Sustainable Solutions for the 21st Century: Integration of Water Treatment Systems With Energy From Municipal Wastes

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Often referred to as the water-energy nexus, water and energy are inextricably linked in the overarching goal of public works to provide clean water. They are also key to the successful development of sustainable economic projects on local, regional, state, and national levels. Globally, 6 to 7 percent of the energy consumed every year is for the production and delivery of water. Ironically, in order to meet the future demand for electrical power in the United States, new power facilities may result in the consumption of vast quantities of water.

The competition for water resources has resulted in reduced water allocations, along with delay, and in some cases, cancellation of new power projects across the U.S. Advanced treatments for potable water production required for the processing of lower-quality waters, while meeting higher environmental standards for a growing family of water chemistry parameters and chemicals of concern, require greater demands for energy. Ozone disinfection, which requires a significant input of electrical energy, is one such emerging disinfection technology.

Integrated utility systems may grow in potential value as the average cost of electricity in the U.S., which is currently around 10 cents per kilowatt-hour (kWh), is expected to increase as the drive for clean and renewable energy continues to gain momentum. While there have been successful implementations of solid waste management campuses for optimized treatment of municipal waste, a larger utility network that includes water, wastewater, solid waste, and recycling remains fertile ground for energy efficiency. Finding a site that may be suitable for this marriage of technologies may not be a challenge, as there are a surprising number of "brownfield" sites in urban areas that may be ideally suited for integrated public work projects. Brownfields, along with wastewater treatment facilities, may provide excellent sites to locate an integrated water utility campus in close proximity of urban wastes.

Modern Energy-From-Waste Technology

Currently, energy-from-waste (EfW) facilities process approximately 13 percent of the total municipal solid waste (MSW) in the U.S. As a result, there is an immense untapped resource that can be converted to green energy in various forms. While some of this waste is currently being converted into methane in landfills, there are potentially more than 16,000 megawatts of electric power that are not currently being utilized because municipal wastes are not converted into energy. Much of this potential renewable energy can be developed within the areas in close proximity to the source of the waste. Renewable energy production from wastes can provide significant economic development to local economies. In addition to the immediate impact of local employment during construction and the dollars spent within the local community, there is a long-term benefit throughout the operation and maintenance phase of the EfW projects with a 45- to 50-year service life, including high-quality and well-paying jobs, along with the purchase of local goods and services.

Federal and State Legislation

Federal Renewable Portfolio Standards

There is a long history of MSW being recognized as a renewable fuel, including Section 203 of the Energy Policy Act of 2005, President Bush's Executive Order 13423, Federal Power Act, Public Utility Regulatory Policy Act, Biomass Research and Development Act of 2000, Regulations of the Federal Energy Regulatory Commission, and American Clean Energy and Security Act (ACESA) of 2010.

The integration of EfW and water treatment processes as part of a municipal utility campus would qualify as renewable green energy, or low-carbon energy for many of the federal incentives, and would be well-suited to attract future incentives in the form of federally-supported grants and/or loan guarantee programs. Successfully integrated municipal utility projects could become role models for numerous urban communities across the U.S. In fact, the development of an integrated municipal utility campus dovetails nicely with the "microgrid" concept, which is currently being promoted as a way to provide resiliency and reliability for essential power and water utilities.

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State Renewable Portfolio Standards

In the absence of federal renewable portfolio standards (RPS), more than half of the states have enacted legislation in one form or another that requires electric power utilities to generate or purchase from other renewable energy generators a certain percentage of electricity produced from renewable fuels. Florida, however, does not currently have a mandate for RPS that provides a legislative and/or financial incentive for development of EfW facilities. Most of the 11 operating EfW facilities in the state currently sell electricity to local electric suppliers under a wide range of power purchase agreements (PPA). The absence of an RPS in Florida actually provides an incentive for municipally owned EfW facilities to use their green renewable electricity internally for the treatment of water resources and other public works.

Electricity From Municipal Wastes

The average waste generation of pounds per capita per day (PCD) in the U.S. has stabilized over the past decade at approximately 4.5 PCD. The availability of EfW facilities has increased over the past decade due to advancements in the industry. The current annual availability of 90 to 92 percent is relatively high compared to modern fossil power plant industry standards. For the purpose of the following analysis, the use of 4 PCD is conservative and allows local recycling programs to continue to increase in the future. The average net electrical power generation of EfW facilities has also increased over the past decade to approximately

550 kWh per ton (kWh/ton) of waste processed. The amount of electrical energy that can be produced from an EfW facility serving a given population is shown in Figure 1.

Water Treatment Electrical Demand

Energy is expended in each of a water treatment facility's process steps, including extraction, transport, treatment, disinfection, and distribution. Urban areas are fast becoming the largest centers of population that concentrate the demand for water supply into a dense area. The estimated demand for potable water in a community varies widely, ranging from a low of 75 gal per person per day, to a high of 150 gal. The estimated water demand for a population of up to 3 million people is illustrated in Figure 2.

Potable Water Treatment Electrical Demand

Using water resources wisely will be of growing importance in the future, and fortunately there are a number of advanced technologies that may help meet the demands of a growing population for production of high-quality potable water, efficient wastewater treatment, and the distinct possibility for recycling reclaimed water for both indirect and direct potable reuse.

Energy input for water treatment plants (WTPs) varies widely with the quality of the supply water and type of treatment process required to meet potable water standards. Groundwater can be energy-intensive, with energy demands significantly impacted by the depth at which water is withdrawn from the aquifer. Energy inputs may range from 250 kWh/mil gal (MG) at a depth of 75 ft to 2,500 kWh/MG at a depth of 2,500 ft.

Conventional water treatment processes have many steps that require the input of energy, with pumping (raw water supply, in-plant, and finished water distribution) being the major user of energy. Desalting of marginal waters, including surface water, brackish groundwater, and seawater, can range from 5,000 to 15,000 kWh/MG. Recent demonstration tests using innovative treatments for affordable desalination have set a goal for production of desalinated water at approximately 7,000 kWh/MG.

Looking to the future era of indirect reuse of reclaimed water, energy inputs for these types of multibarrier processes with advanced disinfection can range from 10,000 to 15,000 kWh/MG, and wastewater treatment processes typically range from 2,000 to 5,000 kWh/MG. The typical range of energy input for various

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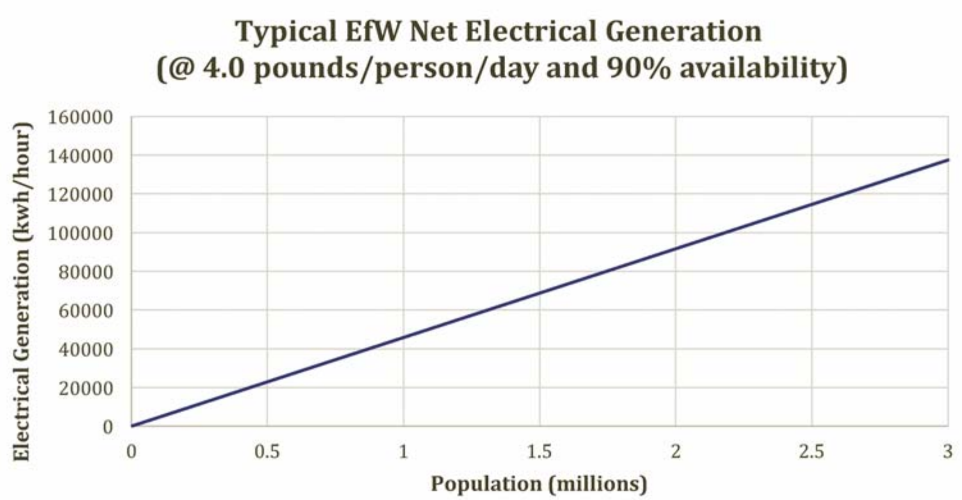

Figure 1. Typical energy from waste net electrical output as a function of population.

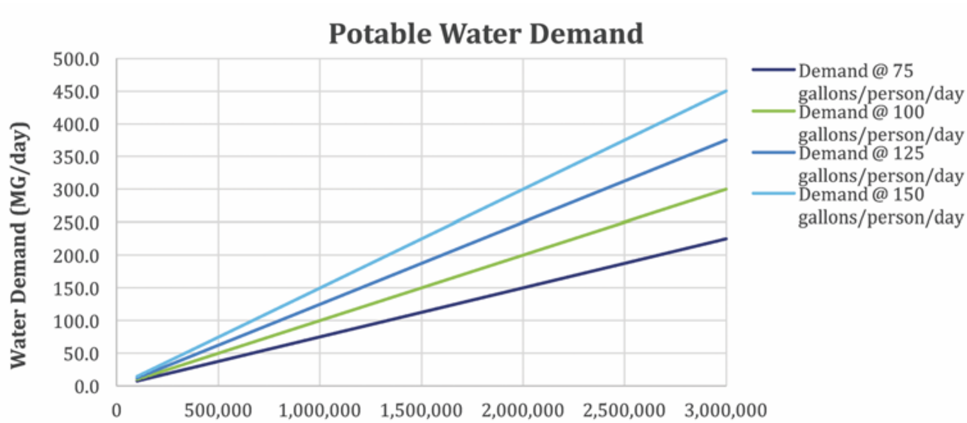

Figure 2. Typical water demand as a function of population and use.

Table 1. Energy required for various water treatment technologies.

Water Source	Treatment Technology	Required Energy Input
Groundwater	Conventional Softening, Filtration, and Disinfection	150 – 750 kWh/MG
Surface Water	Conventional Softening, Filtration, and Disinfection	150 – 250 kWh/MG
Brackish Water	Reverse Osmosis (RO)/Membrane	4,000 – 10,000 kWh/MG
Seawater	RO/Membrane	10,000 – 20,000 kWh/MG
	Multistage Flash Evaporation (MSF)/Multiple Effect Distillation (MED)	15,000 – 20,000 kWh/MG
Reclaimed Water	RO/Membrane	10,000 – 15,000 kWh/MG
	MSF/MED	15,000 – 20,000 kWh/MG
Wastewater	Biological Treatment/Disinfection	1,000 – 3,000 kwh/MG

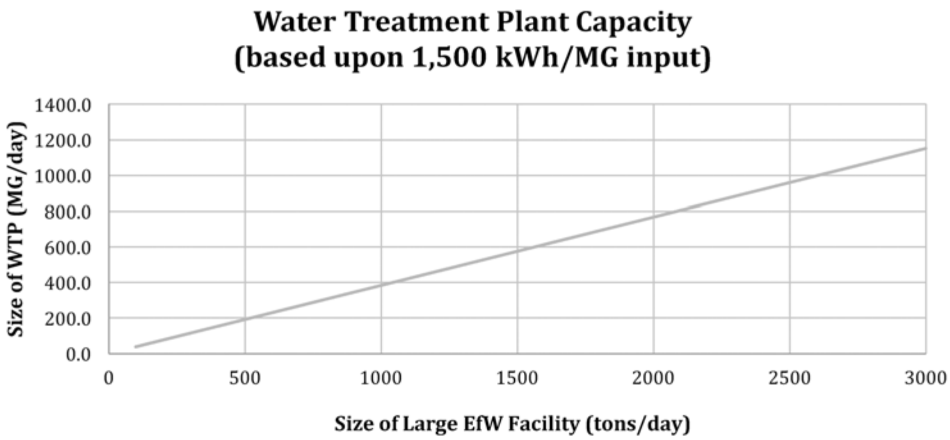

Figure 3. Water treatment capacity if powered by 100 percent of electricity from a large energy-from-waste facility.

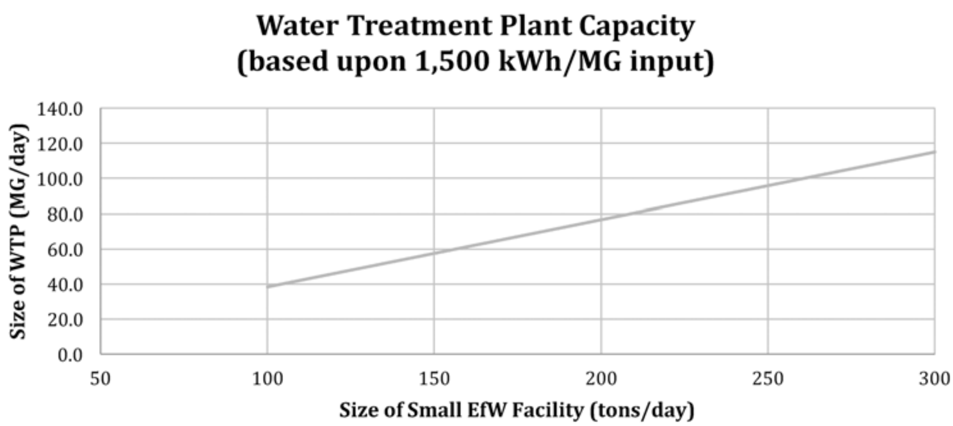

Figure 4. Water treatment capacity if powered by 100 percent of electricity from a small energy-from-waste facility.

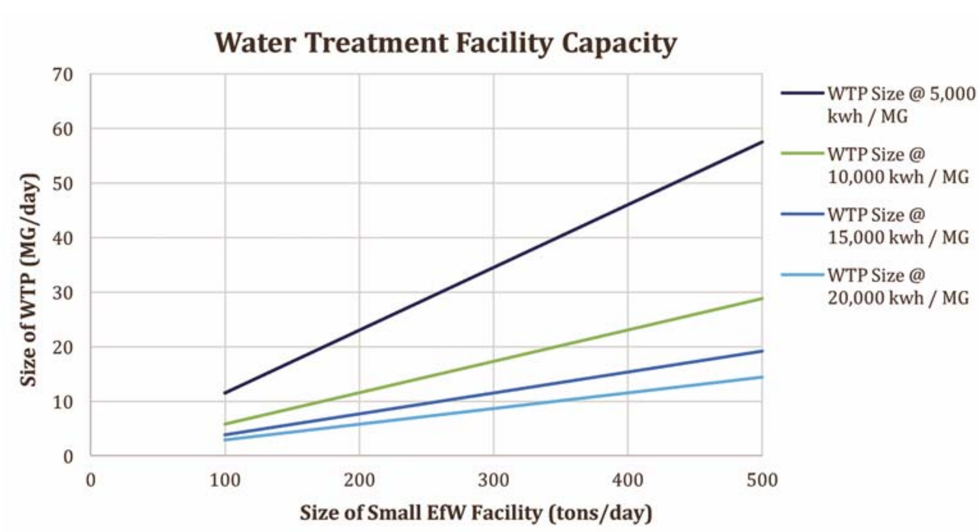

Figure 5. Water treatment capacity for advanced technologies that demand higher inputs of energy.

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water treatment processes, including raw water withdrawal and transfer, treatment, disinfection, and distribution, is summarized in Table 1.

Energy From Waste With Potable Water Production

Matching the electrical output from a modern EfW facility with water treatment processes can vary significantly, depending upon the source water and type of treatment. Assuming a system wide input of 1,500 kWh/MG for the water treatment process, Figure 3 illustrates the relationship between the size of the EfW facility and the potential production of potable water if all the electricity were used for water production. As shown, an EfW facility can literally provide six to eight times more potable water than demanded.

Figure 4 is a similar graph to figure 3, developed for a smaller range of EfW facilities scaled for smaller communities in the range of 50,000 to 150,000 people.

For communities in need of securing additional water supplies from alternate water sources, such as lower-quality surface water, brackish water, or seawater, the compatibility of EfW and WTP processes improves due to the greater demand for energy. Figure 5 shows the range of water production that can be produced if 100 percent of electricity from the EfW facility is used for a range of higher-energy-demand treatment processes. A process that uses 5,000 kWh/MG may be typical for a membrane treatment process, whereas a process such as seawater reverse osmosis may be in the range of 10,000 to 20,000 kWh/MG.

An ever-growing percentage of the U.S. population currently lives in coastal states. Much of this population resides in large- and medium-sized coastal communities, where the demand for additional water supply may require seawater desalination technologies. The use of reverse osmosis (RO), multistage flash (MSF) evaporation, and multiple effect distillation (MED) processes may be ideally suited to use 100 percent of the EfW electricity. In many cases, the size of the EfW plant may be selected to produce the required amount of potable water that is needed for serving an expanding population. Figure 6 illustrates the relationship between EfW facility size and the potential production of potable water from seawater desalination.

Energy From Waste With Wastewater Treatment

The average per-capita demand for water has declined over the years due to a variety of conservation measures. For estimating purposes in this article, a value of 100 gal per capita per day is used. The generally accepted demand rate for wastewater service is 90 percent of the potable water demand, or in this case, 90 gal per person per day.

Wastewater treatment plants (WWTPs) make perfect companions for EfW facilities. In addition to accepting the process wastewater (including cooling tower blowdown) from the EfW facility, the WWTP may also provide reclaimed water for use as process water, such as ash quench water and process makeup water. In some communities with existing EfW facilities, biosolids from their WWTPs are also processed in the EfW facility. The generally accepted rule of thumb is that WWTP biosolids provide a positive energy balance when dried to greater than 45 percent moisture content. Below this condition, they do not provide energy, but they may still be disposed of at a reasonable cost in the EfW facility.

The energy required for WWTPs vary as a function of capacity, type, and level of treatment, disinfection, recycling, and disposal. The WWTPs are often the single largest electricity users in local municipal operations, with the secondary wastewater treatment process as the most energy-intensive. The ultraviolet disinfection process, which is also energy-intensive, is being used at an increasing number of municipal WWTPs due to its many advantages. Figure 7 shows the estimated capacity of WWTPs that could be powered by 100 percent of the electricity from EfW over a wide range of energy inputs for EfW facilities up to 3,000 tons per day (TPD), which is capable of serving a population of approximately 1.4 to 1.5 million.

Figure 7 shows promise for major urban areas that currently do not employ EfW or have excess MSW that could be used by an EfW facility to power existing WWTP facilities. In this case, the capacity of WWTPs that could be powered by an EfW can be significant, in the range of 200 mil gal per day (mgd) to more than 1 bil gal per day. A similar graph for the smaller range of EfW facilities that would serve a population in the range of 50,000 to 250,000 is provided in Figure 8.

As seen in Figures 7 and 8, WWTPs that are larger than needed by a community's population can be operated, in most cases, on 100 percent of the electricity from EfW. In this case, a community will need to find additional internal uses for the remaining electricity (including potable water treatment), or sell it to the local grid.

Summary of Water Treatment Opportunities

Based on the screening analysis, a comparison of the sizes of water treatment processing capacities that can be powered by a commu-

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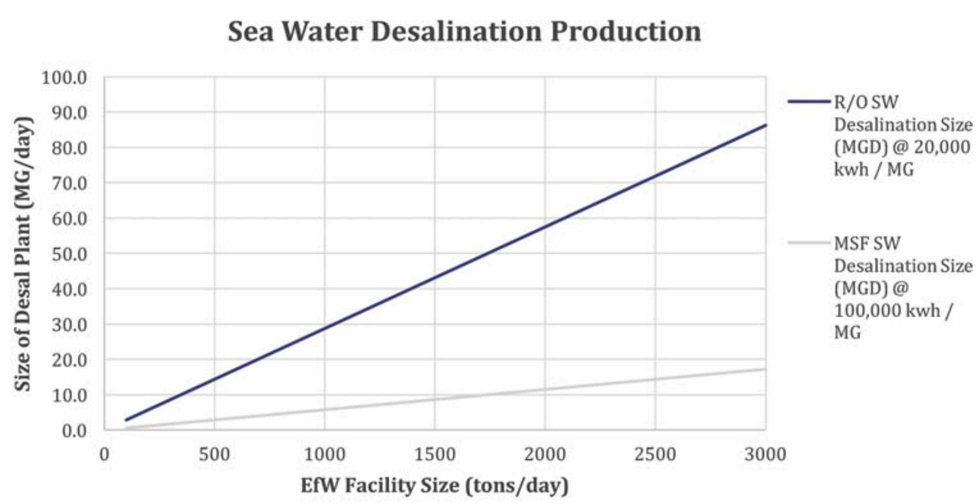

Figure 6. Water treatment capacity for seawater desalination if powered by 100 percent of electricity from an energy-from-waste facility.

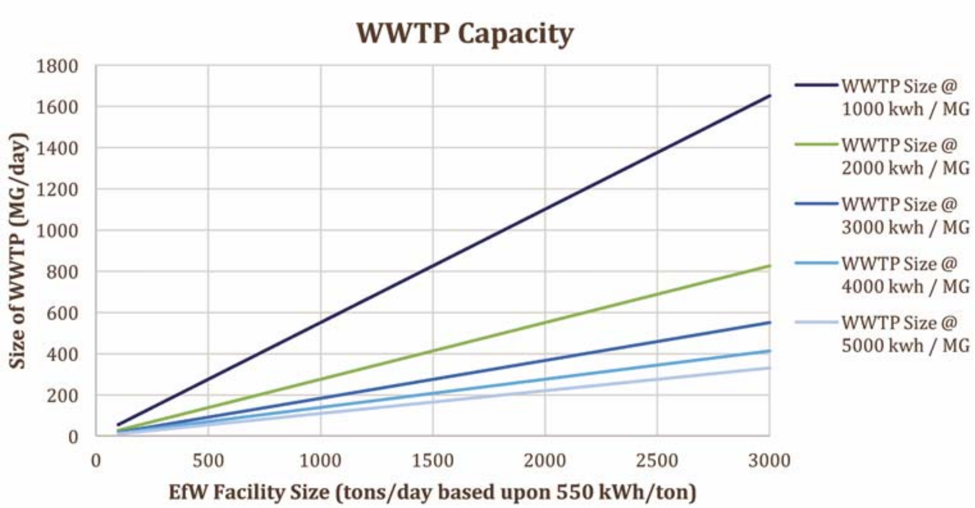

Figure 7. Typical wastewater treatment plant capacity if powered by 100 percent of electricity from a large energy-from-waste facility.

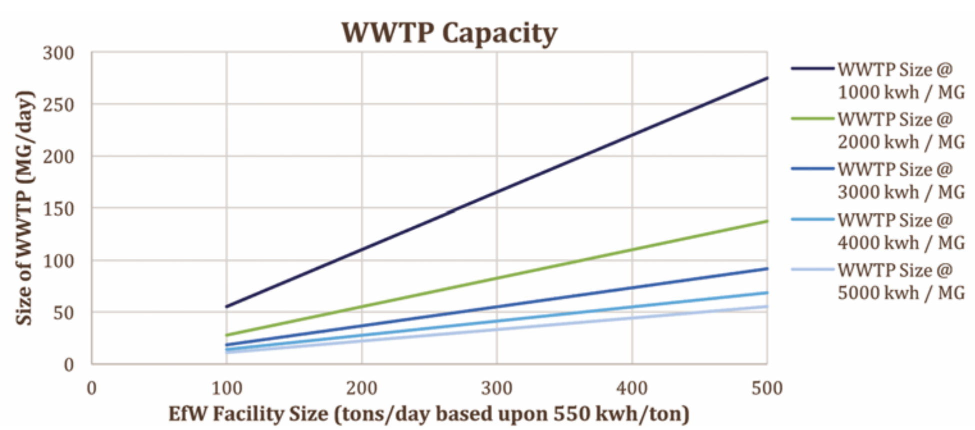

Figure 8. Typical wastewater treatment plant capacity if powered by 100 percent of electricity from a small energy-from-waste facility.

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nity's solid waste is graphically displayed in Figure 9. From a greenfield perspective, conventional WTPs and WWTPs may not be ideally matched to use 100 percent of the electricity from a community's EfW facility, assuming that the EfW plant has been sized to process 100 percent of the available MSW; however, most existing EfW facilities are not always sized for 100 percent of the local MSW stream due to a variety of reasons.

In the case of large urban areas with concentrated population centers, a new EfW facility may be sized to provide 100 percent of its electricity for operation of the existing WTP and/or WWTP facilities. When properly sized for local water resource demands, the project can be designed for optimal performance in providing cost-effective services to both the solid waste and water resources departments. The integration of both WTP and WWTP facilities will increase the use of electricity from an EfW facility to approximately 38 percent when all facilities are sized to serve the same local population base.

Future water management may include: reclaimed water distribution systems for local residential, commercial, and agricultural irrigation; reservoir storage for reclaimed water and excess stormwater during wet seasons; and stormwater treatment systems for removal of excess nutrients and pollutants. In such an arrangement, the demand for energy in the form of electricity or steam will increase significantly and provide an opportunity for a well-matched size of an EfW facility to provide all of the integrated campus needs.

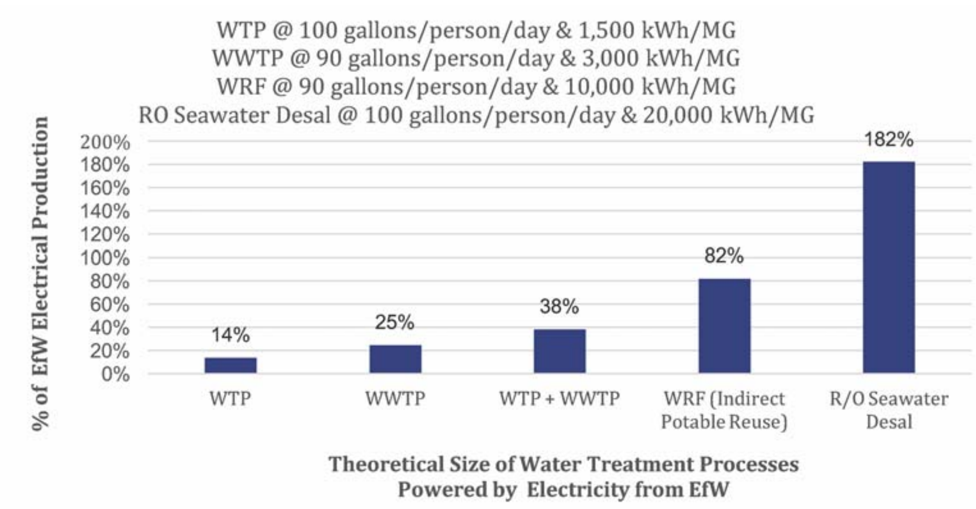

Figure 9. Range of sizes of water treatment processes that can be powered by a community's municipal solid waste.

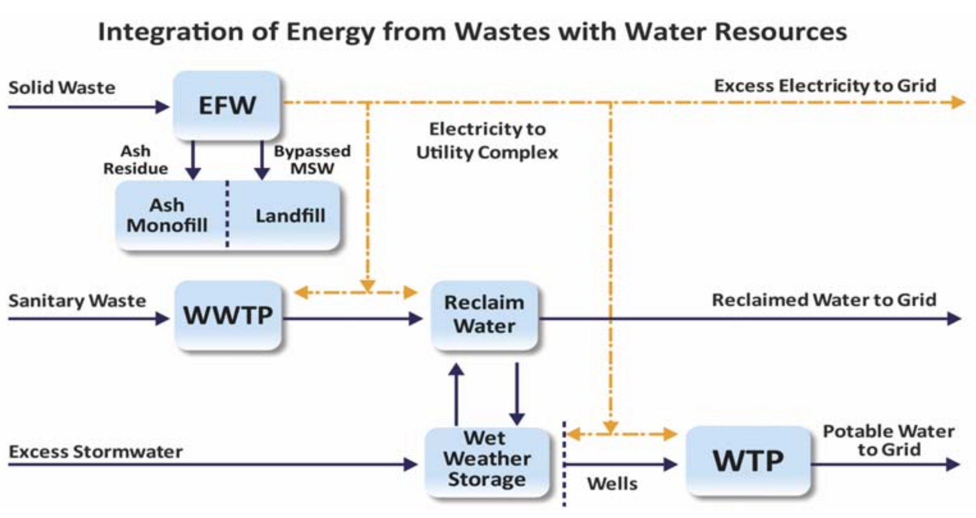

Figure 10. Future integration of energy from waste and water.

As noted in Figure 9, with the addition of a water reclamation facility (WRF) that is designed to treat and disinfect reclaimed water and/or lower quality stormwater, the energy demand increases significantly to the point where a good fit can be developed to use 100 percent of the EfW electricity for treatment and distribution of the various water systems. Figure 10 illustrates diagrammatically how such a future water resource system and EfW facility could be integrated into a single utility campus.

Seawater and brackish water sources may also be included in the discussion of advanced water treatment, especially for coastal and low-lying inland communities. The removal of salts and other impurities from brackish and seawater requires significantly higher inputs of energy, either in the form of electricity or steam.

Proven technology exists to generate renewable electrical energy from municipal solid wastes, along with recovery of biomethane from landfills and anaerobic digesters. Looking to the future, renewable energy systems, such as solar, wind, anaerobic digestion, codigestion, and other emerging waste treatment technologies could help satisfy the need for backup power supply to cover the infrequent periods when the EfW facility is offline for planned and unplanned maintenance outages.

The majority of urban communities in the U.S. do not employ EfW and have large MSW streams that are currently being disposed of in landfills. As local and state goals for landfill diversion gain momentum as part of a drive for sustainability, the development of regional EfW facilities may also become viable when combined with regional water supply and distribution projects. In these cases, there is likely sufficient MSW available that could allow an EfW facility to be sized to match the demand of the community's existing and future water resource needs.

The scoping analysis is encouraging for a number of reasons, the most important of which is financial. The shared electrical savings that will result from the internal use of electricity may warrant an evaluation of the various options and a full feasibility study for those options most suitable for each community. These synergistic opportunities often require that the various processes be owned by a single entity (municipality) and also be colocated on a contiguous property if electricity is to be used internally.

Currently, there are rules that prevent the sale of electricity by anyone other than regulated electric utilities in the U.S. Alternately, the transfer and sale of steam, hot water, biomethane, and syngas via a pipeline may be both technically and economically feasible for re-

Continued on page 44

Continued from page 42

motely located municipal and private facilities. Each of these opportunities should be explored to fully evaluate the vital municipal services that could be synergistically integrated.

Hillsborough County Case Study

One such recent example of the internal use of renewable energy is in Hillsborough County (Figure 11). In 2009, approximately 2 megawatts of electricity from the county's EfW facility was delivered to its adjacent 12-mgd advanced wastewater treatment plant (AWTP). In this arrangement, the solid waste department generates greater revenues than if it sold renewable energy to the local electric utility, while the water resources department saves by avoiding the purchase of electricity at the full commercial rate. This win-win arrangement has saved local rate payers millions of dollars over the past eight years. In order to avoid "demand charges" imposed by the local utility if the AWTP facility remained connected to the local electric grid, a backup diesel electric power system was provided to ensure uninterrupted electric service at the AWTP. The AWTP has 100 percent backup diesel generation to ensure that the facility will operate when the EfW facility is temporarily offline for planned or unplanned maintenance.

Figure 12 illustrates the potential savings to public works for a variety of EfW facility sizes based upon the percentage of electricity that is used for the treatment of water resources. As shown, the savings can be significant—potentially tens of millions of dollars per year based upon a three-cent differential between the rates at which the EfW would sell power to the local grid versus the rate at which water resources would purchase electricity from the local grid.

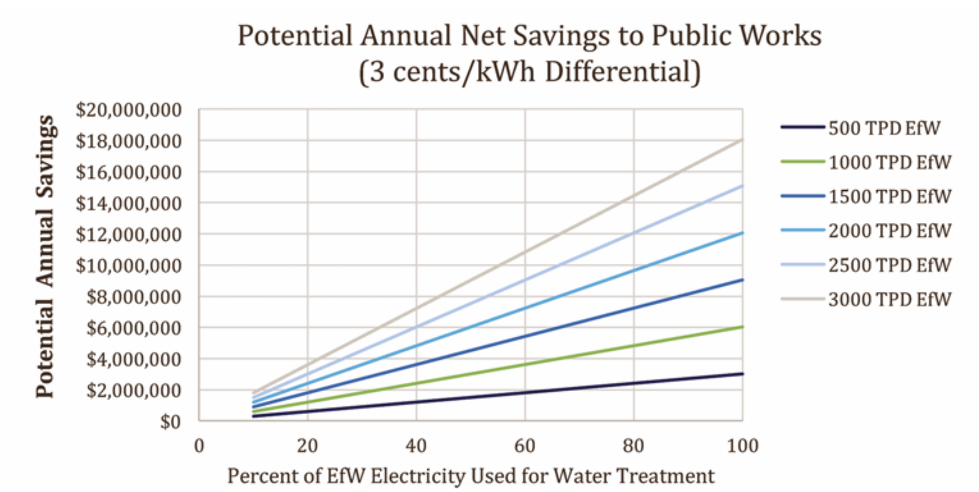

Figure 11. Potential benefits for use of renewable electrical energy from energy-from-waste facilities.

Conclusion

A synergistic approach to managing several municipal processes on a single water utility campus is compatible with the goals of sustainability, waste reduction, and development of alternate water supplies, while answering the challenge of the water-energy nexus. In addition to this successful Florida project, there are numerous opportunities to integrate energy from waste with water treatment processes for various alternate water sources, including surface water, wastewater, reclaimed water, stormwater, brackish water, and seawater as viable options for the future era of sustainable public works.

Acknowledgments

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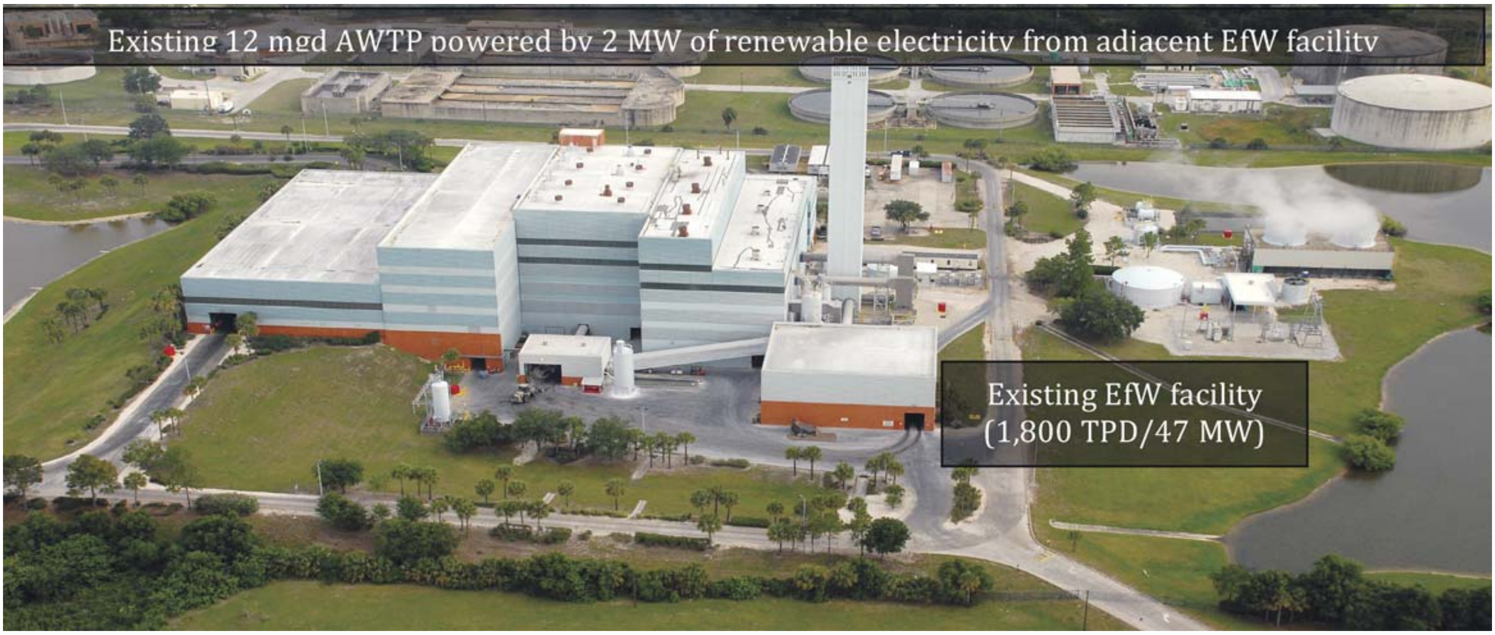

Figure 12. Hillsborough County energy-from-waste facility powers an adjacent advanced wastewater treatment plant with approximately 2 megawatts of electricity.