MUNICIPAL WASTEWATER TREATMENT PLANT ENERGY BASELINE STUDY

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PG&E NEW CONSTRUCTION ENERGY MANAGEMENT PROGRAM*

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A. Executive Summary

Wastewater treatment is an essential public service. Wastewater treatment plants are large energy users with excellent conservation potential. Wastewater treatment energy consumption will increase in the future due to population growth, increasingly restrictive environmental regulations, and demand for wastewater reuse.

There are many methods and processes to treat wastewater. The most common approach uses primary treatment (screening and clarification) to remove solids; aerobic, suspended growth, activated sludge secondary treatment to reduce organic pollutants; and chlorine disinfection to reduce pathogens. Secondary treatment is the largest energy consumer (30 to 60% of total plant usage), followed by pumping and sludge processing. Although suspended growth, activated sludge is the most common wastewater treatment process, it is not the most energy efficient. Aerated lagoons, trickling filters and rotating biological contactors are significantly more efficient. They are not as widely used because aerated lagoons require a large land area, and trickling filters and rotating biological contactors are better suited for smaller capacity applications.

Many wastewater treatment plants are shifting from chlorine-based disinfection to UV disinfection to eliminate the risk of storage and handling of toxic chemicals. Although UV disinfection is energy intensive, it adds no chemical residue to the effluent. This feature is particularly important for discharge to sensitive aquatic environments or for wastewater reuse. In general, low pressure UV systems are substantially more efficient than medium pressure systems.

Energy efficiency opportunities in wastewater treatment include the use of fine bubble diffusers, dissolved oxygen control of aeration, high efficiency blowers, variable frequency drives on pumps and blowers, premium efficiency motors, and the reduction of the head against which pumps and blowers operate.

There is enormous variability from plant to plant in wastewater flow rates, concentration of contaminants, type of process used, the discharge regulations the effluent must meet, disinfection method used and the wet weather flows the plant must treat.

This lack of standardization and site-specific regulatory requirements make it impractical to establish a definitive wastewater treatment baseline in terms of a system configuration or a universal performance metric for wastewater treatment facilities. Consequently, it is recommended that PG&E should participate early in the design phase of new plants or major retrofits with support from consultants to analyze the design for base energy consumption. Options for energy efficiency improvements and applicable incentives can than be identified and presented for review by the plant management.

Within each plant's operation, however, the standard baseline design has been established as shown in Table 1:

Table 1 – Summary of Baseline Designs

Operation	**Baseline Design**
Influent Pumping	On/Off Level Control and EPACT Motors
Primary Treatment	EPACT Motors
Secondary Treatment	
Fixed Film	EPACT MOTORS
Mechnical Aeration	EPACT MOTORS
Fine Bubble Aeration	Coarse or Medium Bubble Aeration
Aeration Blowers	Multi-Stage Centrifugal Blowers with EPACT Motors
DO Control	Continuous DO monitoring with Manual Control
WAS/RAS Pumps	Timed Operation and EPACT Motors
Tertiary Treatment	Flow Control Valves and EPACT Motors
Sludge Processing	EPACT Motors and case-by-case VFD designs
UV Disinfection	Medium Pressure UV Lamps
Effluent Pumping	Flow Control Valves and EPACT Motors

This document was prepared for the Savings By Design program at Pacific Gas and Electric Company (PG&E). Savings By Design (SBD) is an energy efficiency program administered by California gas and electric utilities under the auspices of the California Public Utilities Commission, and is funded by the ratepayers. Savings By Design provides design assistance and financial incentives for new construction, expansion, or gut rehab projects (where there is an increase in load or production) in order to improve the energy efficiency of the installations. Participating customers are eligible to receive free design assistance and a one-time financial incentive, based on the energy saved in one year when compared to what would have been installed in a typical or "baseline" design. Incentives for "process" measures, such as those found in wastewater treatment plants, are paid at $0.03/kWh and are intended to help defray some of the incremental costs of designing and installing more energy efficient equipment. Incentives are not intended for standard industry items, and there should be an extra investment in the energy efficient design as compared to the baseline design.

B. Industry Background

Municipal wastewater treatment provides an essential community service that is vital for the protection of public health and the environment. Without affordable water and wastewater services, economic growth and the quality of life are diminished. Most cities, towns and communities in the US provide drinking water and wastewater treatment services. Currently the wastewater treatment industry faces a number of challenges, including urban population growth, the need to treat wet weather flows, more stringent discharge regulations, and demand for water conservation through wastewater reuse. The EPA estimates that water and wastewater capacity will need to grow by 5 to 8% annually over the next decade. There are over 800 publicly operated wastewater treatment plants in California. There are over 1200 water and wastewater facilities located in PG&E's service territory.

Industry recent trends include increasing adoption of UV disinfection as a substitute for chlorine based processes. Although energy intensive, UV provides a high degree of disinfection without adding any chemical residues to the water. There is also rapid growth in the re-use of municipal wastewater for irrigation and ground water recharge, which necessitates enhanced treatment to remove nutrients (nitrogen and phosphorus), suspended solids, and other contaminants. Biological nutrient removal can increase plant energy consumption by as much as 40 to 50%.

Water and wastewater plants represent large electric and gas loads. Their energy conservation potential is high, and they are cooperative customers to work with. Overall, wastewater treatment consumes approximately 1.5% of total US electric power. After labor, electricity is the largest operating cost at wastewater treatment plants, typically 25 to 40% of total operating costs. The California Energy Commission reported that wastewater treatment plants are usually the single largest electricity user in local governments. Energy consumption at wastewater treatment plants will continue to grow to meet the future challenges listed above.

C. Wastewater Treatment – Aerobic Activated Sludge

Each wastewater treatment plant will have differences in influent flow rates, wastewater composition, discharge regulations and other local constraints. An example of estimated plant to plant variation in wastewater influent conditions is shown in Table 2. These variations can be large and have a major impact on the type of process used, and the amount of energy consumed, during treatment.

Table 2 - Variation in Wastewater Inlet Characteristics

Variable	**Flow Rate MGD[1]**	**Suspended Solids TSS[2]**	**Strength BOD[3]**	**Pathogens CFU/100ml[4]**
Typical Range	0.01to 300	100 to 400	100 to 600	$1x10^{5\ to}\ 1x10^{6}$

Footnote:
1. *Million Gallons per Day*
2. *Total Suspended Solids in Milligrams per Liter*
3. *Biochemical Oxygen Demand in Milligrams per Liter*
4. *Colony Forming Units per 100 Milliliters of Wastewater*

All wastewater treatment plants must meet discharge regulations as set by Federal, State or Local regulatory bodies. A typical National Pollution Discharge Elimination System (NPDES) Permit for a wastewater treatment plant is shown in Table 3.

Table 3 - NPDES Permit Requirements-Discharge Limitations

Constituent	Units	Monthly Average	Weekly Average	Daily Maximum
Settleable Solids	ml/l	0.1	--	0.2
BOD	mg/l	30	45	90
TSS	mg/l	30	45	90
Total Chlorine Residual	mg/l	--	--	0.1

Discharge permits may also specify a certain percentage of BOD that must be removed, often 80 or 90%. Discharge limits on residual chlorine and nitrate content are also common. These permits often specify tighter limits on BOD, pathogens and nutrients during warm weather months. Warm weather increases biological activity in the receiving body of water and increases the likelihood of human contact from recreational use.

This energy baseline study focus on Aerobic Activated Sludge (AAS), which is by far the most frequently used wastewater treatment process consisting of primary treatment, secondary treatment, optional tertiary treatment, disinfection, and sludge processing.

C.1. Primary Treatment

Primary treatment involves screening, grinding and sedimentation/clarification, to remove the floating and settleable solids found in raw wastewater. When raw wastewater enters the treatment plant it is typically coarse screened to remove large objects, ground to reduce the size of the remaining solids, and then flows to primary sedimentation tanks.

The sedimentation tanks provide sufficient capacity to establish quiescence in the wastewater, allowing solids with a higher specific gravity than water to settle and those with a lower specific gravity to float. Well-designed and well-operated primary treatment should remove 50 to 70% of the suspended solids and 25 to 40% of the BOD. Free oil, grease and other floating material are removed by skimmers from the surface of the primary sedimentation tanks. Typical detention time in the primary sedimentation tanks is 1.5 to 2.5 hours. Chemical flocculants/polymers are frequently added to the primary sedimentation tanks to increase solids removal. Solids removed during primary treatment are dewatered and disposed of as part of the sludge treatment.

C.2. Secondary Treatment

Conventional secondary treatment is accomplished by a biological process called aerobic, suspended growth, activated sludge treatment. Activated sludge secondary treatment typically accounts for 30 to 60% of total plant energy consumption. Effluent from primary treatment is treated in large reactors or basins. In these reactors, an aerobic bacterial culture (the activated sludge) is maintained, suspended in the liquid contents. Hydraulic detention time in the secondary reactors ranges from 6 to 8 hours. The secondary process removes organic material that is either colloidal in size or dissolved.

Secondary treatment typically removes 70 to 85% of the BOD entering with the primary effluent. Aerobic conditions are produced by injection of dispersed air, or by injection of pure oxygen dispersed by mechanical agitation. The bacteria metabolize the organic carbon in the wastewater, producing carbon dioxide, nitrogen compounds and a biological sludge. Treated effluent from the aeration basins flows to secondary clarification. A portion of the sludge from the clarifier is recycled to the aeration basins/reactors and the rest is withdrawn, or "wasted". The waste sludge is dewatered and disposed of by various methods. The clarified effluent from secondary treatment is disinfected and discharged.

Although secondary treatment is the most energy intensive operation in wastewater treatment, most plants do not routinely collect sufficient data to accurately calculate the energy usage for this process. One of the objectives of the PG&E Wastewater Treatment Energy Benchmarking Project (see appendix E) was to address this issue. In this benchmarking project, actual energy consumption in the secondary treatment process was measured for a variety of plant sizes and processes. Table 3 is a summary of the energy monitoring carried out in ten plants, all using activated sludge, but in a variety of forms including attached growth (RBC and Biotower/AAS), suspended growth (AAS), suspended growth with nitrification/denitrification (AAS-N/D), and high purity oxygen (HPO). The secondary energy usage was measured and the metric of kWhr/MG treated was calculated. The total plant energy usage in kWh/MG of total plant flow was also computed. Secondary treatment energy consumption ranged from a low of 27% to a high of 57% of total plant energy consumption, in general conformance with the expected range of 30 to 60%.

As expected, these energy benchmarking measured results document how much variation there is in real world operating plants using the same activated sludge process. The results confirm that secondary treatment using attached growth (plants A and B) consumes significantly less energy per million gallons treated than the suspended growth processes. However plants using suspended growth with nitrification/denitrification (plants F and G) were not significantly more energy intensive than those plants not using nitrification/denitrification (plants C, E, and G). These discrepancies are not unexpected given the varying age of the facilities, discharge permits, plant size, etc. They do, however, confirm the impracticality of developing single value, energy baseline criteria for the various wastewater treatment processes.

Table 4 - Activated Sludge Plant Energy Consumption Energy Benchmarking

Plant	Process	Flow Rate MGD	Secondary Treatment kWh/MG	Total Plant kWh/MG
A	RBC	1.8	648	1073
B	Biotower/AAS	10.1	508	1485
C	AAS	2.4	2428	4279
D	AAS	11.5	811	1690
E	AAS	1.7	1465	2524
F	AAS-N/D	19.4	1247	4630
G	AAS-N/D	5.4	1505	NA
H	HPO	5.5	2220	4023
I	HPO	19.8	726	2286
J	HPO	63.0	755	1410

Note: RBC: rotating biological contactor. AAS: air activated sludge. AAS with N/D: air activated sludge with Nitrification and Denitrification. HPO-AS PSA: high purity oxygen activated sludge, oxygen produced by pressure swing adsorption. HPO-AS Cryo: high purity oxygen activated sludge, oxygen produced by cryogenic process.

C.3. Tertiary Treatment

Tertiary treatment (also known as "advanced wastewater treatment) is becoming more common as discharge permits increasingly call for the removal of specific contaminants not normally removed during conventional secondary treatment. Removal of nutrients (particularly nitrogen) prior to discharge requires additional treatment. Nutrients encourage algal growth in the receiving waters, reducing dissolved oxygen and causing fish kills and odor.

The air activated sludge secondary treatment process can be combined with anoxic processing for removing nitrogen from the wastewater. The anoxic zone is a section of the aeration basin where no aeration is provided. The purpose of the anoxic zone is to provide an environment for nitrification-denitrification to occur.

Nitrification is the biological conversion of ammonia to nitrites and nitrates. Denitrification is the biological conversion of nitrate to nitrogen gas. When nitrogen gas is formed, it rises through the wastewater and is released into the atmosphere. The purpose for incorporating the nitrification-denitrification process is to reduce the amount of nitrates, which would otherwise be in the plant effluent. Nitrogen removal during nitrification-denitrification requires additional oxygen over what would be required for BOD removal. Approximately 4.5 lb. of O_2 are consumed per lb. of ammonium nitrogen removed. Consequently if nutrient removal is required, substantial additional energy will be consumed in providing the additional oxygen needed. The biological nitrification/ denitrification process may increase total plant energy consumption by 40 to 50 percent.

In addition to nutrient removal, tertiary treatment is also used to: remove suspended solids to very low levels usually accomplished by filtration, remove refractory toxic organic compounds using activated carbon, or remove dissolved inorganic solids using ion exchange or membrane processing.

C.4. Disinfection:

Chlorine - Clarified effluent from secondary treatment is usually disinfected with chlorine before being discharged into receiving waters. Chlorine gas is fed into the water to kill pathogenic bacteria, and to reduce odor. Done properly, chlorination will kill more than 99 percent of the harmful bacteria in an effluent. Some municipalities have switched from chlorine gas to sodium hypochlorite disinfection to avoid the risk and liability of transporting and storing large amounts of chlorine gas.

Chlorine or hypochlorite in treated effluents may be harmful to fish and other aquatic life. Consequently, many states now require the removal of excess chlorine before discharge to surface waters by a process called dechlorination. Chloramine and chlorine dioxide are also used as chemical disinfectants.

Ultraviolet - Ultraviolet irradiation is gaining market share as an alternative to chlorine disinfection. It obviates the risk and cost of storing and handling chlorine gas or other toxic chlorine containing chemicals. In addition, it leaves no chemical residue in the effluent, which is important if the water is to be reused or discharged to a river or estuary with vulnerable aquatic life.

An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. The effectiveness of UV disinfection depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the UV reactor configuration.

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either low pressure or medium pressure mercury arc lamps with low or high intensities. The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Medium-pressure lamps are often used in large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium-pressure lamp disinfects faster and has greater penetration capability because of its higher intensity. However, these lamps operate at higher temperatures with significantly higher energy consumption. Low pressure UV systems are generally 40 to 50% more energy efficient than medium pressure systems, but the large number of low pressure lamps required may result in higher maintenance and capital costs.

As part of the PG&E Energy Benchmarking Project, the energy usage of seven plants using UV disinfection was compared (Appendix E). Four plants (BB, EE, FF, and GG) use medium pressure mercury vapor lamps while the other three use low pressure lamps.

Table 5 - Energy consumption UV disinfection

Plant	Flow Rate MGD	Type of Lamp	Discharge Limit CFU/100ml	Energy usage kWh/MG
AA	43	Low Pressure	200 Fecal Colif.	250
BB	21	Medium Press.	2.3 Total Colif.	1,001
CC	2.8	Low Pressure	200 Fecal Colif.	117
DD	1.4	Low Pressure	200 Fecal Colif.	171
EE	3.4	Medium Press.	200 Fecal Colif.	464
FF	3.8	Medium Press.	200 Fecal Colif.	536
GG	0.3	Medium Press.	200 Fecal Colif.	557

The very large energy consumption by plant BB is the result of the plant's extremely restrictive discharge limit of 2.3 CFU/100ml total colliform, which are at least two orders of magnitude more stringent than the other plants. However the three low pressure plants with identical discharge permits consumed only 25 to 45% of the energy of the medium pressure systems.

C.5. Sludge Processing

Sludge processing is complex and can consist of a variety of operations, including: sludge thickening, sludge stabilization by lime addition or digestion (either aerobic or anaerobic), sludge de-watering, and ultimately disposal by landfill, composting, land application, or incineration. In most plants, primary and secondary sludge are combined, thickened by sedimentation or flotation, stabilized, and dewatered by use of a belt filter press or centrifuge.

Thickening - Thickening is used to reduce the volume of sludge prior to further treatment. Combined primary and secondary waste activated sludge will typically be less than 1% total solids. Thickening can achieve an increase in total solids to 4% to 6% and thus greatly reduce sludge volume that must be handled in subsequent processing. There are two principal sludge-thickening methods: gravity thickening (GT) and dissolved air flotation (DAF).

GT is similar to primary sedimentation. Dilute sludge is fed into a circular tank through a center feed well. The sludge settles, compacts, and is withdrawn from the bottom of the tank. In DAF, air is introduced into the liquid sludge held under pressure. The sludge and air mixture is introduced into a flotation tank where the dissolved air comes out of solution as tiny bubbles, carrying the sludge to the surface of the tank for removal by skimmers.

Stabilization - Sludge is stabilized to reduce pathogens and eliminate odor. Lime stabilization involves mixing the sludge with lime to achieve a ph of 12 or higher.

Aerobic stabilization is similar to activated sludge secondary treatment. It is carried out in open tanks with air introduced from the bottom of the tank. The aerobic digestion not only stabilizes the sludge, but also reduces the sludge volume as organic material is biodegraded. Digested sludge is decanted from the tank and dewatered.

Anaerobic digestion is carried out in large sealed tanks or digesters in the absence of air or oxygen. Anaerobic conditions promote the development of bacteria that biodegrade the sludge producing methane and carbon dioxide gas. The digesters are heated and mixed both by re-circulated gas and with mechanical mixers. The digester gas produced has a heating value of about 600 BTU/cubic foot, and is used for digester heating, producing steam or for generation of electricity. Sludge is removed from the digester and dewatered.

De-watering - Sludge de-watering is usually accomplished by either a belt filter press (BFP) or a centrifuge (CF).

A BFP is a continuous feed de-watering device that involves gravity drainage and mechanical pressure to de-water sludge. Conditioned sludge is fed to a gravity drainage section of the filter press where free water drains from the sludge. Following gravity drainage, pressure is applied by squeezing the sludge between opposing cloth belts forcing additional water from the sludge. The dewatered sludge is removed from the belts by scraper blades. Belt filter presses can produce a de-watered sludge of 15 to 30% total solids.

In CF de-watering, sludge is fed at a constant flow rate into the rotating bowl of the centrifuge, where it separates into a dense cake and a centrate containing low-density solids. The centrate is returned to the plant headworks. The cake is typically 20 to 30% solids and is discharged from the centrifuge by a screw feeder onto a conveyor belt.

D. Energy Efficiency Opportunities

There are many opportunities for energy savings within the wastewater treatment industry. The following list with a brief discussion identifies some of the options with the most potential. The eligibility of a particular option for a Savings By Design rebate will be determined on a case-by-case basis.

Variable Frequency Drive - A Variable Frequency Drive (VFD) is an electronic controller that adjusts the speed of an electric motor by modulating the power being delivered. VFDs provide continuous control, allowing the motor speed to be matched to the specific demands of the work being performed. VFDs allow operators to fine-tune processes while reducing costs for energy and maintenance.

VFD applications are increasing rapidly in the water and wastewater industries, where the greatest energy consumption is for pumping and aeration, two applications often suited to the use of VFDs. A recent study by the American Council for an Energy-Efficient Economy (ACEEE) showed that there are approximately 88,000 motors (>50 hp) operating in the Water and Wastewater Industry. Twenty four percent of them have variable load and are typically used in aeration equipment where forty eight percent utilized VFD control. Therefore, more frequent use of VFD is encouraged. However, the eligibility for rebate should be based on whether the use of VFD is a result of design requirement to control or meet predetermined flow or not.

For applications where flow requirements vary, mechanical devices such as flow-restricting valves or moveable air vanes are traditionally used to control flow. This control method uses excessive energy and may create harsh conditions for the mechanical equipment involved. VFDs enable pumps to accommodate fluctuating demand, running pumps at lower speeds and drawing less energy while still meeting pump flow needs. Energy savings of up to 50% are achievable. VFDs work with most three-phase electric motors, so existing pumps and blowers that use throttling devices can be retrofitted. VFDs can also be specified for new equipment.

Single speed drives start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current. In contrast, VFDs provide a “soft start” capability, gradually ramping up a motor to operating speed. This lessens mechanical and electrical stress on the motor and reduces maintenance costs and extends motor life. VFDs allow more precise control of processes such as wastewater pumping, aeration, and chemical feed. Plants can consistently maintain desired dissolved oxygen concentrations over a wide range of flow and biological loading conditions by using controls to link dissolved oxygen sensors to control the aeration blowers.

Energy savings from VFDs can be significant: A VFD controlling a pump motor that usually runs less than full speed can substantially reduce energy consumption over a motor running at constant speed for the same period. For a 25 hp motor running 23 hours per day (2 hours at 100% speed: 8hours at 75%: 8 hours at 67%: and 5 hours at 50%) a VFD can reduce energy use by 45%. At $0.10 per kWh, this saves $5,374 annually. Because this benefit varies, depending on system variables such as pump size, load profile, amount of static head and friction, it is important to calculate benefits for each application before specifying the use of a VFD.

Given the large diurnal flow variation in many municipal wastewater facilities, it is important to develop curves of actual flow (GPM or CFM) at hourly time increments during a typical day. This variable flow curve can be overlayed on the pump or blower system head/capacity curve and a baseline consumption developed assuming a single speed motor and a throttling valve to achieve the required hourly flow. A daily time weighted energy usage for the pump or blower can than be established using the pump or blower efficiency at each hourly flow rate. This baseline energy consumption can than be compared to achieving the required hourly flow rate using a variable speed drive. This analysis can be repeated for each pump or blower, and for typical summer and winter diurnal flow rates and wet weather flows.

In the design of new wastewater treatment plants, or major expansions the actual selection of the type, capacity and number of pumps or blowers is complex. Flexibility to meet flow variation can be achieved by using multiple units sized for some fraction of maximum flow, with one or more units equipped with VFD’s. The successful application of VFD’s is also a function of the head against which the pump or blower must operate. In applications where a large static head must be overcome, VFD’s may not be effective, as a very small reduction in speed can result in an excessive reduction in flow and head.

VFDs are reliable, easy to operate, increase the degree of flow control, and reduce pump noise. VFDs can produce harmonic distortion affecting power quality. However, manufacturers have developed methods to correct this problem.

In certain cases, baseline design for VFD’s should be established on a case by case basis because the target application can be for different types of equipment using a variety of flow control methods. For example pumps or blowers can be centrifugal or positive displacement, and flow control may be accomplished by pressure reducing valves, suction to discharge bypass, or timed on/off operation. Consequently establishment of the baseline design must take into consideration the particular type of equipment and existing flow control method. For most liquid pumping operations, baseline design would be flow control using pressure reducing valves, although this method is not suitable positive displacement or for sludge pumping due to the problems of solids plugging.

Premium Efficiency Motors - The Energy Policy Act (EPACT) requires that most motors sold in the U.S. meet minimum energy efficient standards. The Consortium for Energy Efficiency (CEE) developed a standard for Premium Efficiency Motors. Premium Efficiency Motors exceed EPACT efficiencies by approximately 1 to 4%, and can be used as a specification when purchasing motors. Premium Efficiency Motors use energy more effectively, and their superior design provides a higher power factor. As a result premium efficiency motors require less maintenance, and are more reliable. Premium Efficiency Motors are most cost effective for applications with a high capacity factor.

Premium Efficiency Motors owe their higher performance to design improvements and more accurate manufacturing tolerances. Lengthening the core and using lower-electrical-loss steel, thinner stator laminations, and more copper in the windings reduce electrical losses. Improved bearing and a smaller, more aerodynamic cooling fan further increases efficiency.

Pump and blower motors account for 80 to 90% of the energy costs in wastewater treatment, and lifetime energy costs to run a continuous duty motor are 10 to 20 times higher than the original motor cost. Thus Premium Efficiency Motors can play a major role in reducing facility-operating costs.

Premium Efficiency Motors should be evaluated for all new installations, replacement of failed motors, or as spares. They are often an economic substitute for well functioning motors in high duty applications.

Premium Efficiency Motors generally have longer insulation and bearing lives, lower heat output and less vibration. In addition, they are often more tolerant of overload conditions and phase imbalance. This results in lower failure rates, and most manufactures will offer longer warranties for Premium Efficiency Motors.

Table 6 outlines the energy-saving potentials of Variable Frequency Drives (VFD), Premium Efficiency Motors (PEM), and Design & Process Improvement (DPI) in the following areas:

Table 6 - Energy Efficiency Opportunities

Process	VFD	PEM	DPI
Influent Pumping	Yes	Yes	Yes
Primary Treatment		Yes	Yes
Secondary Treatment	Yes	Yes	Yes
Tertiary Treatment	Yes	Yes	Yes
UV Disinfection			Yes
Effluent Pumping	Yes	Yes	Yes
Sludge Processing	Yes	Yes	Yes

D.1. Influent Pumping

Ideally, wastewater flows by gravity to a treatment plant, which is typically located at the lowest feasible point with respect to the sources of wastewater. In the real world, however, it is often not possible to attain complete gravity flow. There are usually a number of wastewater lift stations where pumps provide the needed head to reach the treatment plant. At the plant, influent pumping is sometimes provided to convey the wastewater into the primary treatment system. These influent and lift station pumps are usually high capacity, large horsepower units. They usually run on level control and typically are installed in multiple units for redundancy and to accommodate the variation in diurnal flows. They are candidates for VFD's and Premium Efficiency Motors if the capacity factor justifies the expense. The baseline design would be on/off operation with EPACT efficiency motors.

D.2. Primary Treatment

Primary treatment is not a large energy user, but does have motor driven skimmers and submerged sludge rakes that operate at a high capacity factor. These applications could be candidates for premium efficiency motors. The primary sludge pump is typically not operated continuously but may still be a suitable premium efficiency motor application. The baseline design would be EPACT motors.

D.3. Secondary Treatment

D.3.1. Aeration Blowers - There are two types of blowers that are commonly used in the air activated sludge process: centrifugal or rotary lobe positive displacement blowers.

Centrifugal blowers are commonly used for higher flows (greater than 3000 CFM), while positive displacement blowers are used for lower flows, or where the discharge pressure exceeds 8 to 10 psi. Both types of blowers can have similar efficiencies when properly sized and operated close to the design flow rate. Centrifugal blowers are of two types - multistage or single stage. Older plants will typically have multistage centrifugal blowers, as they were required to develop sufficient pressure for discharging air below the surface of deep aeration tanks. Newer design single stage compressors can be constructed to develop the required pressure, by using large diameter impellers and high rotation speeds.

Multistage centrifugal blowers have limited turndown capability (typically 70%) and lower efficiencies than single stage units. Single stage blowers with variable inlet vanes and variable discharge diffusers allow flow adjustments while maintaining constant impeller speed. They are capable of compression efficiencies of up to 80% from full output down to 40% output. Disadvantages are higher cost and noise levels. Centrifugal blower head capacity curves are flat, and the discharge pressure is reduced by the square of the blower speed, so a small change in speed can cause such a reduction in pressure as to be unable to overcome the static head of the aeration basin. Variable frequency drives for application to aeration blowers must have very precise control of the variable speed.

The output of rotary lobe, positive displacement blowers cannot be throttled. However, capacity variation can be obtained by using multiple units or variable frequency drives. Since some aeration blowers will operate at a high capacity factor, there can be a suitable application on one or more units for premium efficiency motors.

The baseline design would be multistage blowers with EPACT efficiency motors. For an example of an actual Savings By Design award calculation for the installation of high efficiency blowers, see Appendix A.

D.3.2. Dissolved Oxygen Control - Fundamental to energy efficiency of any air activated sludge process is the ability to vary the oxygen supplied to meet diurnal changes in flow and BOD loading. Inlet throttling, adjusting inlet vanes or outlet diffusers and variable frequency drives are the usual methods to vary the output of centrifugal blowers.

Activated sludge treatment systems usually require dissolved oxygen concentrations of 1.0 to 1.5mg/L for stable aerobic operation. For efficient operation and control, it is necessary that accurate dissolved oxygen measurements be obtained for the wastewater in the aeration basins. This can be done manually, with a portable oxygen analyzer. The operators learn the amount of air needed to maintain the necessary dissolved oxygen at each time of the day and manually adjust the aeration blowers accordingly. This is the typical operating mode at many small plants in the 1 to 5MGD size range. Such manual control systems depend on operator attention, and are subject to system upsets when unanticipated flow variations or increases in BOD occur. It is almost always cost effective to install recording, continuous dissolved oxygen measurement in aeration tanks. Because reading the DO concentration in the aeration basin requires less time with continuous DO probes, the operator can more closely control the aeration system and reduce energy usage. Once continuous DO measurement is installed, it is possible to use the DO signal to automatically control the aeration blowers utilizing energy management instrumentation or a Supervisory Control and Data Acquisition (SCADA) system.

The baseline design would be continuous DO measurement with manual control.

D.3.3. **Fine Bubble Aerators** -Many older plants use coarse or medium bubble aerators because they are cheaper, and less likely to foul from impurities in the air flow or from exposure to wastewater. Typical oxygen transfer efficiency (Lb of oxygen utilized for BOD removal/Lb of oxygen supplied X 100) for coarse bubble diffusers is in the range of 9 to 13%. Fine bubble aerators are more expensive, require cleaner air, and must be periodically cleaned. However they provide an oxygen transfer efficiency of 15 to 40 %, and with today's higher priced energy are cost effective. Most retrofits from coarse bubble to fine bubble will produce aeration energy savings of 20 to 40% and simple paybacks of 2 to 4 years including the increased capital cost (for fine bubble diffusers, piping, tankage and gas transfer domes) and the additional maintenance/cleaning cost.

The baseline design would be coarse or medium bubble aerators.
Note: For all projects designed and installed after December 31, 2005, fine bubble aeration will be considered as baseline design.

D.3.4. Waste activated sludge (WAS) and Return Activated sludge (RAS) Pumps - In an activated sludge plant, WAS is typically 1 to 3% of plant influent flow. At many plants wasting is not a continuous operation, hence WAS flows could be as high as 10 to 15% of plant influent if wasting is carried out for only 5 minutes every hour. WAS pumps are not large energy users because of their low heads. VFD drives and premium efficiency motors are energy efficiency options for application to WAS pumping.

The baseline design for WAS pumps would be timed on/off operation with EPACT motors

RAS flows are large, often 25 to 50% of plant influent flow. RAS pumps are not large energy users as they also are low head applications. RAS pumps, however, are often operated continuously and flow paced based on influent plant flow rate to avoid treatment disruptions from intermittent flows. Energy efficiency options for RAS pumping are VFD's and Premium Efficiency Motors.

The baseline design for RAS pumps would be on/off or flow control valves, with EPACT motors.

D.3.5. Fixed Film and Mechanical Aeration - Fixed film treatment processes are also called attached growth processes and include trickling filters and rotating biological contactors. The trickling filter consists of a bed of highly permeable medium to which microorganisms are attached, and through which wastewater is percolated or trickled-hence the name "trickling filter". The filter media usually consists of rock or a variety of plastic media. A rotating distributor distributes the liquid wastewater over the top of the bed. The organic material in the wastewater is degraded by aerobic microorganisms attached to the media, and forms a biological film or slime layer. As the slime layer grows, it eventually loses the ability to cling to the media and sloughs off as a sludge, which is removed. The treated wastewater is than clarified to remove the sludge, disinfected and discharged. A rotating biological contactor is a series of closely spaced disks of PVC or other synthetic material. The disks are partially submerged and rotated through the wastewater. Aerobic biological growth occurs on the disks and forms a layer over the entire wetted surface. The rotation of the disks alternately contacts the "attached" microbial growth with the organic in the wastewater and than air for the adsorption of oxygen. The rotation is also the mechanism for removing excess solids from the disks by shearing forces it creates and maintains the sloughed solids in suspension so they can be carried from the unit to a clarifier for solids removal after which it is disinfected and discharged.

The Baseline Design for fixed film treatment processes would be anEPACT motor.

Mechanical aeration typically involves the violent agitation of the wastewater to promote the dissolution of air from the atmosphere. Two common forms of mechanical aeration are surface aeration and submerged turbine aerators. Surface aerators are typically float or platform mounted and may be equipped with submerged draft tubes. They can be positioned at various depths to achieve different levels of mixing, aeration and circulation. Submerged turbine aerators include a motor and gearbox drive mounted over the aeration basin or lagoon, with one or more submerged impellers and air piped from a blower to a diffuser ring mounted below the impellers.

The Baseline Design for mechanical aeration would be EPACT motors.

D.4. Tertiary Treatment

Tertiary treatment for nitrogen removal is usually accomplished as an adjunct to secondary treatment, through establishment of an anoxic region within the secondary treatment system.

Treatment using filters, activated carbon, ion exchange and membranes are typically pump driven so VFD's and premium efficiency motors are options.

The baseline design would be flow control valves and EPACT motors.

D.5. UV Disinfection

As previously discussed, low pressure UV is significantly more energy efficient than medium pressure UV. However, the higher intensity, greater penetration and fewer lamps required with medium pressure UV results in lower capital and maintenance costs. The reduction in energy costs with low pressure UV can still be attractive if a plant can obtain a satisfactory return on the additional capital and maintenance costs required.

The baseline design would be a medium pressure UV system. Appendix B gives an example of an actual Savings By Design award calculation for the installation of a low pressure UV system.

D.6. Effluent Pumping

In many instances where gravity effluent flow is not possible, effluent pumping is required. Effluent pumping can be high flow and high head, particularly if the effluent must be transported long distances, for instance from an inland treatment plant to an ocean discharge outfall system. The effluent volume will also vary widely with diurnal flow unless storage or equalization is utilized. As a result, effluent pumping energy efficiency options include Premium Efficiency Motors and VFD's.

The baseline design would be EPACT motors and flow control valves. For an example of an actual Savings By Design award calculation for the installation of premium efficiency motors for effluent pumping, see Appendix C.

Pump energy consumption is a function of head or pressure differential against which the pump must move the liquid flow. Many treatment plants use gravity flow from process to process with weirs and wet wells feeding pump inlets. It is often possible to adjust plant fluid levels to reduce static headloss. Appendix D gives an example of an actual Savings By Design calculation for headloss reduction that increased the suction head for effluent pumping.

D.7. Sludge Processing

As previously discussed, sludge processing is very complex with a number of operations. The energy efficiency options for thickening, stabilization, and de-watering include VFD's and premium efficiency motors.

For VFD's in sludge processing baseline design must be determined on a case by case basis because of the variety of processing options ranging from belt filter presses, centrifuges, anaerobic or aerobic digestion etc. Liquids removed from the sludge are typically returned to the wastewater treatment plant headworks, and may be pumped using on/off or pressure reducing valves which may be suitable applications for VFD's. Centrifuges and belt filter presses are usually not good applications for VFD's.

The baseline design for motors would be EPACT.

The baseline design for VFD's should be established on a case-by-case basis.

E. Conclusions and Recommendations

The traditional wastewater treatment plant consists of primary treatment to remove solids, secondary treatment to reduce the organic content, and disinfection to kill pathogens prior to discharge of the treated effluent.

Aerobic treatment is the most common secondary treatment process. There are a number of aerobic secondary treatment processes, including aerated lagoons, trickling filters, and rotating biological contractors, but the most common process is suspended growth activated sludge using air or pure oxygen to maintain aerobic conditions.

Influent wastewater has large variations from plant to plant in both flow and composition. There is a wide disparity in the discharge regulations that wastewater plant effluent must meet depending on the regulatory jurisdiction, and whether the effluent will be discharged to freshwater, saltwater or will be reused for irrigation. In order to complying with new regulations many plants must now use tertiary treatment in addition to secondary treatment thus showing a growing shift in disinfection processes from chlorine based to ultraviolet, which dramatically increases plant energy consumption.

These issues make it impractical to establish a definitive wastewater treatment baseline in terms of a system configuration or a performance metric for wastewater treatment facilities.

PG&E has administered energy conservation programs to participate early in the design phase of new plants or major retrofits, and also encouraging engineering firms responsible for plant design to identify the energy use of design alternatives (not just costs) to allow assessment of both the costs and benefits of energy efficient options.

This PG&E's Energy Baseline Study facilitates the analysis of designs for base energy consumption and opportunities for energy savings. It also supports the calculation of applicable rebates to new construction of treatment systems under the Savings By Design Program.

Acknowledgement & Reference:

Activated Sludge- Second Edition, Water Environment Federation Manual of Practice No. 9, 2002.

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Opportunities for Energy Conservation and Demand-Side Management in Pumping and Aeration Systems, EPRI TR-101599, Final Report-1992.

Quality Energy Efficiency Retrofits for Water Systems, A Guide to Implementing Energy Efficiency Upgrades in Water Supply Facilities, EPRI P400-97-003, Report CR-107838, June 1997

Appendix A Savings By Design Award Calculations - High Efficiency Blowers

A wastewater treatment plant in PG&E's service area was expanding from 10 MGD to 17 MGD. The existing plant used multistage blowers and had the option to add additional multistage blowers for the expansion or shut down the existing blowers and install new more energy efficient single stage blowers. The plant's consultant conducted an energy requirement analysis of the two alternatives. The analysis was based on extrapolating current air requirements to expansion requirements, and using blower vender efficiency curves for the required multistage units and a complete change out to single stage blowers.

Based on the calculated air requirements, the blower Hp and Hph/year were calculated for each alternative. The multi-stage blower alternative required 5.4 million Hph/year versus 3.7 million Hph per year for the single-stage option. This translates to a saving of 1.7 million Hph per year for the single stage alternative with an incremental capital cost of $854,000. The baseline design for the blower system would be the less costly multistage alternative.

The power savings from the single stage blower alternative resulted in approximately a 6 year simple payback on the incremental cost of the more efficient single stage alternative based on an electricity cost of 13 cents per kWh.

Converting Hph/year to kWh/year and using a SBD rebate of $0.03/annual kWh saved (for process measures), resulted in a cash award of approximately $37,597, as shown in Table 1 below.

CALCULATED SAVINGS AND REBATE

BLOWER TYPE	**Hph per year**	**kWh per year[1]**	**Savings kWh per year**	**Reduced Demand[2]**	**SBD Rebate[3]**
Multi-stage	5,394,264	4,022,503	1,253,375	148 KW	$37,597
Single-stage	3,713,634	2,769,256			

Footnote:
1) Based on 0.7457 kW Per hp
2) Based on 8760 hours per year
3) SBD rebate of $0.03 per annual kWh of saving

Appendix B Savings By Design Incentive Calculation - High Efficiency UV Lamps for Recycled Water Disinfection

Two UV alternatives were evaluated – 1) a medium pressure, high intensity, lower efficiency lamp system and 2) a low pressure, high intensity, higher efficiency lamp system.

The first alternative had a significantly lower construction cost but required the greatest power consumption. The second alternative (low pressure lamps) had a total construction cost almost 50%, or $1.4 million greater than the first alternative (medium pressure), but a lower power consumption. It requires 552 lamps of 0.25 kW each, compared to the first alternative, which requires 192 lamps of 2.80 kW each. The calculated energy savings between the alternatives is 761,250 kWh/yr. The detailed calculation is given below. The baseline design for the UV disinfection process would be the less costly installation, which requires fewer lamps (192) and less space. It would cost $2,909,000 to install, and use an average of 135 kW. The more expensive system requires more lamps (552) and space. It will cost $4,331,000 to install, and use an average of 48 kW to provide the same level of disinfection. The energy savings of 761,250 kWh/yr will save about $100,000 per year (assuming $0.13/kWh). The incremental cost of the system is $1,422,000, which implies a simple payback of over 10 years.

High Efficiency UV Lamp Energy Savings

	Medium Pressure	Low Pressure
Number of Lamps Required	192	552
Power Requirement per Lamp (kW)	2.80	0.25
Lamp Design Flow (MGD)	6.75	6.75
Phase I Average Flow (MGD)	2.35	2.35
Service Factor	0.722	1.000
Average Power Requirement (kW) [1]	135	48
Annual Operating Hours per Year	8750	8750
Total Annual Power Requirement (kWh/yr)	1,181,250	420,000
Annual Energy Savings (kWh/yr) =	761,250	
Note: Installed Cost	***$2,909,000***	***$4,331,000***

[1] Avg Power=Nb Lamps * Power/Lamp * (Phase 1 Flow / Lamp Design Flow) * Service Factor

Savings By Design Rebate = 761,250 kWh/yr X $0.03/Annual kWh = $22,838

Appendix C Savings By Design Incentive Calculation - Premium Efficiency Motors on the Secondary Effluent Pumps

Premium efficiency motors will be used on the secondary effluent pumps, which pump water from disinfection to either a holding basin or to the pumping station for discharge to the SF bay. The average flow over the next five years was estimated to be 13.8 MGD, based on information provided by the engineering design firms.

The effluent pumps are 200 Hp each designed to pump 25 MGD during wet weather flows against a 36 ft. head. Since the analysis is based on an average flow of 13.8 MGD, the average head was estimated to be 11 ft. (using the relation that head loss is proportional to the flow squared). The detailed calculations of the energy savings are provided below. The baseline motor efficiency is based on a high efficiency motor, which is required by the Energy Policy Act (EPAct). For 200 Hp motors (TEFC, 1200 RPM), the EPAct high efficiency requirement is 95.0% and the NEMA premium efficiency motors are rated at 95.8%. The SBD energy savings calculation is based on the difference between the premium and high efficiencies.

Effluent Pump Premium Efficiency Motor Savings

Average Flow =	13.8	MGD (average over first 5)
=	9583	GPM

Pump Curve Design Point =	25	MGD
	17361	GPM
and	36.0	feet

Head at Average Flow Condition = 36ft * (13.8 / 25)^2 =	11.0	feet head
WaterHorsepower = 9583 GPM * 11 ft / 3960 =	26.55	Hp
Pump Efficiency =	83	%
Premium Efficiency Motor =	95.8	%
High Efficiency Motor =	95	%
Motor Power Draw = WaterHp * .7457 / Eff pump / Eff motor =		
Motor Power Draw with Premium Eff Motor =	24.9	kW
Motor Power Draw with High Eff Motor =	25.1	kW
Difference in Power Draw (High Eff - Premium Eff)	0.21	kW
Annual Energy Savings = 0.21kW * 24hr * 365 days/yr =	1837	kWh/yr

Savings By Design Rebate = 1837kWh/yr * $0.03/kWhr/yr Saved = $55

Appendix D Savings By Design Incentive Calculation – Headloss Reduction on the Secondary Effluent Pumps

The head loss between the secondary sedimentation tanks and the effluent pump suction well will also be reduced. Currently, the plant effluent falls over a weir at the end of the chlorine contact tank and flows to the suction of the existing effluent pumps. The drop varies with plant flow – a larger drop at low flows and a smaller drop at high flows. At 11 MGD (close to the average flow assumption of 13.8 MGD), the drop was 3.75 feet. The drop over the weir to the suction side of the pump will be eliminated.

The water level will be raised another 2 feet above the weir, to just below the secondary clarifier weir. The total head saved will be 3.75 plus 2 feet, or 5.75 feet. The calculation for the energy savings is provided below.

The baseline for this measure is the way the plant has been typically running their levels. The addition of new VSD pumps and improved controls will permit the plant to control the pump suction head at a higher level in order to reduce head loss.

Head Loss Reduction - Energy Savings

Average reduction in Head Loss = 5.75 feet

Average Day Water Flow = 13.8 MGD (average over next 5 years)

Water Horsepower = Q (gal/min) * H (ft) / 3960 = 13.92 Hp
Water Kilowatts = Hp * .7457 = 10.38 kW Pumping Energy

Pump Efficiency = Water Hp / Brake Hp (from 24" 8312 Pump Curve - App C)
0.83 Pump Efficiency
Motor Efficiency = (Premium Efficiency 200 HP Motor)
0.958 Motor Efficiency
Electrical kW to Pump Motor = kW (water) / (Eff (pump) * Eff (motor))
13.05 kW
Annual Energy Savings = kW * 365 days/yr * 24 hr/day
114,340 kWh/yr

Appendix E Energy Benchmarking Secondary wastewater and Ultraviolet Disinfection Processes at Various Municipal Wastewater Treatment Facilities, Pacific Gas and Electric Company, February 28, 2002.

*** Excerpt ***

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Project Team

PG&E	Consultants
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Stephen Fok (Project Manager)	Erik Dyrr (Xenergy Inc.)
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Table of Contents

Executive Summary

The California Energy Commission reported that wastewater treatment plants are often the single largest electricity users in local governments. The secondary wastewater treatment process is usually the most energy intensive unit process at municipal wastewater treatment plants. The ultraviolet (UV) disinfection process is being used at an increasing number of municipal wastewater treatment plants, due to the many advantages of that method of disinfection. However, UV disinfection is also an energy intensive process.

In an effort to facilitate sustainable energy efficiency improvements in the wastewater treatment sector, the Pacific Gas and Electric Company undertook this project to develop benchmark information quantifying the amount of energy used by various secondary wastewater treatment and UV disinfection processes based on actual operating data. Treatment plant enlargements and upgrades are being undertaken as a result of increasing population, increased regulatory requirements and increasing interest in water reuse. This energy benchmark report provides useful information about the energy requirements of various secondary treatment and disinfection processes and equipment options. With better knowledge of the energy requirements of various options, plant designers and plant managers will be able to make more informed decisions when selecting a secondary treatment or disinfection process. The benchmark information will also be valuable to plant managers who do not have near term enlargement projects. Plant managers will be able to compare the amount of energy used by the secondary treatment and disinfection processes at their existing plant to the benchmark information. Those plant managers will be in a more knowledgeable position to assess whether additional energy efficiency measures would be appropriate for their plant.

Because municipal wastewater treatment plants receive wastewater with varying characteristics and effluent permit limits vary for each plant, the performance requirements of the secondary treatment and disinfection processes vary from plant to plant. In addition, treatment plants utilize equipment of varying ages and types to provide the same unit process. For these reasons, it is important to include information regarding the influent quality, effluent permit requirements and other treatment plant characteristics when presenting benchmark information.

The three benchmark parameters calculated for the secondary wastewater treatment process were energy used per pound of BOD removed (kWh/lb BODr); energy used per million gallons of wastewater treated (kWh/MG) and oxygen transfer efficiency (OTE). The benchmark parameters observed during the project are summarized in Table A.

Table A. Summary of Energy Benchmark Parameters and Energy Use Information for the Secondary Wastewater Treatment Process and for Total Plant Operations

Parameters	Range of Values	
	Observed	Generic (3)
Energy (1) /lb BODr (kWh/lb BODr)	0.4 - 2.6	
Energy (1) /MG treated (kWh/MG)	508 - 2,428	279 - 928
OTE (%) (2)	2.6 - 83	
Electrical Use for Total Plant Operations (kWh/MG)	1,073 - 4,630	978 - 1,926
% of Total Plant Energy Used for Secondary Treatment Only (%)	27 - 60	29 - 48

(1) Electrical energy for the secondary wastewater treatment process only
(2) Oxygen Transfer Efficiency for air activated sludge and high purity oxygen activated sludge processes
(3) See reference [2].

While conducting the site investigations, some plants were identified as using a significantly larger amount of energy than the other plants in the study. Thus, even during the benchmarking process, the information was useful in identifying plants for which further investigation of energy efficiency improvements appears warranted.

The energy used for UV disinfection ranged from 117 to 557 kWh per million gallons treated when meeting disinfection limits of 200 MPN of Fecal Coliform /100 ml of wastewater. When complying with an NPDES effluent permit requiring a very high level of disinfection, 2.2 MPN of Total Coliform/100 ml of wastewater, energy use of 1,001 kWh per million gallons treated was required, even though the plant had an effluent TSS concentration of 1 mg/l and uses an automated control system to adjust the energy used for disinfection based on flow and UV transmittance.

Based on information from the benchmarking study, UV disinfection performance is not a linear function of the applied energy. An increasing amount of energy needs to be applied in order to obtain successive reductions in microorganism concentration. This observation is supported by findings in the report "Recent Developments in Ultraviolet Disinfection" [7]. The above conclusion is also supported by the findings in the report "Investigation of Energy Use and Disinfection Performance at a Wastewater Treatment Plant" provided in Attachment C of this report.

The UV disinfection process required 14% and 23% of the total electrical energy used by the two plants for this benchmarking study. It is inappropriate or statistically insignificant to draw a definitive conclusion regarding the comparative energy efficiency of low vs. medium pressure UV systems from the limited treatment plant data obtained for this study. However, it appears that low pressure systems are more energy efficient than the medium pressure systems. This observation is consistent with information reported in the literature [6] that low pressure lamps are more efficient than medium pressure lamps.

A "Back-of-the-Envelope" calculation was prepared to provide a comparison of the energy required for a chlorine/hypochlorite and dechlorination process compared to the energy used by an ultraviolet disinfection process. The analysis is included in Attachment D of this report. On a global energy basis, it appears that UV disinfection can be competitive with chlorine/hypochlorite disinfection and dechlorination.

Project Description and Objectives

The California Energy Commission reported that wastewater treatment plants are often the single largest electricity users in local governments [1]. The secondary wastewater treatment process is usually the most energy intensive unit process at municipal wastewater treatment plants. The ultraviolet (UV) disinfection process is being used at an increasing number of municipal wastewater treatment plants, due to the many advantages of that method of disinfection. However, UV disinfection is, also, an energy intensive process.

In an effort to facilitate sustainable energy efficiency improvements in the wastewater treatment sector, the Pacific Gas and Electric Company undertook this project to develop benchmark information quantifying the amount of energy used by various secondary wastewater treatment and UV disinfection processes that are in operation. Treatment plant enlargements and upgrades are being undertaken as a result of increasing population, increased regulatory requirements and increasing interest in water reuse. This energy benchmark report provides useful information about the energy requirements of various secondary treatment and disinfection processes and equipment options. With better knowledge of the energy requirements of various options, plant designers and plant managers will be able to make more informed decisions when selecting a secondary treatment or disinfection process. The benchmark information will also be valuable to plant managers who do not have near term enlargement projects. Plant managers will be able to compare the amount of energy used by the secondary treatment and disinfection processes at their existing plant to the benchmark information. Those plant managers will be in a more knowledgeable position to assess whether additional energy efficiency measures would be appropriate for their existing plant.

Because municipal wastewater treatment plants receive wastewater with varying characteristics and effluent permit limits vary for each plant, the performance requirements of the secondary treatment and disinfection processes vary from plant to plant. In addition, treatment plants utilize equipment of varying ages and types to provide the same unit process. For these reasons, it is important to include information regarding the influent quality, effluent permit requirements and other treatment plant characteristics when presenting benchmark information.

Energy Benchmarking Secondary Treatment Processes

A site investigation of the secondary wastewater treatment process at ten treatment plants was conducted. Extensive information was obtained about each plant, including flow and loading to the plant, unit processes employed, equipment used for secondary treatment, NPDES effluent permit requirements, plant performance data and energy use data. The treatment plants investigated ranged in size from about 1 to 72 MGD. Most of the plants receive wastewater from residential, commercial and industrial facilities. One plant (Plant G) receives approximately half of its Biochemical Oxygen Demand (BOD) load from a food processing facility. All the plants provide primary wastewater treatment prior to the secondary treatment process. Some of the plants provide tertiary treatment. Each of the ten treatment plants has a National Pollutant Discharge Elimination System (NPDES) permit written specifically for the plant. The NPDES permits for the treatment plants investigated require effluent BOD and Total Suspended Solids (TSS) concentrations that range from 10 to 45 mg/l BOD, as a monthly average. Some key characteristics about the plants are summarized in Table 1. Additional information about the plants is provided in Attachment A.

Table 1. Key Characteristics of Treatment Plants Investigated

WWTP	Annual Avg Plant Flow (MGD)	Primary Treatment Provided	Secondary Treatment Process (1)	Type of Equipment for Secondary Treatment	Additional Treatment Provided (2)	NPDES Permit Requirements
A	1.8	Yes	RBC	---	None	Mo. Ave. 10 mg/l BOD 10 mg/l TSS
B	9.8	Yes	Bio-tower/ AAS	Fine bubble aeration	None	Mo. Ave. 25 mg/l CBOD 30 mg/l TSS
C	2.8	Yes	AAS	Fine bubble aeration	None	Mo. Ave. 10 mg/l CBOD 15 mg/l TSS
D	12.7	Yes	AAS	Fine bubble aeration	None	Mo. Ave. 20 mg/l BOD 15 mg/l CBOD 20 mg/l TSS
E	1.8	Yes	AAS	Fine bubble aeration	None	Mo. Ave. 10 mg/l BOD 10 mg/l TSS
F	19.4	Yes	AAS with N/D	Fine bubble aeration	Nitrification/ Denitrification	Mo. Ave. 10 mg/l BOD 10 mg/l TSS
G	5.5	Yes	AAS with N/D	Fine bubble aeration	Nitrification/ Denitrification	Mo. Ave. 30 mg/l BOD 30 mg/l TSS
H	5.5	Yes	HPO-AS PSA	Surface mixers	None	Mo. Ave. 45 mg/l BOD 45 mg/l TSS
I	19.9	Yes	HPO-AS PSA	Surface mixers	None	Mo. Ave. 30 mg/l BOD 30 mg/l TSS
J	72	Yes	HPO-AS Cryo	Surface mixers	None	Mo. Ave. 30 mg/l BOD 30 mg/l TSS

(1) RBC: rotating biological contactor. AAS: air activated sludge. AAS with N/D: air activated sludge with Nitrification and Denitrification. HPO-AS PSA: high purity oxygen activated sludge, oxygen produced by pressure swing adsorption. HPO-AS Cryo: high purity oxygen activated sludge, oxygen produced by cryogenic process.
(2) Treatment provided integral with the secondary treatment process, not a downstream treatment process.

Operation and Performance of the Secondary Treatment Processes

Selected data characterizing the operation and performance of the secondary treatment processes during the period of data collection is provided in Table 2.

Table 2. Selected Operation and Performance Data about the Secondary Treatment Processes During the Period of Data Collection

WWTP	Secondary Treatment Process	Plant Flow During Data Collection (MGD)	MCRT (days)	BOD Concentration		Lb of BOD Removed/ Day
				Influent to Secondary Treatment (mg/l)	Effluent from Secondary Treatment (mg/l)	
A	RBC	1.8	NA	172	12	2,402
B	Bio-tower/ AAS	10.1	5.4	151	10	11,877
C	AAS	2.4	19	165 (1)	2	3,199
D	AAS	11.5	0.33 (2)	175 (1)	18	15,101
E	AAS	1.7	NA	NA	NA	1,118
F	AAS with N/D	19.4	6.3	180	10	27,454
G	AAS with N/D	5.4	NA	85	4	3,694
H (3)	HPO-AS, PSA	5.5	3.5	228	31.5	9,000
I (4)	HPO-AS, PSA	19.8	NA	88	15	12,055
J (5)	HPO-AS, Cryo	63	NA	175	15	84,139

(1) Estimated influent concentration
(2) Appears low, but is the data reported
(3) BOD based on conversion of COD data, using historical BOD:COD ratio 0.5
(4) Typical plant values for dry weather flow
(5) BOD based on conversion of COD data, using historical BOD:COD ratio .26

Some treatment plants do not conduct comprehensive sampling and laboratory analysis of the wastewater at intermediate locations within the plant. Thus, for some plants, it was necessary to estimate the BOD concentration of the influent to the secondary treatment process. Because some of the treatment plants have tertiary treatment, the BOD concentration of the secondary effluent is not necessarily the BOD concentration of the plant effluent.

All of the plants investigated were meeting BOD and TSS effluent permit requirements.

Figure 1 shows the annual average effluent BOD concentration from the secondary treatment process for each plant. Figure 2 shows the pounds of BOD removed by only the secondary wastewater treatment process per million gallons of wastewater treated.

Figure 1. Effluent BOD Concentration from the Secondary Treatment Process

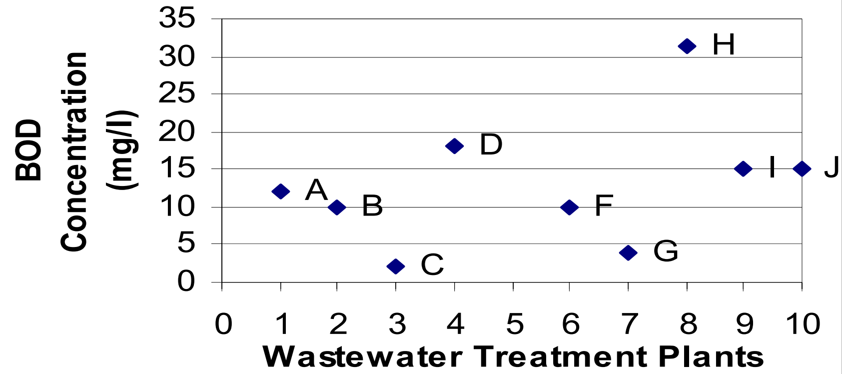
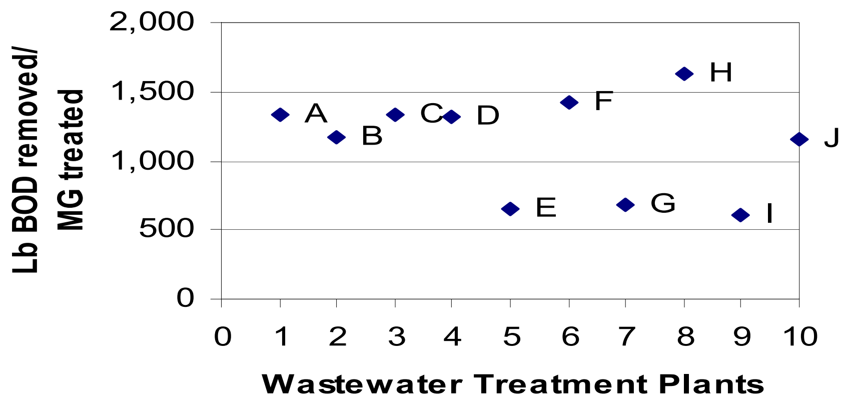


Figure 2. Pounds of BOD Removed by Secondary Treatment per Million Gallons Treated



<u>Benchmark Parameters</u>

Several parameters were calculated in order to compare the performance and energy used by the secondary treatment process at the various treatment plants. The benchmark parameters that were calculated were: energy used per pound of BOD removed (kWh/lb BODr); energy used per million gallons of wastewater treated (kWh/MG) and oxygen transfer efficiency (OTE). Table 3 summarizes the results from the ten plants investigated. In addition, information is provided for three generic treatment plants that represent theoretical estimates of energy used in wastewater treatment plants.

Table 3. Energy Benchmark Parameters for Secondary Wastewater Treatment

WWTP (1)	Secondary Treatment Process	Plant Flow During Data Collection (MGD)	Energy Used for Secondary Wastewater Treatment (kWh/d) (2)	Energy Used for RAS, WAS & ML (%) (3)	Energy Used per Pound of BOD Removed (kWh/lb BODr) (2)	Energy Used per MG Treated (kWh/MG) (2)	Oxygen Transfer Efficiency (%)	Electrical Use for Total Plant Operations (avg kWh/d)	Electrical Use for Total Plant Operations (avg kWh/MG)	% of Total Plant Energy Used for Secondary WWT (2)
A	RBC	1.8	1,166	10	0.5	648	NA	1,931	1,073	60
B	Bio-tower/ AAS	10.1	5,007	8	0.4	508	17.0	15,000	1,485	33
C	AAS	2.4	5,708	6	1.9	2,428	3.8	10,270	4,279	56
D	AAS	11.5	9,328	7	0.6	811	5.7	19,433	1,690	47
E	AAS	1.7	2,471	12	2.6	1,465	2.6	4,290	2,524	58
F	AAS with N/D	19.4	24,189	10	0.9	1,247	6.1	89,813	4,630	27 (4)
G	AAS with N/D	5.4	8,107	4	2.2	1,505	5.2	NA	NA	NA
H	HPO-AS, PSA	5.5	12,168	2	1.5	2,220	60.0	22,124	4,023	55
I	HPO-AS, PSA	19.8	14,375	8	1.2	726	60.0	45,716	2,286	31
J	HPO-AS, Cryo	63.0	46,557	22	0.7	755	83.0	101,650	1,410	49
A1	TF	5.0	1,397	NA		279		4,892	978	29
C1	AAS	5.0	2,873	7		575		6,779	1,356	42
F1	AAS with N/D	5.0	4,640	6		928		9,631	1,926	48

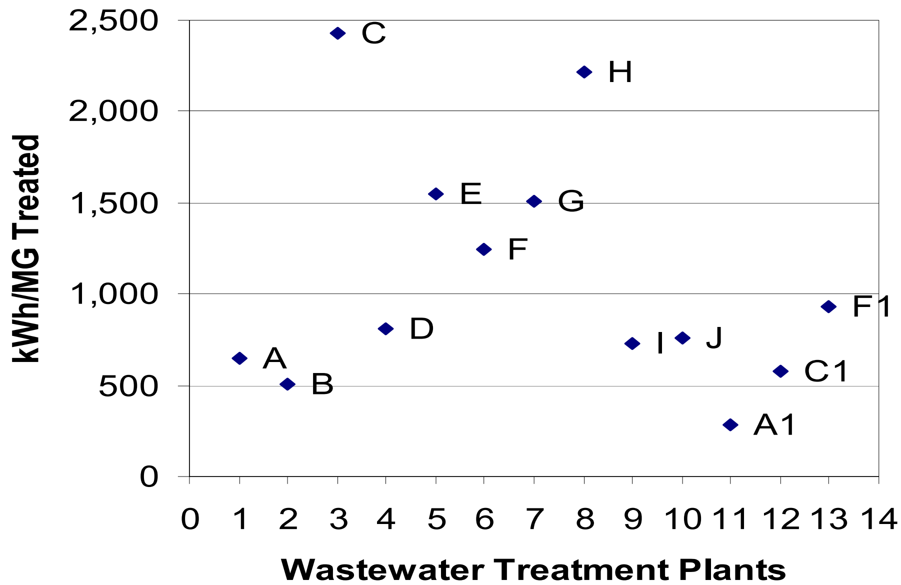
Note:
RBC - rotating biological contactor. AAS - air activated sludge. AAS with N/D - air activated sludge with Nitrification and Denitrification. HPO-AS PSA - high purity oxygen activated sludge, oxygen produced by pressure swing adsorption. HPO-AS Cryo - high purity oxygen activated sludge, oxygen produced by cryogenic process. TF - Trickling Filters.

(1) Wastewater treatment plants A1, C1 and F1 are generic plants. Reference [2] was the source of the data. No background information regarding the basis for reported values was provided.
(2) Energy used for secondary wastewater treatment unit process only, including return activated sludge pumping (RAS), waste activated sludge pumping (WAS) and mixed liquid pumping (ML).
(3) Energy used for RAS, WAS & ML is provided as a percentage of the previous column, energy used for the secondary treatment unit process.
(4) The % of total plant energy is low for this plant because the plant uses UV disinfection, which uses 21,020 kWh/day, approximately 23% of the electrical energy used by the plant.

Because some plants conduct limited BOD analyses, those parameters that utilize BOD results have a lower level of reliability for benchmark comparison. The parameters based on energy use and plant flow are expected to have the greatest reliability and comparability.

Excluding the three generic treatment plants, the energy used to process a million gallons of wastewater through a secondary treatment process ranged from a low of 508 to a high of 2,428 kWh/MG, as shown in Figure 3. For the generic treatment plants, the energy used to process a million gallons of wastewater through a secondary treatment process ranged from a low of 279 to a high of 928 kWh/MG. Fixed film processes had lower energy requirements while activated sludge processes had higher energy requirements. Plants C and H use a substantially larger amount of energy per million gallons treated than the other plants investigated.

Figure 3. Energy Used per Million Gallons Treated for the Secondary Treatment Process Only



As shown in Figure 4., the energy used per pound of BOD removed during secondary wastewater treatment ranged from a low of 0.4 to a high of 2.2 kWh/lb BOD removed. Again, the fixed film processes had the lower energy requirements and activated sludge processes had higher energy requirements. HPO-AS by PSA plants had a significantly higher energy requirement per pound of BOD removed than the HPO-AS by Cryo plant. Plants C, G and E use considerably more energy per pound of BOD removed than the other plants investigated.

Oxygen transfer efficiency (OTE) ranged from 4-20% for air activated sludge processes and 60- 83% for high purity oxygen activated sludge processes, as shown in Figure 5.

Figure 4. Energy Used per Pound of BOD Removed by Secondary Treatment Only

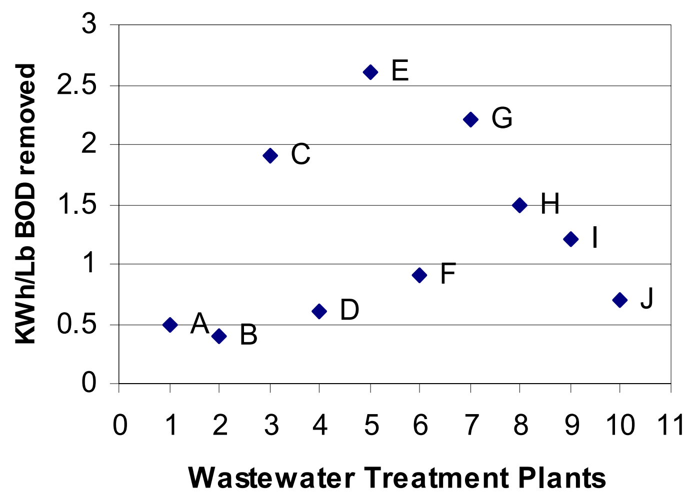


Figure 5. Oxygen Transfer Efficiency

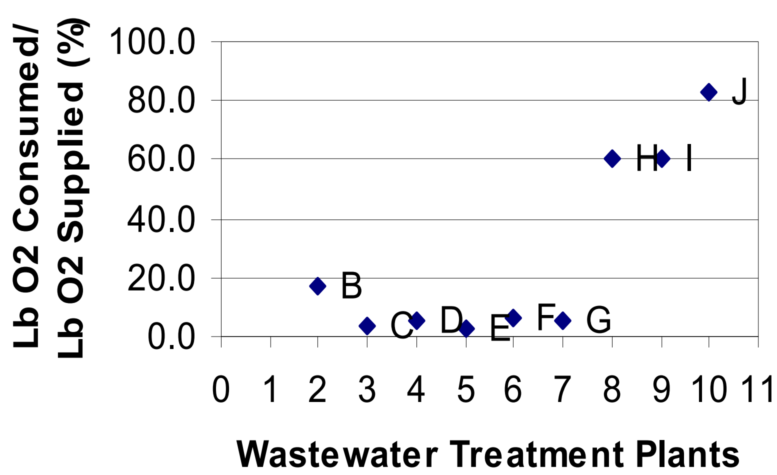
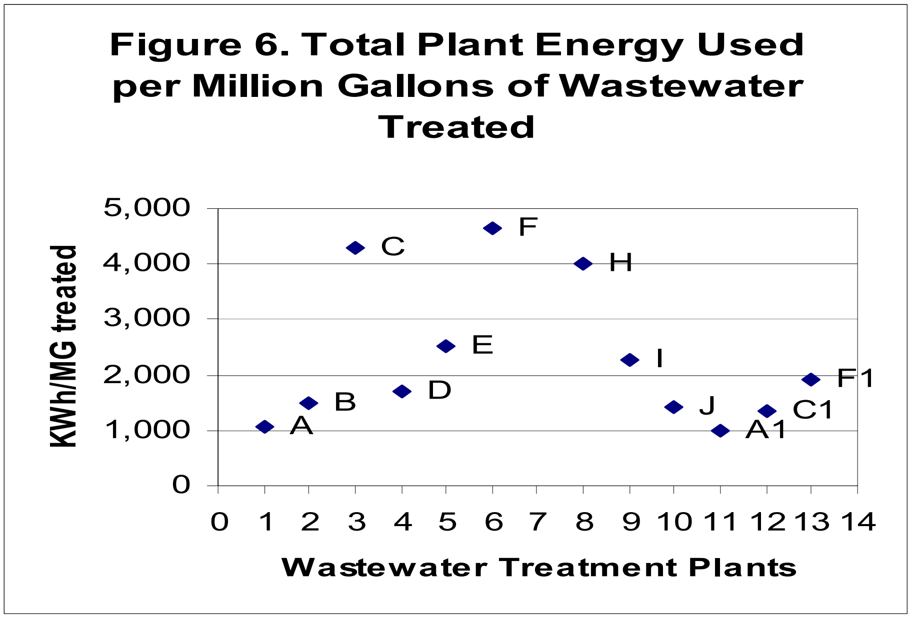
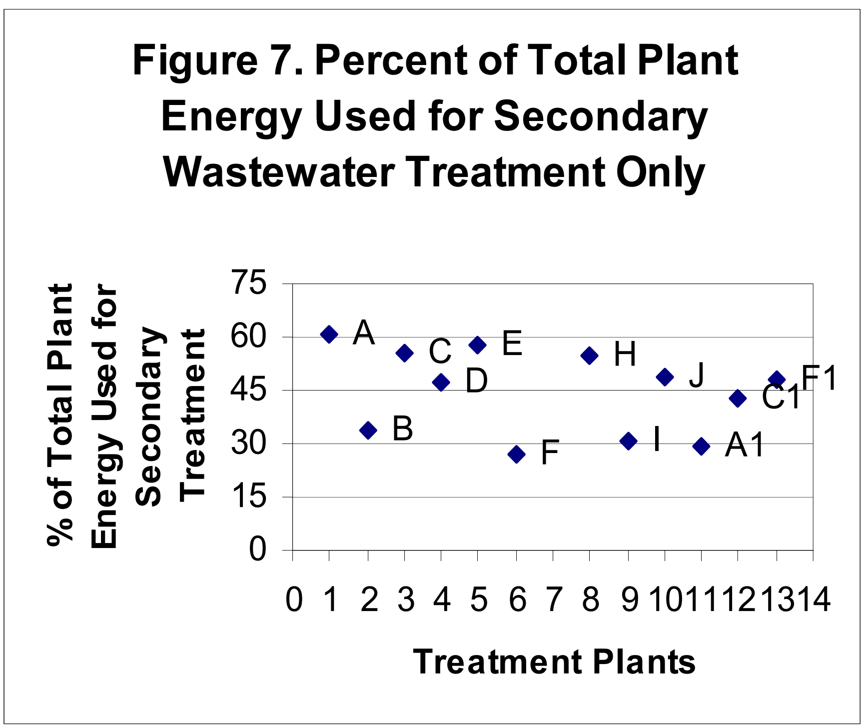


Figure 6 shows the total plant energy used per million gallons of wastewater treated. Plants C, F and H had substantially higher energy use than the other plants.



The secondary treatment process accounted for a low of 27% (for Plant F) to a high of 60% of total plant energy used, as shown in Figure 7. As noted previously, Plant F has nitrification and denitrification and uses UV for disinfection. These processes would account for the low percentage of total plant energy used by Plant F for secondary wastewater treatment.



<u>Summary of Benchmark Parameter Results and Discussion</u>

The three benchmark parameters calculated were energy used per pound of BOD removed (kWh/lb BODr), energy used per million gallons of wastewater treated (kWh/MG) and oxygen transfer efficiency

(OTE).

Table 4. Benchmark Parameters and Energy Use Factors for Total Plant Operations

Parameters	Range of Values	
	Observed	Generic
Energy (1) /lb BODr (kWh/lb BODr)	0.4 - 2.6	
Energy (1) /MG treated (kWh/MG)	508 - 2,428	279 - 928
OTE (%)	2.6 - 83	
Electrical Use for Total Plant Operations (kWh/MG)	1,073 - 4,630	978 - 1,926
% of Total Plant Energy Used for Secondary Treatment Only (%)	27 - 60	29 - 48

(1) Energy usage for only the secondary wastewater treatment process

Plants C had high energy usage per million gallons of wastewater treated for the secondary treatment process, high energy usage for the total plant per million gallons of wastewater treated and relatively high energy used per pound of BOD removed by secondary treatment. Although the effluent BOD concentration is very low, a more detailed evaluation of the equipment, process control and operations of Plant C appears warranted.

Plant H had high energy usage per million gallons of wastewater treated for the secondary treatment process. In addition, the Plant has a high BOD effluent concentration from the secondary treatment process. For these reasons, a more detailed evaluation of the equipment, process control and operations of Plant H appears warranted.

Plants E and G had high energy usage per pound of BOD removed by secondary treatment. Although Plant E has restrictive NPDES permit limits for BOD and TSS effluent concentration, a more detailed evaluation of the equipment, process control and operations at those plants appears warranted.

Plant F had high total plant energy usage per million gallons of wastewater treated. However, Plant F has restrictive NPDES permit limits for BOD and TSS effluent concentrations and a very restrictive limit for disinfection requirements. An ultraviolet treatment system is used to achieve the very high level of disinfection required by the NPDES permit. Based on the very high levels of wastewater treatment required at Plant F, the level of energy use appears reasonable.

In general, fixed film processes (RBCs and bio-towers) were more energy efficient than activated sludge processes. This observation is supported by the values reported in literature and by the information about the generic plants. Subsequent efforts to refine energy benchmarking the secondary wastewater treatment process could obtain information on a larger sample of treatment plants and thus produce a better understanding of the energy usage by the various secondary treatment options.

Energy Benchmarking UV Disinfection Processes

A site investigation of the UV disinfection process at two wastewater treatment plants was conducted. Extensive information was obtained about each treatment plant, including flow and loading to the plant, unit processes employed, equipment used for UV disinfection, plant performance data, NPDES effluent permit requirements and energy use data. Information about five additional treatment plants that utilize UV disinfection is included in this discussion, also. The information about those plants was drawn from the report, "Assessment of Operation and Maintenance Costs for Ultraviolet Disinfection Systems", presented at the Water Environment Federation Exposition and Conference in year 2000 [3]. The five plants in that study are located in the state of Washington.

Light in the wavelength range of 240 to 280 nm, particularly light having a wavelength around 254 nm, penetrates the cell wall of microorganisms and is absorbed by cellular material, including the DNA and RNA. The absorbed light changes molecular bonds within the DNA and RNA. Because the DNA and RNA carry genetic information for reproduction, if the microorganism is subjected to a sufficient dose of UV light, those portions of the DNA and RNA which regulate reproduction will be damaged and the microorganism will not be able to reproduce. A microorganism that is incapable of reproduction is generally considered to be ineffective and no longer poses a health concern to humans. A larger dose of UV light can cause the organism to die. A more detailed description of the mechanism by which UV light causes disinfection can be found in reference [4].

The principal types of UV systems can be classified as 1) monochromatic low-pressure low intensity, 2) monochromatic low-pressure high intensity, and 3) polychromatic medium-pressure high intensity. In addition to the types of UV systems available, there are several other variables that impact the performance of UV systems, including:

- output spectra of the lamp: lamps of the same principal type but produced by differing manufacturers produce different spectra
- lamp age: as a lamp ages, the output of the lamp declines
- extent of algae growth and mineral deposits on the sleeve surrounding the lamp: usually, the UV lamp is enclosed in a transparent quartz sleeve, and it is the sleeve which is in contact with the wastewater
- water quality parameters, such as amount and size of suspended particles, turbidity and heavy metals concentration, in particular, iron concentration: particles can shade microorganisms from UV light, hence, reducing the effectiveness of the UV dose in achieving disinfection
- mechanism for controlling the UV dose: methods of control range from manual startup & shut-down of lamps at the bank level to automated control systems with adjustable power levels based on continuously monitored parameters
- the indicator microorganism used in assessing the degree of disinfection: Fecal Coliform, Total Coliform and Enterococci are the principal microorganisms used by regulatory agencies as the indicator for assessing disinfection performance. However, the same dose of UV light produces differing levels of disinfection on those microorganisms.

Additional information about the factors affecting the UV disinfection process can be found in references [5] and [6].

Information is provided in Table 5 about the two plants located in California (Plants AA and BB) and the five plants located in Washington (Plants CC to GG). Additional information about Plants AA and BB is also provided in Attachment B. All seven plants are publicly-owned treatment plants serving primarily residential populations with some commercial and industrial loads. Plant BB has a very restrictive NPDES effluent permit requirement of 2.2 MPN/100 ml of Total Coliform as a 7-day median value. All the other plants have a much less stringent effluent permit requirement. All the plants were operating at less than their design capacity at the time of data collection.

Table 5. Key Characteristics of the Treatment Plants Evaluated - UV Disinfection Benchmark Study

WWTP	Avg Annual Plant Flow (MGD)	Secondary Treatment Process	Treatment Subsequent to Secondary Treatment	Type of Equipment for UV Disinfection	Layout of UV Equipment	NPDES Permit Requirements (1) (MPN/100 ml)	UV System Control
AA	43	AAS	none	Low pressure, low intensity, horizontal	2 basins: 3 channels/basin: 3 banks/channel	Max. 30 day log mean value: 200 FC	Manual, "On" or "Off", no turn down
BB	19.4	AAS with N/D	Anthracite filter	Medium pressure, high intensity	3 channels: 2 reactors/channel: 2 banks/reactor	**7-day median value: 2.2 TC Daily max. 23 TC**	Programmable controller with turn-down
CC	3	AAS	none	Low pressure, horizontal	2 channels: 2 banks/channel	Monthly geometric mean: 200 FC	1 bank used normally, 2nd bank for peak flow
DD	1.8	RBC	none	Low pressure, vertical	2 channels: 4 modules/channel	Monthly geometric mean: 200 FC	Constant power used
EE	3.6	AAS	none	Medium pressure, high intensity, open channel	2 channels: 2 banks/channel	Monthly geometric mean: 200 FC	Flow paced
FF	5.3	AAS	none	Medium pressure, high intensity, open channel	1 channel: 2 banks always in operation	Monthly geometric mean: 200 FC	Flow paced at higher flow
GG	0.4	Oxidation Ditch	none	Medium pressure, high intensity, in-vessel	2 vessels, 4 lamps/vessel	Monthly geometric mean: 200 FC	Flow paced at higher flow

(1) FC is used as the abbreviation for Fecal Coliform. TC is used as the abbreviation for Total Coliform.

Operation and Performance of the UV Disinfection Processes

Operation and performance information regarding the disinfection process at each plant is provided in Table 6.

Table 6. Plant Operations and Performance Data

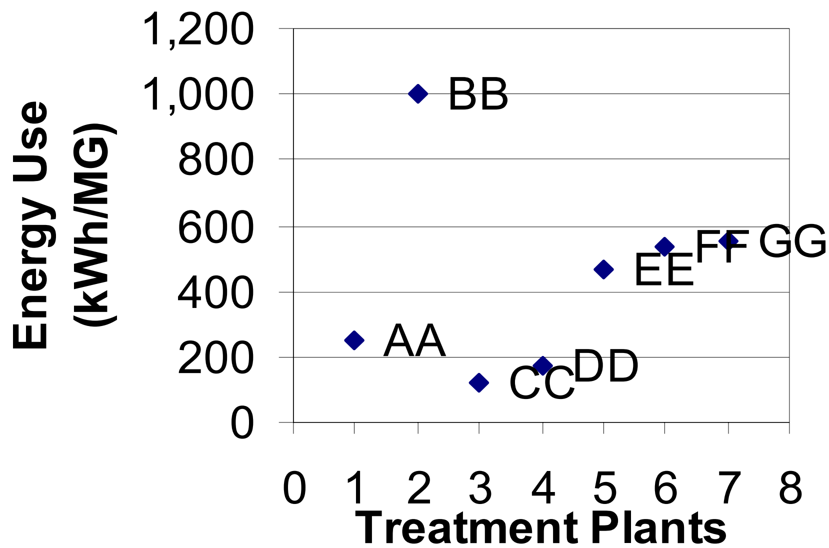
WWTP	Flow to UV System (MGD)	Coliform Concentration after disinfection (MPN/100 ml)	Effluent TSS (mg/l)	Lamps Changed after __ Hours of Operation	Energy Used for UV Disinfection (kWh/d)	Energy Used per MG Disinfected (kWh/MG)	Energy Used for Total Plant Operations (1) (avg kWh/d)
AA	43	60 FC	8	12,000	10,743	250	76,992
BB	21	<2 TC	1	5,000	21,020	1,001	89,813
CC	2.8	4 FC	5	13,000	328	117	
DD	1.4	100 FC	7	9,000	239	171	
EE	3.4	15 FC	9	5,000	1,579	464	
FF	3.8	1.4 FC	3	5,000	2,038	536	
GG	0.3	NA	NA	11,000	167	557	

(1) Note: Plant AA uses steam drive for blowers supplying air for secondary treatment, thus lowering its total plant electric energy usage.

Benchmark Parameters

The energy used for UV disinfection ranged from a low of 117 kWh per million gallons disinfected to a high of 1,001 kWh per million gallons disinfected. UV disinfection accounted for 14% and 23% of the total electrical usage at the two California plants investigated. Figure 8 shows the energy used for disinfection per million gallons treated at each of the plants.

Figure 8. Energy Used for UV Disinfection (kWh/MG)



Discussion of Performance Parameters

Table 7 provides a summary of key information and parameters relevant to UV disinfection at the seven treatment plants.

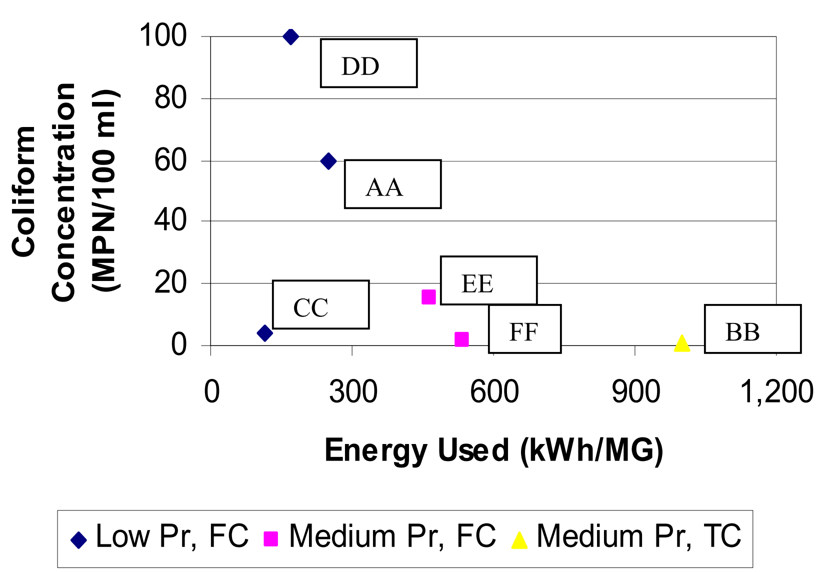
Table 7. Summary of Key Information and Parameters

WWTP	Avg Annual Plant Flow (MGD)	Secondary and other Treatment Processes	Plant Effluent TSS (mg/l)	Type of Equipment for UV Disinfection (Pressure)	Max. Lamp Hours	UV Dose Control System	Effluent Coliform Concentra-tion (MPN/ 100 ml)	Energy Used/ MG Disinfected (kWh/MG)
AA	43	AAS	8	Low	12,000	On/off	60 FC	250
BB	19.4	AAS & ND with Anthracite Filtration	1	Medium	5,000	Program-able Controller	<2 TC	1,001
CC	3	AAS	5	Low	13,000	On/off	4 FC	117
DD	1.8	RBC	7	Low	9,000	Constant	100 FC	171
EE	3.6	AAS	9	Medium	5,000	Flow Paced	15 FC	464
FF	5.3	AAS	3	Medium	5,000	Flow Paced at High Flow	1.4 FC	536
GG	0.4	Oxidation Ditch	NA	Medium	11,000	Flow Paced at High Flow	NA	557

The energy used for disinfection ranged from 117 to 557 kWh per million gallons treated when meeting disinfection limits of 200 MPN/100 ml of Fecal Coliform. When complying with an NPDES effluent permit requiring a very high level of disinfection of Total Coliform, energy use of 1,001 kWh per million gallons treated was required, even though the plant had an effluent TSS concentration of 1 mg/l and uses an automated control system to adjust the energy used for disinfection based on flow and transmittance.

Plants AA, CC and DD are low pressure UV systems with no automated turndown control. Plants EE and FF are both medium pressure UV systems with some automated turndown control. If all other factors were equal, the plants with automated turn-down should be more energy efficient, however, Plants AA, CC and DD use considerably less energy for each million gallons of wastewater treated than Plants EE and FF. Plants AA, DD and EE had similar effluent TSS concentrations. Plant EE had considerably lower effluent Fecal Coliform concentration, however considerably more energy was used. Plants CC and FF had similar effluent TSS concentration. Although Plant FF had a slightly lower effluent Fecal Coliform concentration, Plant FF used considerably more energy. Figure 9 shows the above information in graphical form. (Plant GG is not included in the graph since effluent Coliform concentration and effluent TSS were not available.)

Figure 9. Coliform Concentration as a Function of Energy Used for Disinfection



It is inappropriate to draw a definitive conclusion regarding the comparative energy efficiency of low vs. medium pressure UV systems from the limited data in this report. However, comparing similar facilities, Plant CC with Plant FF indicates the low pressure system is more energy efficient than the medium pressure system. In the literature, it is reported that low pressure lamps are more efficient than medium pressure lamps [6].

The graph of coliform concentration as a function of energy used for disinfection, shown in Figure 9 suggests that UV disinfection performance is not a linear function of the applied energy. An increasing amount of energy appears to be needed in order to obtain successive reductions in microorganism concentration. This observation is supported by findings in the report “Recent Developments in Ultraviolet Disinfection” [7]. The above conclusion is also supported by the findings in the report “Investigation of Energy Use and Disinfection Performance at a Wastewater Treatment Plant” provided in Attachment C.

The energy used for UV disinfection ranged from 117 to 557 kWh per million gallons treated when meeting disinfection limits of 200 MPN/100 ml of Fecal Coliform. When complying with an NPDES effluent permit requiring a very high level of disinfection, 2.2 MPN/100 ml of Total Coliform, energy use of 1,001 kWh per million gallons treated was required, even though the plant had an effluent TSS concentration of 1 mg/l and uses an automated control system to adjust the energy used for disinfection based on flow and transmittance.

A "Back-of-the-Envelope" calculation was prepared to provide a comparison of the energy required for a chlorine/hypochlorite and dechlorination process compared to the energy used by an ultraviolet disinfection process. The analysis is included in Attachment D of this report. On a global energy basis, it appears that UV disinfection can be competitive with chlorine/hypochlorite disinfection and dechlorination.

References:

[1] California Energy Commission (1990) *The Second Report to the Legislature on Programs Funded Through Senate Bill 880.* PL 400-89-006.

[2] Kennedy, T., et.al., *Energy Conservation in Wastewater Treatment Facilities*, Water Environment Federation Manual of Practice No. MFD-2, 1997. pg 6-9.

[3] Swift,J., Wilson, J.k et.al. *Assessment of Operation and Maintenance Costs for Ultraviolet Disinfection Systems*, Presentation at the Water Environment Federation Exposition and Conference (WEFTEC), 2000.

[4] Darby, J., Heath, M., et.al. *Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance*, Water Environment Research Federation, Project 91-WWD-1, 1995.

[5] *Disinfection 2000: Disinfection of Wastes in the New Millenium*, Proceedings from the Water Environment Federation Conference March 15-18, 2000, New Orleans, LA.

[6] Water Environment Federation, Manual of Practice FD10, 1996.

[7] Tchobanoglous, G., Emerick, R., et.al., *Recent Developments in Ultraviolet Disinfection*, Presentation at the USEPA 6th National Drinking Water and Wastewater Workshop, August 2-4, 1999, Kansas City, MO., August 2-4, 1999.