Energy-Efficient Wastewater Treatment at Hilmar, California: A Case Study

F. Bailey Green, Tryg J. Lundquist, and Richard E. Brown,
Lawrence Berkeley National Laboratory

ABSTRACT

Hilmar County Water District is a small rural water utility in the Central Valley of California that provides water supply, wastewater and storm drainage services to a population of about 5,000 water customers. The service population is expected to double over the next fifteen to twenty years. Seven years ago, the Hilmar County Water District began planning for a new wastewater treatment facility to replace the existing plant that was constructed in the early 1960s. In considering a range of wastewater treatment technology options, the District carefully considered capital costs, life-cycle costs, process performance and ease of operation.

Electricity use and cost data were collected from billing records for each of the fifteen electricity billing records for the Hilmar County Water District starting beginning in July 2003 when the new WWTF was commissioned. Electricity use and electricity costs and average flows treated over monthly billing periods were used to calculate an electrical energy use intensity (kWh/MG) and an electricity cost intensity (EE$/MG) for the Hilmar WWTF during its first two years of operation.

This water enterprise case study describes the Hilmar County Water District facilities and services and the WWTF in particular and explains why the AIWPS® Technology is less energy intensive than most conventional wastewater treatment technologies. And if methane-rich biogas produced during primary treatment at the Hilmar WWTF were collected at some future date and used for power generation, the electrical energy intensity would approach zero for secondary treatment. Should irrigation reuse be implemented at some future date, the Hilmar WWTF could be easily upgraded to advanced tertiary treatment with no additional land and would require only a fraction of the electrical energy required for conventional tertiary wastewater treatment. The Hilmar case study illustrates one option for more energy-efficient wastewater treatment and water reclamation and how such options can improve the overall energy and life-cycle efficiency of the water enterprise thereby enhancing the sustainability of communities.

Introduction

The Hilmar County Water District (District) provides water, wastewater and stormwater drainage services to approximately 5,000 people who live in the community of Hilmar. Hilmar is located in Merced County in the San Joaquin Valley of California. The District provides drinking water services to its customers through 1,540 drinking water connections and wastewater services through 1,370 sewer connections. Most connections are single family residences. There are two mobile home parks, a school, and a handful of commercial connections. There is no industry within Hilmar, other than Hilmar Cheese, that has its own wastewater treatment facility that does not discharge its effluent into the Hilmar sewer system.

Hilmar's water supply facilities consist of three wells and drinking water pumping stations with chlorine disinfection prior to distribution. The wastewater system includes the network of sewers, three lift stations and two forced main pumping stations. The wastewater treatment and disposal facility provides advanced treatment more complete than conventional secondary treatment although it is categorized as a secondary treatment plant. Wastewater disposal facilities consist of five Percolation Beds into which treated effluent is discharged and from whence it recharges groundwater. The stormwater drainage system includes storm sewers and three storm drainage pumping stations that pump storm drainage into local irrigation canals during winter rainfall events. Adding the electrical meters at the District's office and maintenance shop and the operations building at the WWTF site, there are fifteen electrical meters.

The water supply services provided by the Hilmar County Water District are regulated by the State of California Department of Health Services (DHS). Wastewater and storm drainage services are regulated by the State Water Resources Control Board (SWRCB) and the Central Valley Regional Water Quality Control Board (RWQCB). Final disposition of residual wastewater biosolids produced at the Hilmar Wastewater Treatment Facility (Hilmar WWTF) are regulated by the U.S. Environmental Protection Agency (EPA), Region 9. In the case of the Hilmar WWTF and the AIWPS® Technology, due to the more complete anaerobic digestion and methane fermentation of the primary solids, the only residual biosolids are microalgae. And these algal biosolids have been given Class A biosolids equivalency under 40 CFR 503.32 (a)(8) by U.S. EPA, Region 9 and they can be used as crop fertilizer and soil amendment in the surround agricultural land after sufficiently long on-site storage period of two years (U.S. EPA 1997).

Seven years ago, the Hilmar County Water District began planning to replace its existing WWTF that was constructed in the early 1960s and whose capacity was insufficient to meet present and future needs. In considering alternative wastewater treatment technologies, the District wanted an affordable and reliable technology that would be simple to operate. Based on the recommendation of the District Engineer, the District selected a proprietary technology developed at the University of California, Berkeley by Professor William J. Oswald. Advanced Integrated Wastewater Pond Systems® (Oswald 1990) have been proven over the past forty years of commercial application for residential developments, small towns and municipalities, farms and industries in California and elsewhere (Oswald 1990; Oswald 1995). Advanced Integrated Wastewater Pond Systems® have proven to be more cost effective and more energy efficient than most, if not all, conventional wastewater treatment technologies because as engineered natural systems they optimize ambient-temperature anaerobic digestion culminating with methanogenesis, stable methane fermentation, and because they utilize microalgae to evolve oxygen from water and accelerate oxidation and the removal of nutrients (Oswald 1960; Green et al. 1995; Green et al. 1996).

The first municipal WWTF in California that was designed by W.J. Oswald to provide simple yet advanced anaerobic primary treatment culminating in ambient-temperature methanogenesis followed by advanced secondary treatment with photosynthetic oxygenation and high-rate oxidation followed by secondary clarification followed by effluent storage prior to discharge was constructed at the City of St. Helena in the mid 1960s. Years later at the annual meeting of the American Society of Civil Engineers (ASCE) held in San Francisco in 1989, Professor Oswald presented a paper that described his classical series of four, uniquely designed pond types and named his wastewater treatment technology "Advanced Integrated Wastewater Pond Systems" (1990). Since the mid 1960s several other municipal wastewater treatment facilities have built using the AIWPS® Technology by small- and medium-sized towns and cities, as well as planned residential developments. Each of these WWTFs has operated without an accumulation of residual sludge biosolids avoiding the operational requirement and cost of sludge handling, drying, transport and disposal. By optimizing methane fermentation and the more completion conversion of organic solids to biogas, the onerous and increasingly costly task of residual sludge biosolids management and disposal and the associated life-cycle environmental impacts are avoided by use of the AIWPS® Technology.

Figure 1. Maps of Hilmar and Merced County Showing the District Service Area and the Location of Hilmar County Water District's Drinking Water Wells (1, 2, 3), Sewer Lift Stations (5, 6, 7), Two Forced Main Pumping Stations (8, 9), and Storm Drainage Pumping Stations (10, 11, 12); the Hilmar WWTF (4) That Is Actually Located 2 Miles Southeast of Town

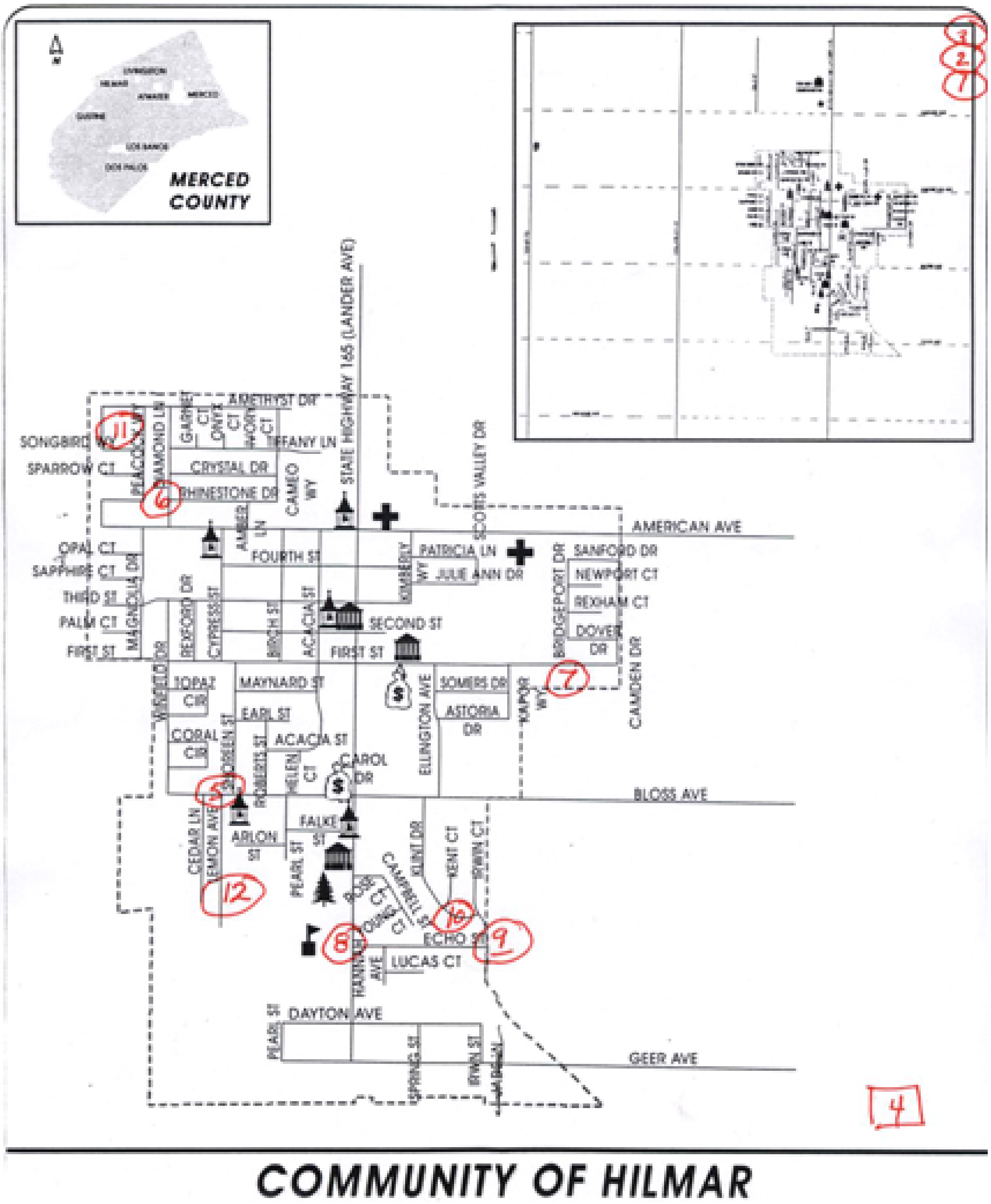
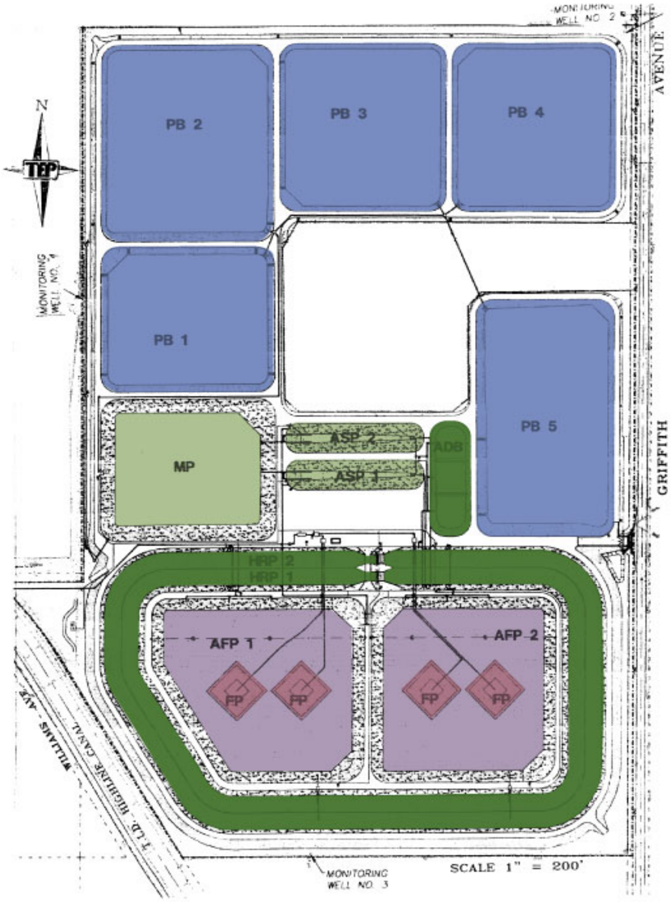
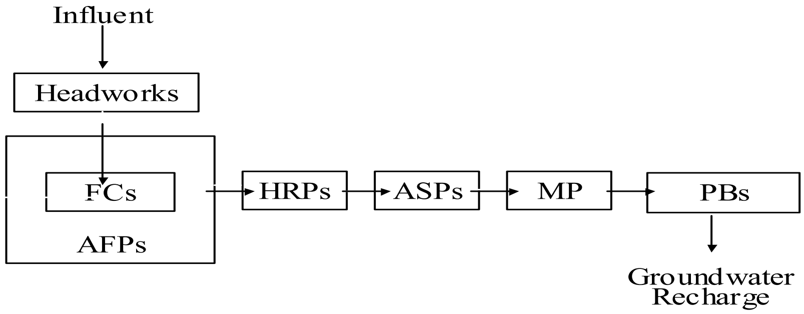


Figure 2. Layout of the Hilmar AIWPS® Wastewater Treatment Facility



In 1994, the Hilmar County Water District Engineer attended a three-day short course sponsored by the American Society of Civil Engineers (ASCE) entitled "Advanced Integrated Wastewater Pond Systems and Constructed Wetlands" that was given in over 50 cities around the United States between 1992 and 1995 by William J. Oswald, then Emeritus Professor of Civil and Environmental Engineering and of Public Health at the University of California, Berkeley. Intrigued by its inherent energy and ecological efficiency, its operational simplicity, its economy, and its novel sequence of multiple biological and physical-chemical processes, all well proven at several communities within California, the Hilmar District Engineer recommended to the District that they consider the AIWPS® Technology. Oswald Engineering Associates, Inc. was retained as the Process Engineer to provide system and process design for the new WWTF at Hilmar. Facility planning for the new Hilmar AIWPS® WWTF began in 1999. In 2000, the District purchased the land selected for the new facility. Final design was completed in early 2001, and construction was completed by mid 2003.

Figure 3. Process Schematic for the Hilmar AIWPS® WWTF Wherein the Treatment Sequence Is Primary Anaerobic Treatment in Fermentation Cells (FCs) within Advanced Facultative Ponds (AFPs) Followed by Secondary Aerobic Treatment in High Rate Ponds (HRPs) Followed by Algae Removal in Algae Settling Ponds (ASPs) Followed by a Single, Vertically-Baffled Maturation Pond (MP); MP Effluent Is Discharged to Pecolation Beds (PBs) Where It Recharges Groundwater

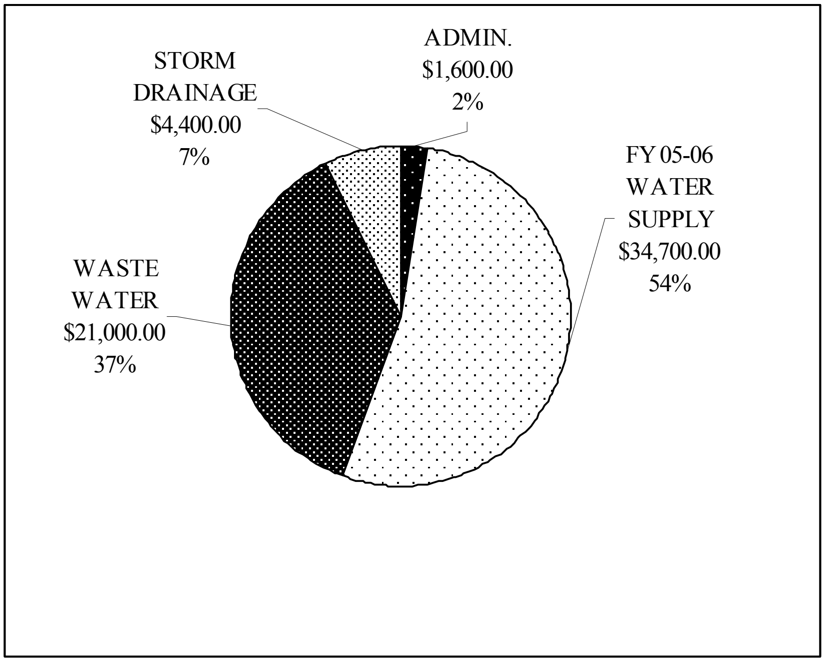


The level of treatment provided by the Hilmar AIWPS$^{®}$ WWTF is classified by the State of California and the RWQCB as a secondary treatment. However, the quality of its effluent in many respects is better than the effluent quality of most conventional secondary treatment processes. The Hilmar WWTF effluent is low in total nitrogen and nitrate-nitrogen and, by virtue of its gravity discharge into one of five Percolation Beds, it recharges groundwater and dilutes the background nitrate concentration in the "receiving" groundwater after infiltrating through approximately 20 feet of local sandy soil. Water reclamation and reuse for agricultural irrigation, or for residential landscape irrigation, whether secondary restricted reuse or tertiary unrestricted reuse, was not selected by the Hilmar County Water District largely due to the low cost of irrigation water provided by the Turlock Irrigation District. Unlike the cities, towns and communities of coastal and southern California, there is at present no market for reclaimed water in Hilmar. But in the future, the farms surrounding the Hilmar WWTF and the irrigation canal system by which they are currently irrigated are conveniently located to facilitate irrigation reuse.

Results

Since start-up, the energy intensity of the Hilmar WWTF has ranged from a lowest monthly average of 328 kWh/MG during September 2005, when solar insulation, temperature and algal growth were near their peak, to a highest monthly average of 2,919 kWh/MG during April-May 2005 and not as expected during winter when solar insulation, hours of sunlight and algal photosynthesis are most limited but rather during the transitional season of late spring. The average energy intensity of the Hilmar AIWPS$^{®}$ WWTF over a thirty month period since start-up was approximately 1,520 kWh/MG. The average annual electrical energy intensity of the Hilmar WWTF was 1,647 kWh/MG in 2004 and declined to 1,376 in 2005. One would expect this downward trend in electrical energy intensity to continue as the flow being treated at the Hilmar WWTF approaches the design capacity of 1 MGD. It should be noted that the thirty-month average electrical energy intensity of 1,520 kWh/MG corresponds with an average daily flow (around 0.45 MGD) slightly less than half of the treatment design capacity (1 MGD) and without on-site power generation from produced biogas. So as the average daily flow approaches the treatment design capacity of the Hilmar WWTF, the average energy intensity is expected to decrease to around 800 kWh/MG. With biogas recovery and on-site power generation at conservative internal combustion to electrical power conversion efficiencies of around 30%, the average monthly energy intensity of the Hilmar WWTF at present flows would be in the low hundreds of kWh/MG treated, and as the wastewater flow approaches the treatment design capacity, the Hilmar WWTF would approach zero net energy (Green et al. 1995). With biogas recovery and on-site power generation, and with improved energy management and process control, advanced tertiary treatment could be provided by the Hilmar WWTF with an average electrical energy intensity around 1,000 kWh/MG or less, and with advanced power conversion processes the average electrical energy intensity for advanced tertiary treatment could be reduced even further.

Figure 4. Percent of Total Electricity Use and Annual Electricity Costs for the Hilmar County Water District's Water Supply; Wastewater Collection, Treatment and Disposal; and Storm Drainage Services during Fiscal Year 05-06



In 2001, one of the early secondary wastewater and UV disinfection energy benchmarking reports was commissioned by the Pacific Gas & Electric Company (PG&E) and was prepared by SBW Consulting, Inc. of Bellevue, Washington (SBW Consulting, Inc. 2002). Ten municipal wastewater treatment plants (WWTPs) were included in the energy benchmarking study that focused primarily on secondary treatment and UV disinfection. Of the ten WWTPs studied, nine used the activated sludge process, or some variation thereof, including air activated sludge and pure oxygen activated sludge. The other WWTP used a Rotating Biological

Contactor (RBC) for its secondary treatment process in contrast with the mechanical aeration used in all of the activated sludge WWTPs. The RBC plant treated an average daily flow of 1.8 MGD and had an average total plant electrical energy intensity of 1,073 kWh/MG, the lowest energy intensity of the ten WWTPs studied. The nine activated sludge WWTPs treated average daily flows ranging from 1.8 MGD to 72 MGD, and their "total plant operations" electrical energy intensities ranged from 1485 kWh/MG to 4,630 kWh/MG. Only two of the nine activated sludge WWTPs included nitrification-denitrification for more complete nitrogen removal. And one of those two, a 19.4 MGD air activated sludge with nitrification/denitrification (AAS with N/D) had the highest "total plant" electrical energy intensity of 4,630 kWh/MG. The range in average electrical energy intensity for secondary and "total plant operations" that was established by the secondary energy benchmarking study was from 508 kWh/MG to 2,428 kWh/MG for secondary treatment alone, and from 1,073 kWh/MG to 4,630 kWh/MG for "total plant operations." For secondary treatment alone, the least energy intensive WWTP was a hybrid that combined air activated sludge with a fixed-film bioreactor or "trickling filter," referred to in the report as a Bio-tower with air activated sludge ("Bio-tower/AAS"). For "total plant operations" the least energy intensive WWTP was the RBC. The effluent requirements of the RBC WWTP are 10/10 mg/L of TSS/BOD and this 10/10 requirement was only matched by two other WWTPs in the PG&E benchmarking study; the other seven WWTPs' effluent standards were not as restrictive on TSS/BOD effluent concentrations allowing up to 30/30 mg/L and in one case 45/45 mg/L.

In comparison with the average energy intensities reported for the ten WWTPs included in the PG&E benchmarking study whose average daily flows ranged from 1.8 MGD to 72 MGD, the average energy intensity of Hilmar AIWPS® WWTF, even in least efficient first two years of operation, compares quite favorably. Only one of ten WWTFs surveyed--the 1.8-MGD WWTP that uses an RBC for secondary treatment--had an average energy intensity less than the present average energy intensity of the Hilmar WWTF. There is no discussion in the SBW benchmarking study of the period of time for which energy data were analyzed; nor is there any discussion of the energy use and energy costs for on-site handling and off-site disposal of residual sludge biosolids at these ten WWTPs. So "total plant operations" energy use and average energy intensities are actually lower than they would be if residual biosolids energy were included. Therefore, it is difficult to confirm that the RBC WWTF is actually more energy efficient, or as energy efficient, as is the Hilmar WWTF where there has been no accumulation of residual sludge biosolids and therefore no associated biosolids energy use for many decades to come.

While engineered natural systems such as the AIWPS® Technology used at Hilmar may be inherently more energy efficient, there are always opportunities to save energy through better process control. The largest single user of electricity at the Hilmar WWTF is the surface aerators used during winter months during the night for a period of four to eight hours per day. Due to daylight photosynthetic oxygenation at the surface of the primary ponds, supplemental mechanical aeration is only required during some of the hours of darkness.

Larger water utilities with greater infrastructure size and complexity are able to link an energy management system management with their process controls and SCADA systems. Some of these same energy management opportunities exist for small rural water utilities. For any WWTF with motors, adjustable speed drive or variable frequency drive (VFD) motor controllers can save significantly on electricity use. At Hilmar the 3-HP gear-reducing motors that turn the HRP paddle wheels at around 8 revolutions per minute are controlled by VFD controllers, and they allow the Hilmar WWTF Operators to adjust the rotational speed of paddle wheels more precisely to achieve the desired mean surface velocity. Two 60% load VFD controlled motors or around 4 HP is the total electrical energy use for secondary (and initial tertiary) wastewater treatment at the Hilmar WWTF. The best future energy management strategy for the Hilmar WWTF would be to better link nocturnal supplemental mechanical aeration at the surface of the primary ponds with improved dissolved oxygen probes and sensors. The next would be to capture the biogas emerging from the fermentation cells of the AFPs and to utilize this renewable energy resource on-site to generate combined heat and power (CHP) or at the Hilmar WWTF for algal biomass heat drying and pasteurization. If the District is able to recover biogas for its Advanced Facultative Ponds and in-pond digesters in the future, then the recovered methane-rich biogas would presumably be a tradable carbon credit.

In the coming decades, most secondary-level WWTFs in the United States will be upgraded to tertiary-level treatment, as a result of more stringent water quality, public health and environmental regulatory requirements. This move from secondary to tertiary treatment will increase and with conventional mechanical wastewater treatment technologies may even double the overall energy intensity of a particular WWTF. Furthermore, in the coming decades, many existing WWTFs will need to be renovated, upgraded, expanded or replaced in order to accommodate future growth, greater treatment capacity and higher effluent quality to permit greater water conservation through wastewater reclamation and recycling. WWTF renovations, upgrades, expansions, and replacements, even equipment replacements, all provide opportunities to improve energy efficiency.

Retrofitting the Hilmar AIWPS® WWTF to tertiary would increase, but not double, its overall energy intensity; however, if biogas collection and on-site power generation were included in the upgrade and plant expansion that will be needed over the next twenty years when Hilmar's population is expected to grow from 5,000 to 11,000 (Merced County 2006), then the overall energy intensity of the Hilmar WWTF, upgraded possibly to advanced tertiary-level treatment would most likely remain below 1,000 kWh/MG, further increasing its energy advantage over conventional advanced tertiary-level wastewater treatment processes that require as much as 5,000 kWh/MG. With biogas collection and advanced tertiary-level treatment, the average energy intensity of the AIWPS® Technology would be between one-third and one-tenth the average energy intensity of most conventional technologies. This Hilmar case study illustrates how greater energy efficiency in municipal wastewater treatment can enhance the sustainability of communities by protecting and conserving increasingly scarce water and energy resources.

Approximately 107 billion kWh of electricity, roughly three percent of annual U.S. electricity sales, were used in the municipal water and wastewater sectors during 2004, and electricity use in this sector is expected to grow to 120 billion kWh over the next four years (Carns 2005). As energy prices continue to rise, demand for water and sanitation services continues to increase, and as regulatory requirements for higher quality potable water and higher quality treated wastewater or reclaimed wastewater continue to increase, it will be necessary to deploy more energy-efficient wastewater collection, treatment and disposal/reuse equipment, processes, technologies, systems and facilities in the municipal water and wastewater sectors, and also in the agricultural and industrial water and wastewater sectors. The need for more energy-efficient water and wastewater services is especially acute in developing countries where over 1 billion people live without safe drinking water supplies and over 2 billion number live without access to adequate sanitation.

One such energy efficient wastewater treatment technology has been developed at the University of California at Berkeley over the past fifty years. The Advanced Integrated Wastewater Pond Systems® Technology uses simple, economical earthwork reactors (ponds) and a scientifically derived sequence of naturally occurring biological and physical-chemical processes to optimize primary treatment, anaerobic digestion and methane fermentation of primary sewage solids, and secondary treatment using solar energy and microalgae grown symbiotically with aerobic and facultative bacteria to oxygenate wastewater and oxidation and nutrient removal by algal assimilation.

Today, with Hilmar's anticipated population growth, the average daily flow into the Hilmar WWTF is steadily approaching the presently permitted discharge capacity (not treatment capacity) of 0.55 MGD. The Hilmar WWTF effluent disposal capacity is based on the Percolation Bed disposal area, the local soils and the measured infiltration and groundwater recharge rates. Therefore, facility planning may be initiated in the not-too-distant future to expand the disposal capacity and eventually the treatment capacity of the Hilmar WWTF to meet the future population projected for Hilmar by the Merced County Planning Department of 11,000 persons by 2021 (Merced County 2005). Secondary-level reclamation for restricted irrigation reuse and advanced tertiary-level reclamation for unrestricted irrigation reuse, more common among communities and cities located in the coastal regions of California, are once again being reconsidered by the District. But even with the additional energy that would be used for advanced tertiary-level treatment, the AIWPS® Technology has been proven to be significantly less expensive to build and less energy intensive to operate as compared with conventional wastewater technologies such as activated sludge, extended-aeration activated sludge, aerated lagoons, and the newer membrane bioreactors or biological nutrient removal processes that also provide tertiary treatment but with significantly higher capital costs, significantly higher operational costs and significantly greater operational complexity.

The shallow groundwater in this area of the San Joaquin Valley has elevated concentrations of salt and nitrate, and thus the recharge from the Hilmar WWTF actually improves the quality of the local groundwater quality by lowering the concentration of nitrate nitrogen. Water recycling for agricultural irrigation in adjacent fields and orchards, or for landscaping irrigation in future residential developments that are near the Hilmar WWTF, whether secondary “restricted” reuse or advanced tertiary “unrestricted” reuse, would only slightly increase energy use and operational costs at the Hilmar WWTF, and it would ease the growing demand for new water supplies as Hilmar continues to grow. It would also improve water use efficiency and save energy now used to pump, chlorinate and distribute additional potable water resources presently use to irrigate residential landscape, playgrounds, parks and recreational open spaces with the community.

Discussion

Over the past two plus years, the electrical energy intensity of the Hilmar WWTF has ranged between a lowest monthly average of 328 kWh/MG in late summer, the peak solar insulation, temperature and algae growing season, to a highest monthly average of 2,919 kWh/MG. The thirty-month average energy intensity of the Hilmar WWTF is approximately 1,520 kWh/MG. The annual average energy intensity of the Hilmar AIWPS® WWTF has decreased from 1,647 kWh/MG in 2004 to 1,376 kWh/MG in 2005. As expected, the average energy intensity has decreased as the average daily flow has increased approaching the treatment design capacity when the Hilmar WWTF will achieve its optimal energy efficiency and its lowest energy intensity. Since the average daily flow into the Hilmar WWTF is still around 0.45 MGD or 45% of its treatment design capacity, at an average daily flow of 1 MGD its average energy intensity should decrease to around 750 kWh/MG. Again, this optimal average energy intensity is estimated without the recovery of biogas produced during primary treatment and without its use for on-site power generation. With biogas recovery and on-site power generation, the net energy use for advanced secondary treatment using the AIWPS Technology might well be near net zero energy or even slightly negative net energy. The electricity use, cost and energy intensity of wastewater treatment at the Hilmar WWTF is significantly less than the electricity use, cost and energy intensity of wastewater collection at Hilmar. The three wastewater lift stations and the two wastewater forced main pumping stations have a total of five pumping station and a total 55 HP; whereas the Hilmar WWTF has a total of four surface aerators and a total 20 HP for supplemental surface aeration of the primary AFPs. The Hilmar WWTF also has two 3-HP gear reducing motors to power the HRP paddle wheels and a couple of small pumps that provide recirculation from the HRP to the AFPs, decanting of the ASPs and transferring the settled algal biosolids to the Algae Drying Beds. Total District electricity use and costs and the fraction for each of its three major categories of water services are shown in Figure 2.

A period of approximately twenty (20) 8-hour operator days per year are required for residual algal biosolids handling, drying and storage. This period of approximately twenty 8-hour operator days includes the time devoted to the quarterly harvesting of settled algal solids from each of Hilmar WWTF's two Algae Settling Ponds (ASPs) by pumping (decanting) the ASP supernatant back to the surface of the AFPs and then pumping the settled algal slurry to one of four Algae Drying Beds (ADBs), where the algal biosolids are then dried by the sun over a period of spring, summer or fall days to winter weeks depending on season and local precipitation. Then these dried algal biosolids, as specified by the Class A Biosolids equivalency requirements, are removed from the ADBs and stockpiled on-site for a period of two years to insure the die-off of any associated sewage pathogens before they are utilized either on-site, or off-site in neighboring farmland, as a nitrogen-rich, slow-release plant fertilizer and soil conditioner.

Herein lies a significant distinction and ease of operation difference between the AIWPS® Technology that requires little or no electrical energy to dry, store, transport and land apply its residual algal biosolids as compared with more conventional wastewater treatment technologies for which residual biosolids handling and drying are required on a daily basis, and for which transporting, disposal or land application of these residual sludge biosolids is a daily, weekly or monthly requirement. The energy, operational and management requirements of residual sludge biosolids and their associated life-cycle environmental impacts are often omitted from a WWTF energy audit and energy intensity analysis. Therefore, if these energy use requirements for residual sludge biosolids management are included, the AIWPS® Technology will prove to be 2 to 10 times more energy efficient and with significantly lower energy and environmental impacts and costs, as compared with most conventional wastewater treatment technologies.

The District's drinking water supply services consume 56% of the District total electricity consumption. The District wastewater services consume 42% of the total (12% by wastewater collection and 30% by wastewater treatment). Stormwater drainage consumes around 1% of the total as do the administration facilities.

The AIWPS® Technology used at the new Hilmar WWTF uses a patented method to optimize sedimentation and methane fermentation of primary solids in primary wastewater treatment ponds known as Advanced Facultative Ponds (AFPs). These AFPs remain odorless due to the recirculation of secondary effluent containing abundant dissolved oxygen and microalgal concentrations from the High Rate Ponds to the surface of the AFPs. AFPs with their uniquely designed in-pond digesters and submerged biogas collectors also offer an opportunity to recover methane-rich biogas, to generate power on-site and to prevent a potent and controllable anthropogenic GHG emission. Finally, AFPs remove between 60% and 80% of the influent organic load, and there are virtually no biodegradable primary biosolid residuals, no sludge, to be removed, processed, dried, transported and disposed; sludge bioconversion to methane-rich biogas is sufficiently complete in the AIWPS® Technology that on-site sludge handling, sludge drying and off-site sludge transport and disposal have not been required for many decades. However, residual algal biosolids removed from AIWPS® WWTFs are easy to dry, store and utilize on-site or off-site without significant energy or operational expenditures.

Conclusions

As fossil energy resources become more scarce, their environmental impacts more pronounced and their price continues to rise, and as the demand for increasingly scarce water resources also continues to increase with population growth, and as the realities of climate change become more widely recognized, interest in the fundamental connections between water and energy is growing (Green 1995; Burton 1996; CEC 2005; Carns 2005; Elliott 2005; U.S. EPA 2005). Sustainable communities need both energy-efficient and more carbon-neutral water and wastewater technologies, infrastructure and services and water-efficient energy infrastructure and services at the least life-cycle cost and environmental impact. Presently, we consume just over 100 billion kWh/year in the municipal water and wastewater sectors (Carns 2005). Over the next twenty to fifty years, we will need to replace most of our present water and wastewater infrastructure adding capacity and more complete treatment. And with water quality objectives and regulations increasing in the future, the energy intensity of the water and wastewater infrastructure and services can only increase; but with new and emerging technologies that are both more energy-efficient and carbon-neutral, more complete, higher quality treatment can be provided for a greater service population with less energy intensity and less environmental impact. Greater energy efficiency in the water sector, just as greater water efficiency in energy sector, will reduce carbon emissions and slow the rate at which we are changing our climate and approaching a tipping point of irreversible damage. If our cities, towns, communities are to become more sustainable in the future, they will need and must have better, more affordable, more energy-efficient and more carbon-neutral water and wastewater infrastructure and services.

Although some engineered natural systems and emerging wastewater treatment technologies such as the AIWPS® Technology may be inherently more energy efficient, there are always opportunities to save additional energy through improved operations, better process control and other developmental improvements. One of the most energy-efficient and carbon-neutral elements in the AIWPS® Technology is primary treatment in which upflow fermentation cells or in-pond digesters in deep primary ponds provide optimal sedimentation and more complete ambient temperature anaerobic digestion and methane fermentation of primary sewage solids. The recovery of methane-rich biogas (88% methane) using submerged collectors prevents its emission to the atmosphere, and the methane-rich biogas may be used for on-site power generation or some other on-site energy end use such as drying and/or heat-pasteurizing (disinfecting) microalgal biosolids for use as a protein-rich animal feed. This type of primary treatment using in-pond digester and submerged biogas collectors prevents the emission of a potent yet controllable GHG by recovering a renewable energy resource from wastewater. Another energy-efficient and carbon-negative element of AIWPS® Technology is its use of microalgae that in symbiosis with sewage bacteria can utilize CO_2 while providing photosynthetic oxygenation and nutrient assimilation.

A shift towards more sustainable environmental infrastructure that is more energy and water efficient and more carbon neutral wastewater treatment technologies can only help to slow and stabilize the rate of atmospheric carbon loading and climate change. The next two decades are also critical because the majority of municipal wastewater treatment facilities in the United States, secondary-level plants, will be upgraded to tertiary treatment. These upgrades to advanced tertiary wastewater treatment will increase the value of the reclaimed water safe for irrigation of public parks, school grounds, farms, urban greenbelts and other recreational open space. Water quality standards and the requirements of treatment will continue to stimulate WWTF upgrades to tertiary treatment. With conventional technology, tertiary treatment with full denitrification using an energy intensive bacterial process known as Biological Nutrient Removal (BNR) activated sludge based process nearly doubles energy use and cost. The move from secondary to tertiary treatment will increase significantly the energy intensity of conventional wastewater treatment infrastructure and services unless new and emerging technologies are implemented that are more energy-efficient, and more carbon-neutral, more affordable, easier to operate, in short, that provide better treatment at less cost and with less environmental impact. Upgrades, expansions, renovations, retrofits, even the replacement of equipment, all provide opportunities to improve energy management. Upgrading the Hilmar WWTF to advanced tertiary-level treatment using the AIWPS® Technology would increase the energy intensity of the treatment by the addition of physical chemical and mechanical tertiary processes such chemical coagulation, flocculation, suspended or dissolved air flotation, multi-media filtration and final disinfection. However, if methane-rich biogas produced during primary treatment is recovered for on-site power generation, then the overall energy intensity would most likely remain below the average energy intensity of conventional secondary-level wastewater treatment and would be far less than the energy intensity of conventional tertiary-stage wastewater treatment (Green et al. 1995).

The Hilmar WWTF case study illustrates how more energy efficient wastewater treatment can enhance the overall efficiency, life-cycle economy and environmental performance of the water enterprise and the sustainability of communities. By conserving energy, water, financial and human and environmental resources are conserved. The AIWPS® Technology is certainly not a new technology. It has been proven and refined over the past forty years of engineering research and application. It is affordable, more energy-efficient, and easier to operate; provides superior environmental performance; and has fewer life-cycle environmental impacts as compared with conventional energy intensive wastewater treatment technologies. With biogas collection from primary treatment and its unique use of microalgae to accelerate secondary and tertiary treatment and to utilize CO_2, the AIWPS® Technology provides an opportunity for communities to lower infrastructure costs, energy use and carbon emissions as compared with more conventional and more commonly used technologies. Yet, AIWPS® Process improvements continue to be made particularly with methods to enhance the removal, and beneficial use, of microalgae. As an engineered natural system, the AIWPS® Technology might be considered an emerging technology; or the demand and market for more energy efficient, ecologically efficient, and carbon-neutral technologies may be emerging. Whichever it is, whenever small towns, cities, rural water districts, planned residential developments up to larger cities and municipal water utilities certainly in the sunbelt states of the United States and most parts of the temperate subtropical and tropical regions of the world need to construct, replace, renovate, upgrade, expand or hybridize their wastewater treatment facility, the AIWPS® Technology offers an attractive and proven alternative to conventional systems. For wastewater design engineers, water district and water utility managers, community planners, energy utilities and managers, energy planners, rate payers and communities-at-large, all who embrace energy efficiency, water efficiency and greater environmental performance as essential components of sustainable communities, the AIWPS® Technology offers an opportunity to do more with less, to save energy and thus the water associated with the life-cycle of fossil-fuel derived power generation while providing a fundamental service that safeguards public and environmental health. What other wastewater treatment technology can provided advanced treatment and be so easily integrated into agricultural land, urban parks and greenbelts, planned residential developments combining the functionality of sanitation infrastructure with wildlife habitat and recreational open space?

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