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Indicators for Minimizing Energy Consumption and GHG Emissions at Wastewater Treatment Facilities

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Indicators for Minimizing Energy Consumption and GHG Emissions at Wastewater Treatment Facilities

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
In partial fulfillment of the
requirements for the degree of

Master of Science
in
Engineering

By

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Abstract

Wastewater treatment facilities around the world use significant amount of energy which contributes to large quantities of greenhouse gas (GHG) emissions. According to the U.S.EPA, nearly 3% of the USA's energy is used to treat wastewater. This consumption is increasing at faster rates with increase in population and regulations. Wastewater facilities use large number of pumps in their transfer stations, treatment plants, and effluent pump stations. All these pumps consume considerable amounts of energy.

This study presents a preliminary energy inspection of two facilities from Louisiana. This audit provides an inventory of the energy consumed for various activities like pumping, treatment, and discharge. This analysis helps the operators to identify the potential power consuming areas and optimize by adopting several energy conservation measures (ECMs). This study also involves the quantification of GHG emissions based on the energy consumption. The benefits of the study include minimizing energy and GHG emission.

Keywords:

Energy consumption, greenhouse gas emissions, Wastewater Treatment, Indicators for energy Optimization, Energy conservation measures, Total suspended solids, 5-day biochemical oxygen demand, Energy audits, Walk through process audit, and Energy resource mix.

Chapter 1: Introduction and Background

A wastewater collection and treatment facility is the most expensive capital structure in a community. According to the U.S. EPA, nearly 3% of the USA's energy is used to treat and move wastewater, and this consumption is increasing at faster rates. After labor, electricity is the largest operating cost for the wastewater treatment facility, comprising nearly 25 to 40% of the total operating cost. Pumping and aeration often account for about 75% of the total energy budgeted for a facility. There are several other units which cannot be stopped without compromising the level of treatment, but there are ways in which we can lower our energy usage. Medium to large wastewater facilities use a large number of pumps of various horse- powers in their lift/ transfer stations, treatment plant, and effluent pump stations to handle the raw sewerage or treated effluent. All these pumps consume a large amount of energy.

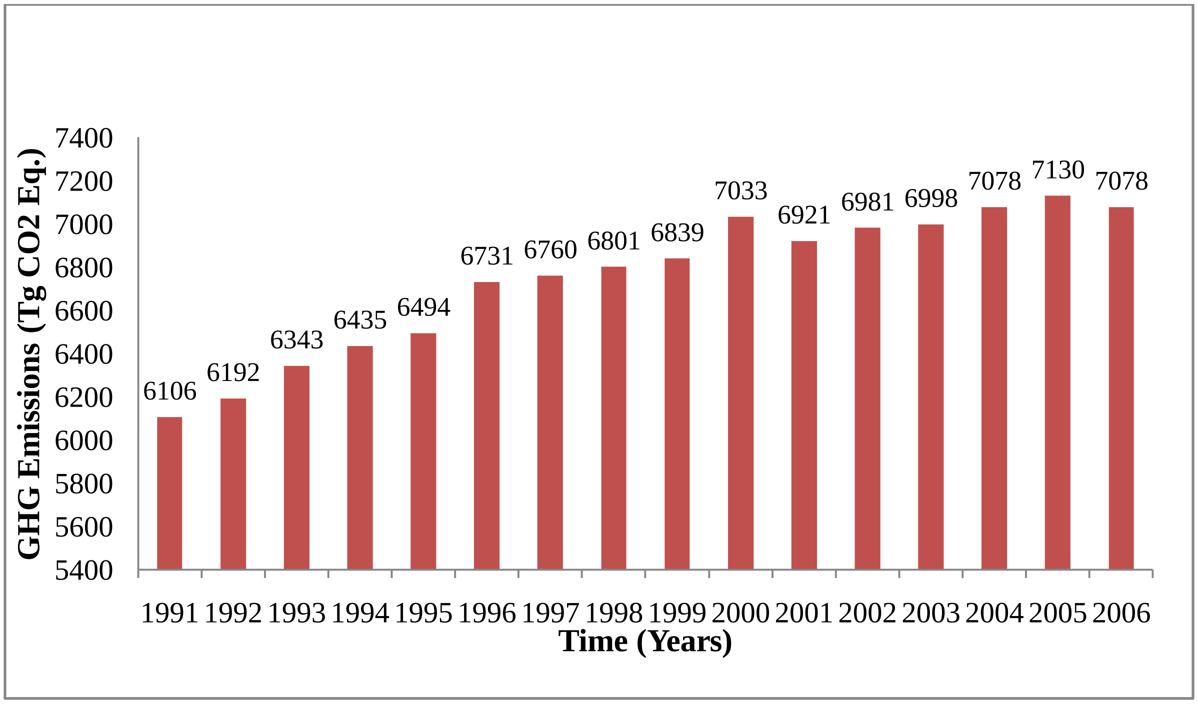
A preliminary energy audit of a wastewater treatment facility will provide an inventory of the energy consumed for various activities like pumping, treatment, and discharge. This audit will also give an account of the amount of energy being utilized and wasted at several treatment and pumping units. This account can be useful in creating an efficient energy conservation program by implementing several energy conservation measures (ECMs). The ECMs would be most required at places where there is no control for the operator and at places where there is a frequent change in the electricity load. Pumps are a very good example for having an ECM where there is a scope for saving much of energy. The ECMs would help plant operators in saving large amounts of energy, money, and the environment by reducing GHG emissions.

Chapter 1.1: Need for Research

Greenhouse gas is the most threatening phrase to the environment these days. The emission of these gases into the environment is increasing greatly every year. In 2006 the GHG emissions amounted to 7,078 Tg CO_2Eq (U.S. Inventory), which is a 15% increase since 1990 (shown in Figures 1 and 2) and wastewater treatment amounted to 2.7% of the overall U.S. GHG emissions (U.S. EPA 1990-2006). According to the U.S EPA, wastewater treatment and human sewage are one of the major sources of GHG's. Carbon dioxide, methane and nitrous oxide are major greenhouse gases emitted from wastewater treatment. Nitrous oxide and methane are emitted from the treatment processes and carbon dioxide from operation of a wastewater treatment facility. Though nitrous oxide and methane are the main emissions from the treatment processes, they are finally quantified in terms of carbon dioxide equivalents. In 2000 worldwide methane emitted from wastewater accounts for over 575 Tg of CO_2Eq and worldwide nitrous oxide emitted from the same source was 78 Tg of CO_2Eq (U.S. EPA 1990-2006). And these emissions are expected to grow by 20% and 13%, respectively, between 2005 and 2020. Another major GHG emission source in a wastewater treatment facility is the distribution system. Several pumps and generators are used to move the water from low lying areas to elevated areas and even at the final discharge. A lot of energy is involved in running these pumps resulting in GHG emissions.

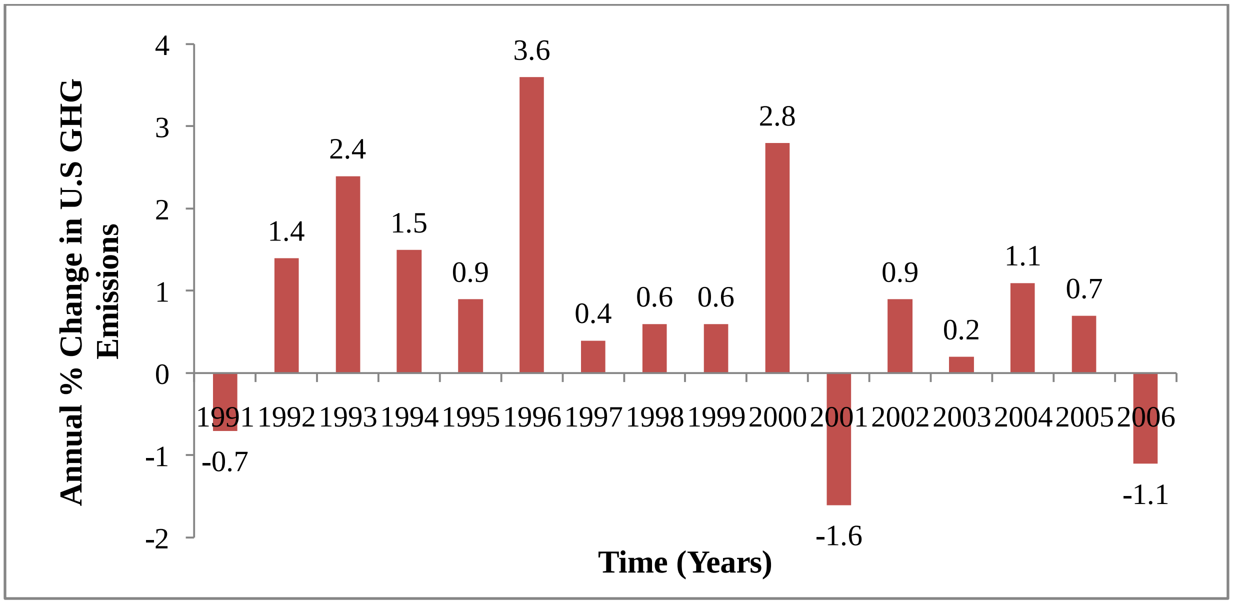
The wastewater treatment is one of the most required public services and the need for these facilities is increasing at a faster rate. These services cannot be stopped to avoid GHG's emitted into the atmosphere, but the emissions may be reduced by altering the treatment processes (to reduce methane and nitrous oxide), shifting to energy efficient processes, avoiding energy wastage, using highly efficient pumps, and so on. The above would be done by conducting several audits of equipment and processes and audits of energy. The audits would help in creating an energy efficient program which would not only reduce emissions but also cut operating costs for the operators.

Figure 1: U.S. GHG Emissions



(Source: U.S. EPA, 1990-2006)

Figure 2: Annual Percent Change in U.S. GHG Emissions [1]



(Source: U.S. EPA, 1990-2006)

Chapter 1.2: Scope and Objectives

Scope

This thesis is limited to developing certain indicators for minimizing energy consumption and associated GHG emissions at wastewater treatment facilities and developing recommendations on ECMs. Since a detailed process audit is not really required for recommending ECMs, the audit will be limited to a walk through process audit for two facilities. Due to limited resources and time constraints, this work will be only for domestic wastewater facilities equipped with primary and secondary treatment processes with disinfection and sludge handling units included.

Objectives

- Compare two wastewater treatment plants (WWTPs) with respect to (a) power consumption per capita basis, (b) power consumption based on unit volume of wastewater treated, (c) power consumption based on removal of total suspended solids (TSS), and (d) power consumption based on removal of 5-day biochemical oxygen demand (BOD_5).

- Compute the probable potential carbon dioxide (CO_2) emissions resulting from the power consumed at the two facilities studied based on energy consumed and the energy generation mix (viz., nuclear, coal, natural gas etc.) appropriate for the regions.

- Compare the probable CO_2 emission potential based on (a) per capita, (b) unit wastewater volume, (c) unit amount of TSS removed, and (d) unit amount of BOD_5 removed based on the Louisiana energy mix.

Chapter 2: Literature Review

Energy Consumption in Wastewater Treatment

Wastewater treatment is an essential public service, whose requirement is gradually increasing every year. The energy cost accounts for about 30% of the total operation and maintenance costs of a WWTP (Sauer and Kimber 2002). The demand for wastewater treatment is gradually increasing every year with the increase in population. As there is a high demand for wastewater treatment, the wastewater facilities have to be updated and improved to meet future requirements. These facilities also need to be improved in terms of efficiency so as to face the coming demand and to conserve energy by treating more wastewater using less energy. If necessary, these facilities should be remodeled or rebuilt with new technologies and highly efficient equipment. Energy consumption in treating wastewaters occurs mainly in the following activities:

- Pumping,
- Treatment,
- Utilities.

Pumping:

Pumping, which is the major energy consumption activity in the whole facility, consumes about 80% of the total energy consumed for moving and treating wastewater. And about 25% is consumed only for pumping (Sauer and Kimber 2002). Pumping is one of the unavoidable activities of the whole process because it takes a great deal of energy to move water from various locations to the treatment plant. Pumping is required at places where gravity flow is practically not possible. In a facility pumps may be used at various locations, such as follows:

- Lift stations,
- Influent pump station,
- Pumps used at various locations within the treatment plant,
- Effluent pump station.

Treatment:

Various processes in wastewater treatment consume large amounts of energy. The most common treatment processes are primary treatment, secondary treatment, tertiary treatment, disinfection, and sludge processing.

Primary treatment includes processes like screening, skimming, grinding, and sedimentation etc. These processes are the most simple and effective because they operate with much less energy and remove about 50 to 70% of the suspended solids and 25 to 40% of the BOD (M/J Industrial Solutions 2003). These units effectively remove contaminants from the wastewater and reduce the load on further processes.

Secondary treatment mostly involves biological processes like microbial growth, activated sludge treatment etc. They are most commonly known as aeration, clarification, and digestion. These processes are most important for removal of organic material. Secondary treatment typically removes 70 to 85% of the BOD from the primary treatment effluent and consumes about 30 to 60% of the total plant energy consumption (M/J Industrial Solutions 2003). Of all the secondary treatment processes, aeration is the most power consuming process. Aeration involves continuous pumping of air (oxygen) by several pumps. Digesters and clarifiers also consume considerable amounts of energy to treat wastewater.

Tertiary treatment is also an advanced wastewater treatment which is not very frequently used to treat municipal wastewater. But with increasing regulations, this process is becoming common. Tertiary treatment mainly involves nutrient removal, mainly nitrogen, by nitrification and denitrification processes. These processes also involve pumping oxygen into the water for removal of BOD to very low levels, which increases the total plant energy consumption by 40 to 50% (M/J Industrial Solutions 2003). Additionally, tertiary treatment also removes suspended solids to low concentrations, toxic compounds by filtration and activated carbon processes, respectively.

The most common disinfection process is chlorination. If properly done, chlorination is the most effective disinfection process removing about 99% of the harmful bacteria from effluent streams. This process involves large amounts of energy for the utility waters used in chlorine injectors and sometimes to manufacture chlorine or chlorine compounds. Due to increase in concern over the effects of chlorination, two alternative disinfection processes have gained lot of interest. These two processes are Ozonation and Ultraviolet radiation. Energy consumers for several disinfection processes are as follows (WEF 1997):

- Chlorine Gas- evaporator hearer, pumping of dilution water, and pumping of chlorine solution.
- Hypochlorite-pumping of dilution water and metering pumps for hypochlorite.
- Ozone- air compressor, air dryer, ozone generator, and pumping of dilution water.
- Ultraviolet- power for UV tube lighting.

Sludge processing includes various operations like dewatering, thickening, stabilization or digestion, and disposal. Application of these processes may vary from facility to facility depending upon the requirements. Energy is required for pumping the sludge between the processes and to pump the final sludge to the belt press or into the sludge discharge truck (WEF 1997). Thickening and stabilization involve solidification of the sludge, and dewatering of sludge is the removal of water from sludge, usually accomplished by continuous belt press. Continuous belt press is the major power consuming operation in sludge processing. These processes are needed to be carried out effectively to reduce the loads on the other treatment processes and landfills.

Utilities:

In a wastewater treatment facility the most common utilities that consume energy are:

- Heating and cooling systems,
- Lighting,
- Miscellaneous uses.

These utilities may not consume large amounts of energy, but cannot be ignored for the facilities with large office spaces and laboratories. Energy efficient systems are recommended to reduce consumption.

Energy Audit

An energy audit is a count of the amount of energy consumed. In this case, an energy audit determines the overall energy consumption for moving and treating wastewaters. The main purpose of an energy audit is to improve the efficiency of the plant and, hence, consume less energy. A comprehensive energy audit allows a facility to determine the largest, most energy-intensive operations. By determining the energy demands of the various processes and equipment at a WWTP, personnel can look at improving the treatment energy efficiency. The objectives at most facilities are lower energy consumption, demand, and cost. In some cases, life-cycle cost analyses can be used to help assess and optimize the selection of individual components and systems. There are several types of energy audits that can be performed at a wastewater treatment facility, and the most commonly performed audits are the following (EPRI 1994):

- Lighting,
- HVAC,
- Pumping,
- Walk through process,
- Detailed process.

Lighting Audit:

This is the most common audit that is performed at a WWTP. It is very similar to a general building audit with small changes. The main purpose of this audit is to assist customers in reducing energy consumption for the lighting systems in the facility.

HVAC Audits:

A heating, ventilating, and air conditioning (HVAC) audit is performed to check the efficiency of the electric utilities and can be modified or replaced with more efficient units depending upon the requirements. This will help in cutting operating costs and reducing the wear and tear of the units. This kind of audits is useful only for buildings in wastewater treatment facilities.

Pumping Audits:

This is one of the most important audits as the most amount of energy consumed in a wastewater facility is for pumping wastewater. Wastewater is pumped through force mains from various locations into the treatment plant. After the treatment, the treated water is discharged to various places through pumps, which are also used in some of the treatment processes. This makes pumping one of the most important parts of wastewater treatment. About 80% of the energy consumed for treating wastewater is used for pumping.

A pumping audit is very important for operating and maintaining the pumps and pump stations with high efficiency. This audit helps the operator to know the required modifications and replacements for achieving higher efficiencies.

Walk through Process Audits:

This type of audit is the most important audit as it provides a first cut assessment and, hence, decides if a detailed process audit is required or not. This kind of audit involves physical field investigation for about four hours for small and simple plants and about two days for a complex plant. The duties of this process audit is to understand the plant design and design parameters, collect energy data of the plant, review energy bills, make an equipment inventory, and identify the places where energy consumption can be reduced. This audit is a base for a detailed process audit and the potential energy savings will decide if a detailed process audit is needed or not. A walk-through process audit is not always required to proceed to a detailed process audit so as to implement or recommend a few ECMs. Lighting audits, HVAC audits, and pumping audits can also be performed as a part of a walk-through process audit.

Detailed process Audit:

This type of an audit is extensive and complex. It can be considered as an extension for a walk-through process audit. This audit is generally carried out by experts and several analyses are made to come up with efficient ECM's. This audit is very uncommon in small to medium sized wastewater treatment facilities unless the plant is very complex.

Energy Efficiency Opportunities at Wastewater Treatment Facilities

Water and wastewater transport and treatment accounted for over 3% of U.S. electricity, of which one third is accounted for water and two thirds is accounted for wastewater systems. Water and wastewater facilities are energy intensive accounting for about 35% of the energy used in the municipalities (Neal R. Elliot and Steven Nadel 2003). In order to reduce the energy consumption at wastewater treatment facilities, several energy efficiency opportunities must be identified. In wastewater treatment, blowers for aeration of activated sludge account for almost half of the electricity, and pumping for 35%. This clearly indicates that aeration and pumping are the most energy consuming actions in wastewater treatment and there is a need for identifying opportunities for optimizing energy in performing these actions.

Energy Efficient Pumping:

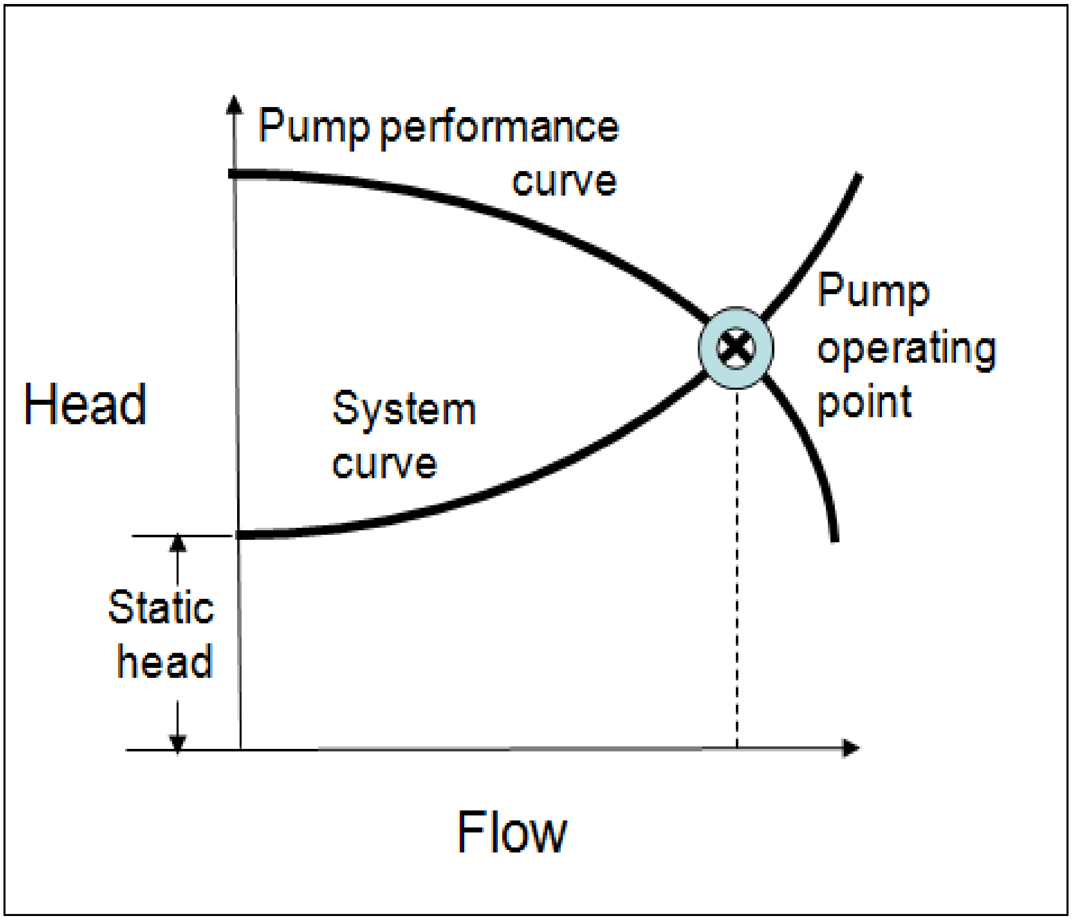
Attempts to increase energy efficiency can reduce electricity consumption for pumping by as much as 5%-25%, and sometimes even greater reductions are possible (Neal R. Elliot and Steven Nadel 2003). Several steps are needed to be followed in order to develop an efficient pumping system. The most basic steps include (UNEP 2006):

- Selecting the right pump
- Controlling the flow rate based on speed variation

- Pumps in parallel to meet varying demand
- Eliminating flow control valve
- Eliminating by-pass control
- Start/stop control of pump
- Impeller trimming

Selecting the right pump: In order to select a right pump, several parameters must be analyzed and all pump performance curves must be studied to match the system curves. The selection should be mainly based on the flow rate and available head. The pump performance curve and system curve is developed by several duty points (rate of flow at certain head) and the pump operating point is the intersection of pump performance curve and the system curve as shown in Figure 3.

Figure 3: Pump Performance Curves



(Source: UNEP, 2006)

Another important parameter in pump selection is the Best Efficiency Point (BEP). BEP is the pumping capacity at which the efficiency of the pump is highest. All points on the curve to the left or right of BEP will have lower efficiency. To obtain higher efficiencies, oversized pumps must be avoided. The BEP is affected when the selected pump is oversized. The reason is that the flow of oversized pumps must be controlled with different methods, such as a throttle valve or a by-pass line. These provide additional resistance by increasing the friction. As a result the system curve shifts to the left and intersects the pump curve at another point. The BEP is now also lower. In other words, the pump efficiency is reduced because the output flow is reduced but power consumption is not. Inefficiencies of oversized pumps can be overcome by the installation of variable speed drives (VSDs), two-speed drives, lower rpm and, smaller impeller or trimmed impeller.

Controlling the flow rate based on speed variation: Pump performance parameters (flow rate and head) will change with varying rotational speeds. To safely control the pump it is important to understand the following relationships (UNEP 2006):

- Flow rate (Q) is proportional to the rotating speed (N)
- Head (H) is proportional to the square of the rotating speed
- Power (P) is proportional to the cube of the rotating speed

From the above relationships we can clearly say that doubling the rotating speed of the pump will increase the power consumption by 8 times. Conversely a small reduction in speed will result in a very large reduction in power consumption. This forms the basis for energy conservation in pumps with varying flow requirements. The most efficient way to control the pump speed is by using VSD. These drives allow variation of pump speeds on a continuous basis and hence reduce power consumption. On the other hand these drives also improve the system reliability and reduce the maintenance costs.

Pumps in parallel to meet varying demand: Operating two or more pumps in parallel and turning some off when the demand is lower, can result in significant energy savings. Pumps with different flow rates can be used for more efficient pumping.

Eliminating flow control valve: Provision of flow control valves reduces efficiency by increasing the head loss and friction. By closing the control valve, the head increases without any reduction in power consumption. The control valves also result in vibration and corrosion and hence reducing the efficiency and lifetime of the pumps

.

Eliminating by-pass control: The flow can also be reduced by installing a by-pass control system, in which the discharge of the pump is divided into two flows going into two separate pipelines. One of the pipelines delivers the water to the delivery point, while the second pipeline returns the fluid to the source. In other words, part of the fluid is pumped around for no reason, and thus energy is wasted. And hence, the by-pass control system must be eliminated.

Start/stop control of pump: Start/sop control of the pump is a suitable way of optimizing energy only if not done too frequently. This method is followed to make use of the non-peak hours. Pumping in non-peak hours would reduce the load on the pumps and hence lower the energy consumption.

Impeller trimming: Change in impeller diameter to control the flow rate should be carried out in an energy efficient way. But there are certain limitations for changing the impeller diameter. The limitations include:

- Impeller should not be trimmed more than 25% of the original impeller size, otherwise it leads to vibration due to cavitations and therefore decreases the pump efficiency.
- The balance of the pump has to be maintained, i.e. the impeller trimming should be the same on all sides.

Apart from the above, energy efficient pumping can also be carried out by using various other methods. These methods include many computer systems (SCADA, Telemetry, etc.) for operating and maintaining the pumps. These systems provide a continuous observation of the flow rates, head, and the pump performances and hence, allow the operator for efficient operations. As mentioned before, aeration and pumping are the major energy consuming activities in a wastewater treatment facility. The energy efficiency opportunities in pumping are discussed above and energy efficient aeration is discussed in the next section of this chapter. Apart from aeration and pumping a few other areas for energy optimization are summarized in the Table 1 below. Table 1 provides some of the general areas that may improve energy use at wastewater treatment facilities. These areas may differ for each facility and a complete energy assessment will determine the most energy efficient, cost effective and beneficial to the facility.

Table 1: Few general Areas for Energy Optimization at Wastewater Treatment Facilities

Area	**Action for Energy Optimization**
Aeration	Install automatic DO control on aerators
	Variable Speed Drives (VSDs) on mechanical aerators or aeration blowers
	Convert to diffused air aeration
	Convert from coarse to fine bubble aeration
	Reduce air pressure when possible
	Consider anaerobic and deep well treatment technology
Pumping (General)	Install VSDs on pumps with long run hours and that are throttled or have Bypasses
	Run pumps in parallel
	Reduce pressures where possible
	Install improved efficiency motors/pumps/valves
	Downsize where oversized
Lift Stations	Install VSDs on pumps
	Install improved pump controls
	Install improved efficiency pumps/motors/valves
	Vary well levels to reduce loads, especially during peaks
Sludge Handling and Disposal	Install VSDs on sludge pumps
	Improve dewatering before incineration
	Install VSDs on incinerator fans
	Consider land disposal or pelletizing vs incineration
Reducing Peak Load	Consider self-generation at system peaks
	Schedule pumping during lower cost periods
	Identify loads that can be reduced or interrupted
	Consider more storage

(Source: Richard Brown, 2009)

Efficient Wastewater Aeration Systems

The wastewater treatment accounts for approximately 35% of the energy consumed by a municipality, including street lights, heating and cooling. The aeration process of a wastewater treatment plant consumes 50% to 70% of all the power used by the plant and represents the second largest operating cost after labor. Aeration process introduces air into a liquid, providing an aerobic environment for microbial degradation of organic matter. The purpose of aeration is to supply the required oxygen to the metabolizing microorganisms and to provide mixing so that the microorganisms come into contact with the dissolved and suspended organic matter (Steven A. Bolles).

Although there are many types of aeration systems, the two basic methods of aerating wastewater are through mechanical surface aeration to entrain air into the wastewater by agitation, or by introducing air or pure oxygen with submerged diffusers. Fine pore diffusers are most common form of aeration in which air is introduced in the form of very small bubbles. Since the energy crisis in the early 1970s, there has been increased interest in fine pore diffusion of air as a competitive system due to its high oxygen transfer efficiency (OTE). When it comes to improving the efficiency of a wastewater aeration process, there are three primary technologies that have the greatest impact on the overall power consumption:

Diffuser Technologies: Fine bubble disc diffusers are considered the most efficient system available for oxygen transfer in wastewater treatment applications. Typically, power costs can be reduced by up to 50% when compared to other aeration processes such as mechanical or course bubble diffusion (U.S. EPA 1989). Fine bubbles provide larger total surface area, create more friction and rise slower than coarse bubbles. The combination of more transfer area and a greater contact time enhances transfer efficiency.

The diffusion of air can be accomplished with several types of diffusers. Typical clean water oxygen transfer rates are shown in Table 2. To compute the relative rate of the oxygen transfer in wastewater compared to the clean water, typical alpha values are provided in Table 3. Beta value provides the correction for solubility of oxygen due to the constituents of wastewater. The beta value for municipal wastewater is 0.95 to 1.0 (Steven A. Bolles).

Table 2: Typical Clean Water Oxygen Rates

Diffuser Type and Placement	**Oxygen Transfer Rate lb O_2/hp-hr**
Course Bubble Diffusers[1]	2.0
Fine Bubble Diffusers[2]	6.5
Surface Mechanical Aerators	3.0
Submerged Turbine Aerators[3]	2.0
Jet Aerators[4]	2.8

[1] For 2.7 - 3.6 m (9-12 feet) submergence

[2] For 18 - 26 w/m3 (0.7-1.0 hp-hr/100 ft3)

[3] Includes both blower and mixer horsepower

[4] Includes both blower and pump horsepower

(Source: EPA, 1984)

Table 3: Typical Alpha Values for Wastewater

Aeration System	**Typical Alpha (α)**
Course Bubble Diffusers	0.8
Fine Bubble Diffusers	0.45
Surface Mechanical Aerators	0.85
Submerged Turbine Aerators	0.85
Jet Aerators	0.75

**Typical Alpha (α): Ratio of OTE in wastewater to OTE in clean water* (Source: EPA, 1984).

Blower Technologies: Wastewater treatment typically utilizes one of the following three blower designs;

- Positive Displacement
- Multi-stage Centrifugal
- Single-stage Centrifugal

Positive Displacement Blowers are the least efficient of the three types of blower technologies typically used in a wastewater aeration process, with a maximum efficiency of about 60% range. Multi-stage centrifugal blowers have a maximum efficiency between 68%-76%, while higher speed single-stage centrifugal blowers range from 78% to as high as 85%, for designs utilizing advanced designs (Sri Ruthira Kumar 2007).

Air Control Technologies: Although the type of aeration system is important to deliver air as efficiently as possible, an automated control system provides the most effective energy savings impact for a facility. For aeration systems, dissolved oxygen probes and analyzers are the most commonly used instruments to measure the level of dissolved oxygen in the wastewater and provide a variable signal to adjust air flow, tank level (using adjustable weirs) or mechanical aerator speed.

Both single stage and multi-stage centrifugal blowers offer two types of control technologies namely single point and double point control technology. The single point control technology has significant limitations in wastewater application. The inlet valve in this case controls the overall capacity very well but dramatically reduces the system efficiency. This reduction in efficiency is due to the inlet losses associated with throttling. On the other hand the unique control process of the dual point control technology allows for management of the flow and head functions independently through a multi-variable control process. Typically, the flow function of the blower is managed through discharge control vanes, while the head function is managed through inlet guide vanes. This divided control strategy allows for the base efficiency to be maintained at or near the maximum across an extremely wide range of flow and temperature conditions. A single stage centrifugal blower implemented with a dual point control technology can easily reduce the aeration system power consumption by 30%-50% when compared to other blower and control technologies (Sri Ruthira Kumar 2007) (A.Lekov et al. 2009).

Advantages and Disadvantages of Fine Pore/Bubble Diffusers (U.S. EPA 1999)

Advantages:

- Exhibit high OTEs.
- Exhibit high aeration efficiencies (mass oxygen transferred per unit power per unit time).
- Can satisfy high oxygen demands.
- Are easily adaptable to existing basins for plant upgrades.
- Result in lower volatile organic compound emissions than nonporous diffusers or mechanical aeration devices.

Disadvantages:

- Fine pore diffusers are susceptible to chemical or biological fouling, which may impair transfer efficiency and generate high head loss. As a result, they require routine cleaning. (Although not totally without cost, cleaning does not need to be expensive or troublesome.)
- Fine pore diffusers may be susceptible to chemical attack (especially perforated membranes). Therefore, care must be exercised in the proper selection of materials for a given wastewater.
- Because of the high efficiencies of fine pore diffusers at low airflow rates, airflow distribution is critical to their performance and selection of proper airflow control orifices is important.
- Because of the high efficiencies of fine pore diffusers, required airflow in an aeration basin (normally at the effluent end) may be dictated by mixing – not oxygen transfer.
- Aeration basin design must incorporate a means to easily dewater the tank for cleaning. In small systems where no redundancy of aeration tanks exists, an in-situ, non process-interruptive method of cleaning must be considered.

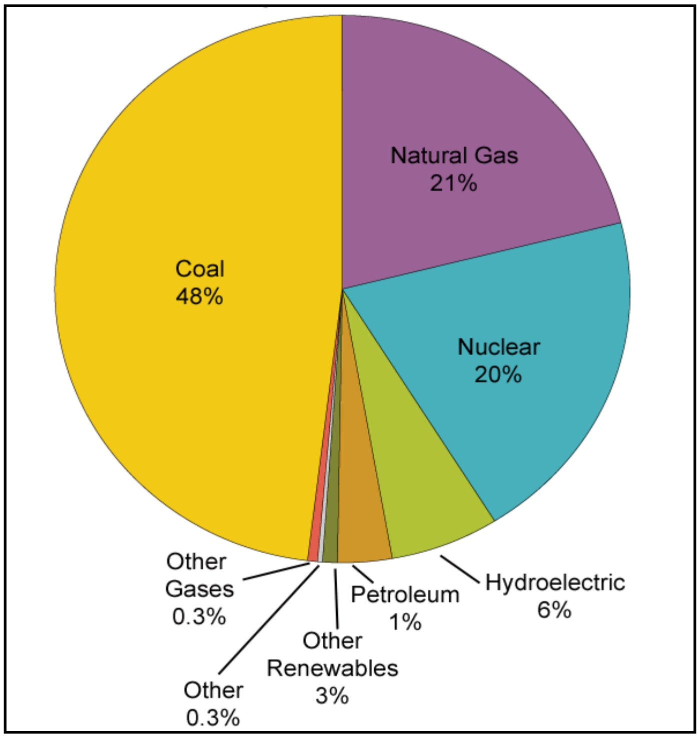
Energy Generation Resource Mix

Energy/electricity is usually generated by electro-mechanical generators driven by steam produced from fossil fuel combustion, or heat released from nuclear reactions, or some other source such as wind or flowing water. Most of today’s electricity is generated by steam turbines that convert the kinetic energy of a moving liquid or gas to mechanical energy. And the generators convert this mechanical energy into electrical energy. The steam turbines are powered by burning fossil fuels and natural gas.

In recent times, green techniques have been introduced to generate electricity. A few such green techniques include generation by nuclear power, renewable energy sources (hydropower, wind biomass, solar, etc.). Energy generation from these sources is increasing every year at faster rates to avoid the exhaustion of natural resources and pollution (mainly GHGs).

According to the U.S. Energy Information Administration, about 70% of U.S. energy is generated from fossil fuels (coal - 48%, natural gas - 21%, and petroleum - 1%), 20% from nuclear power, and the rest from renewable energy sources (hydropower - 6%, biomass - 1%, wind power - 1%, geothermal power - 1%, and solar power - 1%), (EIA 2005). These percentages are nationwide averages, and they are different for different states. The difference occurs because of the availability of resources to generate energy. Figure 5 shows the various sources for energy generation in U.S. in 2008.

Figure 4: U.S. Electric Power Industry Net Generation by Fuel Type (Source: EIA 2005)



Chapter 3: Methodology

An energy audit in a wastewater treatment facility is an inspection, survey, and analysis of energy flows and energy conservation by reducing the energy inputs without affecting the output. The main purpose of an energy audit is to improve the efficiency of the facility and, hence, consume less energy. A comprehensive energy audit allows a facility to determine the largest, most energy-intensive operation. By determining the energy demands for the various processes and equipment at a WWTP, the WWTP personnel can develop customized ECMs applicable to their facility.

As discussed before there are various types of energy audits that can be performed at a wastewater treatment facility and the most commonly performed audits are the following (EPRI 1994):

- Lighting audit,
- HVAC audit,
- Pumping audit,
- Walk Through Process audit, and
- Detailed Process audit.

A very basic walk through process audit (inspection) was conducted at the two facilities. The first part of the inspection included an equipment inventory, as well as understanding the treatment processes and the flow pattern. All the details of various equipment and treatment units were studied to compare the two facilities in terms of their sizes, capacities, and treatment processes. The design parameters and energy bills of both facilities were collected and reviewed, allowing various studies to be developed to compare the two facilities. To avoid seasonal variations, one whole year of data was investigated. The studies included:

- Power consumed per capita,
- Power consumed to treat certain flow rates of wastewater, and,
- Power consumption for treatment and pumping.

In the second part of the inspection, the performances of the two facilities were evaluated based on the wastewater characteristics, the efficiencies of the facilities to treat wastewater, and the power consumed. The wastewater characteristics can be studied based on the various contaminants. A few of such contaminants are:

- TSS,
- BOD,
- Grit,
- Sediments,
- Organic matter,
- Bacteria,
- Pathogens, etc.

Of all these, TSS and BOD are the most important as the facilities have to limit these contaminants to minimal concentrations so as to discharge the water into receiving streams. The second part also included the quantification of power consumed to treat the unit amount of TSS and BOD for the two facilities.

This study also involved the quantification of GHG emissions based on energy consumption. As the main focus of this study was on power consumption and an energy audit, direct GHG emissions from the treatment processes into the air were not considered. Only the carbon dioxide emissions due to power consumption were quantified. The total amounts of carbon dioxide released into the air from the power consumed in both the facilities for one year were quantified. And the amount of carbon dioxide released to treat unit amount of TSS and BOD were also quantified.

Several comparisons were developed for the two facilities from the studies mentioned above and based on those studies several conclusions were drawn. Additionally, several energy optimization opportunities were identified at the two facilities and recommendations were made to attain energy efficient operations. Further studies would be required to study the amount of energy conserved on adapting the recommendations.

Facility 1

Facility 1 is divided into two parts, the south plant and the north plant. The south plant consists of two combined units of aerators and clarifiers; the north plant consists of four digesters, six aerators, and six clarifiers. A whole disinfection unit is available for chlorination before the treated water is discharged into the aquatic environment. The facility has an average daily flow of 17.13 MGD, peak daily flow of 44.05 MGD and peak hourly flow of 56.40 MGD. However, the true capacity of the WWTP is limited to 44 MGD due to the limited capacity of its effluent pump station.

Design Criteria, Organic Loading, Influent Flow and Treatment Process for North Plant

Design Criteria and Organic Loading

The designed Average Daily Flow (ADF), Maximum Daily Flow (MDF) and Peak Hourly Flow (PHF) of North plant are 13.88, 33.9 and 42 MGD respectively. The organic loading for this portion of the WWTP is 140mg/l for BOD_5 and TSS. The designed daily BOD_5 and TSS loading at ADF is 16,148 l/day. Discharge permit requires the effluent concentration to be 30mg/l or better for BOD_5 and TSS.

Influent Flow Pattern

North plant receives 60% of the flow from the influent splitter box (refer figure 5). This section of the plant also receives influent from one of the transfer station. North plant consists of mechanically aerated activated sludge units which are hydraulically separated from South plant. After the splitter box, the flow makes its way to the trough where it mixes with the discharge of a transfer station.

Treatment Process

Primary Treatment and Sedimentation: The sewage passes through the two automated bar screens where most of the larger grit is trapped for landfill disposal. The flow then slows down as it splits and makes its way through the two grit chambers which help the comparatively finer grit settle down due to gravity. As mentioned before the North plant contains 6 aeration basins and 6 clarifiers. Flow from aeration basins (*see secondary treatment*) 1 and 2 is received by clarifiers 1 and 2, flow from aeration basins 3 and 4 goes to clarifiers 3 and 4 and flow from aeration basins (*see secondary treatment*) 5 and 6 is received by clarifiers 5 and 6. There are 3 RAS pumps for clarifiers 1-4 and 3 RAS pumps for clarifiers 5 and 6. All these pumps return the aerated sludge collected from the clarifiers back to the aeration tanks. The RAS flow streams from all 6 North plant clarifiers is routed to the respective aeration bays 1-6. At times it is necessary to route an activated sludge stream from the 6 clarifiers (via the 6 RAS pumps) to the 4 digesters for processing. After a retention time of 3-7 days in the digesters (dependent on process conditions) it goes to the solid processing plant for dewatering by belt press. The 3 scum pumps (1 for each pair of clarifiers) sends back the lighter waste sludge and trash from the clarifiers to the North plant head works, with the help of the in-house pump station for additional treatment.

Secondary Treatment: From the grit chambers the flow is distributed among the six aeration basins. Here the pumps inject diffused air to the sewage for improving its Dissolved Oxygen (D.O.) content thereby encouraging the growth of desirable bacteria which help in reducing the organic compounds present in the sewer water. The measured D.O. at the upstream and downstream sections of the aeration basin are maintained at a range of .5 – 2.0 respectively. The effluent from all the clarifiers then goes to the effluent pump station for disinfection and final disposal through a 42 inch concrete force main. Table 4 and Table 5 provide the detailed design specifications of aeration and clarification basins.

Unit Sizing North Plant

Table 4: Aeration Basin Design Specifications.

Details	**Basin 1-4**	**Basin 5-6**
Dimension	34' (W) x 134' (L)	34' (W) x 134' (L)
Water Depth	13'	13'
Total Aeration Volume	1.32 MG	0.88 MG
F/M Ratio	0.32	0.42
Volumetric Loading Rate	411 BOD5/1000 FT-3 Day	511 BOD5/1000 FT-3 Day
Hydraulic Retention Time	5.1 Hr @ ADF	3.8 Hr @ ADF
Air Requirement	1,400 scfm/Basin	1,900 scfm/Basin
Aeration Equipment	Fixed grid-fine bubble, diffused air	Fixed grid-fine bubble, diffused air

Table 5: Design Specifications of the Clarifiers.

Details	**Clarifiers 1-4**	**Clarifiers 5-6**
Diameter	70'	85'
Sidewater depth	12'	15'
Floor Slope	0.052 ft/ft (3/4"/ft)	0.104 ft/ft (1 1/4/ft)
Mechanism Type	Peripheral Feed/ Central Launder	Centre Feed/ Peripheral Launder
Design Surface Overflow Rate	ADF = 540GPD/ft2-day	ADF = 500 GPD/ft2-day
	MDF = 1325 GPD/ft2-day	MDF = 1200 GPD/ft2-day
	PHF = 1659 GPD/ft2-day	PHF = 1500 GPD/ft2-day
Design Solids Loading Rate	ADF=14.88 l/ft2-DAY	ADF= 13.92 l/ft2-DAY
	MDF=36.72 l/ft2-day	MDF= 33.12 l/ft2-day

Influent, Design Criteria and Treatment Process for South Plant

South Plant receives 40% of the flow from the influent splitter box. South plant has two package tanks which contain both an aeration and clarification chamber, and is hydraulically separated from North plant.

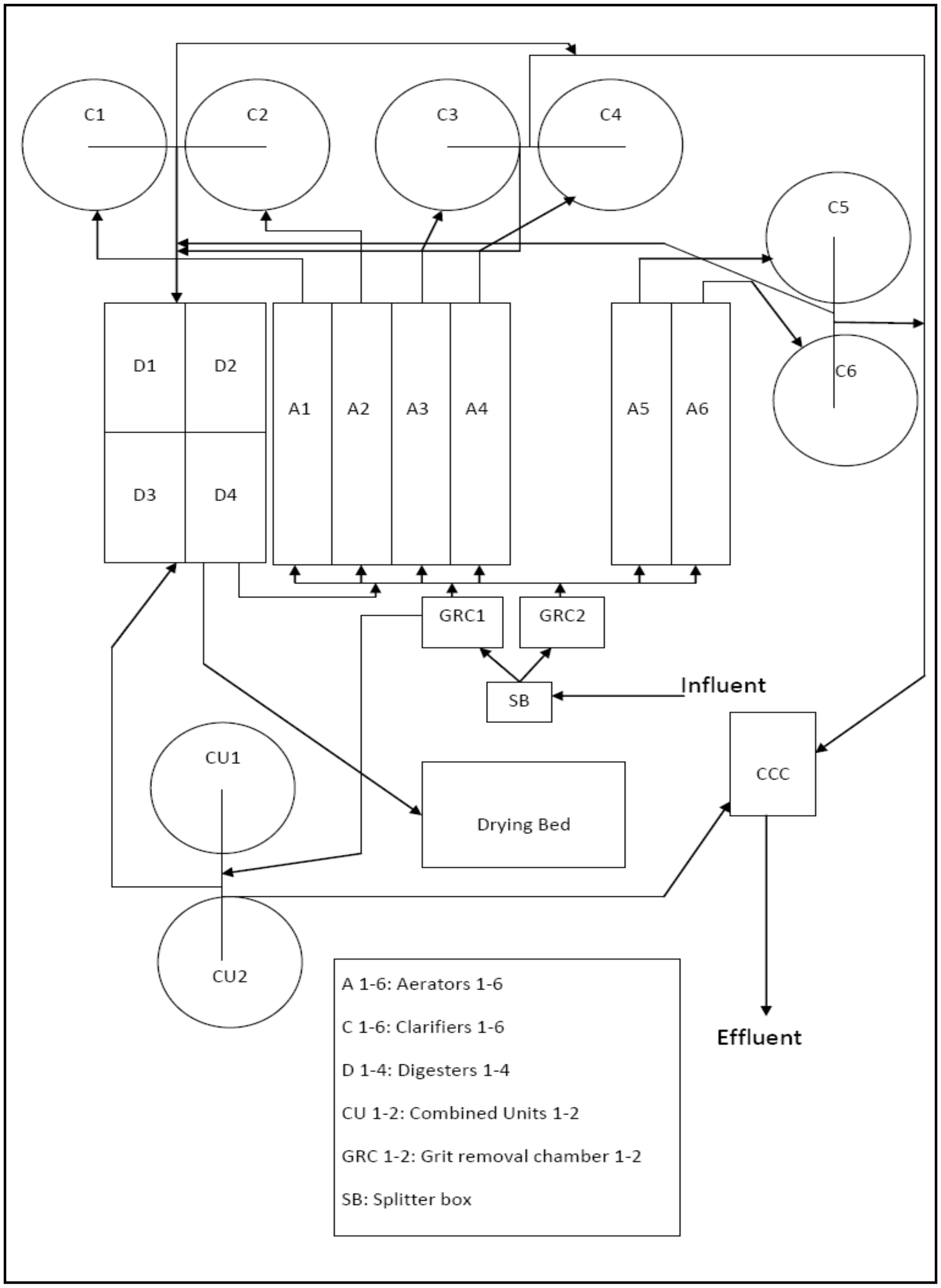
Treatment Process

Primary Treatment and Sedimentation: The sewage passes through an automated bar screen where most of the larger grit is trapped for landfill disposal. The flow then slows down as it splits and makes its way through the grit chamber which helps the comparatively finer grit settle down due to gravity. South plant is comprised of two self-contained activated sludge package plant units which are both identical in process operation. From the grit chamber the flow enters the package plants and moves in a counter-clockwise direction while being aerated. The blowers inject diffused air into the sewage for improving its Dissolved Oxygen (DO) content thereby encouraging the growth of desirable bacteria which help in reducing the organic compounds present in the wastewater. The measured DO at the influent and effluent sections of the aeration chamber are maintained at a range of .5 – 2.0 respectively.

Secondary Treatment: The flow then enters the clarification chamber, where the sludge settles to bottom and the water discharges over the weirs to the effluent pump station for disinfection and final disposal through a 42 inch concrete force main. The return activated sludge (RAS) is hydraulically controlled by a 16” tube routed from the bottom of the clarifier to the aeration well where it then enters the aeration chamber. At times it is necessary to divert an activated sludge stream from the aeration well (via 2 6” pumps) to the 4 digesters for processing. After a retention time of 3-7 days in the digesters (dependent on process conditions) it goes to the solid processing plant for dewatering by belt press. The 2 scum pumps (1 for each package plant) sends back the lighter waste sludge and trash from atop the clarifiers to the North plant head works again with the help of in-house pump station.

The facility also consists of a sludge dewatering unit with a belt press system. A polymer is added to thicken the sludge and then allowed to pass through the belt press for dewatering. The dry sludge is sent to a landfill for disposal. More information of various pumps used in the facility is shown in Appendix D.

Figure 5: Facility 1 Flow diagram



Facility 2

Facility 2 is smaller in size and flow serving a smaller community compared to Facility 1. This facility is a 1.6 MGD activated sludge treatment plant. This plant consists of one mechanical bar screen, two manual bar screens, one influent debris compactor, one influent aerated grit chamber with a grit removal system, two diffused air aeration basins, two final clarifiers, two diffused air digesters, a chlorine contact chamber and one effluent pump station with three 40-Horse power, 10 inch vertical drive pumps. A detailed flow diagram of the whole facility is shown in the figure 6 below.

Treatment Process

Primary Treatment: At the head works, one mechanically operated and two manually operated bar screens trap most of the larger grit is removed. The flow then makes its way to the grit chamber where the finer grit is removed. Both larger and finer grit is compacted at the influent debris compactor for final landfill disposal.

Secondary Treatment: The flow from the grit chamber is distributed into the two aeration tanks. The two 125-Horse power blowers inject diffused air into the sewage for improving its DO content thereby encouraging the growth of the bacteria which help in reducing the organic compounds present in the wastewater. The effluent from the aerators enters the two clarifiers, where the sludge settles down and the water is discharged through the weirs for disinfection and disposal. The sludge from the clarifiers is pumped into the two aerobic digesters with the help of two 7.5-Horse power RAS pumps. These digesters are aerated using blowers and diffusers. The sludge from these digesters is discharged to the plant’s solid handling container where polymer is added to the sludge for dewatering. Table 6 and Table 7 below provide the design specifications of aeration and clarification basins respectively.

Unit Sizing

Table 6: Aeration Basin Design Specifications.

Details	**Aerator 1 & 2**
Dimension	28' (W) x 80' (L)
Water Depth	12'
Total Aeration Volume	0.4 MG
F/M Ratio	0.32
Aeration Equipment	Fine bubble, diffused air

Table 7: Clarifiers and Digesters Dimensions

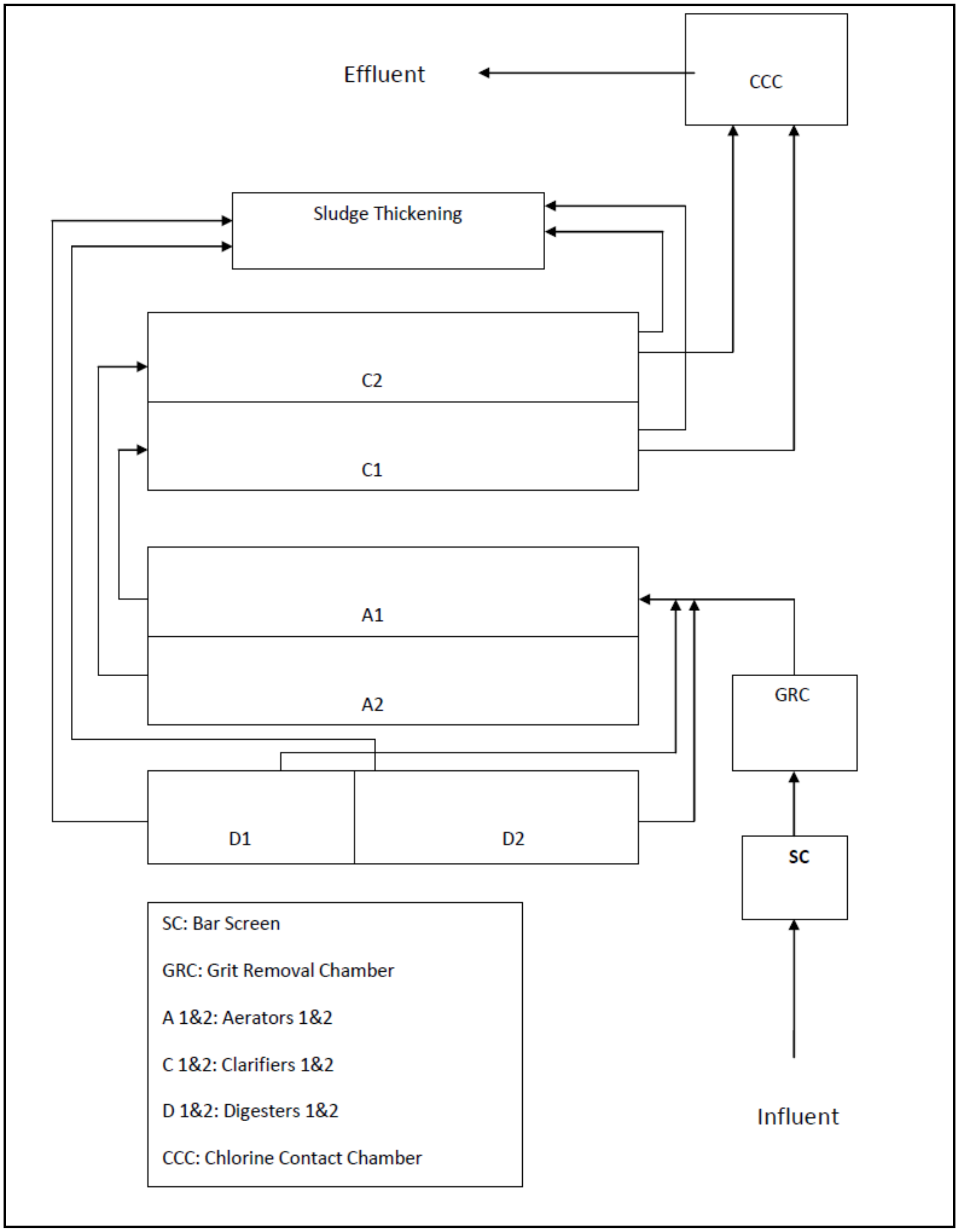
Details	**Dimension**	**Water Depth**
Clarifier 1 & 2	17' (W) x 80' (L)	10'
Digester 1	30 (W) x 30 (L)	12'
Digester 2	30 (W) x 60 (L)	12'

Disinfection and Effluent Handling: Before disposal, the flow passes through the chlorine contact chamber for disinfection. In this chamber the flow is slowed down to add chlorine to kill bacteria in the effluent. In this plant all disinfection occurs at the effluent pump station, via the injection of a 12.5% solution of sodium hypochlorite. The facility also has a drying bed where the sludge from the digesters is blended with polymer before its deposition into the dry beds for dewatering. After disinfection the plant’s effluent is discharged into the receiving streams via 18-inch force main with the help of three 40-Horse power effluent pumps.

Sludge Handling: The plant’s sludge generating and pressing operations do not generate any leachate and therefore, there is no leachate disposal issue. All the sludge from the two digesters is directly discharged into the sludge container through pipes. Hence, no untreated sludge is transported at this facility. Only treated sludge is transported to the landfill for final disposal.

Here the sludge treatment is mainly dewatering. A polymer is added to the sludge, through the effluent pipes of the digesters, before entering the container to promote coagulation and dewatering. The sludge and polymer is allowed to settle for 5 to 7 days before landfill disposal.

Figure 6: Facility 2 Flow diagram



Chapter 4: Results and Discussions

A comparison of the population of the community served and the power consumption for treating wastewater is tabulated in Table 8. This comparison is limited to treatment processes only because the power consumption for a distribution/pumping system depends upon the topography of the community. An extended study would be needed to have a complete understanding of the topography of the two communities and the power consumed. This comparison shows the amount of power consumed per person in one year to treat the wastewater generated in the two communities which vary greatly. The total one year energy consumption for both the facilities is provided in Appendix A.

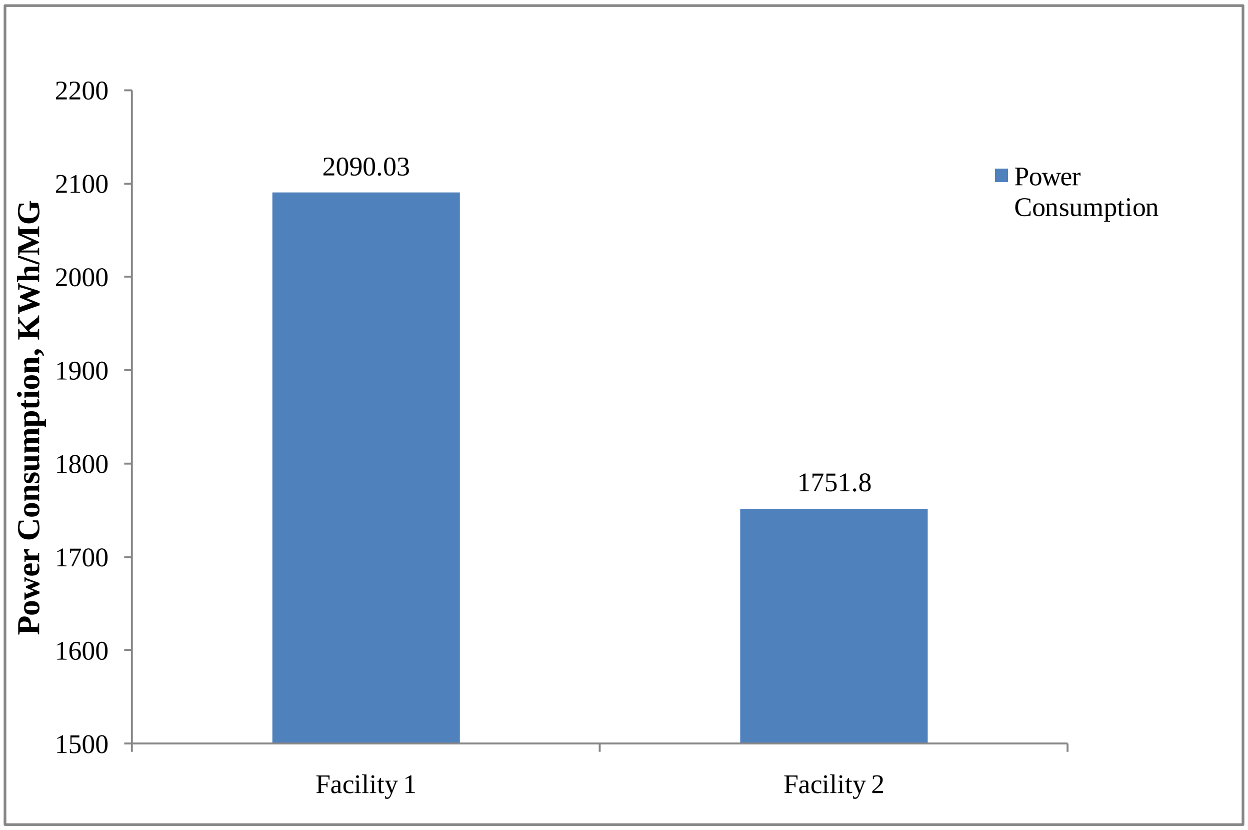
Table 8. Per Capita Yearly Power Consumption (Treatment Only)

	Population	**Yearly Power Consumption (KWh)**	**Yearly Power Consumption per Person (KWh/person)**
Facility 1	62,000	8,150,100	131.45
Facility 2	9,300	1,012,080	108.83

*****The facility identities are not disclosed for various reasons. All populations of the communities are taken from USA Census Bureau, 2007. (KWh- Kilo-Watt hour)

As the size of the community varies, the amount of wastewater generated would vary. To make the comparison more appropriate, the power consumed per unit amount of wastewater treated is quantified and is shown in Figure 7, below. Again, the comparison is limited to treatment only. Figure 7 shows the amount of power consumed to treat one million gallons (MG) of wastewater in the two facilities. Facility 1 consumed 2,090.03 KWh/million gallons, and Facility 2 consumed 1,751.8 KWh/million gallons. Figure 7 shows that Facility 1 is consuming more than Facility 2; this may be because of the change in the treatment processes followed by the operators.

Figure 7: Power Consumed to Treat One Million Gallons of Wastewater



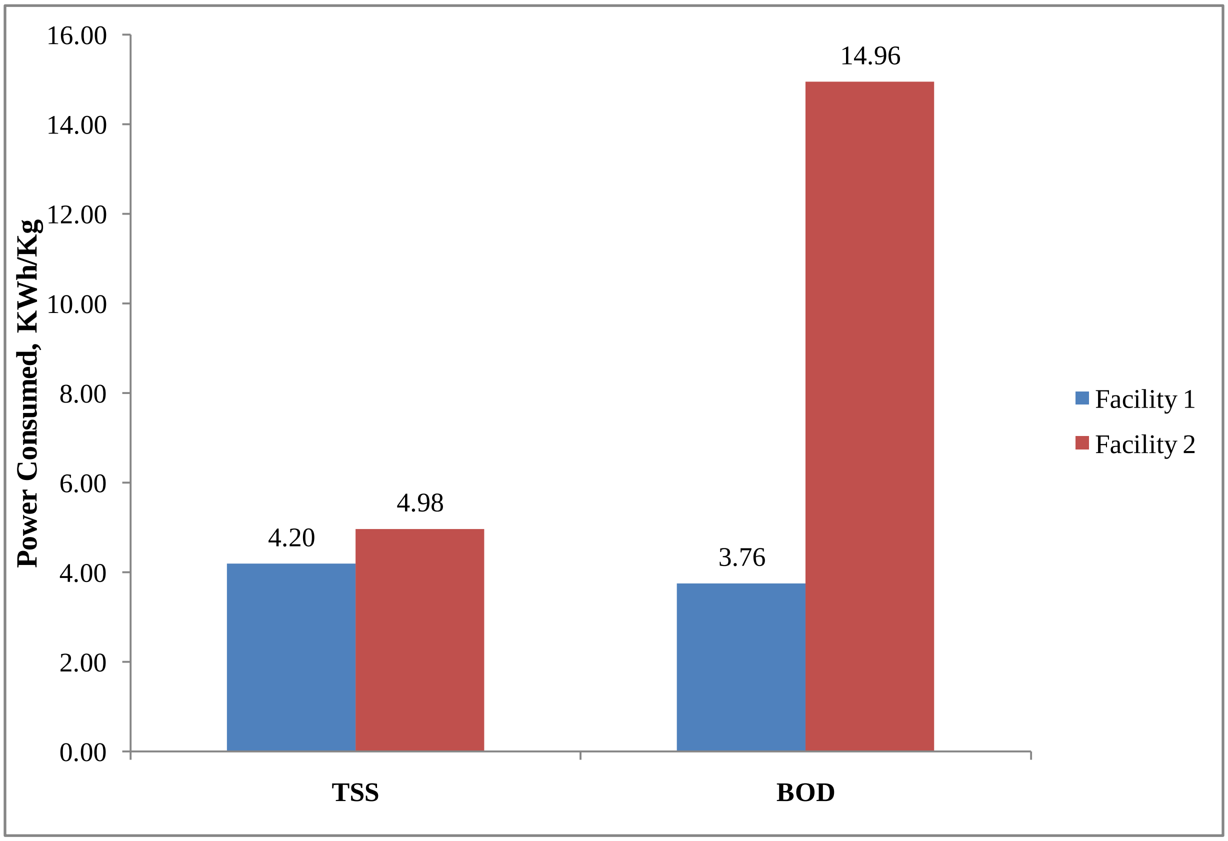
To validate the comparison of the two facilities, their efficiencies need to be checked. The efficiency of the facility can be known by wastewater characteristics and treatment levels. Table 9 shows the comparison of the two main contaminants of wastewater. The comparison includes daily average flow rates, average TSS and BOD concentrations in influent and effluent streams, and the removal efficiencies for TSS and BOD for both facilities. Also, Figure 8 shows the amount of power consumed to treat a unit amount of TSS and BOD in both facilities. The power consumed to treat one kilogram of TSS in both facilities are nearly equal. But there is a large variation in power consumption for both the facilities to treat one kilogram of BOD.

Table 9. Average Influent and Effluent Concentrations of TSS and BOD

	Influent Flow	Effluent Flow	BOD			TSS		
	(MGD)	(MGD)	Influent (mg/l)	Effluent (mg/l)	Removal Efficiency	Influent (mg/l)	Effluent (mg/l)	Removal Efficiency
F1	12.40	12.30	157.00	7.30	95.4%	142.70	7.98	94.4%
F2	1.6	1.6	69.8	38.30	46.1%	97.6	3.2	96.7%

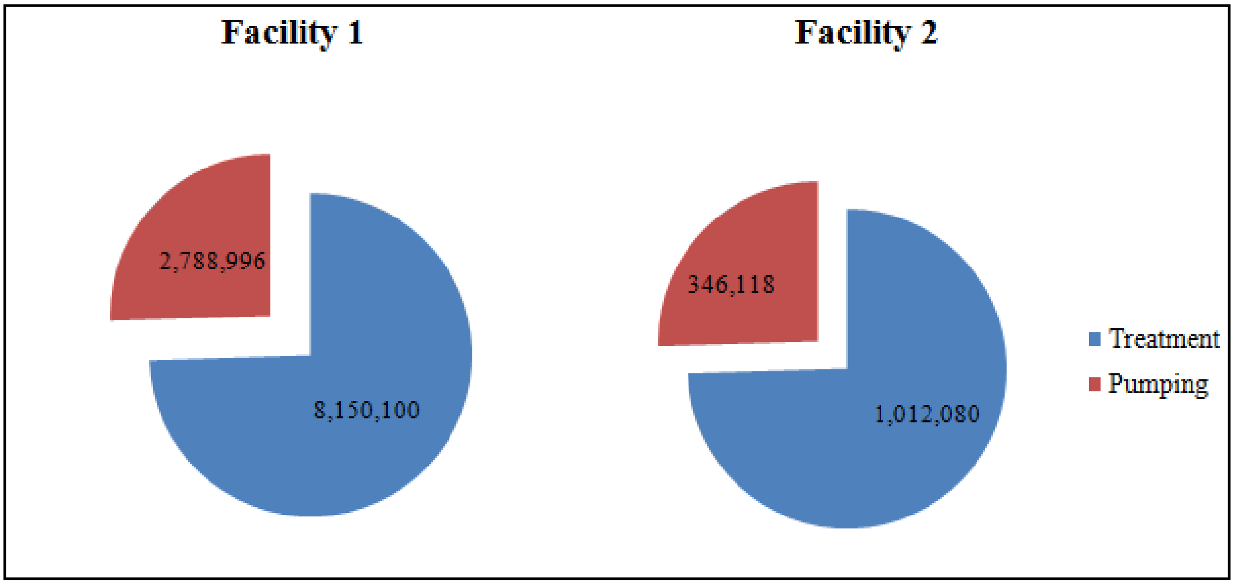
*F1- Facility 1, F2- Facility 2

Figure 8: Power Consumed to Remove One Kilogram of TSS and BOD



Along with treatment, a distribution/pumping system also consumes lot of energy. A significant amount of power is consumed to pump water from various locations to the treatment plant. Pumps in the pumping stations are the most power consuming units in the distribution system. Figure 9 shows the power consumption for treatment and pumping in both facilities. The distribution/pumping system in Facility 1 consumes about 25% of the total power consumption and the value is almost the same for Facility 2. This may be different for different facilities depending upon the geographic profile of the community. Monthly energy consumption for treatment and pumping for the two facilities is given in Appendix B.

Figures 9: Power Consumption in KWh for Treatment and Distribution/Pumping System for Facilities 1 and 2



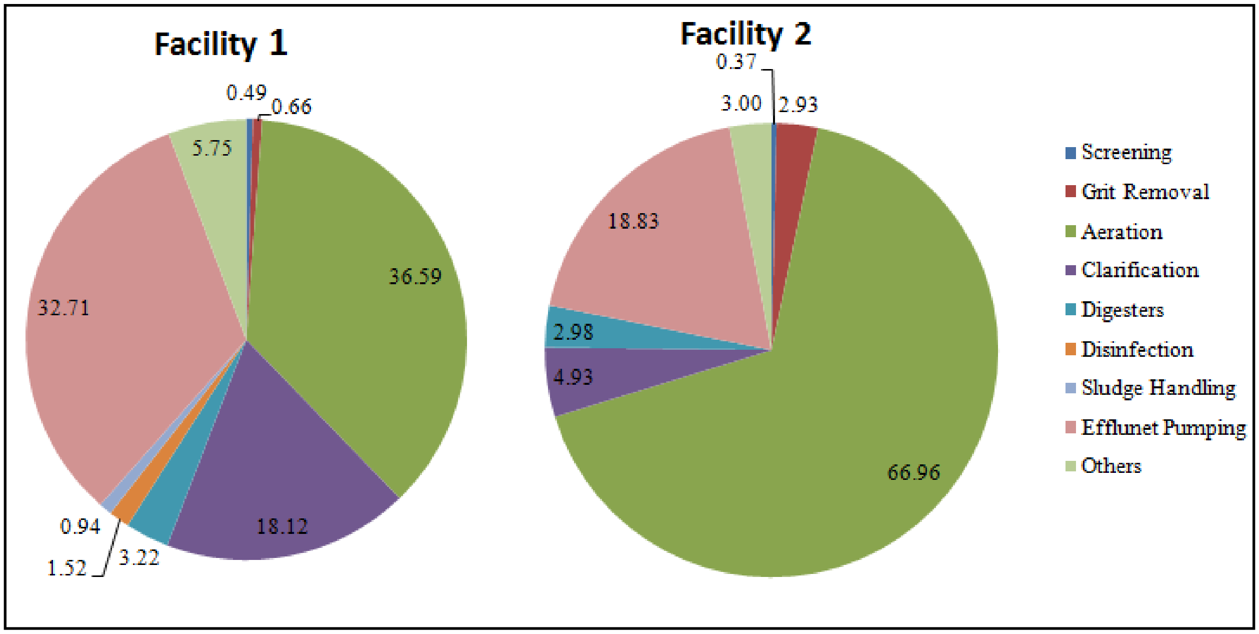
*These figures include power consumed for distribution/pumping system also.

In a treatment plant, each treatment unit has equipment that consumes energy to operate. Table 10 has the rate of power consumption and percentage rate of power consumption for each treatment unit in both the facilities. And Figure 10 shows the percentage rate of power consumption for various processes in both the facilities. In Table 10 and Figure 10 the rate of power consumption should not be misunderstood as the actual power consumption. As the run time of all the equipment in each unit process is not available, the actual power consumption cannot be quantified. More detailed information on the rate of power consumption for each treatment process in both the facilities is presented in Appendix D. Appendix D provides detailed information of each equipment type and their power ratings.

Table 10: Power Ratings for Various Treatment Processes

	Facility 1		Facility 2	
Treatment Process	**Power Rating (KW)**	**Power Rating (%)**	**Power Rating (KW)**	**Power Rating (%)**
Screening	7.52	0.49	0.74	0.37
Grit Removal	10.19	0.66	5.80	2.93
Aeration	563.86	36.59	132.48	66.96
Clarification	279.26	18.12	9.75	4.93
Digesters	49.63	3.22	5.89	2.98
Disinfection	23.45	1.52	0.00	0.00
Sludge Handling	14.54	0.94	0.00	0.00
Effluent Pumping	504.00	32.71	37.26	18.83
Others	88.56	5.75	5.93	3.00
Total	**1541.01**		**197.85**	

Figure 10: Power Ratings of Different Units at Two Treatment Plants



In a wastewater treatment facility the GHG emissions may be of two types:

- Operational emissions,
- Process emissions.

Process emissions are emitted into the atmosphere during various treatment processes and operational emissions are the emissions due to power consumption. Although operational emissions are indirect, they are more significant than process emissions. About 75 - 85% of GHG emissions from wastewater treatment facilities are operational emissions. The GHG's emitted from operational activities are mainly carbon dioxide and others, and are negligible. The carbon dioxide emissions can be quantified by taking into account the amount of power generated from various sources. EPA has certain predefined generation resource mix percentages for various sources (U.S. EPA 2005). These values are different for different states in U.S and Table 11 have these values for Louisiana.

Table 11. Power Generation by Fuel Type for Louisiana and Texas

Source	**Percentage Generation for Louisiana**
Coal	24.90%
Oil	3.76%
Gas	47.30%
Other fossil	3.04%
Biomass	2.89%
Hydro	0.88%
Nuclear	16.90%
Other	0.33%

Based on the above tables and the emission factors for the respective sources, carbon dioxide emissions for both facilities are quantified and tabulated in Table 12. Only coal, oil, and gas are considered, as they are the most potential sources of GHG's, and the others are considered to emit almost negligible amounts. For additional information the power generation by fuel type for all fifty states of U.S. is shown in Appendix C.

Table 12. Yearly Carbon Dioxide Emissions

Source	**Emission Factors for CO_2**	**Facility 1**		**Facility 2**	
	Kg/MWh	**Power, MWh**	**CO_2, Kg**	**Power, MWh**	**CO_2, Kg**
Coal	1012	2,723.84	2,756,662	388.19	392,868
Oil	752.5	411.31	309,470	51.07	38,425
Gas	510.8	5,174.19	2,642,719	642.43	328,122
Total			**5,708,851**		**759,414**

*****These calculations include power consumed from distribution/pumping system also. Emission factors for CO2 are taken from EPA, Clean Energy Program. Emissions due to bio-degradation of wastewater are ignored. (MWh-Mega-Watt hour)

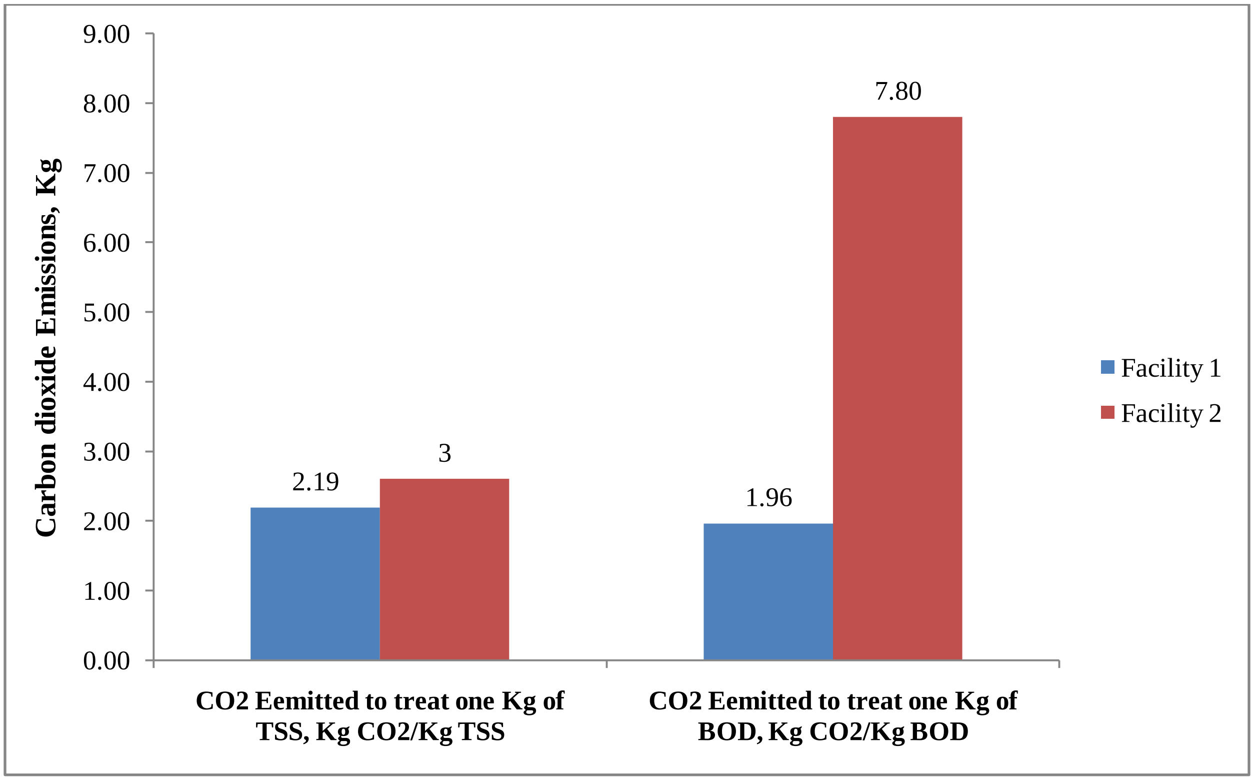
Also, the carbon dioxide emitted from the power consumed per capita, to treat a unit amount of wastewater, TSS, and BOD_5 are quantified and tabulated in Table 13. Comparison of these emissions is shown in Figure 11 below.

Table 13. Carbon Dioxide Emissions

	CO_2 Emitted per person per year, Kg	**CO_2 Emitted to treat One m^3 of Wastewater, Kg/m^3**	**CO_2 Emitted to treat one Kg of TSS, Kg CO_2/Kg TSS**	**CO_2 Emitted to treat one Kg of BOD, Kg CO_2/Kg BOD**
Facility 1	69.21	291.00	2.19	1.96
Facility 2	57.24	244.00	3.00	7.8

*All the above calculations are limited to the power consumed for treatment only.

Figure 11: Carbon Dioxide Emitted to Treat Unit Amounts of TSS and BOD



*The emissions are limited to treatment only

Chapter 5: Conclusions

Wastewater treatment facilities consume large amounts of energy in performing various operations like influent/effluent pumping, treatment, and sludge disposal. The consumption of each unit may be different for different facilities and, hence, this study provides a preliminary understanding about energy consumption for (a) treating wastewater generated by a single person, (b) treating a unit amount of wastewater, (c) removing a unit amount of TSS, and (d) removing a unit amount of BOD at the two facilities. These findings can be easily compared to other facilities and several conclusions can be drawn based on the observations. Also, using these energy consumption indicators, performance of a single treatment plant over year by year can be analyzed using these parameters. This study further helps in improving compliance with NPDES permits, public image and also cut down penalties.

This energy baseline study conducted at the two facilities provided an opportunity to identify various energy optimization measures. This research results in development of critical indicators that will minimize energy consumption and the associated GHG emissions thus promoting pollution prevention. This study will allow the plant operators to benchmark several parameters and by continuously monitoring these indicators, plant operators can efficiently reduce their operational costs. This study is intended to generate an energy base-line study for two facilities, identify the most power consuming areas, and develop possible ECMs. This study also clearly shows that many ECM options for energy optimization are available for WWTPs. These options may vary from facility to facility based on site conditions. Some of these ECMs are most commonly used. And sometimes a combination of these ECMs may drastically reduce energy consumption. So, the key for optimization lies in identifying the right ECM combinations for specific conditions.

This study also helps in understanding GHG emission trends from WWTPs due to energy consumption. These emissions can be reduced either by reducing the consumption, by adapting several ECMs, or by using alternative energy generation sources. Adaptation of both would furthermore reduce GHG emissions. Same approach can also be applied to other criteria pollutants (CO, $So_{2,}$ NO_X) and few hazardous air pollutants.

Chapter 5.1: Energy Optimization Opportunities and Recommendations

This study helps in identifying the most energy consuming processes or equipment within the facility, which allows the operators to efficiently optimize energy consumption and hence reduce GHG emissions. Several ECM's can be developed based on the developed indicators. These indicators must be developed and documented on a continuous basis for proper maintenance, efficient operations and to check the overall plant efficiency.

A few possible ECM's in the area of this study (two facilities) are discussed below.

Influent /Effluent Pumping

In most instances complete gravity flow is not possible due to the geographic profile of the community. Several lift stations are used where high capacity pumps provide the required hydraulic head. In this study, both facilities were operating several lift stations consuming a lot of energy. Figure 9 clearly shows that about 25 - 30% of the total energy consumption for the facilities is for pumping. Both facilities can reconsider their sewer flow designs and provide more gravity flow wherever possible and reduce the burden on the pumps.

Aeration

Efficient aeration is a most important aspect to effective use of energy in the aeration process. In the aeration process, power is consumed for supplying air. Often excessive air is supplied to the aeration tank as there is less control. Excessive air supply not only consumes a lot of energy but also is the reason for the bubbling of surface waters which results in lower aeration efficiencies. Possibly, the operators of Facility 1 having 6 aerators actively working can look into their aeration efficiencies and control the excessive air supply. And in the case of Facility 2, the aeration process consumes more than 60% of the total plant energy demand and hence more detailed study regarding the blowers. The blowers might need to be replaced by high efficient single stage centrifugal blowers with a single control point system. This will allow both facilities to work efficiently and economically. Additional savings would be possible by running the air supply pumps intermittently.

Primary/Secondary Clarifiers

In clarifiers, pumping bio-solids is a process where much energy is wasted due to over pumping of bio-solids during low flow periods. The recycling of supernatant liquid would degrade the performance of the primary clarifiers, which would result in an increase in energy and treatment loads on secondary processes. The operators of both the facilities need to avoid the stress on the clarifiers, which would drastically reduce energy loads on all treatment units (including clarifiers). The two combined aeration and clarifier units in Facility 1 need to be checked for any extra loads on them. The sludge pumps in operation must be checked for efficiency and must be replaced with high efficiency pumps if needed. Apart from this, air and water sprays used to control the scum need automatic operations to reduce energy consumption.

Disinfection

Not very high but a considerable amount of energy is consumed in the disinfection process. A major energy use in disinfection is for utility water used for chlorine injectors. Utility water is a part of the plant effluent used for various purposes. Both facilities use liquid chlorine for disinfection and, hence, consume energy for chlorine injectors. The facilities can consider different disinfection alternatives like using chlorine gas, ultraviolet (UV) disinfection, etc. These alternative methods would eliminate the energy associated with utility water.

Sludge Thickening and Dewatering

Energy use for sludge thickening and dewatering is usually very low. But if this unit is not well maintained and not efficient, there can be a serious impact on energy usage in other units of the plant. For example, recycle loads to the secondary clarifier would increase due to improper maintenance of the dewatering unit. Both facilities need to maintain the sludge thickening and dewatering systems for efficient operation of other units and, hence, can reduce energy consumption.

Variable Frequency Drive (VDF)

A VDF is a device that controls the speed of an electric motor by controlling the electric power supplied to the motor. A VDF at a WWTP provides a continuous control of the pumps, allowing the motor speed to match the fluctuations of the flow. In a WWTP, a VDF system is often very useful for pumping and aeration. A VDF system makes pumping more efficient by controlling the pumps during variable flows. In addition, this system would also help in controlling the air supply during the aeration process. A VDF system saves a significant amount of energy by controlling the pump speed, which usually runs at a constant speed for the same period. For example, a VDF system reduces energy usage by 45% for a 25 horsepower motor running 23 hours per day (2 hours at 100% speed, 8 hours at 75%, 8 hours at 67%, and 5 hours at 60%) (M/J Industrial Solutions 2003).

Energy Efficient Pumps

Upgrading to energy efficient motors can be very effective, especially in smaller motor sizes and where motors are used more than 4,000 hours per year (EPRI 1994). Energy efficient pumps use less energy, need less maintenance, and are more reliable. All pumps in the lift stations and within the treatment plant would consume about 80% of the total energy consumed in a WWTP. Thus, using energy efficient pumps can significantly reduce operating costs.

Cogeneration

Cogeneration is the technique used to generate electricity and useful heat using the heat engine or a power station within the treatment plant. This is one form of energy recycling. Cogeneration is possible only in case of anaerobic plants where electricity can be generated from the digesters which would greatly reduce the power purchase (WEF 1997). The two facilities in consideration are aerobic plants and hence cogeneration is not practically possible. In such cases may other green techniques can be followed to generate electricity. One good example of such techniques is utilization of solar energy. In recent times many kinds of equipment is developed to use solar energy to generate electricity that can be used for various processes. Installation of these kinds of equipment would considerably reduce the energy bills.

Appendices

Appendix A. Total One-Year Energy Consumption (KWh)

Month, Year	**Facility 1**	**Facility 2**
August,08	796,232	64,264
September,08	874,678	105,730
October,08	822,074	77,809
November,08	649,386	71,965
December,08	956,173	89,487
January, 09	872,538	95,434
February, 09	1,210,342	83,822
March, 09	874,905	90,429
April, 09	783,101	87,783
May, 09	787,773	90,200
June, 09	748,682	69,526
July, 09	806,063	72,834
August, 09	757,149	81,323
Total	10,939,096	1,080,606

Appendix B. Monthly Energy Consumption for Treatment vs. Pumping (KWh)

Month, Year	**Facility 1**		**Facility 2**	
	Treatment	**Pumping**	**Treatment**	**Pumping**
August,08	589,300	206,932	40,050	24,214
September,08	621,800	252,878	64,050	41,680
October,08	561,100	260,974	53,550	24,259
November,08	464,600	184,786	49,350	22,615
December,08	780,200	175,973	61,050	28,437
January, 09	604,600	267,938	64,650	30,784
February, 09	981,800	228,542	60,750	23,072
March, 09	577,400	297,505	65,100	25,329
April, 09	551,300	231,801	64,050	23,733
May, 09	613,100	174,673	63,750	26,450
June, 09	588,400	160,282	54,300	15,226
July, 09	639,200	166,863	58,050	14,784
August, 09	577,300	179,849	64,200	17,123
Total	**8,150,100**	**2,788,996**	**762,900**	**317,706**

Appendix C. Power Generation by Fuel Type for U.S.

	Generation Resource Mix (percent)										
State	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydro**	**Bio mass**	**Wind**	**Solar**	**Geo thermal**	**Other Fossil**	**Other**
AK	9.475	11.558	56.619	0.000	22.260	0.080	0.009	0.000	0.000	0.000	0.000
AL	56.851	0.145	10.096	23.080	7.387	2.345	0.000	0.000	0.000	0.087	0.009
AR	48.200	0.432	12.570	28.643	6.493	3.630	0.000	0.000	0.000	0.032	0.000
AZ	39.563	0.043	28.476	25.435	6.411	0.060	0.000	0.013	0.000	0.000	0.000
CA	0.983	1.289	46.706	18.084	19.883	2.908	2.131	0.269	6.514	1.130	0.104
CO	71.668	0.034	24.059	0.000	2.606	0.069	1.564	0.000	0.000	0.000	0.000
CT	11.912	9.407	26.424	46.385	1.420	2.119	0.000	0.000	0.000	2.301	0.031
DC	0.000	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DE	59.398	14.950	19.551	0.000	0.000	0.000	0.000	0.000	0.000	6.101	0.000
FL	28.430	16.926	38.053	13.081	0.121	1.970	0.000	0.000	0.000	0.625	0.794
GA	63.854	0.737	7.154	23.082	2.796	2.340	0.000	0.000	0.000	0.038	0.000
HI	14.157	78.769	0.000	0.000	0.835	2.613	0.058	0.000	1.923	1.645	0.000
IA	77.485	0.340	5.640	10.317	2.181	0.264	3.745	0.000	0.000	0.028	0.000
ID	0.879	0.000	14.320	0.000	78.911	5.331	0.000	0.000	0.000	0.000	0.559
IL	47.520	0.168	3.662	48.035	0.067	0.353	0.073	0.000	0.000	0.123	0.000
IN	94.248	0.203	2.760	0.000	0.336	0.051	0.000	0.000	0.000	2.075	0.326
KS	75.183	2.151	2.480	19.233	0.025	0.000	0.929	0.000	0.000	0.000	0.000
KY	91.066	3.763	1.695	0.000	3.027	0.432	0.000	0.000	0.000	0.017	0.000
LA	24.892	3.761	47.294	16.914	0.875	2.887	0.000	0.000	0.000	3.040	0.336
MA	25.337	14.984	42.692	11.528	1.184	2.528	0.000	0.000	0.000	1.748	0.000
MD	55.689	7.252	3.594	27.932	3.237	1.045	0.000	0.000	0.000	1.251	0.000
ME	1.834	8.619	42.597	0.000	23.276	21.930	0.000	0.000	0.000	1.744	0.000
MI	57.829	0.738	11.206	27.023	0.288	2.086	0.002	0.000	0.000	0.830	0.000
MN	62.116	1.481	5.145	24.260	1.464	1.892	2.991	0.000	0.000	0.564	0.087
MO	85.230	0.185	4.289	8.839	1.371	0.010	0.000	0.000	0.000	0.077	0.000
MS	36.907	3.187	34.025	22.358	0.000	3.479	0.000	0.000	0.000	0.043	0.003

Appendix C. Power Generation by Fuel Type for U.S. Cont.

	Generation Resource Mix (percent)										
State	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydro**	**Bio mass**	**Wind**	**Solar**	**Geo thermal**	**Other Fossil**	**Other**
MT	63.794	1.482	0.129	0.000	34.316	0.234	0.000	0.000	0.000	0.046	0.000
NC	60.471	0.374	2.412	30.818	4.273	1.416	0.000	0.000	0.000	0.057	0.179
ND	94.758	0.107	0.029	0.000	4.202	0.031	0.690	0.000	0.000	0.183	0.000
NE	66.162	0.099	2.554	27.973	2.770	0.136	0.307	0.000	0.000	0.000	0.000
NH	16.683	5.559	27.790	38.731	7.141	3.840	0.000	0.000	0.000	0.257	0.000
NJ	19.102	1.800	25.087	51.580	0.000	1.378	0.000	0.000	0.000	0.954	0.100
NM	85.233	0.105	11.917	0.000	0.470	0.013	2.262	0.000	0.000	0.000	0.000
NV	44.926	0.109	47.445	0.000	4.160	0.000	0.000	0.000	3.086	0.275	0.000
NY	13.754	16.227	22.464	28.664	16.885	1.237	0.070	0.000	0.000	0.699	0.000
OH	87.194	0.886	1.716	9.430	0.329	0.246	0.009	0.000	0.000	0.191	0.000
OK	51.718	0.100	43.005	0.000	3.524	0.412	1.206	0.000	0.000	0.027	0.009
OR	7.001	0.120	27.039	0.000	62.498	1.773	1.483	0.000	0.000	0.088	0.000
PA	55.440	2.274	4.959	34.994	0.695	0.914	0.130	0.000	0.000	0.584	0.010
RI	0.000	0.922	98.967	0.000	0.111	0.000	0.000	0.000	0.000	0.000	0.000
SC	38.704	0.656	5.280	51.834	1.697	1.739	0.000	0.000	0.000	0.091	0.000
SD	45.951	0.319	4.155	0.000	47.150	0.000	2.425	0.000	0.000	0.000	0.000
TN	61.000	0.238	0.548	28.657	8.979	0.575	0.003	0.000	0.000	0.000	0.000
TX	37.348	0.572	49.261	9.625	0.336	0.276	1.067	0.000	0.000	1.303	0.212
UT	94.267	0.107	3.086	0.000	2.056	0.000	0.000	0.000	0.484	0.000	0.000
VA	44.914	5.376	10.435	35.425	0.081	3.117	0.000	0.000	0.000	0.654	0.000
VT	0.000	0.178	0.039	71.221	21.180	7.181	0.201	0.000	0.000	0.000	0.000
WA	10.303	0.100	8.415	8.083	70.684	1.556	0.489	0.000	0.000	0.370	0.000
WI	67.349	1.137	10.481	16.043	2.754	1.892	0.150	0.000	0.000	0.120	0.074
WV	97.656	0.239	0.292	0.000	1.547	0.001	0.164	0.000	0.000	0.102	0.000
WY	95.125	0.093	0.713	0.000	1.774	0.000	1.574	0.000	0.000	0.579	0.143

*Other- All other purchased/unknown fuels. Source: EIA, Energy Resource Mix summary tables, 2005.

Appendix D. Detailed Equipment Inventory and Power Ratings of all Units

Facility 1

Unit Description	Power (HP)	Current (A)	Voltage (V)	Power Consumption (KW)
Bar Screens				
Screening Pump (NP)	1	2.8	480	1.344
Rag Pump (NP)	1	1.9	480	0.912
Screening Pump (SP)	3	4.15	480	1.992
Rag Pump (SP)	5	6.8	480	3.264
Grit chambers				
Grit Works Pump 1 (NP)	1	3.4	480	1.632
Grit Works Pump 2 (NP)	1	3.4	480	1.632
Grit Works Pump (SP)	10	12.9	480	6.192
Grit Collector (SP)	0.75	1.53	480	0.7344
Aerators				
Blower 1	250	275	480	132
Blower 2	250	275	480	132
Blower 3	250	275	480	132
Water Hose Pump	10	12.2	480	5.856
Clarifiers				
Pump1	20	24.5	480	11.76
Pump2	20	24.5	480	11.76
Pump3	20	24.5	480	11.76
Pump 4	0.5	0.97	480	0.4656
Pump 5	0.5	0.97	480	0.4656
RAS valve Motor 1	0.33	2.9	480	1.392
RAS valve Motor 2	0.33	2.9	480	1.392
RAS valve Motor 3	0.33	2.9	480	1.392
RAS valve Motor 4	0.33	2.9	480	1.392
RAS 1	0.75	1.95	480	0.936
RAS 2	0.75	1.95	480	0.936
RAS 3	0.75	1.95	480	0.936
RAS 4	0.75	1.4	480	0.672
RAS 5	40 BHP	50	480	24
RAS 6	40 BHP	50	480	24
RAS 7	40 BHP	50	480	24

Appendix D. Detailed Equipment Inventory and Power Ratings of all Units Cont.

Facility 1 Cont.

Unit Description	Power (HP)	Current (A)	Voltage (V)	Power Consumption (KW)
Digesters (4)				
Motor 1	15	5.6	480	2.688
Motor 2	15	5.6	480	2.688
Motor 3	15	5.6	480	2.688
Motor 4	15	5.6	480	2.688
Motor 5	15	5.6	480	2.688
Motor 6	15	5.6	480	2.688
Motor 7	15	5.6	480	2.688
Motor 8	15	5.6	480	2.688
Sludge Pump1	20	26	480	12.48
Sludge Pump 2	20	26	480	12.48
Grinder Pump	0.5	6.6	480	3.168
Aerator/Clarification Units (SP)				
Blower 1	200	225	480	108
Blower 2	200	225	480	108
Blower 3	200	225	480	108
Disinfection				
Froth Strain Pump	0.75	1.45	480	0.696
Utility water pump 1	20	23.7	480	11.376
Utility water pump 2	20	23.7	480	11.376

Appendix D. Detailed Equipment Inventory and Power Ratings of all Units Cont.

Facility 1 Cont.

Unit Description	Power (HP)	Current (A)	Voltage (V)	Power Consumption (KW)
Belt Press (2)				
Belt Conveyor	3	4.5	480	4.608
Spray water hose Pump	7.5	9.6	480	4.608
Spray water hose Pump	7.5	9.6	480	1.008
Ash Brush Press motor	1.5	2.1	480	2.16
Belt drive Pump 1	3	4.5	480	0
Belt drive Pump 2				
Polymer Pumps				
Effluent Pumps				
Pump 1	150	175	480	84
Pump 2	150	175	480	84
Pump 3	150	175	480	84
Pump 4	150	175	480	84
Pump 5	150	175	480	84
Pump 6	150	175	480	0
In House Pump Station				
Pump 1	7.5	19	480	9.12
Pump 2	7.5	19	480	18
Pump 3	15	37.5	480	20.832
Pump 4	15	43.4	480	20.832
Pump 5	15	43.4	480	0
Others				
Booster Pump1	3/4th	6.3	480	3.024
Booster Pump 2	3/4th	6.3	480	4.608
Booster Pump3	1.5	9.6	480	4.608

Appendix D. Detailed Equipment Inventory and Power Ratings of all Units Cont.

Facility 2

Unit Description	Power (HP)	Current (A)	Voltage (V)	Power Consumption (KW)
Bar Screens				
Screening Pump 1	0.5	0.8	460	0.368
Screening Pump 2	0.5	0.8	460	0.368
Grit chambers				
Grit wash pump	0.5	1.25	460	
Spiral Pump	3/4th	1.55	460	
Agitator	7.5	9.8	460	
Aerators (2)				
Blower 1	125	144	460	66.24
Blower 2	125	144	460	66.24
Clarifiers (2)				
Pump1	0.5	1	460	0.46
Pump 2	0.5	1	460	0.46
RAS1	7.5	9.6	460	4.416
RAS2	7.5	9.6	460	4.416
Digesters (2)				
Yard/sludge pump	10	12.8	460	5.888
Others				
Wash water Pump	7.5	9.2	460	4.232
Booster Pump	2	3.7	460	1.702
Disinfection				
Very less power consumption				
Belt Press				
Polymer addition	Very less Consumption			
Press: Not in use				
Effluent Pumps				
Pump1	40	27	460	12.42
Pump2	40	27	460	12.42
Pump3	40	27	460	12.42

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