Coming Full Circle: Moving Wastewater Treatment Plants Toward Energy Neutrality

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Rising energy prices and increasingly stringent effluent requirements have amplified operating costs for many wastewater treatment plants (WWTP) throughout the United States. The ability to accurately track the energy consumption and recovery throughout the wastewater treatment process—from influent to discharge—is critical to optimizing the operating costs associated with these facilities.

As nutrient limits continue to ratchet downward and electricity costs creep upward, and with an increased focus on carbon footprint, climate change, and greenhouse gases, all consumers are becoming more cognizant of the impacts of their activities on the social, environmental, and financial bottom lines. This triple bottom line approach provides a more comprehensive view of the total impacts that any number of decisions might have on the world. One specific assessment tool for wastewater treatment facilities that will allow these entities to quantitatively assess the impacts of various process decisions on the total amount of energy utilized is presented.

Background

Water and wastewater conveyance and treatment account for approximately 3 percent of energy consumption in the U.S. and may represent a third of a municipality's total energy costs (USEPA). On a national scale, wastewater treatment consumes approximately 21 billion kilowatt-hours (kWh) each year, which corresponds to the equivalent of 1.8 million typical households. Escalation of energy costs is expected, and recent emphasis on sustainability has also led many utilities to consider improvements to optimize energy usage, both for financial and environmental reasons. Coupling these drivers with the fact that raw wastewater can contain up to ten times the energy required to treat it (through a combination of chemical, thermal, and hydraulic energy), opportunities exist within the wastewater treatment sector to move the treatment process closer to an energy neutral state. An energy neutral facility can be generally defined as a facility that produces at least as much energy as it consumes, and over some period of time, has zero net energy inputs from external sources.

Currently, only a small subset of wastewater treatment facilities is operating in a manner that allows them to be considered energy neutral, or nearly so. There are two facilities that are commonly discussed when talking about energy neutrality in wastewater treatment: the Strass Wastewater Treatment Plant in Austria, and the East Bay Municipal Utility District (EBMUD) facility in Oakland, Calif. The Strass plant has utilized full-plant optimization approaches, coupled with innovative treatment process utilization, to drastically reduce the total quantity of energy required to perform wastewater treatment to meet its permitted effluent levels. These optimization procedures, coupled with an energy recovery process using a short solids retention time (SRT) treatment process to route the maximum quantity of carbon possible to an anaerobic digestion process, allow energy consumption and energy production to complement each other, resulting in an energy positive facility. On an annual basis, this facility produces more energy than it consumes and exports some of this energy back to the regional electricity grid, rendering the facility as an electrical generator.

The EBMUD facility took a slightly different approach in its continuing quest toward reduced energy consumption. This large facility did not make significant treatment process changes to mirror the advancement identified at Strass, but instead used overall process optimization, coupled with enhanced energy recovery, to reduce its required energy inputs. The facility has undertaken an aggressive program of anaerobic digestion utilization and its proximity to a large urbanized population base to generate a large quantity of energy for use at the facility. Importing fats, oils, and grease (FOG), as well as food waste, has provided a readily-degradable feedstock for its anaerobic digestion facility. Through the anaerobic digestion process, these influent volatile solids with readily degradable chemical oxygen demand (COD) are broken down through a series of bacterial metabolism

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steps into simpler products that ultimately result in methane gas, carbon dioxide, and water. The methane produced through this degradation pathway can be captured in the digester gas and beneficially used for energy production. By increasing the incoming source material quantity, the total methane generation potential of the facility has increased and resulted in substantial reductions in overall facility energy imports.

To help quantify the total energy use of a wastewater treatment facility, there are numerous modeling tools available that allow varying degrees of detail related to the energy use of a wastewater treatment plant to be calculated and predicted. In general, these tools can fall into three categories:

- Benchmarking tools
- General wastewater plant models
- Plant-specific models

Each of the various types of assessment tools have differing uses and can provide different information that can be applied in various circumstances. A general benchmarking tool, such as the United States Environmental Protection Agency (USEPA) Energy Star Portfolio Manager, provides a relatively quick check of actual energy use for a wastewater treatment plant as compared to other similar plants with data entered into the USEPA database. The main output from this tool is a ranking (0-100) that identifies the relative rank of the electrical consumption for the facility being analyzed to other similar facilities in the U.S. Moving into a slightly more specific realm, a general wastewater plant energy model, such as the Water Environment Research Foundation (WERF) Carbon Heat Energy Assessment and Plant Evaluation Tool (CHEApet), allows for more specificity in the required inputs, resulting in a more detailed evaluation and categorization of the energy use. This tool, however, is publically available and was developed to provide a wide range of common wastewater plant configurations with the ability to be modeled, and as such, is not customizable to a specific plant arrangement. Without this specificity, it is not well suited for use in the implementation process for energy efficiency improvements.

A plant-specific wastewater treatment facility model can remedy some of these limitations of the previously mentioned models. This type of tool allows for complete customization of a treatment facility and can be calibrated to actual operating conditions to provide a very accurate assessment of the total energy consumption of the facility. This type of tool can also address nearly any imaginable plant configuration and operating condition via customization for the plant under analysis. These results can then be used for detailed assessment and implementation of potential plant optimizations. The plant-specific tool that will be described and utilized for the case studies presented is the Hazen Energy Efficiency Tool (HEET).

Description of Modeling Tool

The HEET is a Microsoft Excel-based diagnostic and predictive tool that allows a wastewater treatment facility to be modeled process-by-process to establish an integrated and holistic representation of the actual or predicted energy consumption of that facility. The model includes a variety of liquid and solid treatment processes to enable complete customization of the model to the specific configuration and characteristics of the facility. The tool has numerous options for assessment methodologies and for input specification. A major feature of the tool is the ability to integrate the output from a BioWin model of the treatment facility into the various treatment processes in HEET to utilize the power of BioWin to create an energy consumption profile for the facility. This integration allows for impacts of process changes to be evaluated in terms of the necessary balance between producing effluent meeting regulatory requirements and optimizing annual operating expenditures to meet the demands of increasingly tight budgets. A variety of assessment procedures allows HEET to be used at any stage in process development, from the concept stage through post-construction optimization. The level of specificity that is available through the use of HEET will assist in developing a concrete quantification of energy consumption to evaluate alternatives.

The model has numerous options for outputs to support implementation of optimization improvements. These outputs include graphical depictions of the energy consumption by process in a schematic configuration and multiple options for charting and graphing of the results. In addition to these depictions of energy consumption, the tool also calculates the carbon footprint of the facility that includes the following categories:

- Scope 1 Emissions
  - Direct emissions from electricity produced on site.
  - Direct emissions from natural gas used for heat production on site.
- Scope 2 Emissions
  - Emissions related to the power purchased from the electrical grid customized for the specific state in which the project is located.
- Scope 3 Emissions
  - Indirect emissions from solids hauling from the site.
  - Indirect emissions from chemical deliveries to the site.
  - Indirect emissions from the production of chemicals used on site.

Case Study Descriptions

To provide an evaluation of how the tool can be used to develop optimization options for a wastewater treatment facility, two case studies are summarized. The two case studies represent facilities in two separate states with very different treatment configurations and effluent permit targets: the South Durham Water Reclamation Facility (SDWRF) in Durham, N.C., and the Valley Creek Wastewater Treatment Plant (VCWWTP) in Birmingham, Ala.

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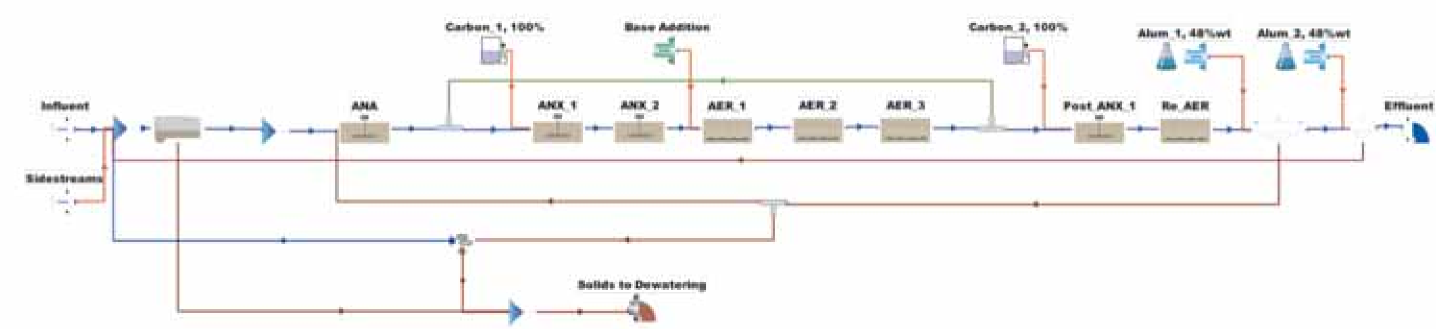

Figure 1. South Durham Water Reclamation Facility BioWin Flow Schematic

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South Durham Water Reclamation Facility

The SDWRF is a 20-mgd facility that provides enhanced nutrient removal wastewater treatment to a current flow of approximately 10.5 mgd. The major process units for the facility include screening, influent pumping, grit removal, primary clarification, five-stage biological treatment, secondary clarification, filtration, ultraviolet disinfection, solids thickening, anaerobic digestion, belt filter press dewatering, and sidestream alum precipitation. The effluent requirements for this facility are mass-based, and for current flow levels are 3.95 mg/L total nitrogen and 0.3 mg/L total phosphorus. The BioWin-generated schematic for the main components of the facility is shown in Figure 1.

Some of the unique features of this facility include the beneficial use of the gas produced in the anaerobic digestion process to offset other energy consumption at the plant. The digester gas is subjected to moisture removal treatment and is then consumed in engine-driven blowers that provide the air supply for the biological treatment process. The exhaust from the engines is used to provide heat for the anaerobic digestion process through heat exchangers and a hot water loop. The heat recovery has been sufficient to provide all of the heat necessary for digester operation for a number of years. The liquid process energy consumption for the baseline configuration is shown in Figure 2, and the solid process baseline energy consumption is shown in Figure 3.

The engine-driven blowers, coupled with 50,000 cu ft of digester gas storage, allow the plant to avoid use of the electric blowers during daily peak power demands. On occasion, blending the digester gas with natural gas was necessary to ensure a sufficient fuel source for the engines. Based on some initial analysis, it appeared that the digester gas production should have been sufficient to provide all of the necessary process air, and natural gas blending should not have been necessary. After further investigation it was determined that the biological process was running with effluent dissolved oxygen (DO) concentrations of nearly 6 mg/L. This high effluent DO was the reason that the electric-driven blowers were necessary and that natural gas was required to fully provide air during the daily peak electric rate periods. With some minor modifications to the air control system, which included valve actuators and some additional control logic, the effluent DO concentrations were able to be reduced to approximately 2 mg/L.

These modifications resulted in a 25 percent decrease in total electrical consumption and the ability of the facility to provide 100 percent of the necessary process air from the engine-dri-

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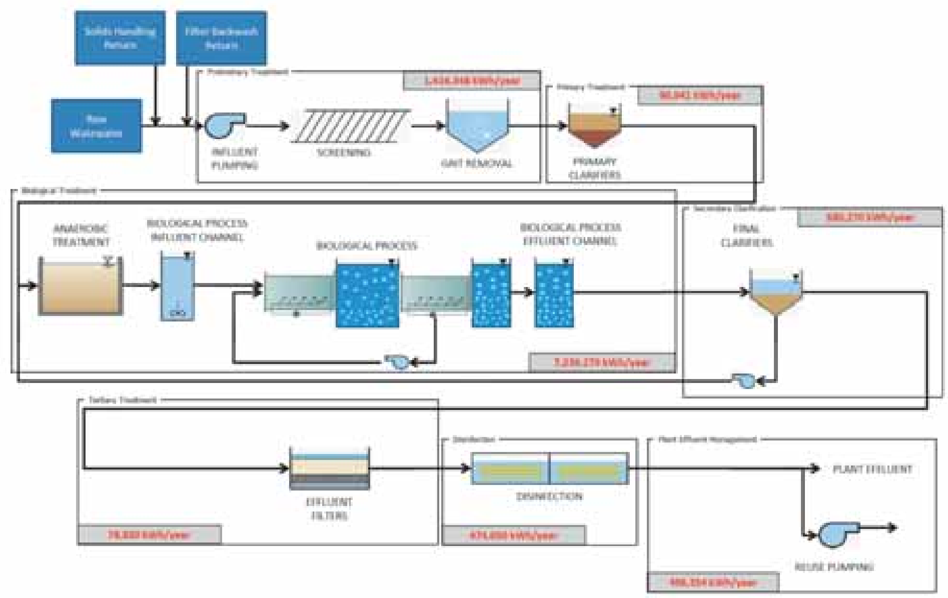

Figure 2. South Durham Water Reclamation Facility Baseline Liquid Process Energy Consumption

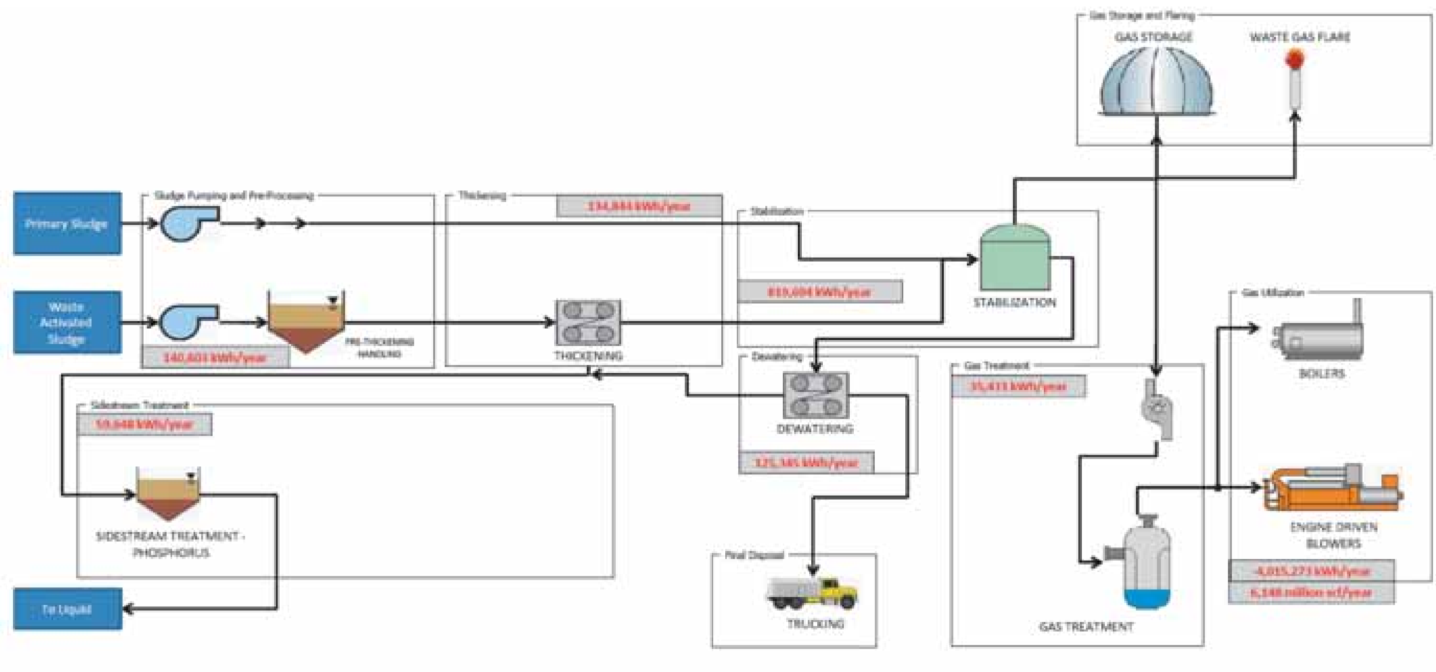

Figure 3. South Durham Water Reclamation Facility Baseline Solid Process Energy Consumption

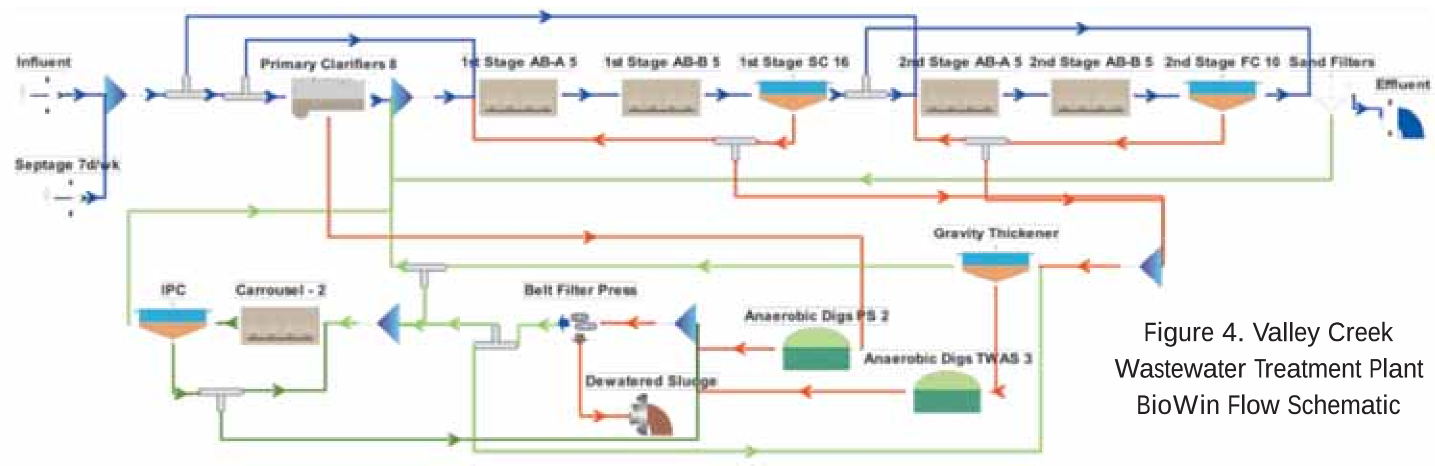

Figure 4. Valley Creek Wastewater Treatment Plant BioWin Flow Schematic

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ven blowers. The digester gas storage tank also allowed for peak air demands to be met even when both engine-driven blowers were required to be operated simultaneously. Overall, the facility is anticipating a savings of $127,000 each year from this process control optimization.

Additional modifications that were also addressed included receipt of FOG as an additional digester feedstock and sidestream nitrogen removal to reduce dewatering impacts on the main liquid treatment process. Due to the current configuration of the digester gas utilization processes, the additional gas generated through co-digestion of FOG would require additional infrastructure, such as an electric generator, to realize any potential benefits. For the quantities of FOG that were used in the assessment, it was unlikely that an attractive project payback period would be generated from this additional energy due to the capital costs for the FOG-receiving system and the generator, as well as the operating costs for the FOG-receiving and -processing facilities and the generator itself. Sidestream nitrogen removal was also investigated, and for certain process configurations of the sidestream nitrogen removal, additional energy savings of 4 percent over the optimized air control results could be realized. A large portion of these energy savings would be realized from the reduction in the number of biological treatment trains that would be required to be in operation. The significant anaerobic and anoxic treatment volumes require a substantial investment in mixing energy, and by reducing the number of trains required to be in operation, substantial energy savings were realized.

Valley Creek Wastewater Treatment Plant

The Valley Creek Wastewater Treatment Plant (VCWWTP) is an 85-mgd facility that currently treats an average flow of approximately 39 mgd. Significant wet weather flows are observed at the facility and numerous alternative operating configurations are used to manage these flows, depending on the total influent flow value. Monthly average effluent permit requirements include a Total Kjeldahl Nitrogen (TKN) summer concentration of 3.0 mg/L, biochemical oxygen demand (BOD) concentration of 8.0 mg/L, and an ammonia concentration of 1.0 mg/L. To achieve these limits, the facility generally operates using screening, grit removal, primary clarifiers, first-stage aeration basins, intermediate clarifiers, intermediate pumping, second stage aeration basins, final clarifiers, filtration, final pumping, ultraviolet disinfection, waste activated sludge (WAS) thickening, anaerobic digestion, belt filter press dewatering, sidestream carousel treatment, and sidestream clarification. The BioWin-generated flow schematic for the facility is shown in Figure 4.

Current operating conditions at the facility resulted in the effluent permit requirements generally being met at the end of the first stage of aeration and clarification. However, the first-stage clarifiers do not have scum removal capabilities, which necessitated that the second stage be used to ensure that the effluent reaching the ultraviolet disinfection process would not cause additional maintenance requirements for this process. The historical operating conditions were estimated to result in 24.5 million kilowatt hours (kWh) of annual electrical consumption, with the breakdown by process shown in Figure 5.

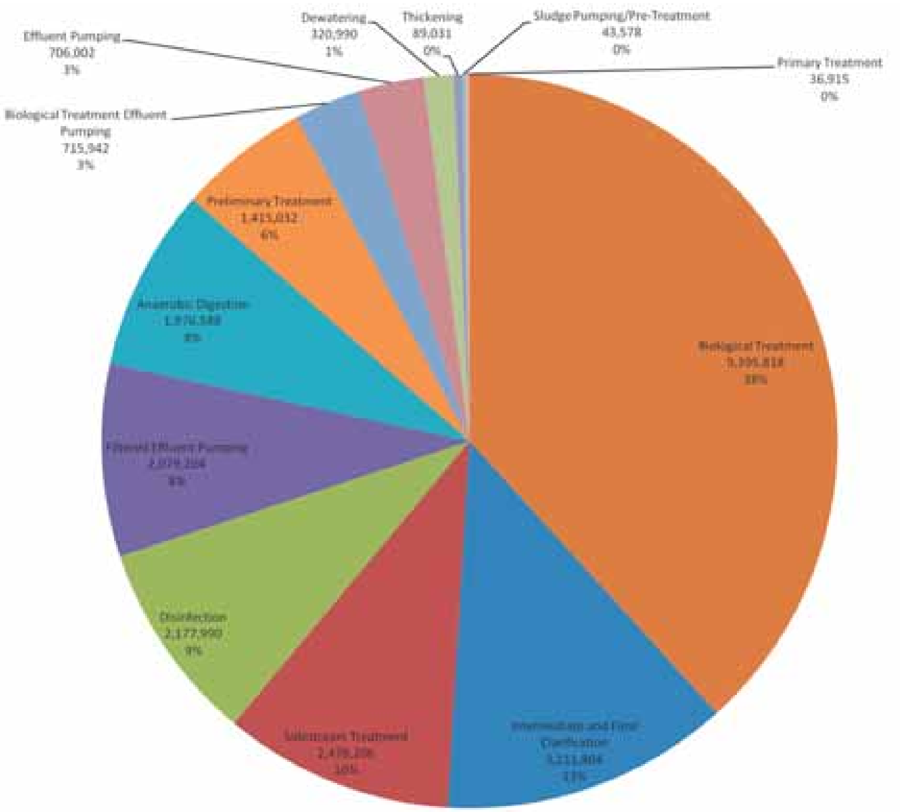

Figure 5. Valley Creek Wastewater Treatment Plant Baseline Energy Consumption

Based on these initial conditions, a series of initial optimization items were proposed to provide near-term cost savings with minimal capital expenditures. The initial modification items included:

- Split the primary effluent 50 percent to the first-stage aeration basins and 50 percent to the second-stage aeration basins.
- Stop use of the sidestream treatment process.
- Improve anaerobic digester mixing.

The projected results from this initial set of improvements resulted in a total predicted annual electricity consumption of 18.5 million kWh, a 24 percent decrease from the historical conditions. Based on the average electricity price for the facility, this was expected to produce annual savings of approximately $447,000.

From this new baseline condition, three alternatives for future improvements were identified:

1. Perform additional optimization using the 50/50 split process.
   a. Improve DO control, diffuser modifications, and air distribution.
2. Further modify the two-stage process configuration.
   a. Operate with 80 percent of primary effluent to the first-stage aeration basins and 20 percent of the primary effluent to the second-stage aeration basins.
3. Convert the process to a single-stage system using the existing second-stage basins.
   a. Discontinue use of the first-stage aeration basins, the intermediate clarifiers, and the intermediate pumping station.

These three alternatives provided additional energy savings, as compared to the initial optimization results. The improved aeration control and distribution elements of Alternative 1 are predicted to result in an additional annual savings of $105,000. The 80/20 split was projected to result in an additional annual savings of $55,000, mainly from utilizing air previously provided to meet minimum mixing requirements for process utilization and reducing the overall air demand in the second stage. The single-stage configuration would greatly reduce electrical consumption through the elimination of intermediate clarification and pumping, as well as first-stage return activated sludge (RAS) pumping and was predicted to result in $256,000 of additional annual savings. The annual electrical consumption is summarized for the baseline condition, the optimized configuration, and the three proposed alternatives in Figure 7.

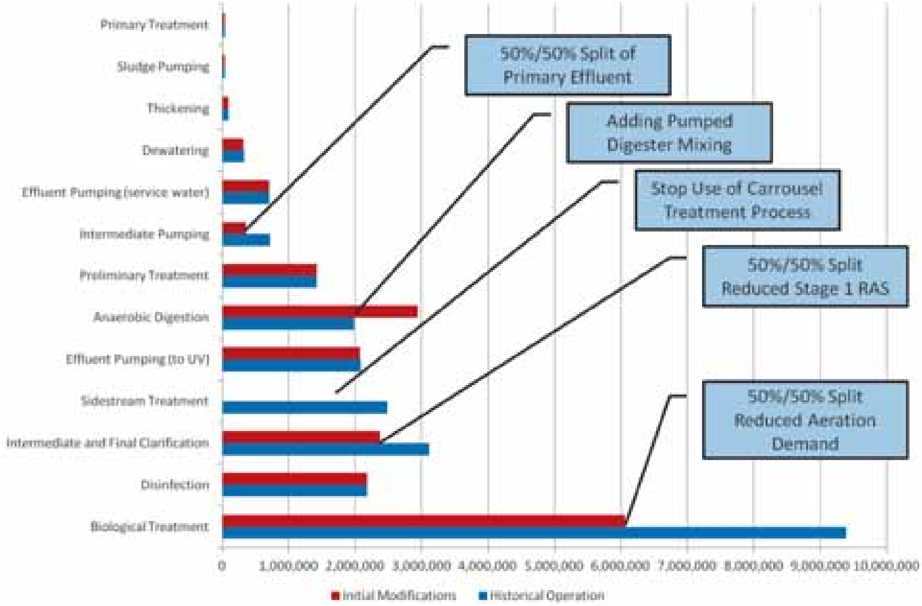

Figure 6. Comparison of Historical and Optimized Electrical Consumption

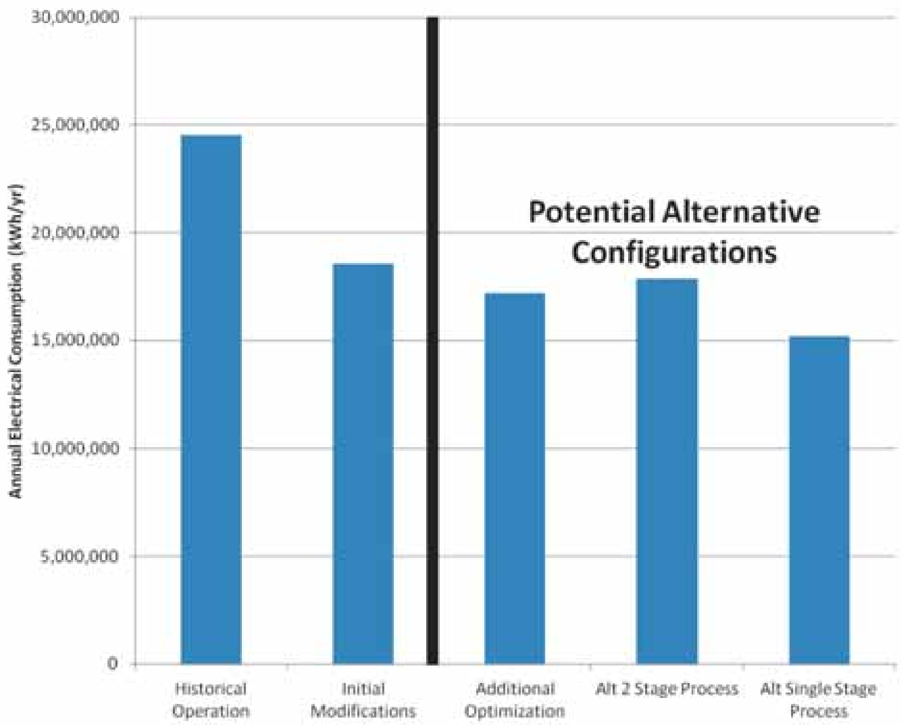

Figure 7. Annual Electrical Consumption Comparison

Conclusions

Benchmarking, accounting for, and evaluating a wastewater treatment facility's energy use can provide significant benefits for a wastewater treatment facility. Using a customized site-specific energy accounting tool can provide significant detail for the impacts of a specific change and is typically the best choice for detailed energy optimization evaluation and design. The two case studies detailed show how the HEET model can assess a variety of process optimizations and improvements to provide substantial economic benefits to the two utilities. The ability to integrate a detailed biological process model into the assessment allows each improvement to conform to the delicate balance between maintaining effluent quality and reducing operating costs. Working from an energy consumption baseline, treatment facilities can target achievable energy reduction goals, and through the use of the model, users can assess the potential benefits and facilitate the process of moving toward energy neutrality.