ENERGY and INFRASTRUCTURE

Energy: Technologies to Increase Efficiency of Wastewater Treatment
Technology Innovation Program
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The Technology Innovation Program (TIP) at the National Institute of Standards and Technology (NIST) was established for the purpose of assisting United States businesses and institutions of higher education or other organizations, such as national laboratories and nonprofit research institutions, to support, promote, and accelerate innovation in the United States through high-risk, high-reward research in areas of critical national need.

TIP seeks to support accelerating high-risk, transformative research targeted to address key societal challenges. Funding selections will be merit-based and may be provided to industry (small and medium-sized businesses), universities, and consortia. The primary mechanism for this support is cost-shared cooperative agreements awarded on the basis of merit competitions.

AN AREA OF CRITICAL NATIONAL NEED

The proposed topic "Technologies to Increase Efficiency of Wastewater Treatment" is within the critical national need areas of Energy and Infrastructure. Currently, an estimated 4 percent of electricity used nationwide is use to move and treat water and wastewater[1]. Table 1 summarizes the current and projected national electrical power requirements[2] and power requirements to treat wastewater.

Table 1: Current and Projected National Total Electrical Power Requirements and Electrical Power Requirements for Wastewater Treatment

	2007/2005, billion kWh/yr	2015, billion kWh/yr	2030, billion kWh/yr	2050, billion kWh/yr
Total Electricity Sales [A]	3,747	3,960	4,609	
Additional Direct Electricity Use [A]	156	198	294	
Total Electricity Use [A]	3,903	4,158	4,903	
Wastewater Treatment Electricity [B]	74	76		90

A. 2007 data and 2015 and 2030 projections from AEO2009.
B. 2005, 2015, and 2050 projections for public and private wastewater treatment from EPRI.

The Energy Information Administration projects that the country's overall demand for electrical power will increase with population, somewhat tempered by efficiency gains, at approximately 1.0 percent per year. The direct use of power is expected to increase faster at 2.8 percent per year as more facilities generate their own power onsite through renewable and combined heat and power projects. These projections are shown in Figure 1.

The Electric Power Research Institute (EPRI) suggests that wastewater treatment energy use will only increase by 0.43 percent per year. This lower per-capita electricity demand is anticipated to result from water conservation, equipment efficiency upgrades, and renewable power generation. EPRI additionally cautions that as treatment requirements become more stringent that the power requirements also increase. Estimated average power consumption per million gallons treated for four different, increasingly-capable publically-owned treatment works (POTWs) process configurations are shown in Table 2. As treatment requirements increase, the

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[1] Electric Power Research Institute (EPRI), "Water and Sustainability (Volume 4): U.S. Electrical Consumption for Water Supply and Treatment – The Next Half Century", March 2002.
[2] Energy Information Administration (EIA), "Annual Energy Outlook 2009 with Projections to 2030", DOE/EIA-0383, March 2009

energy required using conventional technologies also increases dramatically. While not discussed in the EPRI document, new membrane bioreactor processes consume 30 to 50 percent more electricity than plants employing advanced treatment with nitrification; other POTWs are adding nanofiltration or reverse osmosis to meet near-potable effluent standards at almost twice the energy consumption. There are number of drivers suggesting that nutrient removal, specifically nitrogen and phosphorus removal will be increasingly required. Specifically:

Table 2: Unit Treatment Electrical Demands for Increasing Plant Requirements

Process	Average kWh/million gallons treated
Trickling Filter	955
Activated Sludge	1,322
Advanced without Nitrification	1,541
Advanced with Nitrification	1,911

- In a petition filed November 27, 2007, the Natural Resources Defense Council (NRDC), sought to impose technology-based limits for nitrogen and phosphorus on wastewater treatment plants. The petition asserted that limits of 1.0 mg/L total phosphorus and 8.0 mg/L total nitrogen (averaged yearly) could be met with existing technology that uses only improved biological treatment processes and that EPA should update the definition of secondary treatment to include removal of nitrogen and phosphorus. As shown in Table 2, adding a nitrification requirement to activated sludge plants would increase the power consumption by 350 kWh per million gallon treated.
- Chesapeake Bay Protection and Restoration Executive Order
- EPA Inspector General Report identified a need for more state numeric nutrient standards

Figure 1: AEO2009 Projections of Total US Electrical Demand

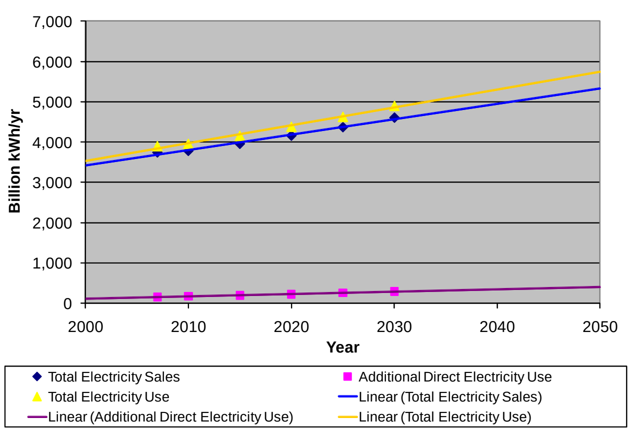
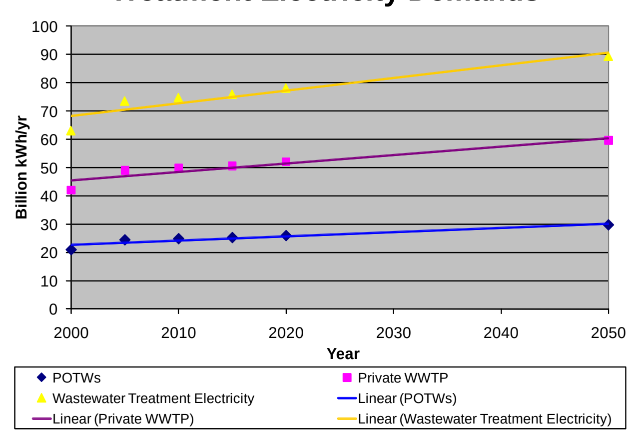


Figure 2: EPRI Projections of US Wastewater Treatment Electricity Demands



The lower escalation rate assumed for future wastewater power requirement than the country's overall increase in power consumption necessarily assumes significant efficiency advances in the treatment systems. The overall increase in national on-site power generation also assumes greater production of renewable power from wastewater-derived methane. In order for these assumptions to prove accurate, investment in development of new technologies is warranted to develop processes that:

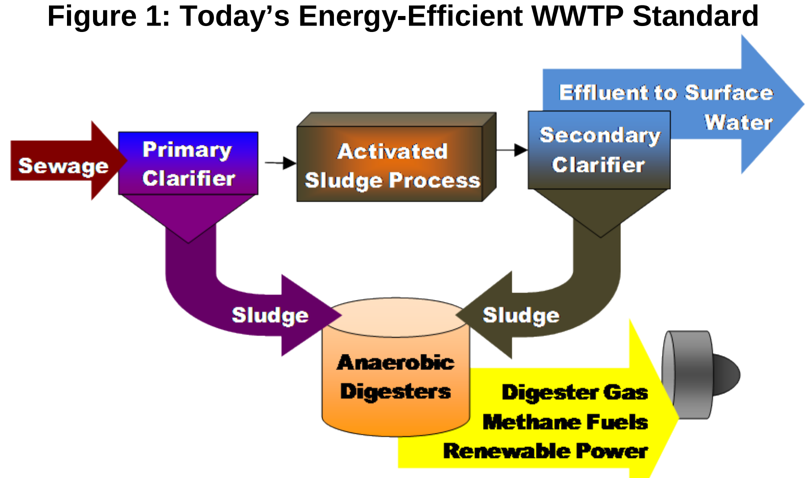
- Dramatically reduce the amount of energy required to provide activated sludge process aeration.
- Convert pollutants to renewable products with significantly lower energy input.
- Dramatically increase the amount of methane-derived energy from wastewater.

The opportunity also falls under the critical national need area of Infrastructure. Much of the capacity existing today was originally built in the 1970's and 1980's using the nearly $60 billion in Construction Grant funds provided under the authority from the Clean Water Act to help broadly implement secondary treatment. As such the existing tankage and process units represent a significant part of the country's environmental infrastructure.[3]

Municipal water and wastewater utility budgets are today challenged to repair and maintain many infrastructure elements in service. While much of this focus has centered on buried assets such as water distribution and sewage collection pipes the wastewater treatment plants themselves represent already-made infrastructure investments that will require upgrades to achieve superior performance. The Water Infrastructure Network[4] summarized that: "New solutions are needed to what amounts to nearly a trillion dollars in critical water and wastewater investments over the next two decades. Not meeting the investment needs of the next 20 years risks reversing the public health, environmental, and economic gains of the last three decades."

Development of new technologies and approaches to meet the more stringent treatment standards with a reduced dependence on electricity is a significant national need. Cost effectively retrofitting these newer processes into the existing plant infrastructure would best leverage the already-existing investment and reduce the trillion dollar burden referenced above.

Figure 1: Today's Energy-Efficient WWTP Standard



Current State of the Art
Presently, the standard energy-efficient POTW includes (a schematic of this overall treatment system is shown in Figure 1):

- Primary sedimentation that uses gravity to remove settlable solids.
- Activated sludge to biologically convert soluble material to cell mass that can be separated in a second clarification stage. Fine-bubble aeration and efficient aeration blowers significantly improve the overall system efficiency. In addition, many activated sludge systems are also configured to either nitrify ammonia or completely remove ammonia and/or to remove phosphorus through either biological or chemical means.
- Sludge (those pollutants removed during treatment) is then anaerobically digested by bacteria that convert a significant portion of the sludge to methane gas. The methane is in turn used to fuel combined heat and power systems. The renewable electricity partially offsets the plant's electrical demand while the heat is used to maintain digestion temperatures at near human body temperatures.

In recent years a number of processes have been developed that slightly enhance the energy profile of portions of the wastewater treatment process. While the improvements on a unit-process basis have been significant, the overall improvements on plant-scale operations have not been as dramatic. Some of these enhancements (unit process efficiency improvements; *plantwide efficiency improvements*) are listed below:

1. Conversion from coarse to fine bubble aeration (30%; *15%*).
2. Higher efficiency aeration blower systems (30%; *15%*).
3. Enhanced primary treatment (40%; *20%* with added chemical use/cost).

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[3] Environmental Protection Agency (EPA), "An Evaluation of the National Investment in Municipal Wastewater Treatment", EPA-832-R-00-008, June 2000.
[4] The Water Infrastructure Network (WIN), "Water Infrastructure Now – Recommendations for Clean and Safe Water in the 21st Century", 2001.

4. Enhanced anaerobic digestion processes: acid-gas, temperature-phased, among others (30%; *10%*).
5. Digestion pretreatment processes: ultrasound, cavitation, thermal hydrolysis, among others (30%; *10%*).
6. Digestion supplemental feedstocks like grease, food waste, and industrial waste products (100%; *35%*).
7. Enhanced CHP efficiencies (30%; *10%*).
8. Recycle treatment using nitrite pathways (70%; *15%*).

While it would seem that application of a select few of these technologies might convert an “energy hog” to a “power plant” the improvements are not directly additive. Two opportunities for making the desired quantum leap include:

A. Microbial fuel cells which convert pollution into direct current and hydrogen. To date, this technology has been implemented at laboratory scale and is just now moving to pilot scale. Questions include treatment effectiveness, impact (if any) on nutrient performance, sludge handling accommodations, suitability to retrofit in existing tankage, scalability, and magnitude of the capital investment/area required.
B. Anaerobic primary treatment that essentially digests the plant influent soluble as well as settleable organic pollution. A number of these systems (upflow anaerobic sludge blankets (UASBs) and anaerobic filters) have been employed in warm climates with very loose/lenient effluent requirements. The challenge is reportedly that hydrogen sulfide (H_2S) is produced by the anaerobic processes in advance of methane formation so that the effluent from these anaerobic processes has very high H_2S concentrations. The H_2S is toxic to the organisms that convert ammonia to nitrate (nitrifiers) and severely limits the ability to nitrogen effluent limits.

A TRANSFORMATIONAL RESULT

Table 1.2 shows how 1 to 2 MWh of electricity are currently required to treat 1 million gallons of wastewater with the likelihood that more and more will be in the 1.5 to 2.0 MWh range as nutrient discharge limits become more stringent. This need for energy is in diametric opposition to the fact that wastewater itself contains a significant amount of energy. From a chemical analysis perspective, the carbon, ammonia and other pollutants in sewage represent potential for 9.3 times more energy to be derived from wastewater than is currently used to treat it.[5] Researchers with the Water Environment Research Foundation further suggest that up to 12 percent of the US electricity demand could be met by technologies that harness this inherent energy in wastewater, significantly advancing toward the Obama Administration’s goal for 10 percent renewable energy by 2012 and 25 percent by 2025.

NIST investment should seek to harness this latent energy in such a manner that wastewater treatment plants become net energy producers in the 21st century, rather than sources of huge electrical demand. Ideally, developed technologies could be cost-effectively retrofit into existing treatment plants while enhancing or at least not diminishing the capability to meet stringent effluent quality. Were such a quantum leap achieved, one of the largest (or the largest at most) operational costs could be avoided. Such operational savings could be passed on to rate payers or used to more proactively address the trillion-dollar investment needs for the industry.

Magnitude of the Problem/Opportunity

There are over 15,000 POTWs treating over 40 billion gallons per day of wastewater. If these plants use 1,500 kWh per million gallons treated at 10 cents/kWh, this represents a daily energy cost of $6 million (or over $2 billion per year) to the US public. If on the other hand, the empirical energy could be fully harnessed, the $2 billion per year cost could potentially be translated into an almost $20-billion-per-year renewable energy source.

A SOCIETAL CHALLENGE

[5] Water Environment Research Foundation (WERF), “Energy Opportunities in Wastewater and Biosolids”, April 2009.

New technologies in the wastewater treatment arena require federal funding. Presently there is little or no motivation for utilities to try new processes; compliance is first and foremost and the cost of compliance (either in terms of new construction or increased energy consumption) is often passed directly on to the water and sewer ratepayer. While rate increases are difficult from a political perspective, the difficulty is eased when utility management is able to place blame on increasingly stringent requirements. There is also little incentive for creativity when such innovation, should it not work, results in non-compliance which is often accompanied by firings of those taking initiative.

Mapping to National Objectives

This program supports the following national objectives:

Energy is a concern of the new Administration (American Recovery and Reinvestment Act of 2009) as well as former Administrations. On January 21, 2009, the White House issued its *New Energy for America Plan* listing five areas for priority attention: the following two map directly to the proposed wastewater investment:

- 10 percent electricity from renewable sources by 2012 and 25 percent by 2025 (up from 2 percent in 2008); wastewater represents a significant potential renewable energy source,
- Reduce greenhouse gas emissions by 80 percent by 2050: Conversion of wastewater treatment to a net energy producer would have a greater than 100% reduction on the electricity-related Scope 2 emissions.