings, including reducing the use of hot water for buildings, treated potable water, untreated water for landscaping and agriculture, and treated and untreated water for industry.

Introduction

Water and energy are linked, intersecting at both the supply side (electric generation and water/wastewater facilities) and the end-use side (residential, commercial, industrial, and agriculture sectors). This linkage is commonly called the energy-water nexus. On the supply side, this intersection is apparent in the massive amounts of water needed to produce electricity and the while large amounts of energy required to treat, process, and transport water. On the end-use side, energy and water are connected in our homes, businesses, and industrial facilities. The water-energy linkage means that end-use efficiency programs that save water will also save energy and vice versa.

Figure 1 from the California Energy Commission's (CEC) 2005 report shows the typical utility water system including water services, end-use water consumption, and wastewater services (Klein et al. 2005). Energy is needed in every part of this system.

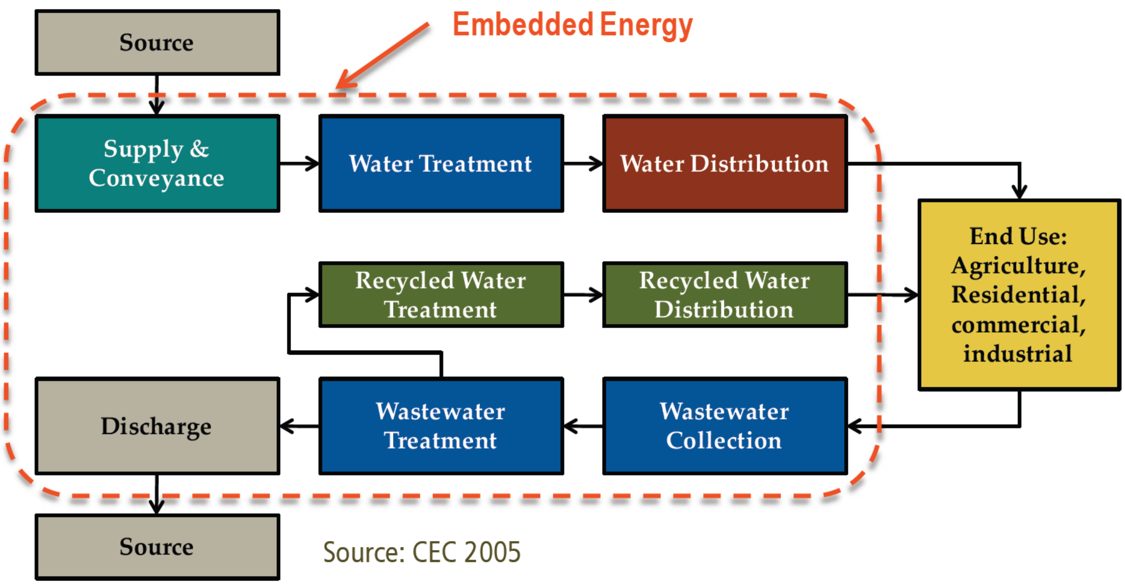

Figure 1. Water system

Despite the inherent connection between water and energy, energy and water utilities have historically had siloed priorities where energy utilities focus on energy use and water utilities focus on water use. Utilities and policymakers have paid little attention to the interactions between energy and water savings. The interactions between water and energy are substantial and could be a significant driver for greater energy savings and more comprehensive energy efficiency programs. And now with increased focus on using energy efficiency to meet greenhouse gas and other pollutant standards, utilities and air regulators should be looking for every opportunity to achieve greater savings. In some local and state jurisdictions, efficiency program planners and evaluators have called for better documentation of the interactions between water and energy to facilitate more integrated program development and evaluation (Copeland 2013).

The purpose of this paper is to demonstrate a range of energy intensities for water and wastewater services, and in residential and commercial hot- and cold-water energy consumption, as examples of the opportunities for quantifying the water-energy nexus. We also examine the potential avoided energy consumption from a residential efficiency program. The energy savings include avoided energy at residential buildings and avoided energy used to provide water and wastewater services. These estimates show the possible energy savings from water efficiency programs. Regulatory policies could consider these savings in order to create more comprehensive and cost-effective efficiency programs.

Methodology

We started by gathering ranges of energy intensity data drawn from currently existing sources that have evaluated the range of energy in water services (source/conveyance, treatment, and distribution), energy to heat water used in residences, and energy in wastewater services (treatment and discharge). [1] Few sources document regional or national energy intensities of water and wastewater services. We looked at four prominent studies that survey water utilities to get a range of energy intensities.

We went on to use the energy intensity ranges outlined in the four reports to estimate the total amount of energy being consumed in the residential U.S. water system. To do so we pulled water consumption and withdrawal numbers from a 2005 United States Geological Survey (USGS) survey that reports national water use in the United States (Kenny et al. 2009).

Last, we provided preliminary estimates of the potential energy savings that could be achieved through some basic efficiency and conservation efforts. We used the energy intensity numbers from the four reports and the total energy consumption in the water system to roughly estimate savings potential. Our estimates of energy savings associated with water savings included energy used in water conveyance, water and sewage treatment, and recycling. We also estimated energy savings associated with end-use water savings, including reducing the use of hot water for buildings and treated potable water.

Background Reports

A limited number of research reports present the water system's energy use and energy intensity. For this analysis we pulled from four prominent reports described below.

In response to massive water shortages, the California Energy Commission (CEC) and the California Public Utilities Commission have been focusing on the water-energy nexus for over a decade to better understand the relationship between water and energy in the state. In 2005 the CEC published a report called *California's Water–Energy Relationship* that estimates the magnitude and intensity of water-related energy consumption. This California-specific report relied on a variety of water data sources, each with different methods of data collection and calculation. Using data supplied from several sources, the CEC assembled energy intensities of water and wastewater services in California (Klein et al. 2005).

In 2002 the Electric Power Research Institute (EPRI) released a report called *Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The*

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[1] As reported by the CEC, energy intensity is defined as the amount of energy consumed per unit of water to perform water management-related actions such as desalting, pumping, pressurizing, groundwater extraction, conveyance, and treatment (Klein et al. 2005). It is typically reported as the number of kilowatt-hours consumed per million gallons (kWh/MG) of water.

Next Half Century. This report estimates typical electricity consumption per unit of water supply and treatment for end-use sectors and thermoelectric generation. It also projects future growth patterns of electricity consumption associated with water supply and treatment over the next half century (Goldstein and Smith 2002). We used the energy intensity numbers reported by EPRI for our estimates in the upcoming sections. This is one of the only reports that tries to give ranges of energy intensities for the United States as a whole. EPRI is now updating the report, but the update was not available in time for our work.

The Illinois Section American Water Works Association (ISAWWA) published a report surveying water utilities in Illinois and a few utilities in Indiana called the *Water-Energy Nexus Survey Summary Report*. The ISAWWA survey focused on water supply and the consumption and cost of energy from withdrawal, conveyance, treatment, and distribution (ISAWWA 2012). The report's energy intensity numbers are mostly specific to Illinois, although they also include some numbers for Indiana. The report is unique because it provides ranges of intensities for various sized utilities and various water sources (groundwater, surface water, and Lake Michigan).

Last, the River Network published a report in 2009 that also looked at studies of water intensity including carbon emissions embedded in water. This report, called *The Carbon Footprint of Water*, developed a baseline estimate of water-related energy use in the United States, as well as a comparative overview of the energy embedded in various water supplies and end uses (Griffiths-Sattenspiel and Wilson 2009). It cites the same numerical ranges as the CEC report. Since the water service numbers are the same, we did not include them in table 1 below; however, the River Network estimated the energy intensity of wastewater discharge and energy savings from water conservation. We include the River Network's analysis of energy savings as a comparison to ours.

Energy Intensity of Water

WATER SERVICES

We assembled the ranges of electrical energy intensity from the reports described above and summarized them in table 1.

Table 1. Energy intensity in water services

<table>
<tr><th rowspan="2">Source</th><th rowspan="2">State</th><th rowspan="2">Year</th><th colspan="3">Water services (kWh/million gallons per year)</th></tr>
<tr><th>Source and conveyance</th><th>Treatment</th><th>Distribution</th></tr>
<tr><td>CEC</td><td>CA</td><td>2005</td><td>0–14,000</td><td>100–16,000</td><td>100–1,200</td></tr>
<tr><td>EPRI</td><td>USA</td><td>2002</td><td colspan="2">300–1,824</td><td>NA</td></tr>
<tr><td rowspan="2">ISAWWA</td><td>IL</td><td>2012</td><td colspan="3">218–12,890 (range for all utility sizes)
1,560–2,912 (range of group means)</td></tr>
<tr><td>IN</td><td>2012</td><td colspan="3">1,981–2,198 (range for three utilities)</td></tr>
</table>

Sources: Klein et al. 2005 (CEC), Goldstein and Smith 2002 (EPRI), ISAWWA 2012 (ISAWWA)

The processes captured in these ranges vary between reports. Only the CEC report broke out the energy intensity of source and conveyance from treatment. The CEC estimates a range of 100–16,000 kWh/MG for water treatment and 0–14,000 kWh/MG for water source and conveyance. The other reports aggregate the intensities for water source, conveyance, and treatment together.

The ranges of energy intensities of water vary dramatically, particularly in the water service sector (source, conveyance, and treatment). This is largely due to differences in the size of the water systems, pumping requirements between geographic locations, and raw water characteristics. Water availability varies greatly between states. In some cases, water must be pumped hundreds of miles to supply cities and towns with potable water, and in other cases, areas primarily get water from underground sources that require energy to pump the water from the ground. The treatment of water can be a very energy-intensive process, depending on the water source. For example, brackish groundwater or seawater desalination requires much more treatment, so the energy intensity is significantly higher. Tables 2 and 3 provide information on the relative energy intensity for systems using various different water sources.

Table 2. Energy intensity by water source (kWh/MG)

Utility water source	Mean	Minimum	Maximum
Groundwater	2,844	1,014	6,361
Lake Michigan	866	75	2,554
Surface	2,019	218	3,538

Source: ISAWWA 2012 (ISAWWA)

Table 3. Energy intensity by water source by sector (kWh/MG)

Sector	Surface water	Groundwater
Domestic	NA	700
Commercial	300	700
Industrial	300	750
Public supply (includes wide area distribution)	1,406	1,824

Source: Goldstein and Smith 2002 (EPRI)

We also see that the size of the water utility matters. The IAWWA survey reported that intensity of water production and mean water production cost from energy both show that smaller utilities use more electricity per unit of water. Table 4 provides information on energy intensity for systems of various sizes in Illinois and Indiana.

Table 4. Energy intensity by utility size (kWh/MG)

Utility size	Mean	Minimum	Maximum
Large (>15,000 service connections)	1,621	218	3,171
Medium (5,000–15,000 service connections)	1,560	75	6,361
Small (<5,000 service connections)	2,912	110	12,890
Wholesaler	1,946	1,308	2,554

Source: ISAWWA 2012 (ISAWWA)

HEATING WATER

In addition to the energy intensity of the water and wastewater systems, ACEEE developed an estimate of the energy required to heat domestic water. This provides us with ranges of the energy required to heat water so that projections of energy savings through hot water conservation programs can be made. The ranges are based on three scenarios: high, typical, and low. The high scenario requires the most energy to heat the water (lowest input temperature, highest output temperature, and lowest efficiency), and the low scenario requires the least amount of energy (highest input temperature, lowest output temperature, and highest efficiency). Table 5 shows three scenarios of energy (electricity and gas) required to heat a million gallons of water.

Table 5. Energy to heat water

Domestic	High	Typical	Low
Input temperature (°F)	47	57	67
Water heater temperature (°F)	140	125	120
Water heater efficiency (EF)			
Electric	0.88	0.92	2.0
Gas	0.52	0.59	0.80
Electric (kWh/MG)	258,010	180,450	64,697
Gas (therm/MG)	14,898	9,601	5,519

KWh per gallon is calculated using the following formula: kWh/gal = (Water heater temperature – Input temperature) * 8.33 pounds of water per gallon / Water heater efficiency /3,412 Btu/kWh. The formula for gas is the same except it uses 100,000 Btu/therm instead of Btu/kWh. *Source*: ACEEE analysis.

WASTEWATER SERVICES

The CEC and the River Network include wastewater collection and wastewater treatment together when reporting the energy intensity of the wastewater system. In general, wastewater discharge has a low energy intensity, but it was not included in the CEC and EPRI reports. Table 6 shows the intensity of wastewater services.

Table 6. Energy in wastewater services

Source	State	Year	Wastewater collection (kWh/MG)	Wastewater treatment (kWh/MG)				Wastewater discharge (kWh/MG)
CEC	CA	2005	1,100–4,600					NA
EPRI	USA	2002	NA	Trickling filter 1,811–673	Activated sludge 2,236–1,028	Advanced treatment 2,596–1,188	Advanced treatment with nitrification 2,951–1,558	NA
River Network	USA	2009	700–4,600					0–400

Sources: Klein et al. 2005 (CEC), Goldstein and Smith 2002 (EPRI), Griffiths-Sattenspiel and Wilson 2009 (River Network)

Energy required to treat wastewater depends on the size of the wastewater utility and the type of treatment (Goldstein and Smith 2002). The EPRI analysis focused on four wastewater systems that represent the majority of treatment systems: trickling filter, activated sludge, advanced treatment, and advanced treatment with nitrification (Goldstein and Smith 2002). Each system requires a different range of energy use, and the range represents smaller to larger utilities (smaller utilities are more water intensive). EPRI did not collect data for energy in wastewater collection and discharge. The CEC and River Network report the energy intensity ranges of wastewater collection and treatment together.

SUMMARY OF ENERGY INTENSITIES

Figure 2 summarizes the ranges of intensities in the water and wastewater services and energy embedded in heating water, using the electric water heater range shown in table 5. The numbers in the figure are what is reported in tables 1–6 and include the lowest and highest intensity reported by CEC, EPRI, ISAWWA, and the River Network.

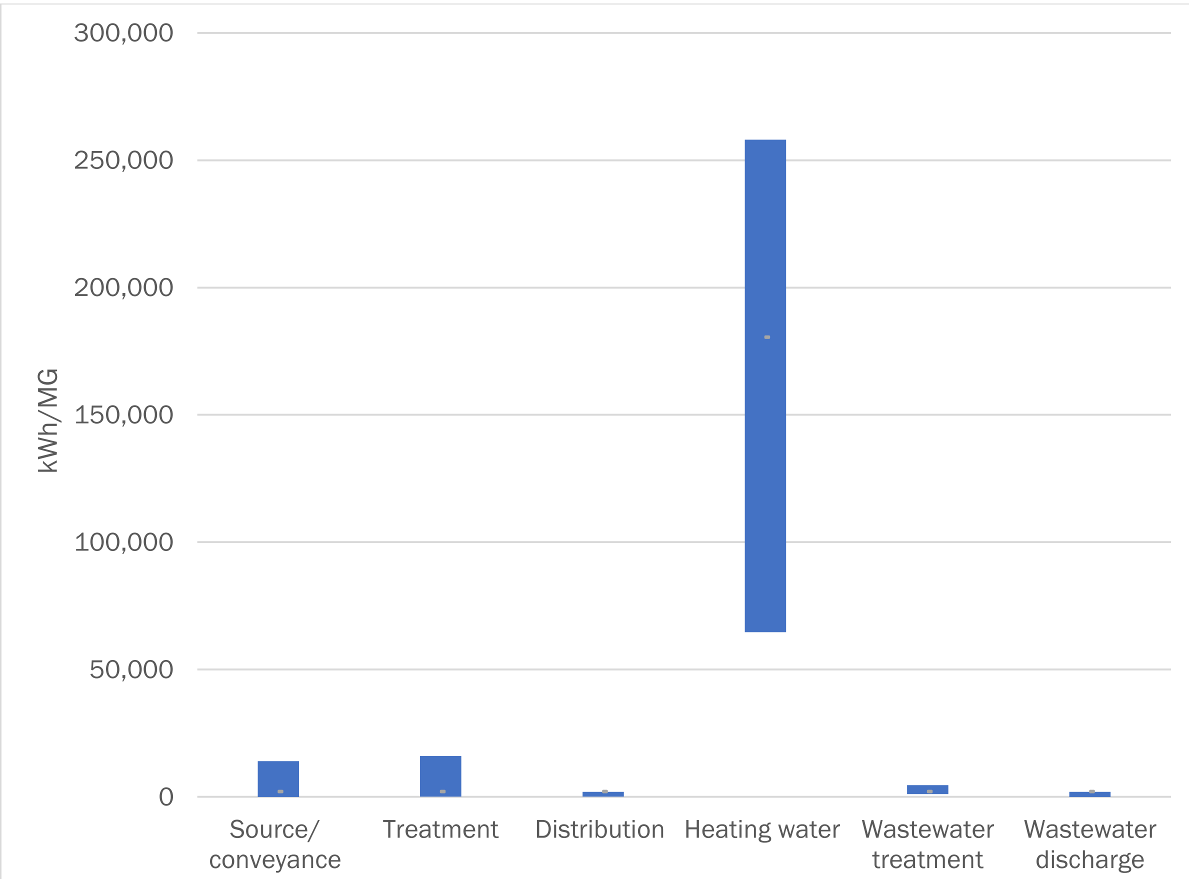

Figure 2. Ranges of energy intensity in water

According to the data gathered from the CEC, EPRI, and ISAWWA and the ACEEE analysis, heating water seems to be the most energy-intensive water-related activity. However, we also see that the water utility system activities to source, convey, and treat water are more energy intensive than the wastewater system activities.

Energy Consumed Through Water Services

We used the energy intensity ranges outlines by CEC, EPRI, ISAWWA, and River Network to estimate the total amount of energy consumed in the United States and the potential savings that can be achieved through some basic conservation efforts.

Table 7 shows the basic amounts of energy used in water services for the residential sector. The results for water use in the United States are based on the USGS 2005 report documenting water consumption by end use. We took the median energy intensity in the ranges provided above to calculate a rough estimate.

We were unable to find accurate numbers that reflect the amount of water that is processed in wastewater services in the United States. We assumed that the amount of wastewater processed is 80% of the water that flows through water services. The U.S. Environmental Protection Agency (EPA) reports that 10–20% of end-use water consumed is lost through leaks and consumption (EPA 2013). It is important to note that the actual amount of water lost is difficult to determine and varies greatly by state; some states have losses as great as 40% (EPA 2013).

Table 7. Energy use in water in the United States

Water service	2005 (million kWh)
Energy in water source/conveyance	18,700
Energy in treatment	23,400
Energy in distribution	5,600
Wastewater service	
Energy in wastewater collection and treatment	11,000
Energy in wastewater discharge	1,500

Sources: Goldstein and Smith 2002 (energy intensity data) and Kenny et al. 2009 (water withdrawal data)

Saving Energy Through Water Conservation

We used the ranges of energy intensities to establish the energy savings potential from some basic water efficiency goals. Most residences and commercial buildings use treated, potable water for all activities, even activities that do not require potable water use, such as landscaping. In our estimates, we assume that every gallon of water consumed by residences and businesses has been treated.

The savings estimates assume a 30% reduction in water consumption (30% conservation). This scenario is based on the technologically available conservation measures as laid out by the Pacific Institute's report *Waste Not, Want Not: The Potential for Urban Water Conservation in California* (Gleick, Haasz, and Henges-Jeck 2003). The report estimates that if all potential efficiency measures were installed, indoor water consumption would be reduced by 50%.

We assumed a 60% market uptake resulting in a 30% reduction of hot and cold water consumption. This assumption is based on increased water conservation efforts across the country and should be viewed as a rough average, with some sectors and regions saving more and some less. It is meant to demonstrate the possible magnitude of energy savings, not to project cost-effective or technological potential.

Of the total residential water consumed (sourced from USGS), about 70% is used indoors (Kenny et al. 2009; AWWA 2014). In our calculation we estimated that 25% of indoor domestic water consumed is heated and 75% is cold. This breakout is based on calibrating hot water use to the nationwide energy use for residential hot water as estimated in the Energy Information Administration (EIA) 2009 Residential Energy Consumption Survey (RECS). RECS collected energy consumption and survey data on more than 12,000 U.S. households representing all regions of the country (EIA 2009). Other data sources include the EPA WaterSense data and the AWWA report (EPA 2014a; AWWA 2014). This estimate of 25% hot water is lower than we expected; if total residential consumption or indoor consumption were lower, then the hot water percentage would be higher given the calibration method we used. For the savings from hot water, we assumed 41% the residential market has electric storage water heaters and 51% has gas storage water heaters, based on the EIA 2009 RECS (EIA 2009). Table 8 shows the magnitude of savings embedded in water if 30% of hot water consumed is saved and 30% of cold water is saved.

Table 8. Energy savings from water conservation estimates

	Hot water energy efficiency scenario (30% savings) (million kWh)	Cold water efficiency scenario (30% savings) (million kWh)
Water service electricity use		
Energy in water source/conveyance	1,000	4,600
Energy in treatment	1,200	5,900
Energy in distribution	300	1,400
Domestic electricity use		
Electricity to heat water consumed (typical water heating scenario)	36,000	-
Gas to heat water consumed (typical water heating scenario) (million therms)	2,500	-
Wastewater service electricity use		
Energy in wastewater collection and treatment	600	2,800
Energy in wastewater discharge	80	400
Total (million kWh)	**39,000***	**14,900**

*Does not include natural gas savings. *Sources*: ACEEE analysis, Kenny et al. 2009 (water withdrawals), and Goldstein and Smith 2002 (energy intensity)

The River Network also provides estimates of energy savings in its report, shown in table 9. We can see that the variance of energy savings is similar to our estimate, with hot water reductions accounting for, by far, the majority of energy savings. It is also notable that the River Network's savings scenarios are far more targeted to specific programs, where ours are based on an overall percent reduction in end-use consumption.

Table 9. Energy savings from water conservation estimated by the River Network

Type of program	Reduction taken	Energy saving (million kWh)
Water service electricity use saving	1% of American homes replaced their older, inefficient toilets with WaterSense	38
Indoor residential electricity use saving	Hot water reduction of 20%	41,000
Water supply and treatment systems	5% reduction in water supply and treatment leaks, equal to 0.5% of total water supply	313

Sources: Griffiths-Sattenspiel and Wilson 2009

Conclusions and Recommendations

ACEEE and others have reported that there are large amounts of energy embedded in water throughout the entire water system (ACEEE and AWE 2011; CPUC 2011). However, the most notable finding, as others have stated (AWE 2013), is the lack of end-use information, empirical data, and examples in the literature. More work must still be done to further explore and quantify the energy-related benefits of the water-energy nexus. Very few studies report energy used at water and wastewater facilities. In many cases, reports are using decades-old data sets to estimate energy in water. More complete and current data need to be collected, collated, and reported to get a better understanding of the specific amounts of energy used by utilities of various sizes and locations.

ACEEE has written previously on the benefits of water-and-electric-utility joint programs (Young 2013). However, many energy and water utilities still struggle to take advantage of the connections between energy and water because of a variety of institutional and regulatory barriers. One of these barriers is the lack of understanding of the embedded energy in water and water in energy. Collecting more and better data for a variety of utilities in a broader area will facilitate the job of quantifying the empirical intensities of embedded energy in water for policymakers and program planners.

Accurate calculation of energy embedded in water consumption depends on data from a variety of water utilities. As described above, many variables create the wide range of energy intensities for water services. For example, the size of the water and wastewater systems, the need to pump between locations, and raw water characteristics lead to variations in the energy required to get potable water to customers. Since so many variables factor into the energy use of a water utility, having plenty of examples and data is crucial to accurate savings calculations.

Solid methods for calculating energy savings would also encourage greater application of water conservation for avoided energy consumption. In particular, under the proposed EPA rule to regulate greenhouse gas emissions from existing power plants (EPA 2014b), states can use energy efficiency to help meet their emission reduction goals. This provides an opportunity for energy utilities to work with water and wastewater providers to conserve water and increase water efficiency, which lowers energy use at water service provider facilities and energy used to heat water. In order to gain credit, water and energy utilities need to have a credible and robust calculation methodology to measure energy embedded in water.

In addition to methods for calculating energy embedded in water, it will be critical to develop a limited number of well-documented kWh-per-million-gallons factors for different types of water systems. This could make crediting water-related energy savings easier under EPA's proposed greenhouse gas rule. Actual energy savings related to reducing water consumption in states must be documented and demonstrated. Well-developed calculations will encourage more utilities to work together to save both water and energy, increase efficiency, and reduce consumption.

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