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Energy costs are a large portion of the operational budget for water and wastewater utilities. Effective energy management strategies can reduce operational costs and increase efficiencies.

BY LAURA DUFRESNE

TAKE A SYSTEMS APPROACH TO ENERGY MANAGEMENT

ACCORDING TO RECENT RESEARCH, water and wastewater services commonly account for as much as 30 percent to 40 percent of the total energy use in a municipality—about 39.2 terawatt hours per year (1 TWh = 1 million MWh). Many water treatment plants and distribution networks were constructed when energy costs weren't a major factor. In current times, however, energy costs can form a large portion (up to 35 percent) of the operational budget for water utilities, second only to staffing.

Although energy is used for many water utility functions, the largest energy user by far is pumping. For surface water systems, the Electric Power Research Institute (EPRI) and Water Research Foundation (WRF) estimate that, on average, 86 percent of total energy demand is for raw, in-plant, and finished water pumping. For groundwater systems, pumping is an even higher proportion, because treatment energy costs are often negligible.

According to the US Environmental Protection Agency (USEPA), energy required for conveying raw water to the treatment plant ranges from 0 to 14,000 kWh/mg. Treatment and distribution require 100–16,000 kWh/mg and 700–1,200 kWh/mg, respectively. The range of energy requirements reflects the wide variety of source configurations (i.e., groundwater versus surface water, deep wells versus more shallow wells, distance to the treatment plant), treatment processes (chlorination-only versus advanced treatment), topography, and layout of customer connections.

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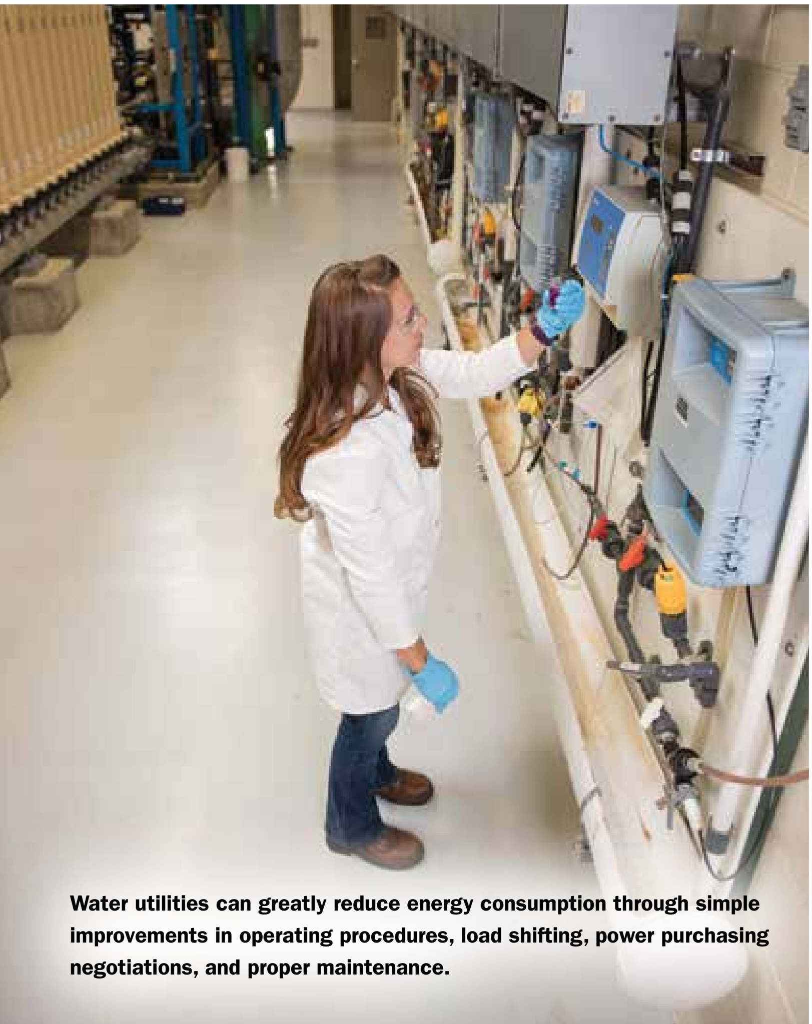

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Energy Management

Water utilities can make great strides in reducing energy consumption by simple improvements in operating procedures, load shifting, power purchasing negotiations, and proper maintenance. Toward that end, utilities should focus on management measures to reduce energy use and associated costs as well as technology measures related to motors, pumping, and water treatment equipment modifications.

MANAGEMENT MEASURES

Water system management has become increasingly complex in recent years. The role of utilities has evolved from simple custodianship into stewardship of the water supply and the watershed as well as its ecosystems and inhabitants. By taking a systems perspective, utilities can ensure the most effective overall management of planning and operations.

A systems approach is a planned, comprehensive way to manage energy use and address the entire water system, beginning with the raw resource and continuing through the entire water "value chain" to the end user—the customer. Effective energy management is achieved by considering the system as a whole, not by isolating individual functional areas. Through a systems approach to energy management, a water utility can achieve a multitude of benefits, including lower energy costs for conveyance pumping and treatment, optimal use of renewables (e.g., hydro, solar, and wind), more effective and efficient procurement and consumption of energy, and a lower carbon footprint.

Common energy management measures include energy cost-saving measures, system operations optimization, water efficiency measures, asset management, and reduction of building energy use. Benefits lie in considering these components from a proactive system-planning, engineering, and operations perspective.

Energy Cost-Saving Measures. Water systems can work with energy providers in many ways to realize cost savings by using alternative energy procurement strategies, evaluating rate structures and fees, and more carefully aligning energy use with rate structures.

System Operations Optimization. Proactively planning and scheduling a water system's operations help to substantially reduce energy and other system operating costs. Proactive system operations have a long-term (annual) and short-term (daily/hourly) perspective. From a long-term perspective, water supplies, treatment, and transmission facilities are allocated and scheduled for operation considering annual consumption forecasting with daily resolution. From a short-term perspective, these same assets are scheduled on a daily/hourly basis, considering a short-term consumption forecast.

Water Efficiency Measures. Water systems can save energy by reducing the amount of water that must be withdrawn, treated, and distributed. Case studies demonstrate substantial opportunities to improve efficiency

Table 1. Energy-Saving Opportunities for Conventional Processes

Most energy reduction opportunities for a conventional water treatment system are associated with pumping, but there are also opportunities in treatment processes.

Treatment Process	Optimization Opportunities	Additional Considerations
Supply Source	Increase use of cleaner/easier-to-treat water supply.	Can reduce energy consumption by minimizing chemical use, sludge handling, and filter backwashes.
	Increase use of water source with lower pumping energy requirements.	Groundwater may require greater pumping energy than surface water sources and typically requires less treatment. Prioritize use of multiple sources based on relative efficiency. With multiple sources, try to use the source at the highest elevation first.
Rapid Mix	Conduct jar testing to optimize coagulant dose and use alternative coagulant, oxidant, acid, or coagulant aid. Consider using smaller-volume mix tanks or even eliminating mechanical mixing.	Can reduce energy consumption by minimizing chemical use, sludge handling, and filter backwashes. Inline power mixers can provide adequate mixing with small horsepower motors.
Flocculation	Use passive or hydraulic flocculation (e.g., over/under baffles) in lieu of mechanical. Use only the number of units needed for current demands (turn off parallel units to maximize flow through fewer units).	Can eliminate electric motors but may impair treatment performance, especially under difficult conditions. Consider turning off third- or fourth-stage flocculator drives.
Sedimentation	Allow solids to settle and thicken as much as possible before removing. Use only the number of units needed for current demands.	Can reduce energy consumption by reducing the volume of solids requiring additional pumping and eliminate the need for a separate thickening process.
Filtration	Optimize upstream treatment performance and filtration performance (e.g., add filter aid polymer, modify filter media, increase terminal head loss) to increase unit filter run time between backwashes.	Can reduce energy consumption by reducing filter backwash supply pumping, backwash waste treatment, and backwash recycle pumping.
Filter Backwash	Use elevated storage and/or reduce pressure for backwash water supply.	Can reduce energy consumption by reducing backwash pump motor size or eliminating backwash pumps.
Residuals Treatment	Use passive thickening and dewatering technologies like gravity thickeners and drying beds.	Large land area required, which may limit the feasibility.

Common technology measures water utilities can take to reduce energy consumption and improve efficiency address three major areas: motors, pumping systems, and water treatment equipment.

through supply-side practices, such as accurate meter reading and leak detection and repair programs, as well as through demand-side strategies, such as conservation-based water rates and public education programs.

In addition to reducing energy demand, water efficiency measures can help water utilities save money and increase sustainability by

- Deferring capital-intensive investment in treatment plant expansion projects and developing new water sources
- Addressing current and potential future issues with water scarcity
- Increasing a community's resilience to climate change

For up-to-date information on tools, resources, and developments related to water conservation planning, visit AWWA's Water Conservation Resource Community website at www.awwa.org/waterconservation.

Asset Management. Asset management implies a planned, monitored, and supervised systematic approach to maintaining and upgrading facilities. Energy management requires the same supervised systematic approach and must meet the balance described with the triple bottom line (economic, environmental, social components). Therefore, energy management should be integrated into any asset management and sustainability program.

Reducing Building Energy Use. In addition to the energy required to treat and deliver drinking water, water utilities use energy to heat and cool buildings, run computers and other office equipment, run laboratory equipment, and provide indoor and outdoor lighting. Although building energy is typically small compared with process energy, EPRI and WRF report that for smaller plants (<1 mgd) in colder climates, building energy use can account for a significant share of total energy use (30 percent or more) and shouldn't be ignored.

Heating, Ventilation and Air Conditioning Systems (HVAC). Cooling systems typically have higher capacities than heating systems and, thus, more opportunity for savings. Many rooftop cooling units are oversized and don't work efficiently. Strategies for improving HVAC systems include the following:

- Replace the existing system with a right-sized, more efficient system.
- Replace the compressor.
- Replace older, inefficient motors with high-efficiency motors.
- Improve insulation.
- Add electronic control systems and temperature sensors to maintain lower or higher temperatures during periods of no occupancy.

Lighting. Upgrading fixtures with the latest energy-efficient technologies, control systems, ballasts, and lamps is a common energy-savings measure that doesn't require major capital investment. Using natural light with skylights and other window treatments may also reduce overall lighting needs during the day.

As lamps age, production efficiency is reduced. Therefore, a newer lamp will increase light output. A study of the overall lighting system is required to assess its efficiency. For example, less light may be required in a filter gallery area than in the control room. Replacing individual lamps or small groups of lamps may not give the overall lighting efficiency required. Group lamp replacement with the overall lighting strategy in mind is a means to effectively conduct energy management with lighting. With scheduled group replacement, the number of fixtures required to maintain the necessary lighting could be reduced because of the light output of the newer lamps versus the dimmer older lamps.

Lighting controls can also be used to save energy. Typical lighting controls include dimmers, timers, motion- and light-sensing sensors, and photocells on outside lighting. Dimmers are controls that allow individuals to adjust the amount of light in a room. Using light at a lower setting can save energy and increase a lamp's life. Timers can be manual or programmable and can save energy by turning off lights automatically when they aren't needed. Motion sensors automatically turn lights on when they sense movement and turn them off a short while later. For more information, go to the US Department of Energy website on lighting controls at www.energy.gov/energysaver/articles/lighting-controls.

TECHNOLOGY MEASURES

Common technology measures water utilities can take to reduce energy consumption and improve efficiency address three major areas: motors, pumping systems, and water treatment equipment.

Motors. The US Department of Energy estimates that more than half of the energy used in the United States is for electric-motor–driven systems, and water treatment plants are a motor-rich environment. Examples of motor applications include raw water pumping, water treatment processes, finished water pumping, mixing, aeration, valve actuators, sludge handling and dewatering, conveyance, and HVAC.

Energy savings based strictly on replacing standard-efficiency motors with National Electrical Manufacturers Association (NEMA) premium-efficiency models are often modest (≤5 percent), and economic payback periods can be long. However, by focusing on older, larger, often-used motors and integrating motor replacement with right-sizing or variable-speed drive (VSD) and control upgrades, more savings can be achieved.

Motor management and considerations for motor upgrades as part of long-term facility planning and asset management should be part of any energy management program. Moreover, if motor size reduction can be accomplished (or if a VSD is used), a utility may be able to realize a cost savings as a result of a closer-to-unity power factor in addition to lower energy usage.

Pumping Systems. Pumps move water from its source (ground or surface), through the treatment plant, into a pressurized distribution system, and to the customer's tap.

As noted at the beginning of this article, energy for pumping can comprise more than 85 percent of the total energy used by drinking water systems. Thus, pumping is an important focus area when evaluating alternatives for reducing energy use in water systems.

Pumping systems can use more energy than necessary or aren't optimized for several reasons:

- Pumps were incorrectly selected.
- Pumps were correctly selected but no longer run correctly because of mechanical or corrosion problems.
- Pumps were correctly selected, but the system hydraulic conditions have changed, so they no longer run efficiently.
- Pumps were correctly selected but aren't operated as designed.

Pump oversizing is a common problem for several reasons:

- High safety factors used to calculate friction head loss within pipes may be a carryover from past practice. Now available pipe materials and lining technologies, starting with mortar lining, have relatively low friction loss coefficients and are cleaned and lined more often.
- Pumps may have been intentionally oversized to satisfy projected future demand or system uncertainty and may not provide for efficient pumping at present conditions. Many operators are forced to throttle, cycle often, or, at best, operate VSDs at low speeds, wasting considerable energy.
- Pumps may have been designed to operate at their best efficiency point under maximum anticipated operating conditions rather than average anticipated operating conditions.

Pumps also may not operate at maximum efficiency because of improper VSD use. There's a misconception that variable-speed pumping always improves efficiency. Although variable-speed pumping is often more efficient than throttling, a variable-speed pump operating at a

Table 2. Energy-Saving Opportunities for Advanced Processes

Each of these advanced treatment processes can be optimized to reduce energy consumption, with the greatest opportunity for savings with NF/RO systems.

Treatment	Optimization Opportunities	Additional Considerations
UV Disinfection	Optimize UV dose based on 2006 USEPA *Ultraviolet Disinfection Guidance Manual (UVDGM).*	UV reactor performance must be validated per *UVDGM* guidelines and design criteria approved by primacy agency.
	Use low-pressure, high-output (LPHO) lamp technology.	LPHO UV reactors have a larger footprint than medium-pressure (MP) reactors and may have higher maintenance costs.
	Use higher-efficiency UV lamps, ballasts, and reactors.	Available for new UV systems only; cannot be retrofitted into existing systems.
	Dose pace in real time based on flow, lamp intensity, and UV transmittance or water.	Available on most new UV reactors and can be retrofitted into existing systems in most instances.
	Optimize upstream treatment to maximize UV transmittance.	Increasing UV transmittance can substantially reduce energy required to meet the target UV dose; must be coupled with dose control.
	Increase cleaning and lamp replacement frequency.	Maintaining clean lamp sleeves and new lamps can reduce the energy required to meet the target UV dose, but must be balanced with overall operating costs.
Ozonation	Use liquid oxygen instead of air for oxygen source.	Liquid oxygen requires truck delivery and on-site storage tanks.
	Increase the ozone mass transfer efficiency of the ozone system.	Increasing the ozone mass transfer efficiency of the ozone system can reduce overall ozone generation/energy required.
Microfiltration/ Ultrafiltration (MF/UF)	Optimize MF/UF cleaning regime to reduce fouling and transmembrane pressure (TMP) accumulation.	Optimization may require pilot- or full-scale testing.
Nanofiltration (NF)	Use NF membranes instead of RO.	NF may be feasible if source water quality has low total dissolved solids (TDS) or permeate water quality doesn't require high levels of constituent removal.
	Use hybrid NF/RO configuration with RO in first stage and NF in second stage.	This approach can reduce energy consumption compared with RO in both stages but will yield higher TDS levels in permeate.
Reverse Osmosis (RO)	Install an energy recovery device (ERD) between first and second RO stages.	Not feasible for all systems and payback period for ERD would need to be assessed.
	Optimize pretreatment processes to reduce fouling and TMP accumulation.	Optimization may require pilot- or full-scale testing.
	Optimize RO cleaning regime to reduce fouling and TMP accumulation.	Optimization may require pilot- or full-scale testing.
	Manage source water quality to minimize treatment requirements and TMP.	This may be feasible for systems using multiple groundwater wells and/or surface water sources.
	Consider decreasing throughput of membrane process and increasing bypassed flow.	Water quality goals may interfere with significant changes to the amount of water treated through the RO process.

A balanced approach will include policies and procedures for operating a system in an energy-efficient way while maintaining water quality.

reduced speed may operate in a less-efficient region of a pump curve. VSD use when not needed is an additional capital expense that also can cost additional energy usage. VSDs have a minimum of approximately 5 percent loss of energy through the drive. For many applications, using a fixed-speed pump can eliminate the 5 percent loss through a VSD.

Improving pumping system efficiency involves matching supply to demand and reducing wasted energy. Wasted energy is a function of efficiency and includes pump longevity and maintenance. Because energy is used when a pump and spare parts are made, selecting pumps to operate within safe limits and extending useful life can reduce cradle-to-grave energy consumption. Improvements to existing pumping systems include the following:

- Operational changes, such as shifting pumping operation from high- to low-rate periods, distributing demand among various pump stations to increase the load factor, and reducing pressure setpoints.
- Pump changes, such as replacing large pumps with multiple pumps to address a wide range of operating conditions, installing a VSD when pumps are operating significantly outside their optimal ranges, and trimming impellers.
- Distribution system modifications, such as eliminating choke points, cleaning and lining water mains, and reducing pressure or tank levels.

Proper pump maintenance also increases a pump's value (i.e., it breaks down less and is in service more often).

Pump operation for energy efficiency needs to be balanced against other system goals, particularly water quality objectives. Considerations include, but aren't limited to, the following:

- Reduced system pressures can reduce leakage and pressure-related pipe breaks. However, reduced pressures may slightly increase the risk of backflow at unprotected cross connections.
- Increased storage levels during off-peak hours to allow for increased demand during on-peak hours may result in increased water age. This practice can lead to loss of disinfectant residual, increased formation of disinfection by-products, and microbiological growth. These problems, however, can be offset by allowing the tanks to drain down during the on-peak hours, creating healthy turnover within the storage tanks or reservoirs within system pressure constraints.
- Use of surge tanks may reduce column separation and other transient pressure events, but surge tanks must be periodically exercised to maintain water quality and prevent stagnant water from entering the distribution system.
- Increasing the number of pressure zones may cause an increase in artificial dead ends in the system, which can increase water age and degrade water quality through settling of particulates in areas of low flow or no flow.
- Changing flow patterns to reduce energy consumption through demand management can, on the one hand, scour accumulated sediments, causing discolored-water events. On the other hand, buildup within the pipes may be reduced by the scour action, which may reduce biological growth in the pipelines.

Water Treatment Equipment. Although pumping is by far the largest energy consumer, treating water to stringent drinking water and reuse standards can consume a significant amount of energy. For a typical 10-mgd water system, ultraviolet (UV) and ozone disinfection consume greater energy compared with conventional treatment, but reverse osmosis (RO) consumes an order of magnitude more energy than these technologies. Power consumption from conventional treatment steps, such as flocculation and filtration, is relatively minor.

Conventional Treatment Processes. Conventional water treatment processes include aeration, coagulation, flocculation, sedimentation, gravity filtration, and chemical disinfection. Although most energy-reduction opportunities for a conventional treatment system are associated with pumping, there are still opportunities for energy efficiency measures in conventional treatment processes. Table 1 summarizes a few of these energy-saving opportunities.

Advanced Treatment Processes. Advanced water treatment processes include (in order of increasing relative energy footprint) UV disinfection, ozonation, microfiltration/ultrafiltration, nanofiltration (NF), and RO. Many membrane systems operate at high feedwater pressure to achieve the desired membrane flux rate and constituent removal.

Advanced treatment processes are typically installed in addition to or as a substitute for a conventional treatment process. For example, microfiltration might be installed as a substitute for gravity media filtration, and ozonation might be added as a supplemental treatment process for taste, odor, and color removal. The energy footprint associated with these technologies is greatly influenced by the treatment objective, source water quality, and system size. Each of these advanced treatment processes can be optimized to minimize energy consumption. Table 2 summarizes a few of these energy-saving opportunities.

WIDESPREAD BENEFITS

Energy management programs have many benefits. For example, water utilities can use energy cost savings to finance other improvements. Reducing energy use will increase a utility's independence from outside energy sources and decrease pollution and greenhouse gas emissions. Also, energy audits can help identify other areas of improvement. A balanced approach will include policies and procedures for operating a system in an energy-efficient way while maintaining water quality.