Energy Efficiency and Renewable Energy Technologies in Wastewater Management

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Madame Chairwoman and Members of this Subcommittee, thank you for inviting me to testify today. My name is Richard Brown, and I am a Research Scientist at Lawrence Berkeley National Laboratory (Berkeley Lab). For nearly twenty years, I have conducted energy efficiency and renewable energy research at Berkeley Lab. My research investigates the potential for energy efficiency technologies to reduce energy use in buildings and industry, as well as opportunities for electricity end-users (such as Federal facilities) to purchase renewable power. The unifying theme of my research is better understanding how energy is used and applying appropriate demand- and supply-side technologies at the point of use, in order to reduce the environmental impact of our energy system. I am honored to be able to share with you my views as a researcher and as a private citizen. This testimony represents my own professional opinion and in no way represents the views or positions of Lawrence Berkeley National Laboratory, the U.S. Environmental Protection Agency, or the U.S. Department of Energy.

I am here today to provide an overview of energy use in the U.S. wastewater sector, and the opportunities for reducing the environmental impact of that energy use through energy efficiency and renewable energy technologies. While the topic of sustainability is necessarily very broad, I will focus my discussion today primarily on the application of these clean energy technologies to the Publicly Owned Treatment Works (POTWs) in the U.S. This summary is based on research I have done for the EPA Energy Star program to help them develop an energy management program for water and wastewater utilities.

Based on this work, I'd like to make the following points:

- The U.S. wastewater sector is very energy intensive, consuming about 1% of national retail electricity sales;
- This energy consumption could be reduced 10% to 30% through the application of proven energy efficiency technologies;
- Use of digester biogas for combined heat and power (CHP), along with other on-site renewable energy technologies, can help wastewater plants approach the goal of net-zero purchased energy use;
- The key to widespread adoption of these technologies is implementation of a comprehensive energy management program by wastewater system operators;
- Finally, over the longer term there is a need and an opportunity to improve the available efficiency and renewable energy technologies for the wastewater sector, and integrate these into a more comprehensive strategy of environmental sustainability.

Overview of Energy Use in the Wastewater Sector

Although many of us take it for granted, one of the hallmarks of modern society is a sanitation system that collects and treats sewage to protect both human health and the environment. The main purpose of wastewater treatment is to remove pollutants and other impurities from wastewater so the water can be safely discharged into the environment or reused for non-potable applications such as irrigation or groundwater recharge. In general, energy consumption in wastewater treatment is a function of the quantity of wastewater treated and the required effluent quality of treated wastewater, as dictated by either discharge requirements or reclamation quality and reuse requirements. The most basic treatment objectives may be categorized as follows: separation and removal of solids, oxidation or 'stabilization' of suspended organic solids, disinfection, and detoxification. Traditionally, the primary goal of municipal wastewater treatment has been the removal of settleable solids and the oxidation of suspended organic waste materials. The latter is a process of adding oxygen to wastewater in order to oxidize and reduce its organic content (also known as "aeration"), making it less reactive and less oxygen-consuming when it is discharged into a receiving surface water or groundwater reservoir.

Wastewater treatment is usually defined by the stage or level of treatment. The quality of the treated effluent is improved with each successive stage of treatment:

- Preliminary: removal of grit, course solids, and debris (e.g., plastic, metal, wood),
- Primary: substantial removal of settleable and floatable solids,
- Secondary: substantial removal of organic material and suspended and dissolved solids,
- Tertiary: nearly complete removal of organic matter and suspended solids, along with substantial removal of nutrients, particularly nitrogen and phosphorus.

Stages of treatment beyond secondary are often referred to collectively as 'advanced' treatment. Each treatment stage can be accomplished through a variety of process types and technologies. The large variation in process types, technologies, equipment, site-specific and regulatory design constraints leads to large variations in plant design and the resulting energy use.

In 2004, approximately 16,600 POTWs operated in the United States. The minimum level of municipal wastewater treatment currently required is secondary treatment, which all but a few treatment plants are designed to provide. In addition, about 5,000 plants go beyond this requirement to provide tertiary treatment. Approximately 75% of the U.S. population is served by POTWs (most of the remainder are served by on-site septic systems). Most POTWs (82%) have small capacities (defined as less than 1 million gallons per day – MGD), but together all of these small systems treat only about 8% of total U.S. wastewater flow. These plants tend to be in rural areas with low population densities. The remaining 18% of all U.S. POTWs handle 92% of the total collected wastewater flow. The largest 41 plants have capacities greater than 100 MGD (US EPA 2008). This testimony mainly focuses on these large treatment systems because that is where most of the energy is consumed. These large systems are characterized by highly-engineered, mechanical treatment systems that can handle large waste flows from urban population centers. Designed primarily with the intent of meeting water quality goals, these systems typically involve energy-intensive processes that are essentially industrial facilities in their scope and complexity.

In aggregate, The Alliance to Save Energy (2002) estimates that U.S. municipal water and wastewater systems consume 75 billion kWh each year, which corresponds to an electricity bill of $3.6 billion. Of this amount, water supply systems consume about 60% and wastewater systems consume about 40% (Burton 1996), or about 30 billion kWh/year for the wastewater sector. This is approximately 1% of U.S. retail electricity sales.

In contrast to drinking water supply systems, where pumping accounts for most of the energy use, wastewater system energy use is dominated by the treatment process itself. Figure 1 shows the division of energy consumption for a typical large municipal wastewater treatment facility. Oxidation is the most energy intensive part of wastewater treatment, accounting for approximately 70% of energy use in municipal secondary-stage wastewater treatment facilities. The most common oxidation process is activated sludge treatment, used in secondary treatment of approximately 70% of the collected municipal wastewater flow in the U.S. (Gibbs and Morris 2005). Sludge conditioning and dewatering processes are also significant energy users in conventional wastewater treatment processes, accounting for approximately 10% of national wastewater sector energy use. Preliminary and primary treatment stages are less energy intensive than conventional secondary treatment, while tertiary treatment can be as energy intensive as secondary treatment, depending on the type and quantity of pollutants being removed and the desired or regulated effluent quality.

The most common energy uses in wastewater treatment are aeration and pumping. Aeration introduces dissolved oxygen into wastewater to support aerobic oxidation and also for nitrogen removal. Mechanical aeration is also used to promote mixing and to promote the bacterial process of waste oxidation. Pumping is used to move and recirculate water and solids through the sequence of treatment processes. Other common uses of energy during wastewater treatment are mechanical mixing, chemical dosing, media and membrane filtration, dissolved air flotation, sludge handling and disposal, and digester heating.

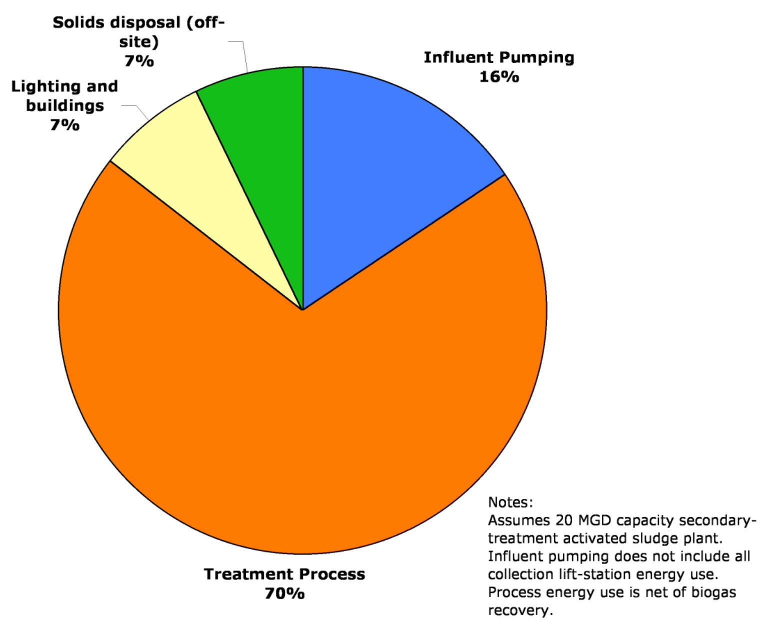

Figure 1: Typical allocation of energy use within a large wastewater treatment plant Source: (Burton 1996), (Owen 1982)

Over time, the trend in the wastewater sector has been to include more, and more energy-intensive, treatment processes. This has generally been driven by more stringent water quality standards (which increasingly require tertiary treatment for nutrient removal or additional treatment types for removal of toxins). In the future, it is likely that energy use will increase further as a result of new treatment processes that address emerging contaminants (such as endocrine disrupting compounds), and the need to treat wastewater for reuse in order to extend our water supplies.

Energy Efficiency Opportunities in the Wastewater Sector

A variety of technologies exist to reduce energy consumption in the wastewater treatment sector while maintaining or enhancing productivity. These technologies fall into several categories: improved equipment that operates more efficiently compared to standard equipment (i.e., delivers the same service for less energy input), improved controls to ensure that equipment is operated as efficiently as possible and turned down or off when not needed, and improved system designs to minimize losses and ensure that the various components operate well together.

Table 1 lists energy efficiency technologies that are commonly applied in the wastewater sector. These are all mature technologies that are commercially available and widely applied in other industries as well. Due to the wide variation in wastewater treatment plant design and conditions, only a subset of these technologies will be applicable to any given facility, thus it is important for the plant operators and managers to conduct an energy efficiency assessment to determine which technologies are appropriate for their situation.

Many of these technologies address the problem that wastewater treatment systems are designed to meet peak wastewater flows but do not operate energy efficiently for the majority of the time when flows are significantly lower (peak flows usually only occur during certain seasons or times of day). Specifically, variable frequency drives and automated controls allow the many pumps and blowers in a wastewater treatment plant to scale their output—and the energy they consume—to match the requirements of the plant loading conditions.

Many of these technologies are considered “drop-in” replacements for existing equipment and thus can be implemented in a relatively short time period. A common package of measures that can be installed during a 12-18 month (from design to commissioning) plant renovation would consist of: replacing motors and pumps with high efficiency models, installing variable frequency drives, installing dissolved oxygen sensors for the aeration process, and installing a SCADA system for overall plant monitoring and control. Energy savings for such a package of upgrades varies depending on current plant design and conditions, but saving 10-30% of baseline consumption is typical (PG&E 2006).

Table 1: Common energy efficiency technologies applied to the wastewater sector

Energy Efficiency Technology/Strategy	Description	Typical Payback (years)
High Efficiency Motors	Motors with lower internal losses; used for pumps, blowers, mixers, etc.;	variable
Variable Frequency Drives (VFDs)	Electronic controller that matches motor speeds to the required load; avoids running at constant full power	½ to 5
High Efficiency Pumps	Pumps with lower internal friction and head losses	variable
Variable Air Flow Rate Blowers	Variable rate blowers efficiently match air supply to aeration requirements	<3
High Efficiency Blowers	Air blowers with lower internal losses	variable
Dissolved Oxygen Controls	Maintains the dissolved oxygen (DO) level of the aeration tank(s) at a preset control point by varying the air flow rate to the aeration system	2 to 3
SCADA System	Supervisory Control and Data Acquisition system collects facility-wide data and allows control of equipment to more precisely meet required flows	variable
Fine-Bubble Aeration	Fine-pore diffusers generate smaller bubbles for aeration processes; improves oxygen transfer to wastewater	1 to 7
Staging of Treatment Capacity	Treatment systems designed and installed to operate efficiently at multiple "stages" (i.e. across a range of flow conditions)	<2
Recover Excess Heat from Wastewater	Excess heat from wastewater reused in low-temperature heating applications	<2
Efficient Mixing of Aerobic Digesters	Mechanical mixing used rather than aeration where possible; mechanical mixing uses less energy	1 to 3
Efficient sludge handling	Screw presses and gravity belt thickening use less energy for sludge dewatering and thickening	variable
Efficient Ultraviolet (UV) Disinfection Lamps & Controls	High efficiency UV lamps convert more of the power they consume into useful light; controls turn down lights when not needed	variable

Source: Wisconsin Focus on Energy (2006), PG&E (2006)

Renewable Energy Opportunities in the Wastewater Sector

The wastewater sector offers several attractive opportunities for generating energy from renewable resources: combined heat and power using biogas, effluent hydropower, and on-site wind and solar installations.

The solid residuals ("sludge") from primary and secondary treatment are often stabilized in a separate sludge digester – a closed vessel that is often heated and mixed, in which anaerobic bacteria "digest" organic solids resulting in the production of biogas. Biogas so produced consists primarily of methane and carbon dioxide and can be captured and used for power generation, to heat and mix the separate sludge digester, or for some other energy end use. The use of waste heat from power generation is known as combined heat and power (CHP) or cogeneration. The EPA CHP Partnership has analyzed the potential for CHP in the wastewater sector and found that it is a good technical fit for wastewater treatment facilities and there is significant potential for power generation. Their study found that if all 544 POTWs in the United States that operate anaerobic digesters and have influent flow rates greater than 5 MGD were to install CHP, approximately 340 MW of clean electricity could be generated (US EPA 2007).

Another renewable energy option is effluent hydropower. Wastewater treatment plants with a large elevation drop to their effluent outfall can place an in-conduit hydro-generator in the outfall pipe to generate power. This is not commonly done, but has been implemented at a few plants, such as San Diego's Point Loma treatment plant, which has a 90-foot drop from the plant to the ocean outfall.

Finally, because POTWs often have significant land area (in many cases the largest parcel owned by the municipality) and are not located close to other developments, the wastewater treatment plant may be a very good host site for on-site solar or wind generation systems. Many water utilities in California have installed photovoltaic arrays on large, flat structures they own such as reservoir covers. Wastewater plants have similar opportunities. Figure 2 shows the Atlantic City, NJ treatment plant with both wind and solar generation on-site. These renewable resources serve essentially 100% of the facility's electrical load.

Figure 2: Atlantic County (NJ) Utilities Authority wastewater treatment plant with 7.5 MW wind system and 500 kW solar array

Energy Management Programs

Despite the potential for the energy efficiency and renewable energy improvements described above, they still have not been widely adopted in the wastewater industry. This is due to several barriers that prevent wastewater managers from adopting new technologies, including: a singular focus on meeting discharge permits, lack of knowledge about energy use and bills (often the wastewater plant operator never sees the energy bills), and a perception that energy costs are uncontrollable, fixed costs. The solution to many of these barriers is an energy management program to help improve the energy performance of the wastewater system on an ongoing basis. Changing how energy is managed by implementing an organization-wide energy management program is key to successfully reducing energy use and implementing renewable energy projects.

A strong energy management program creates a foundation for positive change and provides guidance for managing energy throughout an organization. Energy management programs also help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Furthermore, without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up. Most importantly, energy management programs are most effective as part of an overall process of managing quality within the wastewater utility, and can lead to improvements in non-energy factors such as better permit compliance, odor control, etc.

The major elements in a strategic energy management program, as defined by the Energy Star program, are depicted in Figure 3. The U.S. EPA Office of Wastewater Management has also published a very good guide to implementing an energy management program in water and wastewater utilities.

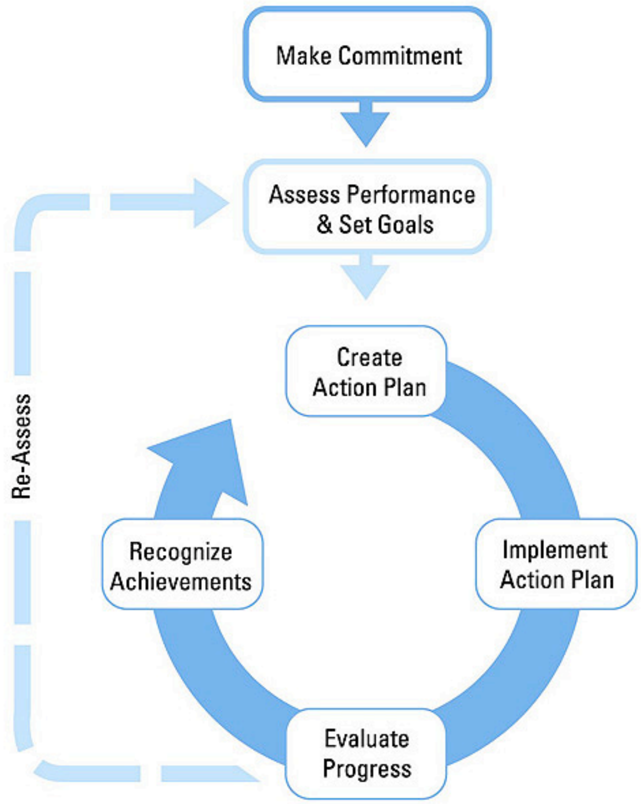

Figure 3: Steps in a strategic energy management program

Source: US EPA (2005)

A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. The Energy Star program has developed an energy benchmarking tool for POTWs that is very useful in this step of the process. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

Progress evaluation involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communications program and seeking recognition for accomplishments are also critical steps. Strong communication and receiving recognition help to build support and momentum for future activities.

An energy management program should also coordinate with the local electric utility for assistance with energy benchmarking and assessments as well financial incentives for efficiency and renewable investments. More and more electric utilities are offering efficiency programs targeted at industrial facilities, including water and wastewater utilities.

A very good example of an effective energy management program is the East Bay Municipal Utility District, located in Oakland, CA. Over the course of five years, their energy management team pursued a long-term plan of implementing energy efficiency improvements in their wastewater treatment plant, which reduced the plant's energy consumption by 20%. They also increased the production of biogas from the plant's digesters in order to increase the production of electricity from their on-site CHP plant. By the end of the five-year period, the on-site CHP generation was meeting 80% of the treatment plant's energy needs (Cohn et al. 2005).

Broader Sustainability Opportunities in the Wastewater Sector

Ultimately, initiatives taken to improve the energy efficiency of wastewater treatment need to be made in the context of improving the overall environmental sustainability of this sector. To achieve sustainability, systems need to be designed to treat wastewater as a resource (of both water and nutrients), not a waste. Eventually, WW treatment systems need to be more integral to local ecosystems, functioning as part of the local water and nutrient cycles rather than once-through industrial systems. For example, a more sustainable system might treat wastewater in a more distributed way so that treatment can be performed by natural systems. These natural systems tend to use more land area and are thus not well suited to centralized wastewater treatment. A more sustainable system might also involve graywater treatment and beneficial reuse of water on-site. Reducing drinking water use, and the resulting generation of wastewater, also needs to be a component of a more sustainable wastewater management system.

There are many opportunities to improve sustainability, but more research needs to be conducted to make these approaches practical for implementation by water and wastewater utilities. Several states (most notably California, but also New York and Wisconsin) are conducting research on issues related to this topic, including quantifying energy savings in the drinking water and wastewater systems due to avoided water use, the energy requirements for water reuse, and new protocols for energy management in the water and wastewater sector. Additional research is needed, however, and the Federal government can serve a useful role in funding research and integrating the findings into a national program.

Conclusion

Madame Chairwoman and members of the Subcommittee, to conclude I want to re-emphasize that I am not here to advocate for any particular policy outcome from this Committee. Instead, I hope that the information that I have presented today will be helpful as you consider how the Federal government can play a role in improving the sustainability of our wastewater management system.

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Brief Biography – Richard Brown

Richard Brown is a research scientist in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. His research analyzes energy use in buildings and industry, customer adoption of renewable energy systems, and the connection between energy and water use. His current research interests include technical support to the ENERGY STAR program, developing a home energy audit web site (the Home Energy Saver), developing solutions to address the growing energy use of electronics and miscellaneous equipment in buildings, and analyzing the energy use of drinking water and wastewater treatment systems. He was the lead author for the federal government's guidebook to purchasing green power for business and institutional customers. Before joining the LBNL staff, he spent four years in the Air Force analyzing the cost and performance of satellite systems. He holds an M.A. degree from the Energy and Resources Group at the University of California at Berkeley, and a B.S.E. in Engineering and Management Systems from Princeton University.