Driving Energy Efficiency in the U.S. Water & Wastewater Industry by Focusing on Operating and Maintenance Cost Reductions

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ABSTRACT

The United States water and wastewater industry is a large consumer of energy and offers significant potential for energy efficiency improvement projects, particularly related to pumping, aeration, and solids treatment processes. However, energy cost savings are often not adequate to justify capital expenditures for identified energy efficiency measures. In such situations, additional non-energy benefits must be linked to the projects to ensure their development. Common non-energy drivers in the industry include system reliability, water quality, and operating costs. The paper presents specific opportunities to leverage the value of increasing reliability, improving water quality, and reducing labor and maintenance costs to advance energy savings opportunities.

Introduction

This paper presents the potential to utilize non-energy drivers to help sell energy efficiency projects within the United States Water and Wastewater industry. Energy use is an important consideration for public water and wastewater utilities. However, the energy cost savings benefits of many improvement projects are not adequate to justify the capital expenditure. By linking other non-energy benefits to a given project, the value of the improvement opportunity increases, and therefore the likelihood of implementing the project also increases.

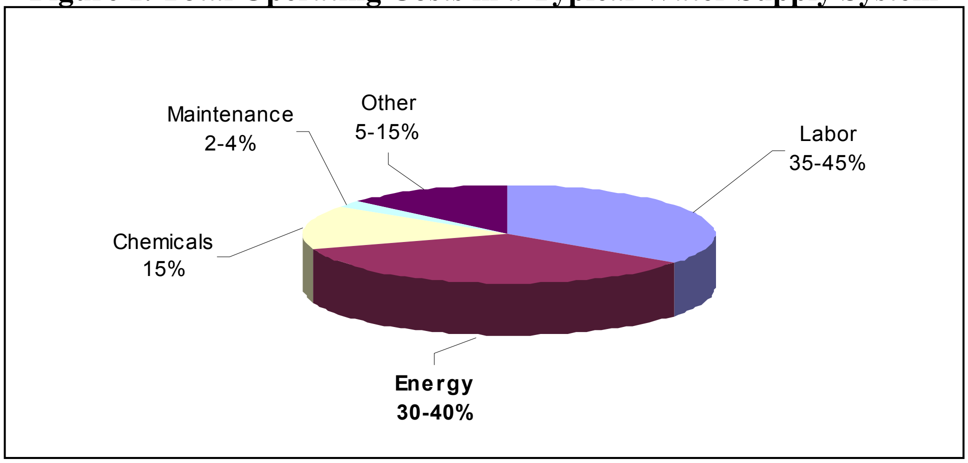
The paper begins with background information on energy consumption and common energy efficiency opportunities in the U.S. water and wastewater industry. Next, common non-energy drivers are discussed along with the types of improvement projects that these lead to. The link between general improvement projects and energy efficiency opportunities is then presented. The paper concludes with specific project examples from around the country.

Background on Energy Use in the U.S. Water and Wastewater Industry

There are about 155,000 public water supply systems in the U.S. serving at least 25 people each. Most of the U.S. population (94%) is served by one of 52,000 community water systems, with 77% served by the largest 4,132 systems (EPA 2008d). There are approximately 16,600 public-owned wastewater treatment facilities and about 21,600 collection systems operating in the U.S. Approximately three-fourths of the U.S. population is served by public wastewater treatment facilities, with the remaining one-fourth served by on-site systems such as septic tanks. Roughly 3% of the public wastewater treatment facilities process 10 million gallons a day (MGD) or more, while as many as 80% of the facilities process less than 1 MGD (EPA 2008b).

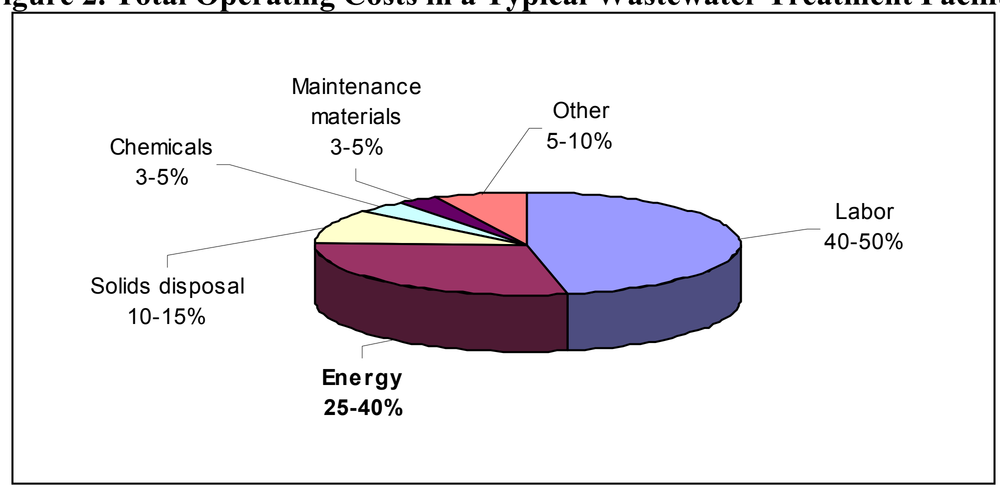
In most public water and wastewater systems, energy is one of the greatest operating costs. For an average public water supply utility, energy costs are second only to labor costs, representing about 30-40% of total operating costs (see Figure 1). For an average waste water utility, energy costs are slightly less, at 25-40% of total operating costs, but still very significant (see Figure 2).

Figure 1. Total Operating Costs in a Typical Water Supply System



Source: Derived from Global 2006

Figure 2. Total Operating Costs in a Typical Wastewater Treatment Facility



Source: Derived from Global 2008a

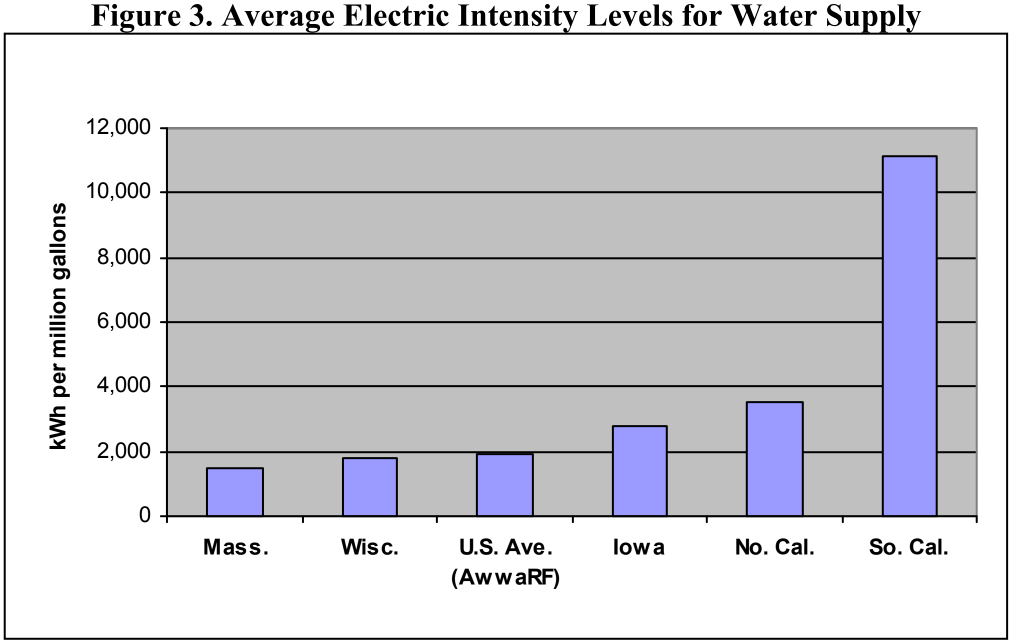
Though wastewater treatment facilities use some natural gas for space heating and heating of anaerobic digesters, they rely primarily on electricity for a wide range of processes including pumping, filtration, aeration, air compression, and sludge dewatering and thickening. Furthermore, electricity accounts for almost all energy use in public water supply systems, where it is used for pumping, flocculation, filtration, and feeding of coagulant and chlorine. Pumping of finished water is especially electric-intensive, accounting for the majority of total electricity use in public water supply systems.

According to the U.S. Department of Energy (DOE), about 4% of total annual U.S. electricity consumption is used for water and wastewater supply and treatment (DOE 2006). In 2008, total U.S. electricity consumption was 3,752 billion kWh (EIA 2009). This implies that approximately 150 billion kWh was used by the U.S. water and wastewater industry. This includes electricity to pump water from ground and surface sources, to treat the water to potable standards, to pump the water through distribution systems, and to collect, treat and discharge wastewater

Electricity End-Use in Public Water Supply Systems

The average U.S. water supply system uses almost 2,000 kWh per million gallons (MG) of treated water, as illustrated in Figure 3. However, the electric intensity level varies widely from one system to another depending on such variables as age and condition of equipment and distribution system, raw water source, and topography in the service territory. For example, water supply systems in California have electric intensity levels that are two to five times greater than the average U.S. electricity intensity. This extra energy is associated with sourcing and conveying raw water. Most notably, the State Water Project and the Central Valley Project transport water from Northern California several hundred miles to Southern California and traverse several large elevation gains.

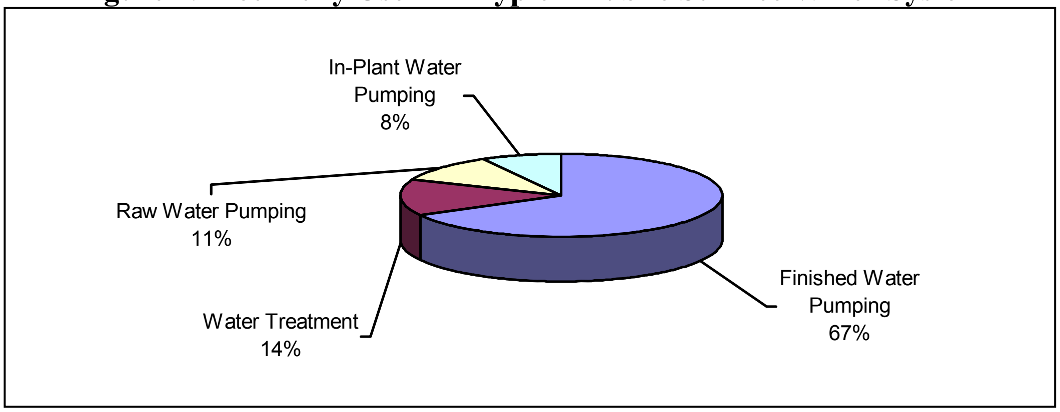
Figure 3. Average Electric Intensity Levels for Water Supply



Sources: Data for California from CEC 2006, Massachusetts data from EPA 2008c, Wisconsin data from WDNR 2008, Iowa data from IAMU 2002, U.S. average data from AwwaRF 2008

The design and layout of sourcing and distribution systems is critical in determining overall electricity use. Figure 4 illustrates that pumping accounts for about 85% of total electricity use in a typical public water supply system that withdraws surface water. The pumping share will be even higher for systems withdrawing groundwater because of the pumping energy required to lift the water to the surface and also because groundwater generally requires less treatment energy.

Figure 4. Electricity Use in a Typical Public Surface Water System



Source: Data derived from Carns 2005

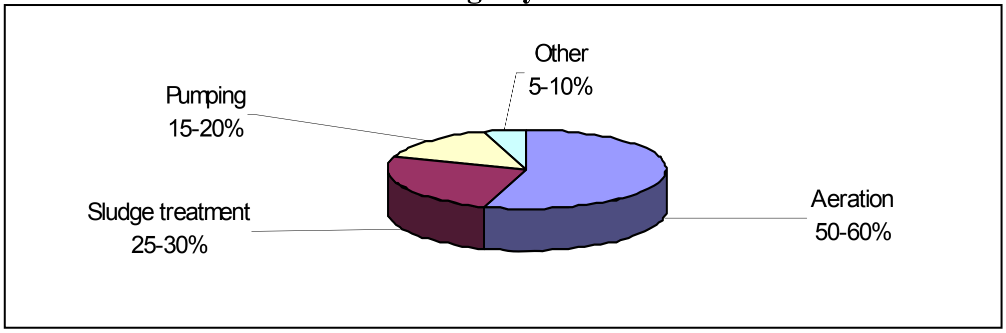
Conventional water treatment relies primarily on chemical energy and gravity. Advanced electricity-based water treatment technologies such as ozone, ultraviolet light, and membranes, are increasingly used for treatment and disinfection. Consequently, the share of electricity use associated with water treatment is expected to increase in the future. Nevertheless, electricity efficiency improvements targeting pumping applications offer the best opportunities for energy cost savings in the public water supply sector.

Electricity End-Use in Public Wastewater Treatment Systems

The national average for electricity use for wastewater treatment is about 1,200 kWh/MG, with about 150 kWh/MG used to pump wastewater from end-users to treatment facilities and another 1,050 kWh/MG for treatment and discharge (EPRI 1996). However, total electricity consumption as well as breakdown by treatment systems varies extensively with type, size, and level of treatment at any given facility. For example, wastewater treatment facilities incorporating advanced treatment processes such as filtration and nitrification can use 1,700 to 4,000 kWh/MG. The electricity use in wastewater treatment facilities with secondary treatment systems is lower, typically on the order of 700-1,500 kWh/MG for plants with trickling filters and approximately 1,300-2,400 kWh/mg for those with activated sludge (Global 2008a).

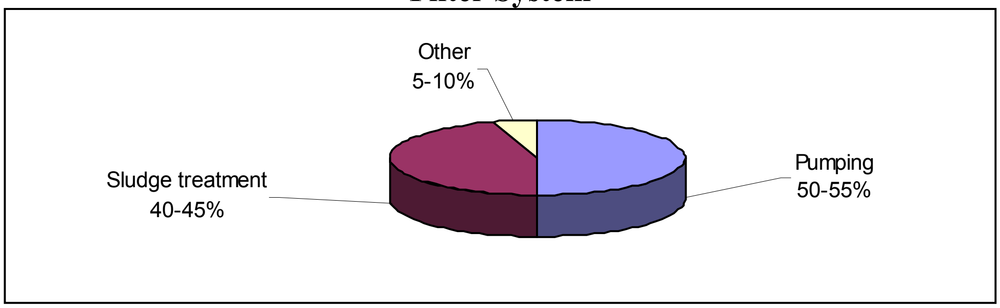
Most U.S. wastewater treatment facilities use either an activated sludge or a trickling filter secondary treatment processes., with activated sludge systems being the most common (EPA 2008b). In a wastewater treatment facility with an activated sludge system aeration typically accounts for approximately 50-60% of all electricity use, followed by sludge treatment (25-30%) and pumping (15-20%), as illustrated in Figure 5. For a trickling filter system, pumping and sludge treatment account for the majority of total electricity use, as illustrated in Figure 6. As a result, aeration, sludge treatment, and pumping processes offer the greatest opportunities for energy savings in most wastewater treatment facilities with secondary treatment processes.

Figure 5. Total Electricity Use in a Typical Wastewater Treatment Plant with an Activated Sludge System



Source: Global 2008a

Figure 6. Total Electricity Use in a Typical Wastewater Treatment Plant with a Trickling Filter System



Source: Global 2008a

Energy Efficient Technologies and Practices in the Water and Wastewater Industry

The best opportunities for energy cost savings in the water and wastewater industry involve electricity efficiency improvements. In particular, advancements to the large energy end-uses of pumping, aeration, and sludge treatment, offer the best savings potential. Table 1 summarizes energy efficiency measures targeting these three areas.

Table 1. Example Efficiency Measures for Pumping, Aeration, and Sludge Treatment

End-Use	Energy Efficiency Measures
Pumping	• Conduct in-field pump testing • Install Variable Frequency Drives (VFD) to control pump speed and flow • Use Supervisory Control & Data Acquisition (SCADA) system to optimize operations • Replace inefficient motors with high-efficiency or premium-efficiency motors
Aeration	• Replace inefficient blowers with energy-efficient blowers • Install single-stage centrifugal blower with VFD control • Install automatic dissolved oxygen (DO) control

Sludge Treatment	• Improve the dissolved air flotation thickening process • Replace centrifuge with screw press or gravity belt

Pumping

Because pumping accounts for over 80% of total electricity use in public water supply systems and for over 50% in wastewater treatment facilities, improvements in pumping efficiencies can generate substantial energy savings for the water and wastewater industry. Electric efficiency measures with the greatest energy cost savings potential include: regular in-field pump testing to determine actual pump performance and the need for repair and replacement; the use of variable frequency drives (VFDs) to control pump speed and flow rather than throttling valves for fixed-speed drives; the use of Supervisory Control And Data Acquisition (SCADA) systems to optimize pumping performance continually; and replacing older, inefficient motors with high-efficiency or premium-efficiency motors (Carns 2005).

Aeration

Aeration accounts for approximately 50-60% of all electricity used in wastewater treatment facilities that rely on activated sludge systems. Aeration blowers must meet a wide range of airflows and pressures to match varying process requirements. This makes them well suited for the application of VFD control. Replacing inefficient submerged coarse pore air diffusers with energy-efficient submerged fine pore diffusers typically can generate aeration energy savings of as much as 40-50% through reduced flow requirements associated with improved oxygen transfer. Installing automatic dissolved oxygen (DO) control to prevent over-aeration of the activated sludge treatment process can potentially save 15-40% of aeration energy. Replacing older, inefficient blowers with more energy-efficient models will also result in energy cost savings, typically saving about 35% of aeration energy (Global 2008a).

Sludge Treatment

Depending on the type of treatment system employed, sludge treatment can account for 25-45% of total electricity use in secondary wastewater treatment facilities. Sludge treatment typically includes sludge thickening, sludge stabilization, sludge dewatering, and disposal. The primary energy end-uses in sludge treatment include sludge thickening and dewatering. Thickening is used to reduce the volume of sludge, typically from 1% total solids contents to 4-6% total solids contents, prior to further treatment. Sludge dewatering increases the total solids contents further, to 15-30%. Dissolved air flotation thickeners typically account for 60% of the electricity used for sludge treatment. The capture and dewatering efficiency of dissolved air flotation thickeners can be improved by adjusting the supply air and/or feeding the highest possible solids content, operating them continuously, and adding polymers to the sludge. Another opportunity for energy savings involves the replacement of the centrifuge with a screw press for improved sludge dewatering or with a gravity belt for improved sludge thickening (Global 2008a).

Non-Energy Drivers for Process Improvements

Despite the ample opportunities for energy savings, many energy efficiency projects are not pursued by water and wastewater utilities due to capital budget limitations and long investment payback periods. However, when potential projects also include non-energy benefits, the chances for implementation greatly increase.

In the 2008 study, *Risks and Benefits of Energy Management for Drinking Water Utilities*, the Awwa Research Foundation surveyed eleven water utilities across the U.S. and Canada (AwwaRF 2008). Each was asked to comment on what their most important priorities were with regard to operations. The most common responses were:

- Reliability – the ability to meet customer demand safely and consistently is one of the main metrics that a water or wastewater utility is gauged on.
- Water quality – water supply utilities must meet strict standards for potability, while wastewater utilities must adhere to rigid effluent discharge requirements.
- Operating costs – labor, maintenance, energy, chemicals, and other operating costs are regular targets for process improvement projects. Public water and wastewater utilities are under constant pressure to minimize service rates and are therefore constantly looking for opportunities to reduce costs.

Several issues impact utilities ability to meet these priorities. Some of the more pressing issues include:

- Infrastructure – the physical assets and processes available to a water and wastewater utility impact reliability, water quality, and operating costs.
- Regulations – environmental and safety regulations are clearly linked with quality and also affect the cost to treat water and wastewater.
- Water scarcity – a significant concern for many water utilities is the availability and associated cost of new water sources to meet growing demand.

Infrastructure Needs

U.S. water and wastewater utilities are facing an unprecedented challenge with regard to infrastructure. Many large municipal systems have reached the end of their expected useful life (some systems are over 100 years old) and require significant upgrades. At the same time, utilities must continually respond to the growing demand of an expanding population. Because most infrastructure systems are very old, there is limited flexibility remaining to facilitate production increases.

The American Society of Civil Engineer's most recent *Report Card on Infrastructure* gives the U.S. water and wastewater industry a failing grade of D-, suggesting water and wastewater utilities are facing great pressure to improve and upgrade their operations (ASCE 2009). The U.S. Environmental Protection Agency reports in its *Drinking Water Infrastructure Needs Survey and Assessment* that water utilities need a total investment of $276.8 billion over the next 20 years to maintain production and quality levels (EPA 2005). Similarly, in the *Clean Watershed Need Survey 2004 Report to Congress* the EPA reports a $202.5 billion need for improvements in existing wastewater collection, treatment, and conveyance systems to supply adequate wastewater treatment over the next 20 years (EPA 2008a, table 2-1).

New Regulations

Water and wastewater regulations are driven primarily through EPA requirements to comply with the Safe Drinking Water Act and the Clean Water Act. Treatment facilities must regularly improve operations to comply with new federal, state, and local requirements. Recent regulations focus on such issues as storm water management, water disinfection, disinfection byproducts, nutrient removal, solids handling, toxic pollutants, watershed protection, and emerging contaminants. As a result of stricter standards for treatment, new and more complex equipment must be installed to achieve regulatory compliance.

Recently adopted regulations for water supply include the "Long Term 2 Enhanced Surface Water Treatment Rule" and the "Stage 2 Disinfection Byproducts Rule". These rules strengthen protection against microbial contaminants and restrict the exposure to disinfection byproducts associated with traditional chemical treatment processes. New rules for wastewater treatment include the "EPA Phase II Storm Water Rule" and the "EPA 503 Sewage Sludge Rules".

Water Scarcity

A survey by the U.S. General Accounting Office reveals that most state water managers are forecasting local or regional water shortages over the next several years (GAO 2003). States like California and Florida have faced water scarcity issues for many years, but now many northern and interior states are facing similar challenges.

With a shortage of fresh surface and ground water sources, water utilities must tap into alternative, and more costly, water supplies. This can include imported water conveyed into a local region by a wholesaler, desalinated brackish or sea water, and local wastewater recycling. The later illustrates how wastewater utilities fit into the equation. Water supply and wastewater utilities face many challenges associated with collectively finding cost effective solutions for using treated effluent as an alternative source for freshwater demand.

Water conservation is also being considered as a "resource" to offset new freshwater demand. This can include influencing consumer behavior so they use less water, implementing new end-use technologies that use water more efficiently, and improving water infrastructure to reduce losses linked to leaks, theft, and process inefficiencies.

Energy Benefits of O&M Improvement Projects

Global Energy Partners, in collaboration with the EPRI Community Environmental Center, has conducted over 80 onsite energy assessments of water and wastewater treatment facilities in North America. The analyses have resulted in significant annual energy cost savings, with paybacks typically less than three years. Table 2 summarizes selected results from these assessments. Some improvements required low or no capital costs but still resulted in significant energy savings. Other improvements required greater capital funds but could be justified based on energy savings alone. Finally, some of the more costly improvements were justified based on the multiple benefits associated with energy reductions and process improvements. Also included in the table are the non-energy drivers and benefits associated with the energy efficiency improvements. In many cases, it was the non-energy drivers that served as the primary motivation for pursuing the project.

Table 2. Selected Results from Water and Wastewater Facility Improvement Projects

Improvement Measure	Non-Energy Drivers	Demand Savings (kW)	Annual Energy Savings (kWh)	Annual Energy Cost Savings ($)	Estimated Capital Cost ($)	Simple Payback for Energy Savings (years)
Lower water pressure	Reduce equipment wear. Reduce loss through leakage.	12	105,100	6,000	0	0
Remove orifice plate and throttle blower intake	Match flow to process requirements. Reduce vibration.	75	58,500	4,900	0	0
Replace sheaves on sludge silo mixing pump	Increase equipment life.	41	29,000	1,700	1,000	0.6
Install SCADA system	Improve reliability and quality through monitoring. Reduce labor costs.	200	0	16,900	30,000	1.8
Install VFD control on return sewage pump	Increase equipment life. Reduce cycling.	22	355,800	18,200	50,000	2.7
Replace return activated sludge (RAS) pump	Reduce maintenance costs.	30	262,800	11,000	33,600	3.0
Install a timer and smaller recirculation pump	Increase equipment life. Reduce cycling.	10	91,980	6,680	23,000	3.4
Lower dissolved oxygen (DO) and install DO control	Match flow to process requirements. Improve quality. Increase equipment life.	146	1,279,000	54,300	305,000	5.6
Install VFD on a 46 MGD high service pump	Increase equipment life. Reduce cycling.	211	462,100	34,000	240,000	7

Data derived from actual energy assessments sponsored by electric utilities and conducted by Global Energy Partners and the EPRI Community Environmental Center

Process improvements always have some energy impact regardless of whether they were implemented to save energy or for some other cost or regulatory reason. Provided below are details on actual process improvement projects that were initially motivated by non-energy benefits but ultimately were revealed to offer significant energy savings.

Example 1: Pump Station Improvements to Reduce Operating Costs

In 2005, Global Energy Partners assisted a large municipal drinking water facility in the Midwest conduct an engineering study to determine how to automate the operation of a remotely located raw water pumping station. The raw water pump station consisted of eight pumps, six of which had a capacity of 50 MGD (600 HP each) and two of which had a capacity of 25 MGD (300 HP each). The pump station was found to be greatly oversized for routine operations. In addition, there were no control valves employed to regulate flow. Standard operating practices entailed manually starting and stopping pumps to satisfy process flow demands. This resulted in pumps routinely being cycled on and off, placing extra stress on the pumps and motors, and also produced upsets in the downstream treatment process due to the flow irregularities. This was an ideal opportunity for energy efficiency but the utility's marginal cost for electricity was only $0.035/kWh, making any significant physical improvements difficult to justify on an energy cost savings basis.

The two best technical options from an energy management perspective were the installation of a VFD on one or more existing pumps or the replacement of one of the existing 50 MGD pumps with a smaller 10-20 MGD pump. Both options would better match pumping flow to process needs and greatly reduce pump cycling. The VFD option would result in an 8-10 year payback, while the new pump option would result in a payback period of 8-15 years depending upon pump size and options. The new pump option was more expensive but would add more operating flexibility by provided a broader variety of pump sizes that could be operated in response to varying process demands. Both the VFD and new pump options would enhance the downstream treatment process by smoothing changes in flow through the system, which was estimated to produce additional operating costs savings of 10-15%. Ultimately, the preferred option was the new pump, along with a new motor. This had an overall efficiency advantage since the pump and motor would be operating close to their peak efficiency points, as opposed to the VFD option that would still be operating with an oversized, and hence less efficient, pump and motor.

Example 2: Improvements to Aeration Process to Reduce Maintenance and Labor Costs

Global Energy Partners worked with a medium-sized, 30-year old wastewater treatment facility in the Southeast that was addressing expansion needs associated with growing residential and industrial demand. The existing activated sludge process was upgraded with the addition of new aeration basins, final clarifiers, and a sludge dewatering system. Fine-bubble air diffusers and air blowers were also installed to improve the aeration efficiency. Specifically, single-stage air blowers with variable inlet guide vanes and a dual vane control system were selected to control flow based on ambient air temperature, differential pressure, and machine capacity.

The new blowers were selected based on maintenance and labor costs savings associated with their use. However, it was determined that they also had the potential to generate energy savings in excess of 20% by precisely matching flow to the actual process loading rates.

Example 3: Automated Monitoring to Decrease Maintenance Costs

As previously mentioned, regular pump testing is an excellent means of achieving energy savings associated with pumping operations. Testing helps identify worn or defective pumps, which can then be repaired or replaced. In addition, testing provides data to generate as-installed pump efficiency curves, which can be used by operations staff to select the optimum pump, or combination of pumps, for specific process flow requirements.

Pacific Gas and Electric Company is currently performing multiple field demonstration projects with water utilities to incorporate virtual real-time pump efficiency data into the operations control systems. By incorporating real-time pump power consumption data into the SCADA system and matching it to water flow and pressure data, a close approximation of instantaneous pumping energy intensity (i.e. kWh/MG) can be derived. This data can then be displayed to the operations staff to assist in decision making in regards to pump operations and pressure zone management.

The energy benefits of this controls innovation is the focus of the demonstrations, but the water utilities have identified other benefits as well. The same pump energy intensity data can be monitored and tracked over time to identify emerging maintenance problems. This will assist with proactive maintenance planning and will help avoid surprise critical failures (Global 2008b).

Example 4: Applying Supply and Demand Forecasting Tools to Decrease Operating Costs

Another controls based strategy for reducing operating costs and energy consumption is the utilization of water supply and demand forecasting tools. Multiple reports have discussed the merits of this technique (AwwaRF 2008, Global 2008b). Based upon a known customer mix with historical seasonal consumption patterns, water utilities can use recent and forecasted weather data to estimate day-ahead water demand by hour. The utility can then forecast its available supply options for the same period. This would factor in pumping capacity, current storage levels, local surface and ground water availability, and water purchase options. The total cost to deliver water (including energy) would be forecasted for various supply options, and the least cost combination calculated for next-day implementation. This technique reduces waste and indirectly ensures that efficient energy supply practices are employed.

A good example of this practice is the San Jose Water Company (SJWC) in California. SJWC has a variety of water supply options that vary in availability throughout the year. This includes its own surface and ground water sources as well as wholesale purchase options. Local surface water is the cheapest, but has limited availability. Local groundwater pumping is energy intensive but can be cheaper than wholesale water purchases depending upon the current price of water. SJWC factors these and other costs into their supply model to generate a supply guide each day for operations to follow. This guide provides hour by hour instructions on which sources to use, and in what quantities, for the day's operation. While the guide is never perfect, it has proven to significantly reduce supply costs over the long run. SJWC reports that over the same period that the forecasting tool has been used the energy intensity of water delivery (kWh/MG) has also decreased.

Conclusion

The U.S. water and wastewater industry is a large consumer of electricity, making the sector an important target market for energy efficiency and other demand side management programs. Energy is a large component of total operating costs for water and wastewater utilities, but it is not the only cost, and is often not the most important one. There are opportunities to leverage non-energy process improvement benefits to help "sell" energy efficiency projects. In particular, projects involving pumping, aeration, and sludge treatment should be identified due to their respective potential for energy savings. Opportunities should also be identified that will link these projects to increased process reliability, improved water quality, and reduced labor and maintenance costs. The combination of multiple benefits will help make individual projects a priority and accelerate project approval and installation, resulting ultimately in greater and quicker energy savings.

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