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The Energy Trilogy: An Integrated Sustainability Model To Bridge Wastewater Treatment Plant Energy And Emissions Gaps

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THE ENERGY TRILOGY: AN INTEGRATED SUSTAINABILITY MODEL TO BRIDGE WASTEWATER TREATMENT PLANT ENERGY AND EMISSIONS GAPS

by

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DISSERTATION

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Approved by:

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Advisor Date

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DEDICATION

To my wife, my children Al Leith, Jenna Lee and the oldest Amanda Alia who continually fought for life and kept her weak heart beating. I appreciate their patience allowing me to study instead of offering them a better quality life.

I also would like to dedicate this work to the memory of my parents, brothers Aziz and Dr. A. Amir who always inspired in me the love for learning, good work and honesty.

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CHAPTER 1

INTRODUCTION

1.1 Background and Need

Wastewater treatment plants are one of the more energy intensive facilities managed by the public sector, with potential of being greatly influenced by energy efficiency at the design as well as retrofit stages [53]. An estimated 4% of national energy consumption, equivalent to approximately 56 billion kilowatt hours (kWh), is used for drinking water and wastewater (WW) services. Assuming the average mix of energy sources in the country, this equates to adding approximately 45 million tons of greenhouse gases (GHG) to the atmosphere. This 4% of the national electricity is used by 60,000 water systems and 16,000 wastewater systems in the United States [1], [2]. At the same time, wastewater plants and drinking water systems can account for up to one-third of a municipality's total energy bill [59], yet a significant amount of controllable energy usage exists in these plants, which represents valuable and cost-effective energy savings opportunities, that are worth investment in energy-efficient technologies. A 2005 study showed that 19% of California electricity was spent on water-related activities [54]. Therefore, the impact of these systems on the emissions of greenhouse gases (GHG) into the atmosphere now and the future will continue today and will likely result in more severe impacts on climate change in the latter half of the century [55].

Moreover, the demand and cost of this energy to a wastewater utility continues to rise due to a number of factors including [57]:

- Implementation of increasingly stringent discharge requirements
- Enhanced treatment of biosolids, including drying and pelletizing

- Higher pumping and treatment requirements and costs associated with increased infiltration and inflow from aging wastewater collection systems
- Increasing electricity rates associated with the cost of fossil fuels used for energy production and with construction of new electric power generating and distribution infrastructure to meet increasing demand

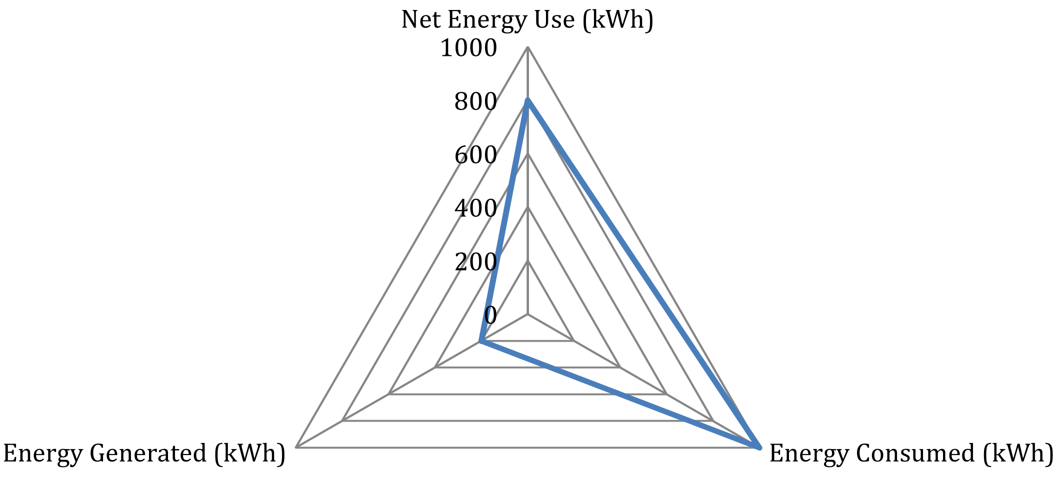
The energy-water-wastewater nexus is a significantly important part of the human activity chain; a link of water use, wastewater generation and energy consumption. Despite public awareness and optimization programs initiated by federal, state and local authorities to promote energy efficiencies, energy consumption is on the rise owing in large part to population and urbanization expansion and to commercial and industrial business growth. The principal concern is that as energy consumption grows, energy production demand will increase, leading to a parallel increase in human carbon dioxide (CO_2) footprint and the increased contribution to global warming potential.

The fundamental goal of wastewater treatment is to protect the public health of the community and the environment at the point of discharge, in addition to compliance with regulatory clauses. To address these issues, treatment processes and advanced technologies used in the design phase of the project need to be well-planned, considering region-specific and socio-economic conditions, to achieve sustainability now and in future generations. In the area of wastewater, several studies and projects have utilized the triple bottom line (TBL) approach for integrating the three beneficiaries – social, economic and environmental – for evaluating the success of a wastewater treatment option (an example is the Philadelphia water department (PWD) project for controlling CSO events [58]. The water chain begins with: 1) water resources conveyance, treatment and distribution, then 2) wastewater collection, followed by 3) treatment and effluent conveyance to receiving body of water. This research work defines the water-energy portion of the chain that is found within the wastewater treatment plant (WWTP), particularly at the treatment plant design phase, at which time attempts can be made to bridge the gap between energy mix use and the amount of generated greenhouse gases (GHG). This research groups WWTP energy processes activities into:

(1) Consuming energy, (2) Producing energy, and (3) Net energy and the resulting climate change actors - CO_2 equivalents.

Similar to the TBL, this research introduces the overall relationship for the three groups above using an enhanced energy projection described as the Energy Trilogy (ET) - a group of three related entities. This relation is illustrated in (Figure 1.1) below.

Figure 1.1: The Energy Triangle – Bridging the Gaps



Source: Author

Previous research has been performed in this field, but such efforts either target plant design only with minimal attention to energy, or uses averaged data for estimating energy, or combination of both; at the same time, accurate, detailed and measurable energy information is not readily obtained for wastewater facilities, specifically during facility preliminary design phases. These limitations call for a detailed, data-intensive research approach on GHG emissions quantification, plant efficiencies and source reduction techniques.

The underwriting of environmental innovations, such as through U.S. environmental protection agency (EPA) annual small business innovation research (SBIR) program competition, is designed to produce technologies for the water and wastewater sector [60], while the use of energy models or calculation tools can help in assessing the performance of technologies to reduce environmentally harmful process emissions. Models or tools may be used by designers and engineers to help compare innovations, available processes, equipment and technologies in order to estimate the best energy performance fit for a particular facility, especially during wastewater plant initial design and rehabilitation phases.

A few states, cities and locations have attempted to define their needs and establish a comprehensive tool capable of easing user's needs, but some data gaps always arise due to different water supply resources, unavailability of data, different WW operators, overlooked factors and the like.

The energy trilogy research is the attempt to find a comprehensive energy and GHG footprint assessment model for wastewater treatment plants during the design phase. This model will detail and encompass within its framework all operations, including baseline technologies responsible for generating emissions associated with wastewater treatment, pumping and ancillary activities inside the facility boundaries - - from wastewater arrival into the inflow structure of the plant to treated effluent pumping to other treatment works or to a receiving water body. Also, energy consumed outside the plant for the production of materials to be used within WWTP energy operations are added to plant energy consumption, and energy generated in-plant from renewable and energy recovery activities are deducted from plant energy balance within the proposed model analyses. The model will attempt to calculate the resulting CO_2 emissions equivalent (CO2e) from a specific plant's net energy consumption. At a later phase, the complete research work should define all data needed to build an electronic tool for calculating projected new WWTP energy needs or existing plant retrofitting and rehabilitation requirements. The goal of this work is to provide a guide for professionals seeking energy information while designing a new WWTF. The model, and later the excel tool will list WWTPs technologies, assess their energy consumptions, estimate emissions and further provide energy comparison ability for conventional and new technology sources and measures.

The adequacy of the model is achieved by comparing a base-study project prepared by WEF, estimating electrical energy consumption averages compiled from several WWTPs, with the energy consumption of a plant audited in this dissertation using the model methodologies, formulas and approaches. The deviation between the two studies was just 14%. This research encountered all other energy sources of the audited plant whose total estimation equated to about 5.5 times the CO_2e generated by electricity alone.

1.2 Purpose of the Research - Energy Sustainability

The focus of this dissertation is to develop a baseline model for wastewater treatment facilities energy requirements in the design phase in order to understand the energy savings impact of various operational strategies and equipment selection on the efficiency of the WWTP. The complex nature of electrical utility billing structures, the variable demand of a WWTF, the regulatory requirements, GHG emissions and global warming issues complicate energy conservation decision-making, in deciding both initial design concepts and which energy conservation measures should be implemented.

During the end of last century, "sustainability" surfaced as a terminology in the area of environmental studies, particularly in the design of the wastewater treatment processes. A "sustainable development" definition first appeared in 1987: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" - from world commission on environment and developments [61], (Figure 1.2). USEPA [62], stated: Sustainability is based on a simple principle: Everything that we need for our survival and wellbeing depends, either directly or indirectly, on our natural environment. The goal of sustainability is to create and maintain the conditions under which humans and nature can coexist in productive harmony, for both present and future generations. Setting a goal of sustainability is important to achieve having, and continuing to have, the water, materials, and resources, to protect human health and our environment.

Figure 1.2: The Three Objectives of Sustainability

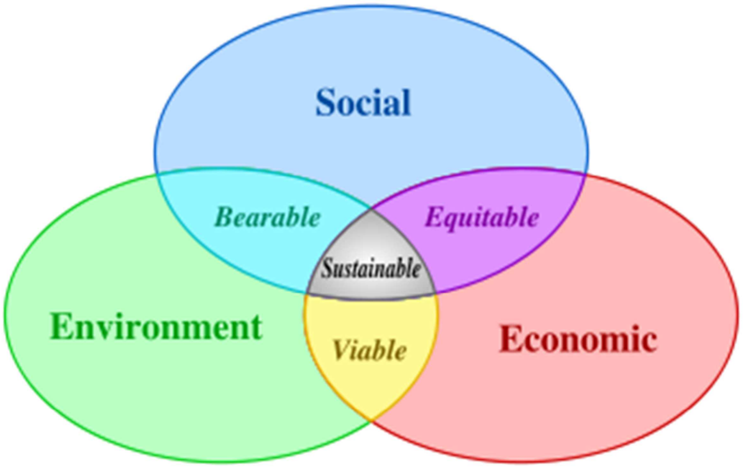


Image from: Terra Firma Consulting

Sustainable development suggests that meeting the needs of the future depends on how well the social, economic and environmental objectives are balanced when making today's decisions. Some of the objectives of this development are to achieve cost reduction (growth), ecological integration and equity as shown in (Table 1.1).

Table 1.1: Sustainable Development

Sustainability	Objective	Development
Economic	Industrial Growth	Plant construction and operation
Environmental	Ecosystem Integrity	The use of environmental remediation actions to treat contaminated soil and groundwater
Societal	Equity	Studying the impact on drinking water wells and public health

		from the implementation of natural attenuation remediation method

Source: Author

This work primarily focuses on sustaining the process of energy decision-making during the design of a wastewater treatment plant in which the outcome of the social, economic and environmental objectives in the short term has to sustain future development in the long term. An energy sustainability approach, therefore, will demand: 1) the compilation of a wide range of data pertaining to fuels, equipment and processes, 2) materials that conform to current needs and comply with future developments, 3) defining the "ins and outs" of wastewater treatment energy balance and 4) a model that serves as a decision-making approach to quantify the balance.

This research links WWTP energy balance through the energy trilogy (ET) approach for studying the relationship between the triple energy corners: imported energy, generated energy and net energy use, or its equivalent, resulting in greenhouse gas emissions.

1.3 The Energy Trilogy (ET) Model

This research is introducing a model integrating all WWTP processes and their pertinent energy sources: imported, pre-combusted and in-plant generated. In a comprehensive, detailed and "fuel generator - to - effluent discharge" pattern, this model is capable of bridging the gaps of a WWTP energy, facilitating plant designers' decision-making for meeting both energy assessment and sustainability, and the environmental regulatory requirements of GHG inventory compilation for reporting and compliance with acceptable permit standards. Protocols for estimating common emissions sources are available for fuels; however, site-specific emissions for other sources have to be developed and are captured in this research.

The ET model helps allocate the energy footprints for individual processes, by type of equipment or fuel, net plant energy consumption (MWh) (Figure 1.1), plant energy intensity (MWh/MGD), which is defined as plant's total energy consumed in the form of electricity, natural gas and other sort of fuels to a base unit (10^6 gallon) of treated and pumped effluent outside facility boundaries per day. The ET model also is capable of calculating facility carbon footprints or GHG from all WWTP energy balance sources, including the non-combustion sources of emissions common to biological treatment activities and sludge degradation, and takes into account in-plant produced energy from combined heat and power (CHP) or alternative and renewable energy sources, if any.

Other benefits of the ET model can be summarized as:

- Energy estimates can be performed based on provided methodologies for calculating emission factors and energy and not on averaged local or state published constants
- Allow for estimating CO_2e for a new plant without pre-established energy information from metering or testing, hence eliminating the need for expensive labor and time needed to obtain data
- Assess separate energy consumption operations utilizing model formulas, and help engineers compare those processes during rehabilitation of existing plants
- Easing the estimation of plant GHG inventory for regulatory compliance

1.4 Problem Statement - Challenges

Many governmental, research and private sector organizations have prepared tools, calculators, models or other aids in conjunction with energy consumption and carbon footprints to help industrial, commercial and institutional entities find their way to better energy conservation and reasonable energy cost savings through the control of energy consumption. Examples of such tools are the Pacific Institute's "water-to-air model" [3], and the research work of Wilkinson, Robert C. 2000 "methodology for analysis of the energy intensity of California's water systems, and an assessment of multiple potential benefits through integrated water-energy efficiency measures"- exploratory research project, Ernest Orlando Lawrence Berkeley laboratory - California Institute for Energy Efficiency [4].

In April 2007, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) [5] issued a report from its workshop in Washington, D.C., recommending forecasting the carbon footprint from building operations, and suggesting some future fields for research, including water and wastewater (W & WW) facilities.

However, none of the above considered studying in detail all sources of energy encompassed within the fence of a wastewater facility, including sources of energy imported into the facility, energy generated by the facility and the energy otherwise consumed outside on products used by the WWTP. Examples of this are the energy spent on the production of chemicals at manufacturing sources, or energy from water consumed on site for cleaning and other purposes. As a result, such current approaches used to estimate GHG emissions of a WWTP are severely limited, since they are not inclusive of all processes encountering all types of fuels, or do not fully consider the balance of imported energy consumed (IE), produced energy (PE) and the resulting net energy consumed (NEC) or its CO_2 e emission integration.

Many other research works depend, as well, on available theoretical formulas without assessing the floor conditions of machines and processes which can hinder the theoretical operation of equipment, causing them to alter a portion of valuable motor efficiency; in other words, increasing or decreasing energy consumption. A close example is the finding of a Fairfax, Virginia, study [43] which concluded that "hydraulic equations for the pumped energy underestimated the embodied energy by 41% compared with electric bills, and that a hydraulic equation can provide a rough estimate, but actual electrical consumption data are preferred when available".

1.5 Research Objectives - Significance

To avoid the challenges mentioned above, the ET model is designed to fill in the gaps missed or not integrated by other works through defining:

- WWTP boundaries pertaining to energy-shed
- WWTP energy consuming operations
- Technologies and energy sources available to a WWTP
- Plant actual energy consumption data, utilizing equipment and process - specific formulae

This research work and the ET model are intended to aid communities, municipalities, engineers and designers during the initial design or rehabilitation phases of wastewater plants; to help determine amounts of energy necessary for a plant's smooth operation while ensuring energy cost savings. The input of different sources of fuels or equipment numbers and models for a process within the model can be continued until an option is chosen and a decision is made that conforms with sustainable plant processes, the desired energy optimization level and the acceptable GHG inventory per permit standards.

The primary objective of this research study is the production of an unprecedented energy model for assessing energy consumption from diversified WWTP operations at a plant's design phase to:

- Estimate site-specific energy requirements during plant design phase. A model that will, through a comprehensive listing of WW operations for all associated energy consumption sources, find site specific emission factors for all energy sources where possible, quantify individual source consumption (annual usage) to assess new plant CO_2e emissions, per the equation:

  $$CO_2e = \text{Imported energy} \sum[(EF_1 \times W_1 + EF_2 \times W_2 \ldots\ldots + EF_n \times W_n) + \text{Pre-combusted} \sum(EF_1 \times W_1 + EF_2 \times W_2 \ldots\ldots + EF_n \times W_n)] - \text{Plant generated} \sum(EFp_1 \times Wp_1 + EFp_2 \times Wp_2 \ldots\ldots + EFp_n \times W(pn) \qquad \ldots\ldots(1.5.1)$$

  Where *EF* - emission factor (ton CO_2e/energy unit) for each GHG (CO_2, CH_4, and N_2O) found in W_1, $W2$, W_n - activity data (fuel consumed, unit mass or volume), EF*p* and W*p* - emission factors and masses of all GHGs for in-plant produced energy.
- Determine plant energy intensity (kWh consumed per 10^6 gallons of WW treated)
- Link the energy trilogy, eliminating the need for using several models or tools
- Replace the expensive on-site energy measurement
- Use for assessing alternative energy optimization measures during plant's life cycle
- Find emissions reduction benefits from the use of alternative, renewable or heat recovery energy systems in relation to conventional energy consumption sources
- Estimate non-combustion emissions (methane from biological sources)

- Allocate data for pre-combusted energy sources (from materials manufactured outside the wastewater plant)
- Provide guidance to aid designers and engineers, comparing benchmarks for carbon footprints/GHG emissions from combinations of wastewater treatment process options
- Compile plant CO_2e for emissions inventory reporting
- Establish a database for a future computational tool/software production

1.6 Research Approach and Organization

The ET research approach is organized as follows:

Phase I: Literature review and survey for data acquisition.

This phase involved reviewing previous research work, scientific studies and reports, governmental–sponsored research, available water and wastewater tools or models, and related governmental and institutional web sites pertaining to the water–energy nexus. In this phase, emission factors for energy consumption sources and formulas associated with production of the ET model are determined. Literature in the general area of energy optimization, conservation and the renewable energy and in the specific area of energy models and tools was consulted and continued to be reviewed throughout the draft of this dissertation. Chapter 3 discusses some of the references as related to this study. A library of the sources used or reviewed for this research, numbered and sorted is found in the back of this book.

Phase II: The WWTP process and equipment data verification.

In this phase, plant processes, designs and professional reports are reviewed through the latest or the most related publications from specialized and trusted publication institutions to wastewater design, operations and treatment, and by consultation with professionals in the field.

Phase III: Organizing the variables and formulas.

In this phase, findings of previous phases, variables including formulas for energy calculation, emissions factors, conversion units, etc., are determined, and discussed in detail in Chapters 4, 5 and 6 for model basic structuring and energy sustainability.

Phase IV: Design work frame of the model.

In this phase, data are coded and organized in a database layout design (tables) representing the model production, that could be adopted as a computational tool for energy analysis, design support and inventory preparation using any operating program such as Microsoft Excel. The tool Excel structure and analysis are designed and completed in this phase and provided in a separate document. Chapters 7, 8 and 9 are integrating this information.

Phase V: This phase involves the discussion and final organization of data into a mathematical model and basic spreadsheets for electronic tool.

Phase VI: preparing comparative study to prove viability of GHG model, formulas used and other data based on a baseline study from reliable source.

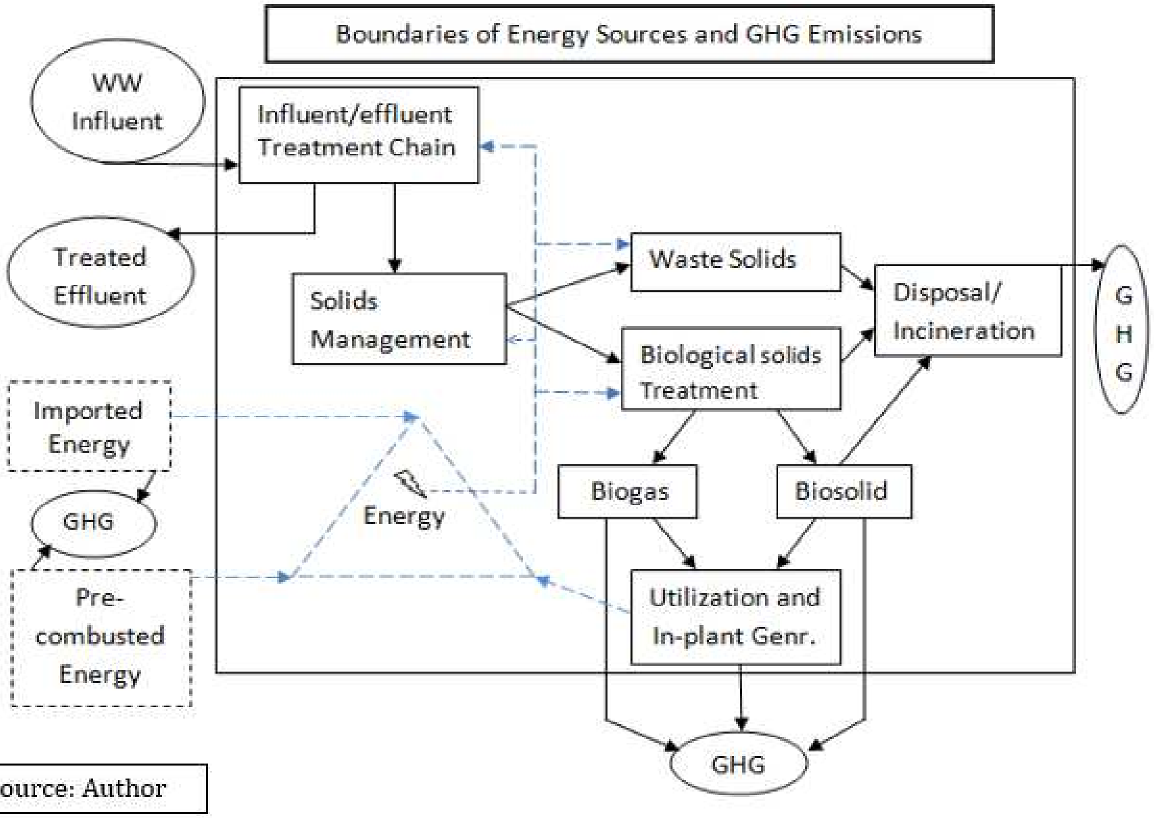
Phase VII: This phase is the development, write up and conclusion of this dissertation, and preparation for dissertation defense.

1.7 Research Energy Boundaries

Defining project boundaries is the first step in quantifying GHG emissions and inventory reporting, and includes defining the processes that are considered in the inventory [63]. The system boundaries of this research are defined by allocating and integrating the energies consumed in a WW treatment plant, starting from influent entrance at the inflow structure, throughout the treatment process and ancillary works until effluent is pumped outside the plant to other treatment works or to a final water receiving body. Defining project boundaries will include all emission-causing combusting fuels, the use of electricity and natural gas sources, whether the source was stationary or mobile, from anaerobic digesters, HVAC, boilers, vehicle use or water pumping. Sources will be detailed in the upcoming chapters.

Boundaries (Figure 1.3) should include the determination of emissions sources gases relevant to energy types and processes utilized in the engineering and operations of a WWTP. For a wastewater plant sited by many protocols, such as the climate registry (TCR), the major GHGs of concern are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Figure 1.3: Plant Energy and GHG Emissions Boundaries



Source: Author

CHAPTER 2

ENERGY - WATER NEXUS

Eleven National Laboratories have formed the Energy-Water Nexus, which highlights the importance of research into relationships between energy and water; this group has developed– with DOE funding - a roadmap to address these research needs [64].

Water and energy are critical, mutually dependent resources—the production of energy requires large volumes of water and water infrastructure requires large amounts of energy [53]. The tie between energy and water is strained by climate change. As weather pattern change, water supply and availability may be altered [65]. Hydropower, energy for mineral extraction and mining, fuel production and thermoelectric cooling all require massive amounts of water; according to USGS, thermoelectric power generation water withdrawals were estimated at 21 billion gallons/day - about 41% of all freshwater withdrawals [66]. About 4% of U.S. electricity is used to distribute and treat water and wastewater [67].

Table 2.1 shows the relative cooling water needs of fossil and nuclear generation, broken out by once-through (typically ocean or river-based) or wet-tower (evaporative cooling) systems [68]. It is important to note that current estimates include a shift from once-through to wet-tower systems. This shift will reduce the amount of total water withdrawals, but it will concurrently increase the amount of total water consumption by thermoelectric generation.

Table 2.1: Cooling Water Needs of Fossil and Nuclear Electricity Generation

Fuel Source	**Technology**	**Withdrawal (gal/kWh)**	**Consumption (gal/kWh)**
Fossil	Once-Through	37.7	0.1

	Recirculation (Wet Tower)	1.2	1.1
Nuclear	Once-Through	46.2	0.1
	Recirculation (Wet Tower)	1.5	1.5

Source: SAIC Report, Units based on EIA Form 767, and Water Estimates from EPRI

In the wastewater industry, a publicly owned wastewater treatment works (POTW) use 0.252 to 0.505 (kWh/m^3) of electricity, depending on the treatment technology employed; [69] WERF 2010 Energy Efficiency in WWT in North America: A compendium of best practices and case studies of novel approaches, owso4R07e, determined that trickling filters use the least, whereas advanced treatment with nitrification uses the most electric energy. POTWs in the U.S. consumed about 21 million kWh of electricity in 2000, and the number is expected to rise steadily through 2050, EPRI 2005 as the population increases, which, in turn translates into increased water withdrawals.

Additionally, regulations that require more aggressive treatment of wastewater flows to reduce contaminants, generally require greater use of electricity [53]. Similarly, wastewater reuse and desalination technologies that augment water supplies are energy intensive. Hecht and Miller [70], argue that challenges go beyond technology trade-offs and include the following:

- Planning initiatives, resource management and legislation must integrate water and energy
- Scientific understanding and technology processes must better understand and work in concert with the nexus

- Industrial systems must be designed to mimic natural systems
- Data on water availability and sustainability is not fully developed.

2.1 Wastewater Treatment Plants

Types

Some communities treat wastewater to higher standards than others, and as a general rule, the higher the level of treatment the higher the energy intensity [7], which is, for the purpose of this work, defined as the amount of plant energy consumed per 10^6 gallons of treated wastewater effluent leaving the plant. The four main grades, or levels, of wastewater treatment are trickling filter, activated sludge, advanced wastewater treatment and advanced wastewater treatment with nitrification.

While the energy intensity of wastewater treatment can be determined without knowing the level of treatment, knowing the level will allow for more accurate estimates of energy intensity if information on energy use cannot be obtained from the wastewater utility. Generic wastewater treatment energy intensities can be found from table; energy intensity of wastewater treatment by size and level of treatment (source B. Griffiths-Sattenspiel and Wendy Wilson, The Carbon Footprint of Water.)

Treatment

Wastewater from municipal sewage is treated to remove soluble organic matter, suspended solids, pathogenic organisms and chemical contaminants [6]. Anaerobic treatment of wastewater produces methane (CH_4), which can be released to the atmosphere if controls to capture these emissions are not in place.

Emissions

Wastewater treatment facilities are the eighth-largest source of human-related CH_4 emissions in the U. S., emitting 24.4 Tg CO_2e and accounting for approximately 4.2% of total emissions in 2007 [71]. More than 75% of the U.S. population is served by centralized wastewater collection and treatment systems [72]. Based on the results of EPA's 2004 Clean Watersheds Needs Survey (CWNS) [73], more than 16,000 municipal wastewater treatment facilities operate in the U.S., ranging in capacity from several hundred millions of gallons per day (MGD) to less than 1 MGD [74]. According to EPA, 1,066 of these facilities operate with a total influent flow rate greater than 5 MGD [75], making them potential candidates for performing anaerobic digestion and off-gas utilization for combined heat and power (CHP) applications (U.S. EPA, 2007). Only 544 of these treatment facilities, however, employ anaerobic digestion to process wastewater, and only 106 of the facilities utilize the biogas produced by their anaerobic digesters to generate electricity and/or thermal energy [75].

Benefits

Because of its ability to produce electricity and heat onsite, independent of the power grid, CHP is a valuable addition for wastewater treatment facilities. A well-designed CHP system that is powered by digester gas offers many benefits to wastewater treatment facilities because it produces power at a cost below retail electricity, displaces fuels normally purchased for the facility's thermal needs, qualifies as a renewable fuel for green power programs, offers an opportunity to reduce GHG and other air pollution emissions and enhances power reliability for the treatment plant (U.S. EPA, 2010f) [76].

Sludge handling

Wastewater treatment facilities use several methods to manage and dispose of sludge produced during sewage treatment, including aerobic or anaerobic digestion. Under aerobic digestion, microorganisms convert organic material to CO_2 and water, resulting in a 35% to 50% reduction in volatile solids content (USDA, 2010a) [77]. The disadvantage compared to anaerobic digestion is that its byproducts cannot be used to make energy, whereas anaerobic digestion produces CH_4 that can be harnessed. Additionally, anaerobic digestion has a higher rate of pathogen destruction as compared to aerobic digestion, eliminating more than 99% of pathogens (U.S. EPA, 2010h) [78].

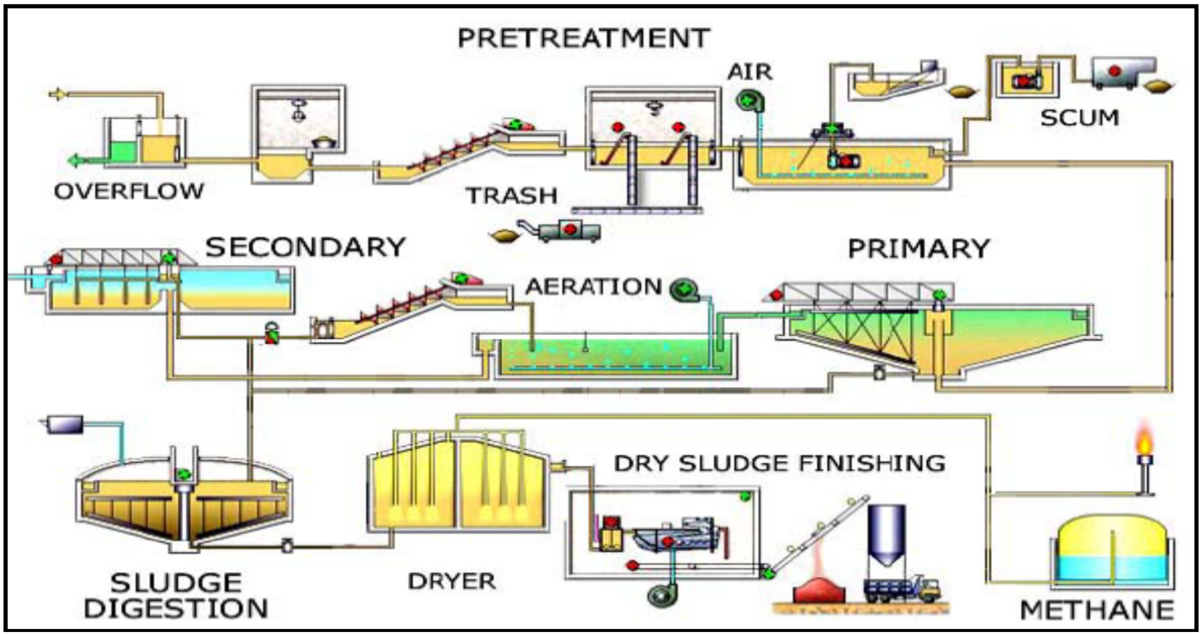
WW plant operations

The most common municipal wastewater treatment plants are primary and secondary treatment plants, tertiary treatment plants and physical-chemical treatment plants [8].

Primary treatment consists of removing a substantial amount of the suspended solids from a wastewater. The collected solids must be treated, in most cases, followed by proper disposal. Secondary treatment consists of bio-oxidizing the remaining organic suspended solids and the organic dissolved solids. The flowsheet of a conventional activated sludge plant, Figure 2.1 below, consists of screening, grit removal, primary clarification, activated sludge treatment and chlorination. The coarse solids are removed by screening, and the sand and silt are removed by the grit removal system. Primary clarification removes as many suspended solids as possible, and the primary effluent is mixed with the returned activated sludge. The mixed liquor then flows to the aeration tank. Bio-oxidation of most of the remaining organic matter occurs in the aeration tank, and the final clarifier removes the biological solids, which are returned to mix with the incoming primary effluent. The effluent from here is disinfected to kill pathogenic organisms and then discharged to the receiving body of water. The primary clarifier sludge and the waste activated sludge are mixed together and then thickened to increase solids content. The thickened sludge is sent to the anaerobic digester for bio-oxidation of the organic solids. The digested sludge is dewatered by vacuum filtration and the dewatered sludge is disposed of in a sanitary landfill.

The above system description illustrates that primary and secondary treatment and the auxiliary operations will require multiple electrically-driven pieces of equipment to complete the process. In addition, a number of trucks, outreach trade allies, deliveries and services will be involved in a plant's daily activities, also burning energy and generating emissions. Many other types of liquid, gaseous and solid fuels and chemicals will be consumed, all of which require energy to be created and cause emissions to be released. As was noted in Chapter 1, EPA-Energy Star estimates the nation's wastewater plants and drinking water systems spend about $4 billion per year on energy to treat water. Individually, these operating costs can add up to one-third of a municipality's total energy bill.

Figure 2.1 Process Flow Diagram for a Typical Large-Scale Treatment Plant



Source: arpa.e. Energy and water recovery in a secondary treatment plant

Future Trends in Wastewater treatment

U.S. EPA Needs Assessment Survey states that total treatment plant design capacity is projected to increase by about 15% over the next 20 to 30 years. During this period, the US EPA estimates that approximately 2,300 new plants may have to be built, most of which will be providing a level of treatment greater than secondary. The design capacity of plants providing greater levels of secondary treatment is expected to increase by 40% in the future (EPA 1997). The future of WWTP design favors the higher level of treatment and therefore higher energy demand.

2.2 Plant Energy Efficiency

In an era in which there are concerns about the adequacy of energy supplies, cost of energy and the increasingly higher levels of wastewater treatment that result in increased energy consumption, the design and operation of wastewater treatment plants are focused increasingly on improving the efficiency of electric energy use and reducing the cost of treatment (M&E) [79]. Given the link between human activity and waste creation, peak energy demand for treatment plants would likely occur from midday to early evening hours when other peak demands for electricity occur in the community. As the wastewater load changes during the course of a day, the requirements for pumping, aeration and solids processing change accordingly. Some plants modify schedules for equipment operations to meet load conditions; however, others operate their system components (such as aeration blowers) continuously at full capacity, regardless of the load. This demonstrates the importance of tools and software implementation to control operations and achieve energy cost savings.

Approximately 85% of the wastewater treatment plants in the United States provide secondary or higher levels of treatment. In conventional secondary treatment, most of the electricity is used for 1) biological treatment by either the activated-sludge process which requires energy for aeration or trickling filters, which require energy for influent pumping and effluent recirculation; 2) pumping systems for the transfer of wastewater, liquid sludge, biosolids and process water; and 3) equipment for the processing, dewatering, and drying of solids and biosolids. In activated sludge treatment, approximately 1200 to 2500 kWh / Mgal of electricity are required to process each 1000 m^3 of wastewater (M&E page. 1704). A typical distribution of energy use in a conventional activated-sludge treatment plant is illustrated in Figure 4.1, chapter 4.

The energy-intensity of blowers and aerators makes aerobic digestion a large energy consumer, yet aerobic digestion is commonly used in practice due to ease of aerobic operations (M&E 1345-1446). Anaerobic digestion processes, on the other hand, facilitate digestion in the absence of oxygen, forming methane-containing biogas and biosolids as products. Biogas produced from anaerobic digestion is a possible fuel source for digester heating or electricity generation (WEF, MOP pp1-142) [80].

2.3 Water and Wastewater Laws and Regulatory Compliance

From the early 1970s to about 1980, wastewater treatment objectives were based primarily on aesthetic and environmental concerns. The earlier objectives involving the reduction of biological oxygen demands (BOD), total suspended solids (TSS), and pathogenic organisms continued, but at higher levels. Removal of nutrients, such as nitrogen and phosphorus, also begun to be addressed, particularly in some of the inland streams, lakes, estuaries and bays (M&E) [79].

Major programs were undertaken by both state and federal agencies to achieve more effective and widespread treatment of wastewater to improve the quality of the surface waters. These programs were based, in part, on 1) an increased understanding of the environmental effects caused by wastewater discharges; 2) a greater appreciation of the adverse long-term effects caused by the discharge of some of the specific constituents found in wastewater; 3) the development of national concern for the protection of the environment. Important federal regulations that have brought about changes in the planning and design of wastewater treatment facilities in the United States are summarized in Table 2.2.

Table 2.2: Summary of the Significant U.S. Federal Regulations that Affect WW Treatment

Regulation	Description
Clean Water Act (CWA)(federal Water Pollution Control Act Amendments of 1972)	Establishes the national pollution discharge elimination system (NPDES), a permitting program based on uniform technological minimum standards for each discharger
Water Quality Act of 1987 (WQA) (Amendments of the CWA)	Strengthens federal water quality regulations by providing changes in permitting and adds substantial penalties for permit violations. Amends solids control program by emphasizing identification and regulation of toxic pollutants in sewage sludge

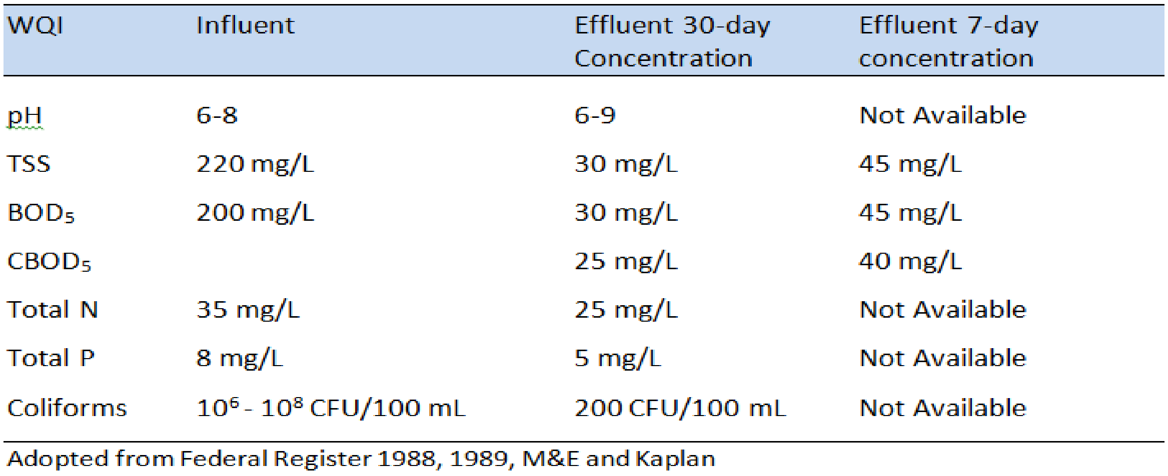
40 CFR Part 503 (1993) (Sewage Sludge Regulations)	Regulates the use and disposal of biosolids from wastewater treatment plants. Limitations are established for items such as contaminants (mainly metals), pathogen content, and vector attraction
National Combined Sewer overflow (CSO) Policy (1994)	Coordinates planning, selection, design, and implementation of CSO management practices and controls to meet requirements of CWA. Nine minimum controls and development of long-term CSO control plans are required to be implemented immediately
Clean Air Act (CAA) of 1970 and 1990 amendments	Establishes limitations for specific air pollutants and institutes prevention of significant deterioration in air quality. Maximum achievable control technology is required for any of 189 listed chemicals from "major sources", i.e. plants emitting at least 60 kg/d
40 CFR Part 60	Establishes air emission limits for sludge incinerators with capacities larger than 1000 kg/d (2200lb/d) dry basis
Total maximum daily load (TMDL) (2000) Section 303(d) of the CWA	Requires states to develop prioritized lists of polluted or threatened water bodies and to establish the maximum amount of pollutant (TMDL) that a water body can receive and still meet quality standards

Adopted from (M&E), 4th Edition [79]

Table 2-2, shows that several regulations cover various aspects of wastewater treatment. The Clean Water Act (CWA) [78] sets limits, via permitting under the NPDES, on the amount of pollutants that may be discharged, and states that pollution discharge must be controlled by best available technology. After wastewater sludge has been digested to form biosolids, wastewater facilities must dispose of or reuse biosolids. The most common methods of biosolids disposal are land filling, land spreading and composting, due to cost effectiveness; incineration is an alternate, but more costly disposal method. Since biosolids contain reduced quantities of the harmful bacteria and pathogens destroyed during digestion [88], EPA encourages use of solids.

The Clean Water Act covers biosolids, which are defined as treated residuals from wastewater treatment that can be used beneficially, and governs land application of wastewater treatment residuals (40 CFR Part 503). Part 133 of the CWA requires municipal waste treatment facilities to meet secondary treatment standards, ensuring that the discharged effluents meet minimal removal standards for biochemical oxygen demand, total suspended solids and pH levels. The primary water quality indicators (WQI) that have discharge limits are TSS, BOD, fecal coliforms, oil and grease and pH. While monthly and weekly average limits must be met, discharges that exceed the average may still occur, albeit on an infrequent basis. A summary of WW characteristics entering and leaving the WWTP can be found in (Table 2.3).

Table 2.3: Minimum National Standards for Secondary Treatment



WQI	Influent	Effluent 30-day Concentration	Effluent 7-day concentration
pH	6-8	6-9	Not Available
TSS	220 mg/L	30 mg/L	45 mg/L
BOD_5	200 mg/L	30 mg/L	45 mg/L
$CBOD_5$		25 mg/L	40 mg/L
Total N	35 mg/L	25 mg/L	Not Available
Total P	8 mg/L	5 mg/L	Not Available
Coliforms	10^6 - 10^8 CFU/100 mL	200 CFU/100 mL	Not Available

Adopted from Federal Register 1988, 1989, M&E and Kaplan

In the U.S. [53], the development of alternative energy supplies are supported by legislation and regulations such as the american recovery and reinvestment act (ARRA), which provides federal funding to stimulate investments in energy efficiency and renewable energy; and the energy improvements and extension act (EIEA) which provides tax credits to homeowners and businesses that improve energy efficiency. The US EPA clean water and drinking water infrastructure sustainability policy supports the increasing sustainability of water infrastructure in the U.S. Laws and policies like these drive industries, including the municipal wastewater treatment industry, not to only create green energy, but also to purchase and use green energy.

2.4 GHG Emissions - Environment Link

2.4.1 Greenhouse Gas Overview

Gases that trap heat in the atmosphere are often called greenhouse gases. Some greenhouse gases, such as carbon dioxide (CO_2) occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases (e.g., fluorinated gases) are created and emitted solely through human activities [23]. The principal greenhouse gases that enter the atmosphere because of human activities are:

Carbon Dioxide (CO_2): Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). As part of the natural biological cycle, CO_2 is removed from the atmosphere (or “sequestered”) when it is absorbed by plants.

Methane (CH_4): Methane is emitted during the production and transport of coal, natural gas and oil. Methane emissions also result from livestock and waste in municipal solid waste landfills and from anaerobic and other WW processes.

Nitrous Oxide (N_2O): Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

Fluorinated Gases: Hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

2.4.2 Global Warming Potential [24]

Global warming potential (GWP) is an estimate of how much a GHG affects climate change over a period of time relative to CO_2, which has a GWP value of 1. Methane is a potent GHG with a global warming potential of 21 over a 100-year timeframe, therefore, methane is 21 times more effective than CO_2 at trapping heat in the atmosphere. In other words, it takes 21 tons of CO_2 to equal the effect of 1 ton of CH_4. Methane has a relatively short atmospheric lifetime (approximately 12 years) when compared to the atmospheric lifetime of carbon dioxide; thus efforts to capture methane from anthropogenic sources provide more near-term climate change abatement than capturing or reducing comparable amounts of CO_2, but less multi-decadal abatement.

Once methane or other GHGs are converted, using GWP or other methods, they can be expressed in a common unit of measurement: carbon dioxide-equivalent (CO_2-eq. or CO_2e). CO_2e takes into account both the potency of each gas and expresses the quantity of the gas. Carbon dioxide equivalent has been adopted as a principal unit of measurement to aggregate or make comparisons across GHGs. CO_2e expresses the tons of a greenhouse gas in the equivalent effect of tons of CO_2 on climate change (more specifically, on "radiative forcing"). Once all gases are converted to CO_2e, they can be compared or added together.

Traditionally, the 100-year GWPs are used when calculating overall CO_2 equivalent emissions, which is the sum of the products of each GHG emission value and it's GWP. Note: be sure when calculating the CO_2 equivalent that each of the GHG emission values has the same measurement units (either all in tons or all in pounds) since in eGRID, CO_2 is expressed in tons, while both CH_4 and N_2O are expressed in pounds [25]. Additionally, in order to compare emissions across previous data years, the GWP for the second (1996) IPCC assessment (SAR), is used, although there have been subsequent third (2001) (TAR) and fourth (2006) (AR4) assessments. A comparison of the three GWP for the three electric power GHG gases is presented in Table 2.4 below (EPA 2012b) [89]:

Table 2.4: Comparison of 100-Year GWPs

Gas	SAR	TAR	AR4
CO_2	1	1	1
CH_4	21	23	25
N_2O	310	296	298

Source: Pechan & Associates, 2010, for EPA

Where: SAR: Second intergovernmental Panel on Climate change assessment
TAR: Third intergovernmental Panel on Climate change assessment
AR4: Fourth intergovernmental Panel on Climate change assessment

<u>To determine the carbon equivalent of a greenhouse gas (mass)</u> [90]:

1) Convert million metric tons (MMT) of greenhouse gas to MMT CO_2 equivalent =

MMT of GHG x GWP

2) Convert CO_2-equivalent to Carbon-equivalent = CO_2 x 0.2727, for example:

a) 2 MMT methane x 21 (SAR GWP of Methane) = 42 MMT CO_2-equivalent

b) 42 MMT CO_2 x 0.2727 = 11.45 MMTCe

2.4.3 <u>Greenhouse Gas Reporting</u>:

U.S. EPA has issued 40 CFR Part 98, which requires reporting of GHG emissions from large sources and suppliers of fossil fuels in the United States. Under Part 98, suppliers of fossil fuels or industrial GHG generators, manufacturers of vehicles and engines, and facilities that emit 25,000 metric tons or more per year of GHG emissions are required to submit annual reports to EPA [91]. Part 98 was published in the federal register on October 30, 2009, and became effective December 29, 2009. On July 20, 2010, EPA signed revisions to certain provisions of the Mandatory Reporting of GHG Rule, and on October 7, 2010, finalized technical corrections and other amendments to the Greenhouse Gases Reporting Rule. Part 98 is intended to collect accurate and timely emissions data to inform future policy decision.

CHAPTER 3.0
STATE-OF-THE-ART (SOA) LITERATURE REVIEW

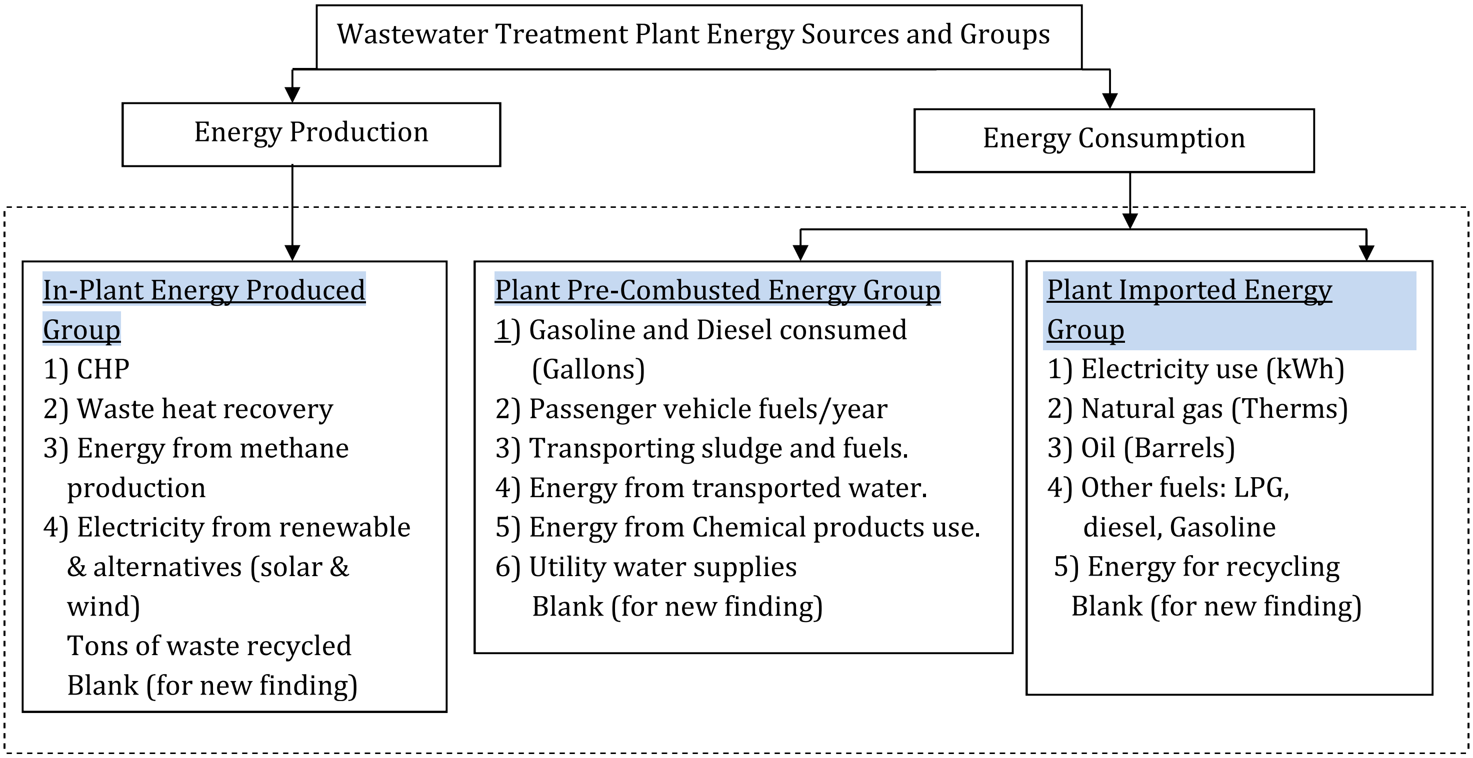
3.1 Initial State-of-the-Art Reviews

An initial State-of-the-Art review was conducted to identify what is currently being done to refine or improve existing models, tools or calculators for the water-wastewater-energy connection, and where could data be found for such models. This chapter examines a few related works that will be used for the compilation of data and mapping the methodology of conducting this research work. Data will be required on different wastewater (WW) energy consuming operations, fuel sources, emissions and other factors, as well as inventory data, equipment type and related calculating formulas for energy consumption and their equivalent GHG generation.

In this review, energy in a WWTP is consumed with a potential to be produced within the plant from the associated operations. WWTP energy falls into one of three major groups of energy sources: 1) Plant imported energy, 2) Plant pre-combusted energy, and 3) In-plant energy produced (Table 3.1). Groups one and two are considered trends source of energy that increase plant's operational cost, liability and environmental responsibility through the emission of GHG to the atmosphere. The third group is a sink source of energy that combines several technologies with proven background of energy gain from renewable sources or energy waste reduction.

The energy type’s mix associated with WWTP operations, therefore, could include a range of sources such as, but not limited to, fuel combustion, plant chemicals and water use, energy recovery systems, carbon sequestration and the daily electric energy and natural gas demand. Table 3.1, shows energy groups with sample sources as identified by the research proposal.

Table 3.1: WWTP Energy Groups and Sources



Source: Author

A review of the existing literature shows that various studies have been conducted, analyses introduced and a number of research works, models and tools published that examine the energy-water nexus for the water and wastewater treatment. Special attention was given to determine whether any previous works were done to 1) assess energy at the wastewater treatment plant design phase, 2) compile treatment plant energy sources, processes, fuels and equipment, and then 3) link all of this data and convert it to CO_2e emissions. The search is continued during proposal preparation and throughout this dissertation's scope of work, to include research papers, web sites, books and other resources. A list of these references is compiled after the appendices in this dissertation.

3.2 Water – Energy Models and Tools

Many reference studies have established models in the area of water and wastewater. However, none of these models or tools compiled or assessed the energy issues at the design phase of a wastewater facility. The energy compilation and estimation for a plant operations and processes requires a wide range of data collection for a variety of equipment and treatment. W. Edward Deming said "in god we trust, all others must bring data" hence, this research is data-intensive and relies upon the many models, formulas and findings from reliable literature and sources.

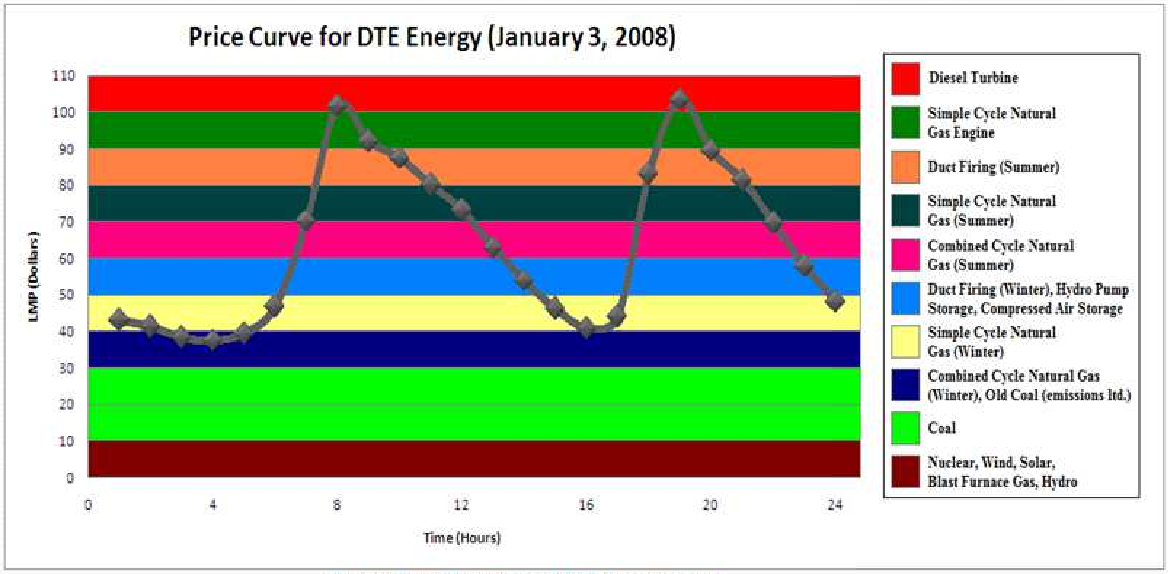
Many wastewater models and research works are available on wastewater energy but do not integrate all energy consumption of a wastewater treatment operations and processes in one model. Nevertheless, many helpful references are available for the compilation of a WWTP energy consumption sources, emission factors, process and operation equipment, off site information, calculation formulas and mathematical modeling, some of which are discussed below.

"Modeling of Power Generation Pollutant Emission Based on Locational Marginal Prices for Sustainable Water Delivery" [1], this paper presents the development of a model that links electric power consumption to the resulting pollutant emissions. The model is applied in particular to a large urban region using locational marginal price (LMP).

This novel approach produced a graph from available data within a certain time span for a certain power producer, such as DTE Energy, Michigan, and U.S.A.

This graph “Price Curve for DTE Energy, Figure 3.1, is developed for any given day for the LMP as a function of time. However, the type of generator is the single most important factor controlling pollutant emissions. The model used a table of LMP price range for every single type of generator available in the power producing industry.

Figure 3.1: DTE Energy Utility Price Curve for a Certain Date, $LMP vs. Time



Wayne State University: GLPF August 1, 2010

Using the price range data contained in the table, the LMP price curve can then be filled in to show which power plants will be producing power for the various price ranges. Using this approach it is possible to determine the type of generator producing power at any given time. A link must then be made between generator type and the pollutant emissions produced per energy consumed.

Emissions are quantified based on the information submitted annually to EPA by electric utilities on the Toxic Release Inventory (TRI) Form –R on July 1 for each of the 581 chemicals covered by the Form. However, this is reported to EPA only on whole power plant basis, it is required to get emission factors based on constituent type. Emission factors for GHG only are available from EIA, pollution control devices, climate seasonal variations are not encountered.

Therefore, three methods for estimating emission factors, which can be used to determine pollution loadings, are presented:

1) Using national average emission factors, as reported to the EIA,

2) Using power plant annual average (composed of multiple generation units)

3) Using a new developed method to quantify emissions for individual generating units within a power plant.

A second set of research is titled "A GIS Methodology for Estimating the Carbon Footprint in Municipal Water and Wastewater in Fairfax County, Virginia", [43]. This work attempted to develop a direct relationship between carbon emissions and the amount of water use in residential, industrial and commercial buildings. Using ArcGIS Version 9.2, a geographical information system (GIS) was developed to convert annual water and wastewater needs for a facility into tons of CO_2/yr. A GIS tool was selected because the estimation of energy consumption and subsequent carbon footprint calculation relies not only on the quantity of water distributed, but also on the geography of the distribution and collection network.

The environmental regulations pertaining to water and air pollution control have pressing an extensive need for research into the area of GHG emissions estimation from municipal and industrial wastewater. Many researchers and organizations have studied the extended effects of energy use in WWTP for the purpose of compiling GHG inventories for reporting purposes, verifying new processes or the control of energy consumption and cost reduction, such as:

"Methodology for analysis of the Energy Intensity of California’s Water Systems". This research work is an assessment of multiple potential benefits through integrated water-energy efficiency measures, exploratory research project [4]. Other works include: Pacific Institute's Water-To-Air Model and River Network, titled ”Estimating the Energy Intensity of Your Water, the Simple Method.”

Monteith, et al. (WERF 2005, 2007) [92], stated that the IPCC (Geneva, Switzerland) approach attributes methane emissions only to wastewater treatment, and that this approach may overestimate GHG emissions from highly aerobic processes. The authors' approach to better estimate GHG was by developing a procedure to be used either with plant-specific data or more general regional data. The procedure was evaluated using full-scale data from 16 Canadian wastewater treatment facilities and then applied to all 10 Canadian provinces.

Data collection from plants included detailed facility-specific data to provide calibration of the general method. A template was developed, requesting information about the biological treatment processes and solids treatment processes (flow rates, reactor volumes, SRT values, influent and effluent concentrations for biological oxygen demand (BOD) and solids and digester gas production, etc.) and additional information, including fossil-fuel consumption (natural gas and diesel), electricity consumed and digester gas use. Treatment plant staff completed the template and returned it to the authors.

The principle GHG emitted from municipal wastewater treatment plants was estimated to be carbon dioxide - CO_2, with very little methane expected. They asserted that increasing the effectiveness of biogas generation and use would decrease the GHG emissions that may be assigned to WWTP. The first step for GHG reduction should be to estimate its current GHG emissions, and that biogas may not satisfy the energy need of wastewater plants, so additional hydrocarbon fuels may be necessary. These supplemental fuels typically include natural gas used in boilers, and diesel fuel used in standby engine generators. The study did not include fuels used for cogeneration on-site. Natural gas burned on-site in a boiler was estimated and assumed to be converted entirely to CO_2 per:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The study concluded that the procedure developed can be used to facility's carbon-based GHG emissions, that CO_2 is the principal GHG; and CH_4 produced during anaerobic solids treatment is oxidized to CO_2, at least in the cases examined in the study. In all cases, however, effective biogas use, both on-site and off-site can provide reductions in GHG emissions.

Shahabadi, et al. [93] developed a mathematical model to estimate GHG emissions by WWTPs resulting from on-site and off-site activities. The contribution of individual processes to the production of GHGs in a typical hybrid treatment system for food processing wastewaters was determined. The results showed that the recovery of biogas and its reuse as a fuel had a remarkable impact on GHG emissions and reduced the overall emissions by 1023 kg (CO_2e/d) from a total of 7640 kg (CO_2e/d) when treating a wastewater at 2000 kg (BOD/d). Furthermore, the recovery of biogas and its combustion may be used to recover the entire energy needs of the treatment plant aeration, heating, and electricity generation while creating emissions credit equal to 34 kg (CO_2e/d). The off-site GHG emissions resulting from the manufacturing of material for on-site usage were identified as the major source of GHG generation in hybrid treatment systems. These emissions account for the generation of 4138 kg (CO_2e/d), or 62% of the overall GHG emissions when biogas recovery is carried out. The inclusion of GHG emissions from nutrient removal, as well as off-site processes in the overall GHG emissions of WWTPs increased the accuracy and completeness of the estimation, as per the authors.

Stillwell, Webber and Hoppock, [88] issued their manuscript for analyzing the potential for "energy recovery from WWTPs in the united states" and the state of Texas via anaerobic digestion with biogas utilization and biosolids incineration with electricity generation. They concluded that these energy recovery strategies could help offset the electricity of the wastewater sector and represent possible areas for sustainable energy policy implementation. They estimated that anaerobic digestion could save 628 to 4,940 million kWh annually in the U.S. In Texas, anaerobic digestion could save 40.2 to 460 million kWh and biosolids incineration could save 51.9 to 1,030 million kWh annually.

The U.S. and Texas case studies are representative of the energy recovery potential through anaerobic digestion, with biogas utilization and biosolids incineration with electricity generation; data for this study were obtained from EPA clean watershed needs survey (CWNS) [73]. The methodology also includes the data use of USEPA, EPRI and TCEQ for plant energy use, Burton and EPRI for biogas energy recovery data, and M&E and Masters, G.M. for biosolids incineration.

Using 2004 CWNS data and EPRI energy factors, total electricity consumption for wastewater treatment in the U. S. was estimated at 18,100 to 23,800 million kWh per year. Based on case studies used in this study, WWTPs could decrease overall electricity use for the U.S. wastewater sector by 2.6% to 27%, depending on the degree of implementation; the large range in wastewater flow leads to a large range of energy recovery from anaerobic digestion. By incorporating both the anaerobic digestion with biogas utilization, and biosolids incineration with electricity generation, wastewater utilities can reduce electricity consumption by 4.7% to 83% in the state of Texas. These wide ranges in electricity percent savings for the wastewater sector are due to the difference in wastewater flows analyzed in each individual scenario of the research analysis.

The Texas case studies also showed in some cases: 1) widely implementing biosolids incineration with electricity generation leads to significantly greater energy recovery than from anaerobic digestion with biogas utilization. This difference is due primarily to the larger heating value for biosolids incineration vs. biogas energy factor (BEF) for anaerobic digestion. That is, biosolids have more inherent energy than biogas when used to generate electricity 2) Biogas also contains water vapor and small amounts of siloxanes and hydrogen sulfides, which must be removed before the biogas can be used as a fuel for electricity generation to prevent damage to the generation equipment 3) WWTPs with treatment capacities less than 5 million gallon per day (MGD) do not produce enough biogas to make electricity generation feasible or cost-effective 4) Additional uncertainty is introduced through changing organic content of wastewater - either increasing with lower flows that concentrate waste or decreasing with improved waste management 5) Rising concerns about water contaminants such as pharmaceutical and personal care products, WW treatment is likely to become more energy-intensive in the future.

Most WWTPs can significantly reduce their energy costs by 30% or more, through energy efficiency measures and treatment process modifications (Means E.G.) [94]. Through optimized aeration and improved pumping alone, plants could save 547 to 1,057 million kWh annually, reducing overall energy use in the wastewater sector by 3% to 6% (Hoppock and Webber 2008) [95].

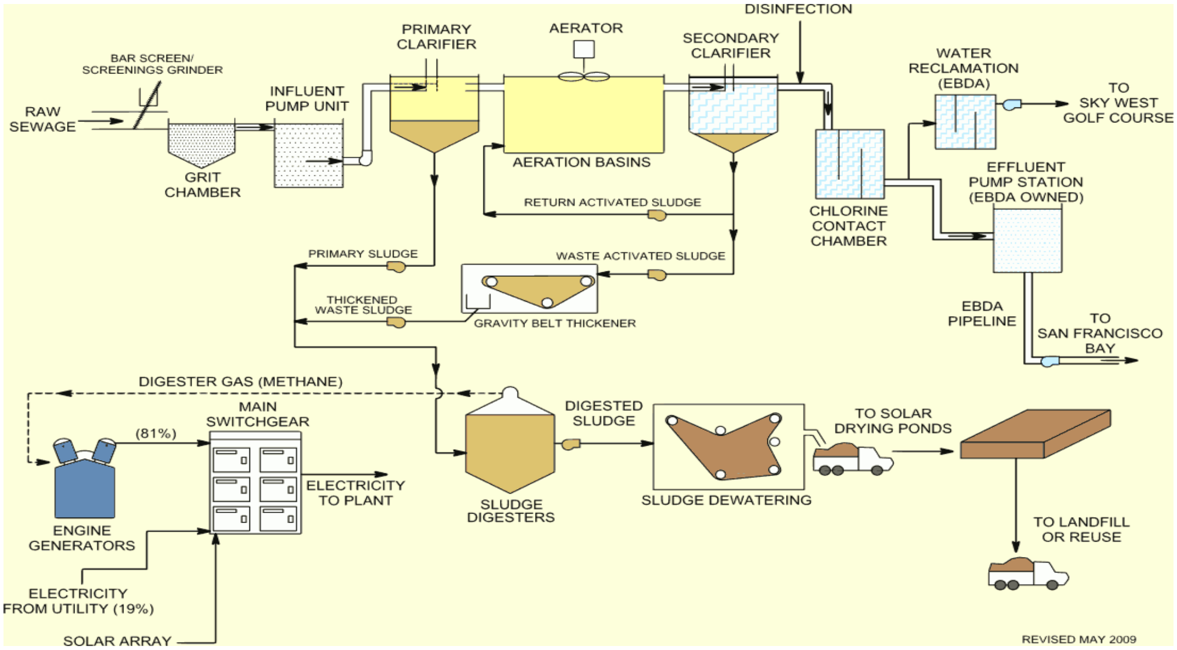
U.S. EPA [96], optimized anaerobic digestion occurs in two temperature ranges, mesophilic, and 32 ^{0}C to 35 ^{0}C, and thermophilic 50 ^{0}C to 57 ^{0}C, thus digester heating might be necessary in some climates. In these temperature ranges, anaerobic digestion produces biogas containing 40% to 75% methane, with a balance of primarily carbon dioxide and other compounds, with 60% methane as a typical composition. As a rule of thumb, anaerobic digestion produces about 35 m^3 of gas per day per person in the service area, which has a typical heating value of approximately 6.2 kWh/ m^3.

3.3 Wastewater Treatment

Methods of treatment in which the application of physical forces predominate are known as unit operations. Methods of treatment in which the removal of contaminants is brought about by chemical or biological reactions are known as unit processes. At the present time, unit operations and processes are grouped together to provide various levels of treatment known as preliminary, primary, advanced primary, secondary (without or with nutrient removal) and advanced (or tertiary) treatment (M&E).

The diagram in Figure 3.2 demonstrates how the treatment plant works, and how the different processes are inter-connected to work as one.

Figure 3.2: Wastewater Treatment Diagram

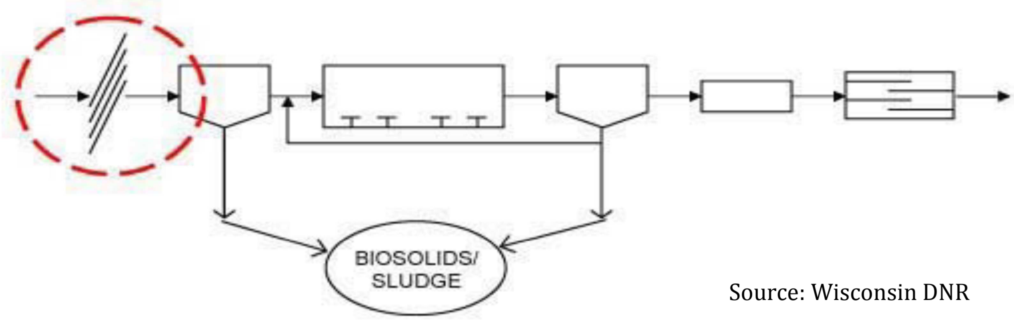


Source: Oro Loma Sanitary District

Concepts of WW treatment chain of operations and their levels are discussed in many reference books, guides and studies; however, a concise introduction of these levels and their imbedded processes by this work have been extracted from M&E, and the Wisconsin department of natural resources (WDNS), including the figures.

Preliminary treatment: Removal of WW constituents such as rags, sticks, floatables, grit (coarse debris) and grease that may cause maintenance or operational problems with the treatment operations, processes and ancillary systems. This is done to significantly reduce the plugging and clogging of pumps and pipes, the abrasive action of grit on equipment and the settling of these materials in downstream tanks and basins. Treatment equipment, such as bar screens, comminutors and grit chambers are used as the WW first enters a treatment plant. Newer preliminary treatment units now automatically clean, dewater and bag/containerize these materials thus greatly reducing exposure to operators. Figure 3.3 below shows the general location of a preliminary level in a WW treatment chain.

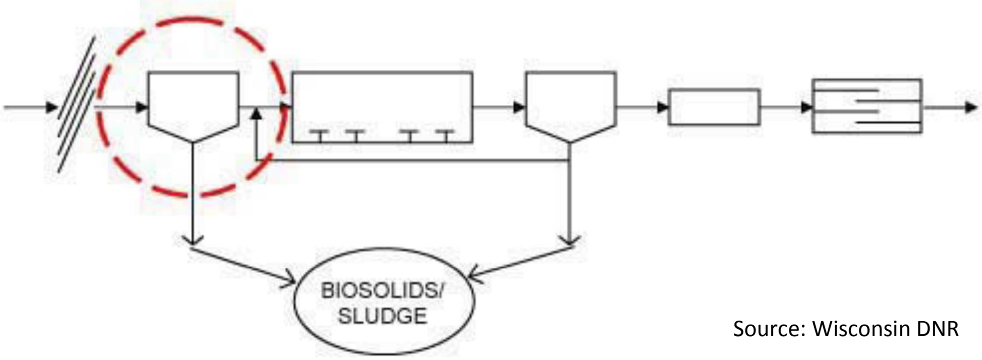
Figure 3.3: Preliminary treatment level



Source: Wisconsin DNR

Primary treatment: Removal of a portion of the suspended solids with some BOD and organic matter through the process of holding the wastewater in a quiet tank for several hours for settling solids and the capture of floatable substances such as oil and grease. The settled solids in primary clarifiers and oil and grease skimmed off the surface are directly removed from the process. Primary treatment commonly consists of circular or rectangular clarifiers. Sometimes, dissolved air floatation (DAF) thickeners or other processes are used for primary treatment. Primary effluent containing soluble BOD and some suspended solids flows to a secondary biological treatment process for further treatment. Figure 3.4 below shows the general location of a primary level in a WW treatment chain.

Figure 3.4 Primary treatment level

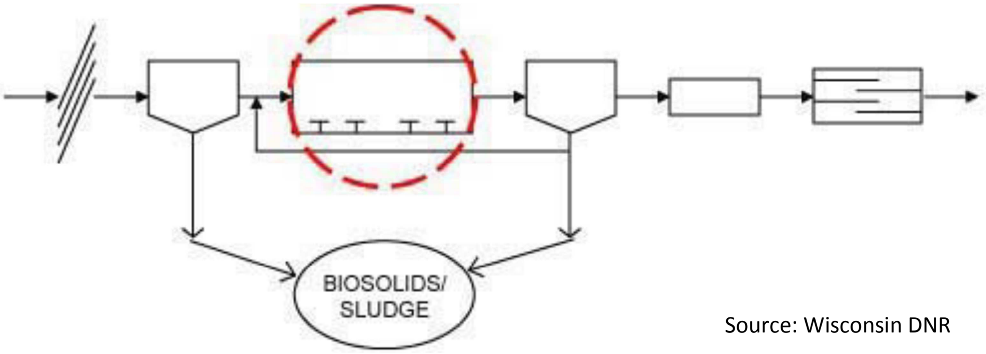


Source: Wisconsin DNR

Advanced primary: Enhanced removal of suspended solids and organic matter from the wastewater. Typically accomplished by chemical addition or filtration

Secondary treatment: Removal of biodegradable organic matter (in solution or suspension) and suspended solids, to produce an environmentally-safe treated effluent and biosolids/sludge. Secondary biological treatment consists of microorganisms, either in mixed suspension in a basin or attached to a media of some type, where the organic material is broken down and consumed as a substrate by the microorganisms which are cultivated and added to the wastewater. Most secondary treatment processes require oxygen for the bacteria. Activated sludge is a suspension of wastewater and microorganisms in an aeration basin. Their mixture is referred to as mixed liquor suspended solids (MLSS). Aeration equipment provides dissolved oxygen to promote the growth of microorganisms that substantially remove organic material. Figure 3.5 below shows the general location of a secondary level in a WW treatment chain.

Figure 3.5: Secondary Treatment Level



Source: Wisconsin DNR

Three approaches are used to accomplish secondary treatment; fixed film, suspended film and lagoon systems, and are discussed below [51].

Fixed Film Systems

Fixed film systems grow microorganisms on substrates such as rocks, sand or plastic. The wastewater is spread over the substrate, allowing the wastewater to flow past the film of microorganisms fixed to the substrate. As organic matter and nutrients are absorbed from the wastewater, the film of microorganisms grows and thickens. Trickling filters, rotating biological contactors (RBC), and sand filters are examples of fixed film systems.

Suspended Film Systems

Suspended film systems stir and suspend microorganisms in wastewater. As the microorganisms absorb organic matter and nutrients from the wastewater they grow in size and number. After the microorganisms have been suspended in the wastewater for several hours, they are settled out as sludge. Some of the sludge is pumped back into the incoming wastewater to provide "seed" microorganisms. The remainder is wasted and sent on to a sludge treatment process. Examples of suspended film systems include activated sludge, extended aeration, oxidation ditch and sequential batch reactor systems.

Ponds and Lagoon Systems

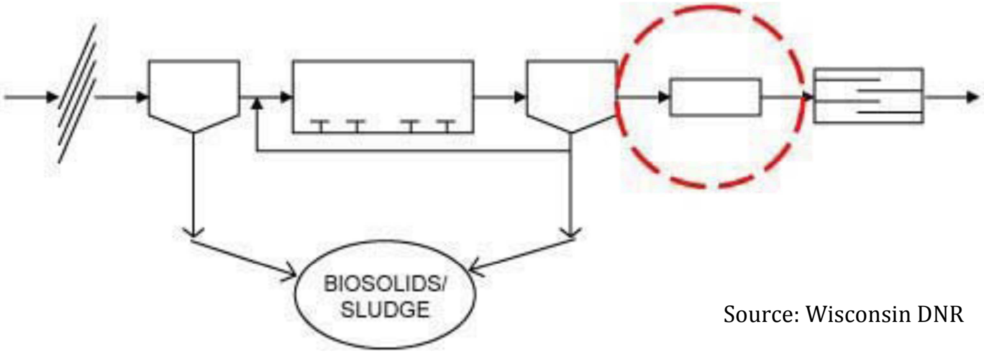
Lagoon systems are shallow basins which hold the wastewater for several months to allow for the natural degradation of sewage. These systems take advantage of natural aeration and microorganisms in the wastewater to renovate sewage. Ponds and lagoons systems are earthen basins with a liner to prevent leakage. They are an economical way to accomplish biological treatment. Pond systems are typically used for BOD and TSS removal when limits are 30 mg/L, however, when limits are more restrictive or include nutrient limits, mechanical treatment is necessary. The large size of ponds, specifically those in series, provide a long detention time for the bacteria to break down the wastes.

Stabilization pond systems are large and non-aerated where the algae growing in the pond provide most of the oxygen to the bacteria to remove pollutants. Normally, they are less than 10 feet deep. Aerated lagoon systems are normally more than 10 feet deep, and are aerated by diffusers or surface aerators. Aerated lagoons are followed by non-aerated lagoons to allow settling of suspended solids before discharge.

Secondary treatment with nutrient removal: Removal of biodegradable organic matter, suspended solids and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus). Disinfection is also typically included in the definition of conventional secondary treatment (M&E).

Tertiary treatment: Removal of residual suspended solids (after secondary treatment) usually by physical means such as granular medium filtration or microscreens or by chemical process to precipitate some pollutants in the wastewater. Air stripping or activated carbon is sometimes used to remove volatile organic chemicals from the wastewater. Tertiary treatment provides advanced wastewater treatment beyond secondary biological treatment, resulting in a very high quality effluent, extremely low in BOD, suspended solids and nutrients. Figure 3.6 below shows the general location of a tertiary level in a WW treatment chain.

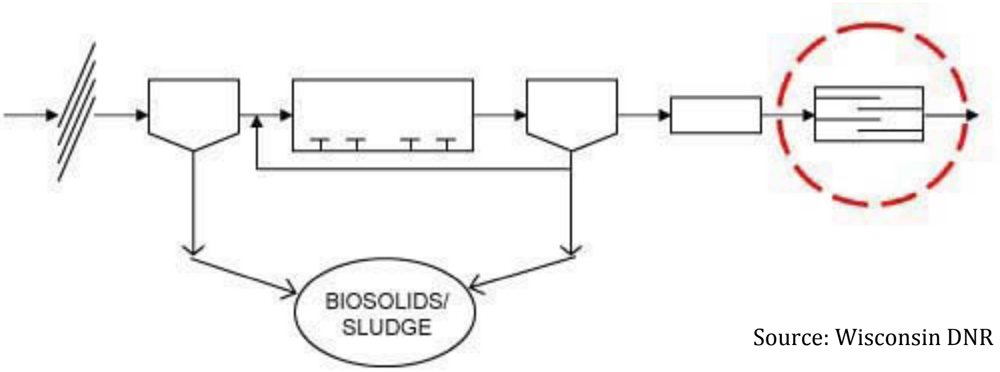
Figure 3.6: Tertiary Treatment Level



Source: Wisconsin DNR

Final or disinfection treatment: Removal of disease-causing organisms from wastewater. This treatment is also typically a part of tertiary treatment. Treated wastewater can be disinfected by adding chlorine or by using ultraviolet light, or ozone. High levels of chlorine may be harmful to aquatic life in receiving waters; therefore, treatment systems often add a chlorine-neutralizing chemical to the treated wastewater before stream discharge. Figure 3.7 below shows the general location of a disinfection level in a WW treatment chain.

Figure 3.7: Disinfection Treatment

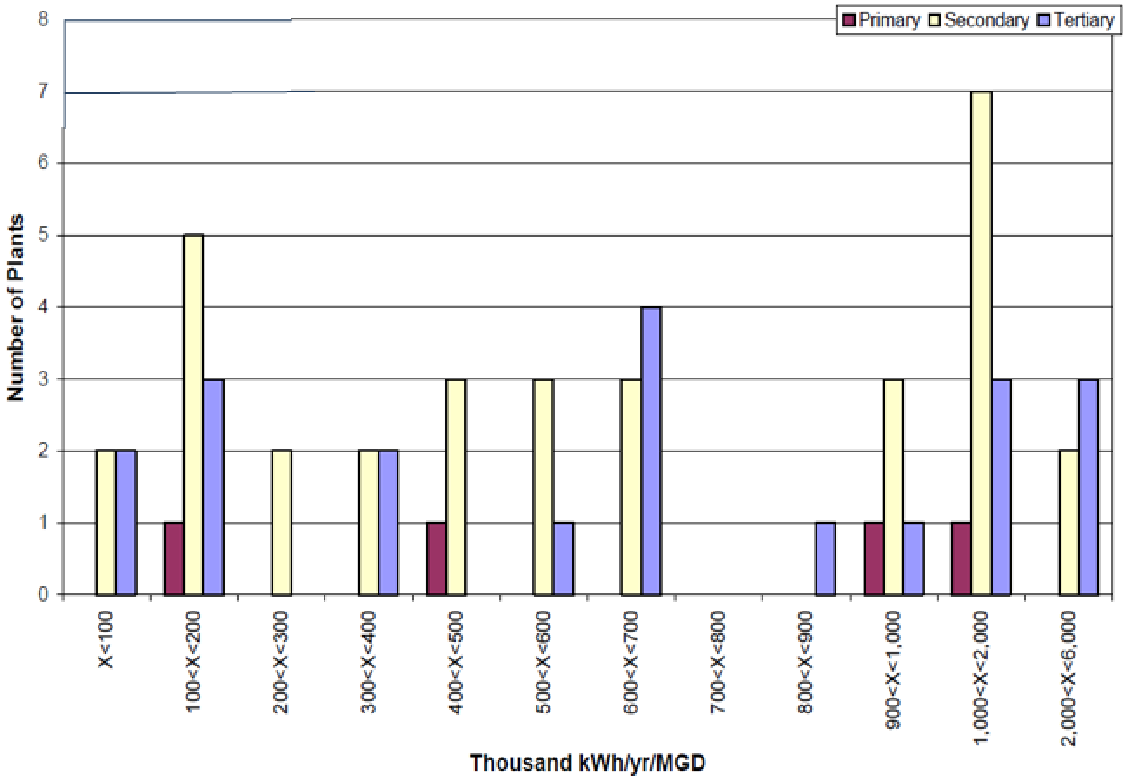


Source: Wisconsin DNR

Advanced: Removal of dissolved and suspended materials remaining after normal biological treatment when required for various water reuse applications. It is necessary in some treatment systems to remove nutrients from wastewater. Chemicals are sometimes added during the treatment process to help settle out or strip out phosphorus or nitrogen. These systems for nutrient removal include coagulant addition for phosphorus removal and air stripping for ammonia removal.

The graph in Figure 3.8 shows the amount of electric energy consumption for the treatment levels described above. The data represent a summary of energy distribution averages from a ninety nine treatment plants survey [97].

Figure 3.8: Electric Energy Usage per Unit Flow Rate per Treatment Level



Treatment Level	Average	Standard Deviation
Primary	817,457	-------------
Secondary	771,357	696,853
Tertiary	1,144,277	1,440,314
All plants	907,836	1,024,249

Source: PG & E/ Base Energy, Inc.

Conclusion for Chapters 1, 2 and 3: The levels and processes of wastewater treatment discussed above can be accomplished only by using a number of mechanical and electrical technologies which may include motors and drive systems for pumps, compressors, microturbines and engines, each of which has specified energy demands. Biological and physical processes and the environmental compliance require the use of chemicals whose production consumes energy outside the WWTP boundaries, and may also contribute to GHGs, while reacting with wastewater constituents during different phases of the treatment process. These processes, chemicals and their energy values are discussed in the upcoming chapters.

Due to the complexity, diversity and continuous process advancement in wastewater treatment facilities, the design phase of a facility is a critical phase in the hierarchy of a plant which suggests a careful decision-making to ensure regulatory and ethical compliance, as associated with the use of energy and the protection of the environment.

This research work intended to model the energy of a plant at its design phase, offers expert guidance to engineers and designers, as it encompasses in the designs the best resolution of combining negative and positive energy sources, in order to find the lowest energy demand result and eventually, the lowest GHG emissions while attaining effluent discharge quality limits. Following chapters 1, 2 and 3, and in order to ease searching available resources for energy sources, emissions and inventory estimations methodologies, this dissertation has organized the rest of the research into the following chapters:

Chapter 4: Explores energy sources, energy consumption and methodologies for estimating energy used via motorized or electricity driven equipment, and as sources of negative energy, while the biological processes are discussed as examples of positive energy sources. The chapter includes as well.

Chapter 5: Explores emissions factors and global-warming calculation methodologies.

Chapter 6: Explores the calculation of energy and emission factors, based on the trilogy model: plant imported energy, pre-combusted energy and in-plant produced energy sources – based on type of fuel or technology.

Chapter 7: Explores a derivation of the energy trilogy model in terms of total energy consumed (negative), energy produced (positive) and the resultant CO_2e emissions.

Chapter 8: Details the composition, design and operation of the WWTP-ET tool.

Chapter 9: Discusses baseline studies of a WWTP, summarizes the measurement and verification methodology (M&V) for determining a new plant's energy savings, and includes the comparative study of WWTP's energy consumption between an existing WEF WWTP's electric consumption study results with the energy results of a study made by the author on a Michigan WWTP of equivalent treatment level and flow rate. The comparison is the backbone of this research work, introducing proof of the viable methodologies and formulae compiled throughout this research work.

Chapter 10: Includes appendices of useful information and tables, such as those used for the comparative study estimation, emissions factors and glossary.

CHAPTER 4.0
BALANCING ENERGY IN WASTEWATER TREATMENT PLANTS

Global warming and climate change have appeared in the recent years as the leading issue in the environmental agenda, owing to the significant impact on earth's future, and on defining the environmental and energy policies in the advanced world. This has resulted, as well, in outlining the importance of taking reliable measures to address international sustainable developments and economic needs to facing climate issues.

The intergovernmental panel for climate change (IPCC), stated that the generation of GHGs, mainly CO_2, CH_4 and N_2O -- from agricultural and industrial human activities, the consumption of fossil fuels and energy generation utilities -- have been responsible for partly preventing amounts of heat energy reflecting from earth surface to find its way to the atmosphere, causing global warming.

Wastewater treatment plants, as a human activity, have been recognized as originators of GHG emissions, since they produce CO_2, CH_4 and N_2O from the treatment processes, and partly causing the emission of CO_2 and other GHGs during the production of utility energy required to meet a plant's energy demand. Some sources of energy might be obtained from in-plant operations and processes. These sources, if utilized, can offset some or most of GHG emissions attributed to overall wastewater treatment activities.

4.1 Energy Sources of a Wastewater Treatment Plant

This work attributes wastewater treatment energy consumption and its overall GHG generation to three major groups:

1. Plant imported energy group

2. Plant pre-combusted energy group
3. In-plant energy produced group

WWTP GHG emissions are mainly attributed to the first two energy groups which use fossil fuels combustion, and to on-site solid and liquid treatment processes. Sludge treatment, aerobic and anaerobic processes then contributes to biosolids and biogas generation. The off-site emissions generation is from the production of electricity, natural gas, chemicals for use on-site, transportation fuels and solids incineration and disposal, all of which are necessary in order to treat wastewater to an environmentally acceptable level of treatment before discharging to a receiving body.

Identifying energy sources and understanding WWTP operations and processes causing the release of GHG emissions have led to the development of energy conservation, optimization and other reduction procedures for these harmful gases emissions. The most important and feasible methods of emissions reductions implemented in the recent decades include group three (3) energy sources; that is utilizing a plant's wasted energy, specifically the wasted energy of heat, and benefitting from useful gases, such as methane (CH_4) which is a by-product of the on-site biological treatment processes. Alternative and renewable energy generation on wastewater treatment plant's grounds has evolved as well in the recent years and continues to increase its share of the energy contribution to wastewater treatment due to reliability, cost drop and governmental financial support. The In-plant energy production group (3) could include, but is not limited to, combined heat and power (CHP), waste heat recovery, methane energy, geothermal energy, electricity generation from solar and wind energy, all of which will be detailed, energy estimated and emissions assessed in the upcoming discussions.

4.2 Pathways of Energy Consumptions

Wastewater treatment is an energy-intensive operation. While primary treatment is relatively standard among different wastewater treatment facilities, there is a wide range of secondary treatment and solids processing alternatives. The energy consumption of these different facilities is highly variable. In addition, many wastewater treatment facilities face increasingly stringent regulatory discharge limits which may lead to higher energy requirements associated with higher levels of liquid treatment and solids processing.

Menendez, [98] using company case studies of past and current projects, and reference books, including Wastewater Engineering Treatment, Disposal, and Reuse (Tchobanoglous and Burton, 1991), and Energy Conservation in Water and Wastewater Facilities, Manual of Practice No. 32 (WEF, 2009) [87], prepared a paper with a twofold purpose to first, quantify the typical range in energy consumption of different wastewater treatment processes to serve as a baseline for the target plants of North Carolina utilities. Second, it provided an analysis of methods to reduce energy consumption of the various current and potential future wastewater treatment processes to be performed.

There exists approximately 80,000 water and wastewater systems in the United States, and nationwide, approximately 4% of the total electricity consumption of 100 billion kilowatt-hours (kWh) is used for water supply and wastewater treatment. While water systems (including water supply, treatment, and distribution) utilize nearly the same amount of electricity as wastewater systems (including collection, treatment, and discharge), more than 80% of the electricity used by water systems is for pumping, while typically 10% to 20% of the electricity used by wastewater treatment (WWT) systems is for pumping.

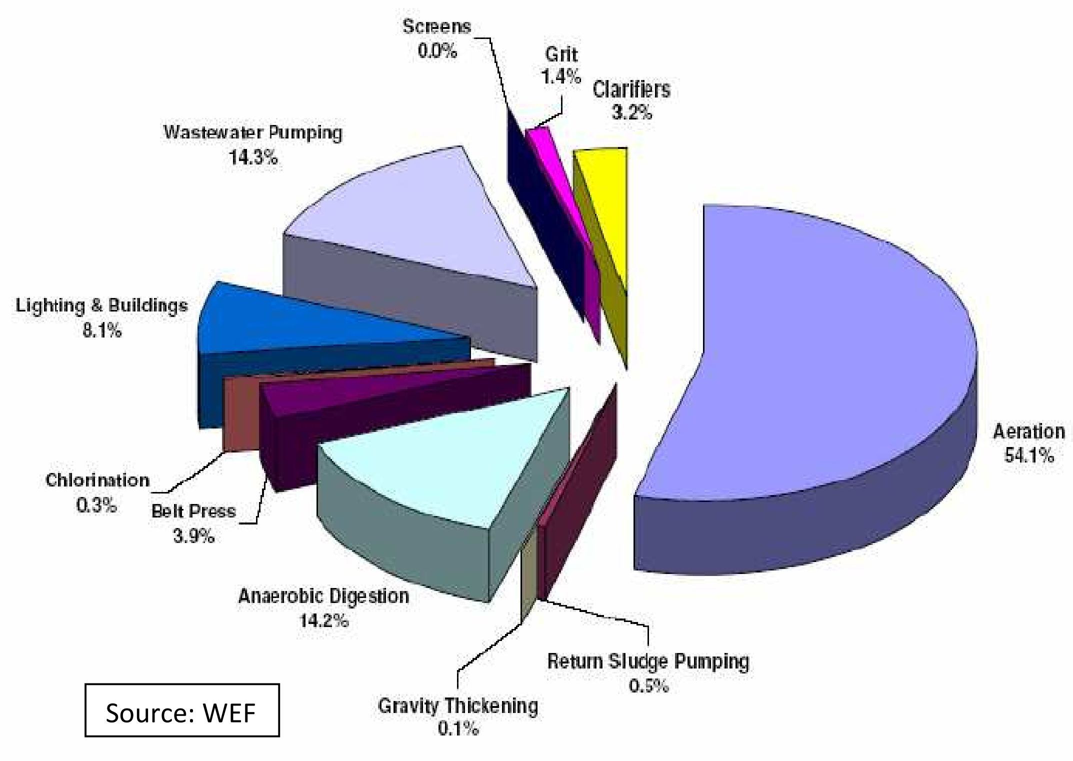
Therefore, most of the energy efficiency gains for water systems can be realized through the process of making water pumping systems more efficient. On the other hand, since most of the electricity consumption for wastewater systems is from wastewater plants, with large variation in treatment systems, the process of lowering electricity demand at wastewater treatment plants is more complex. This variation is illustrated in Figure 4.1, which shows the percentage of total energy demand for various processes of a typical WWT system in the U.S.

In the U.S., wastewater plants utilize an average of 1,200 kWh per million gallons (MG) of wastewater treated. It is important to note, however, a higher treatment volume generally leads to a lower energy demand per MG. For instance, for standard activated sludge treatment plants, a 1 MGD facility may have a 2,200 kWh/MG energy demand, a 10 MGD facility may have a 1,200 kWh/MG energy demand, and a 50 MGD facility may have a 1,000 kWh/MG energy demand (WEF, 2009). This amounts to a 45% energy consumption reduction per MG treated from a 1 MGD facility to a 10 MGD facility, and a 17% energy consumption reduction per MG treated from a 10 MGD facility to a 50 MGD facility.

The pie chart Figure 4.1 (WEF - percentage distribution of typical WWTP energy consumption in the U.S.) shows that for a typical wastewater system, wastewater pumping accounts for approximately 14.3% of the overall energy demand. The energy demand of pumping in wastewater systems is largely dependent on the number and size of pump stations in the system. For systems with a large number of pump stations for the service area (i.e. a service area with a flat topography), pumping may be a larger portion of the overall energy demand. In these cases, for municipalities looking to reduce their energy demand, conserving energy at pump stations becomes even more significant.

Approximately 85 percent of the wastewater treatment plants in the United States provide secondary or higher levels of treatment (EPA). In conventional secondary treatment, most of the electricity is used for 1) biological treatment by either the activated sludge process, which requires energy for aeration, or trickling filters, which require energy for influent pumping and effluent recirculation; 2) pumping systems for the transfer of wastewater, liquid sludge, biosolids and process water; and 3) equipment for the processing, dewatering and drying of solids and biosolids. A typical distribution of energy use in a conventional activated sludge treatment plant, the most common type of plants used in wastewater treatment, is illustrated in Figure 4.1. In activated sludge treatment, approximately 1200 to 2500 kWh of electricity are required to process each MG of wastewater, (EPRI, WERF, and M&E). As currently practiced, domestic wastewater treatment is an energy-demanding process. By far the most common energy demand for wastewater treatment is to provide oxygen for a biological system such as an activated sludge treatment. Approximately 54% of the energy used at activated sludge wastewater treatment facilities is for aeration, as shown in Fig. 4.1 [99].

Figure 4.1: U. S. percentage distribution of typical WWTP energy consumption



Source: WEF

This research work discusses below methodologies and simple theories for estimating energy consumption from the use of electro-mechanical equipment, biological processes and other energy consuming operations in a wastewater treatment plant.

4.2.1 Pumping Systems and Hydraulic Equations

Pumps are the most used machines and systems in a wastewater treatment facility. They are used to add energy to liquid systems (as compared to compressors, which add energy to gases), and may be classified as static-type or dynamic-type [29]. Static type pumps are often called positive displacement (or piston-style) pumps and produce flow through the static forces involved with changing the volume of the pump chamber. This type is relatively uncommon in environmental applications.

Dynamic-type pumps generally use a constant volume chamber, and flow is generated through the energy added by a set of blades (vanes, impellers) that are attached to a rotating shaft which is turned by a motor. The most common dynamic device is the centrifugal pump, comprised of an impeller attached to a rotating shaft and a fixed housing (casing) enclosing the impeller.

Pump performance is a pump characteristic which is based on head delivered, pump efficiency and brake horsepower, which are determined as a function of volumetric flow rate. The power gained by the fluid can be expressed as:

$$P' = Q\,\gamma\,h_p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.2.1.1)}$$

Where: P' is the power gained by the fluid (Nm/s), γ is the fluid specific weight (N/m2)

Q is the volumetric flow rate (m^3/s), h_p is the pump head (m).

The overall pump efficiency (η) is a ratio of the power gained by the fluid to the power delivered to pump by the rotating shaft and can be expressed as:

$$\eta = \frac{\mathit{Power\ gained\ by\ fluid}}{\mathit{shaft\ power\ delivered\ to\ pump}} = \frac{P'}{Ws} = \frac{Q\,\gamma\,HP}{550/\,BHP} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.2.1.2)}$$

Where BHP is the pump brake horsepower, often supplied by pump manufacturer.

<u>Energy or Bernoulli - Field Equation:</u>

In addition to equation of continuity, all steady state, incompressible, 1-D flow systems must also satisfy the energy equation (sometimes called the field equation), which is an expression that ensures conservation of mechanical energy between two specified points within a system. This equation is most often expressed in units of length (also called head) and can be represented as:

$Z_1 + V_1^2/2g + P_1/\gamma + h_P = Z2 + V_2^2/2g + P_2/\gamma + h_L + h_T$ .... (4.2.1.3)

Where: z = elevation (m), V = average velocity, g = acceleration due to gravity (equal to 9.81 m/s^2), P = pressure (Pa, or equivalently N/m^2), γ = specific weight of fluid (N/m^2),

h_p = pump head (m), h_L = loss head, h_T = the turbine head.

If the flow system does not contain a pump or turbine, and if the flow is to be in viscid (viscosity of fuel is negligible) or there are no energy losses due to friction, then h_p, h_T and, h_e should equal to zero, and the energy equation reduces to the familiar Bernoulli equation, which describes ideal flow as:

$Z_1 + V_1^2/2g + P_1/\gamma = Z2 + V_2^2/2g + P_2/\gamma$... (4.2.1.4)

Where: z is the elevation or potential head, V2/2g is the velocity head, P/γ is the pressure (or static) head.

4.2.2 Motors and Auxiliary Machines

Pumps, fans, compressors, generators, and power tools can be classified as auxiliary machines, mainly propelled by electric energy. A wastewater treatment plant could involve several types of treatment processes and utilize several types of environmental systems that include packages made up of auxiliary machines. These machines are included in all WWT stages, starting with preliminary, secondary, tertiary treatment and ending with pumping to final water-body receivers, agricultural or some other beneficiary project.

Sources of energy consumed in this long chain of treatment steps could be electricity, natural gas, propane, or a renewable source of energy. Process equipment could include auxiliaries such as valves, sluice gates, actuators, heaters, condensers, lifters, boilers and others, most of which require energy to operate. For all of these process equipment, initial design perfection will require sitting and proper sizing of system which are very important factors when it comes to assessing and conserving the energy at the design or plant rehabilitation phases.

Compressed air systems are one of the most important energy consuming sources in a wastewater facility. They are used in blowing and supplying air/oxygen into the aeration tanks, for powering pumps in the clarifiers, or in the backwash of sand filtration and many other operations. A rule of thumb is that every one horsepower of compressed air generated requires eight horsepower of source energy. Compressed air systems represent some 20% - 50% of a plant's electric bill [27].

Compressed air systems could be central, departmental or portable. A central system is one in which the total air demand of an operation is satisfied by a central air supply comprised of one or more air compressors and a distribution system throughout the plant [28]. Often these compressors are installed in the powerhouse along with other utilities or in compressor room. A departmental type air system can be used instead of or in combination with the central type. A departmental system is one in which several air compressors are located at principal points throughout the plant. While portable compressors vary in size and output, they are used for sporadic locations and site work.

Compressor energy consumption can be calculated by the principal electric motor equation:

$$\text{kW} = \text{HP} \times 0.746\ (\text{kW/HP}) \times \%\ \text{Time} \times \%\ \text{Load} / \eta \quad \ldots\ldots\ldots\ldots \quad (4.2.2.1)$$

Where:

HP = horsepower of compressor motor, η = motor efficiency, % time = time fully-loaded or unloaded, % full-load hp, loaded or unloaded.

Energy consumed (kWh) = kW x hours of operation per year .... (4.2.2.2)

To calculate the horsepower of an electric motor when current and efficiency, and voltage are known, the following formula applies:

$HP = (V \times I \times \eta) / 746$.. (4.2.2.3)

HP = horsepower, V = voltage, I = Current (amps), η = Efficiency

<u>Methodology for Verification of Motor Load</u>

Motor loads can be calculated in practice using any of the following three formulae:

1) Ratio of Motor load/kW

= 100% (kW input / HP rated x 0.746 / full load efficiency % / 100) .... (4.2.2.4)

2) Motor load per voltage compensated amperage ratio

$$= 100\% \left(\frac{Ampers\ measured}{\text{amps F.L.name plate}}\right) \times \left(\frac{Volts\ measured}{\text{volts name plate}}\right) \qquad (4.2.2.5)$$

Full load efficiency (FLE) for electric motor = 85% - 96%

3) Actual HP load percentage

$$= \frac{(\text{Synchronous speed in rpm} - \text{Measured speed in rpm})}{(\text{Synchronous speed in rpm} - \text{Name plate full load speed in rpm})} \qquad (4.2.2.6)$$

Actual Output HP = Actual HP load % x Name plate HP .... (4.2.2.7)

Calculated motor loads in practice can be verified by two methods; name plate information and on site measurements of particular motors, using measurement devices such as voltmeter for voltage, ammeter for current, wattmeter for power and power factor meter for apparent power [45]. Equipment measurement on site is the most preferable, as it confirms directly the amount of power consumed by a motor for certain application. In addition, it can be used to determine power/energy consumption at different equipment loads during a day.

Generally, motors account for a large part of the monthly electric bill, yet most often motors are oversized for the load they intended to serve. Sometimes motors are oversized because they must accommodate peak conditions, such as when a pumping system must satisfy occasionally high demands. Options available to meet variable loads include two-speed motors, adjustable speed drives and load management strategies that maintain loads within an acceptable range.

Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load. Thus, a 10-horsepower (hp) motor has an acceptable load range of 5 to 10 hp; peak efficiency is at 7.5 hp. A motor's efficiency tends to decrease dramatically below about 50% load.

A motor is considered under loaded when efficiency drops significantly with decreasing load. Overloaded motors can overheat and lose efficiency. Many motors are designed with a 'service factor' that allows occasional overloading. Service factor is a multiplier that indicates how much a motor can be overloaded under ideal ambient conditions. For example, a 10-hp motor with a 1.15 service factor can handle an 11.5-hp load for short periods of time without incurring significant damage. If the operation uses equipment with motors that operate for extended periods under 50% load, then modifications should be considered.

Motor part loads may be estimated through using input power, amperage, or speed measurements. One of the several load estimation techniques is the method used by McCoy, Gilbert A, and John g. Douglas, [100] for the determination of motor loads through the use of three equations.

Through the use of direct-read power measurement from hand-held instruments, the three-phase input power to the loaded motor can be quantified:

$$Pi = \frac{V\ x\ I\ x\ PF\ x\ \sqrt{3}}{1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{4.2.2.8}$$

Where:
Pi = Three-phase power in kW, V = RMS voltage, mean line-to-line of 3 phases
I = RMS current, mean of 3 phases, PF = Power factor as a decimal

Motor's power required at rated capacity (full HP or name plate power):

$$Pir = hp\ x\ \frac{0.746}{\eta fl}\ x\ 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{4.2.2.9}$$

Where:
Pir = Input power at full-rated load in kW, hp = Nameplate rated horsepower
ηfl = Efficiency at full-rated load

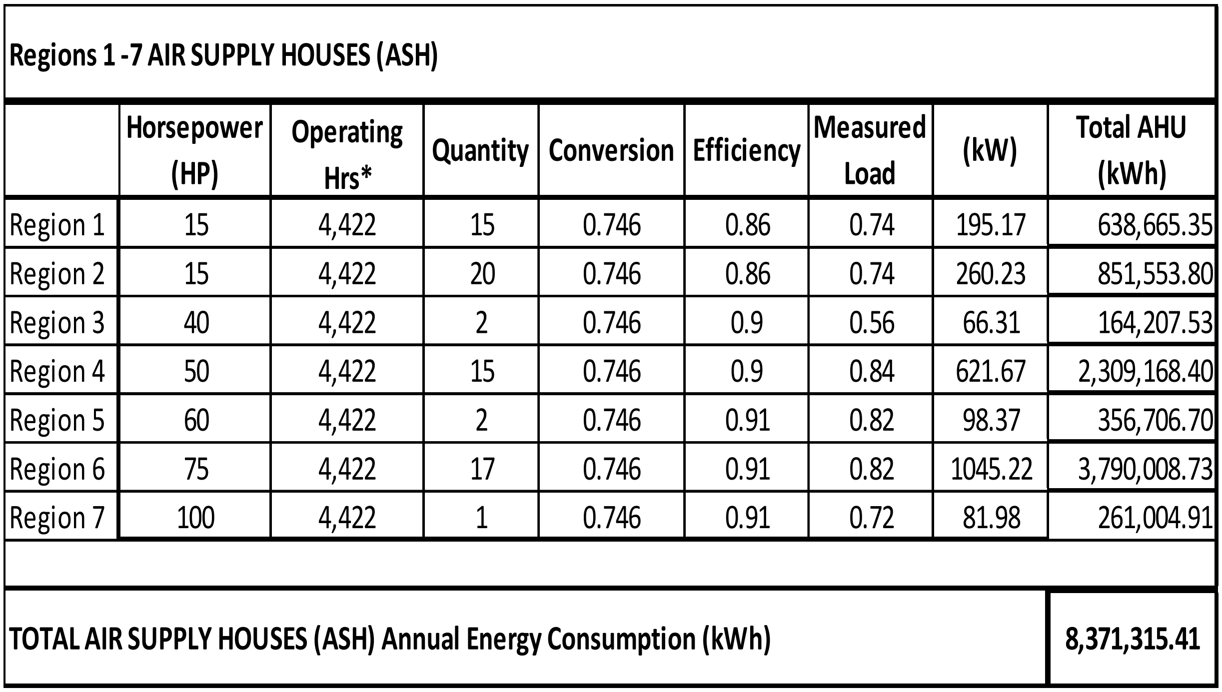
Estimating motor's part load:

$$Load = \frac{Pi}{Pir}\ x\ 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{4.2.2.10}$$

Where:
Load = Output power as a % of rated power, Pi = Measured three-phase power in kW,
Pir = Input power at full-rated load in kW

Table 4.1, shows data required to calculate energy consumption of motor driven equipment, the example is for air supply/handling houses in an industrial plant.

Table 4.1: Example for Air Supply Houses Energy Consumption Calculation



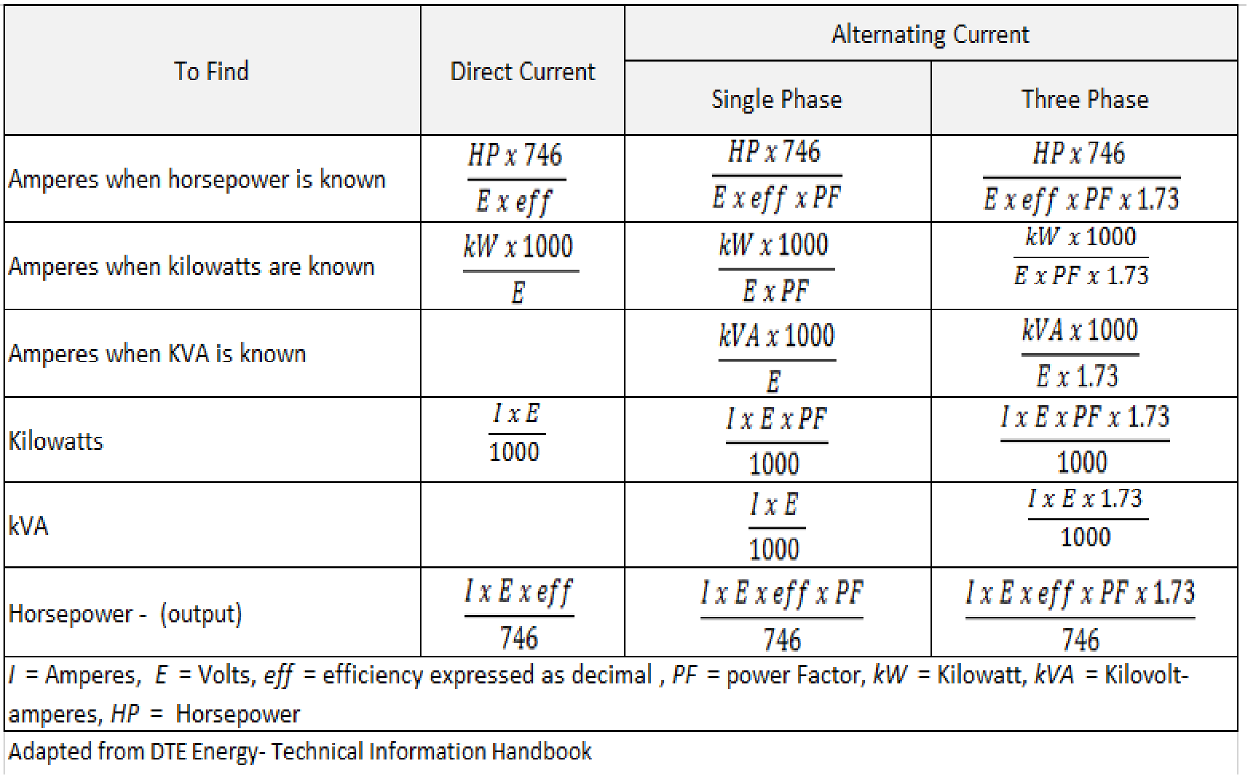
Regions 1 -7 AIR SUPPLY HOUSES (ASH)								
	Horsepower (HP)	**Operating Hrs***	**Quantity**	**Conversion**	**Efficiency**	**Measured Load**	**(kW)**	**Total AHU (kWh)**
Region 1	15	4,422	15	0.746	0.86	0.74	195.17	638,665.35
Region 2	15	4,422	20	0.746	0.86	0.74	260.23	851,553.80
Region 3	40	4,422	2	0.746	0.9	0.56	66.31	164,207.53
Region 4	50	4,422	15	0.746	0.9	0.84	621.67	2,309,168.40
Region 5	60	4,422	2	0.746	0.91	0.82	98.37	356,706.70
Region 6	75	4,422	17	0.746	0.91	0.82	1045.22	3,790,008.73
Region 7	100	4,422	1	0.746	0.91	0.72	81.98	261,004.91
TOTAL AIR SUPPLY HOUSES (ASH) Annual Energy Consumption (kWh)								**8,371,315.41**

Source: Author

Methodology for calculating energy cost savings for motors through the reduction of operating time -- for example, 100 hours a month -- can be achieved by multiplying motor's horsepower by 0.746 to convert to kW, then by number of motors, by load factor and power factor, and then divide by motor efficiency and multiply by energy cost ($/kWh).

A useful summary of formulas used to estimating amperes, kilowatt and horsepower is presented in Table [4.2] below. This comprehensive table includes electric formulas for direct current and alternating current, single phase and three phase currents.

Table 4.2: Determining Amperes, kW, kVA and HP for DC and AC current



To Find	Direct Current	Alternating Current	
		Single Phase	Three Phase
Amperes when horsepower is known	$\frac{HP \; x \; 746}{E \; x \; eff}$	$\frac{HP \; x \; 746}{E \; x \; eff \; x \; PF}$	$\frac{HP \; x \; 746}{E \; x \; eff \; x \; PF \; x \; 1.73}$
Amperes when kilowatts are known	$\frac{kW \; x \; 1000}{E}$	$\frac{kW \; x \; 1000}{E \; x \; PF}$	$\frac{kW \; x \; 1000}{E \; x \; PF \; x \; 1.73}$
Amperes when KVA is known		$\frac{kVA \; x \; 1000}{E}$	$\frac{kVA \; x \; 1000}{E \; x \; 1.73}$
Kilowatts	$\frac{I \; x \; E}{1000}$	$\frac{I \; x \; E \; x \; PF}{1000}$	$\frac{I \; x \; E \; x \; PF \; x \; 1.73}{1000}$
kVA		$\frac{I \; x \; E}{1000}$	$\frac{I \; x \; E \; x \; 1.73}{1000}$
Horsepower - (output)	$\frac{I \; x \; E \; x \; eff}{746}$	$\frac{I \; x \; E \; x \; eff \; x \; PF}{746}$	$\frac{I \; x \; E \; x \; eff \; x \; PF \; x \; 1.73}{746}$

I = Amperes, *E* = Volts, *eff* = efficiency expressed as decimal , *PF* = power Factor, *kW* = Kilowatt, *kVA* = Kilovolt-amperes, *HP* = Horsepower

Adapted from DTE Energy- Technical Information Handbook

Adopted from DTE Energy - Technical Information Handbook

Bill analysis verification is a dependable method determining for total power and energy consumption, but in many cases it doesn't cover break down for individual equipment of processes or systems. Components of a bill can be multiple, complex and require a good bill analysis background. Bill components could include; energy charge, demand charge, fixed charges, penalties, credits, taxes, discounts and surcharges, in addition to two contract dependable values of a bill: the firm demand and the interruptible demand. Neither bills nor readings from electric gear switches or meters might be accessible to non-facility engineers conducting energy studies or audits. Actual site measured values could be the only dependable and realistic measurement approach compared to nameplate data [43].

Accuracy of data used during analysis is a very important factor to ensure successful and true results for estimating volumes of energy consumed in a plant, and finally achieving a good estimate of GHGs generated due to that usage.

A proof of this importance is the finding from Fairfax, Virginia study [43] "A GIS methodology for estimating the carbon footprint in municipal W&WW in Fairfax Co., VA," which concluded that hydraulic equations for the pumped energy underestimated the embodied energy by 41**%**, and that hydraulic equation can provide a rough estimate, but actual electrical consumption data are preferred when available.

4.2.3 Lighting Systems

Light is the portion of electromagnetic radiation that is visible to the human eye, responsible for the sense of sight. The foot-candle or lux is the most common term to measure lighting levels in terms of luminance. Lumen is the derived unit of luminous flux, a measure of the power of light perceived by the human eyes. Lumens / Watt measures the light output (efficacy) compared to the electric input. Types of lighting include incandescent, fluorescent, high intensity discharge (HID), induction lighting and LED (light emitting diode).

EIA estimates that in 2011, about 461 billion kilowatt-hours (kWh) of electricity were used for lighting by the residential and commercial sectors. This was equal to about 17% of the total electricity consumed by both of these sectors and about 12% of total U.S. electricity consumption. And, most recent data available indicates that in 2006, 63 billion kWh were consumed for lighting in manufacturing facilities, which was equal to about 2% of total U.S. electricity consumption in 2006; and about 20% percent of all electricity generated in the U.S. is used for lighting.

There are two methods to design lighting [40]; 1) the point by point system, and 2) the lumen system. The point by point system makes use of the inverse-square law, which states that the luminance at a point on a surface perpendicular to the light ray is equal to the luminous intensity of the source at that point divided by the square of the distance between the source and the point of calculation, as illustrated in formula [103]:

$$E = \frac{I}{D^2} \quad \ldots\ (4.2.3.1)$$

Where: E- luminance in footcandle, I- luminous intensity in candles, and D - distance in feet between the source and the point of calculation. If the source is not perpendicular to the light ray, the appropriate trigonometric functions must be applied to account for the deviation.

The lumen method assumes an equal footcandle level throughout the area. This method is used frequently by lighting designers since it is simplest; however, it wastes energy since it is the light at the task that must be maintained not the light in the surrounding area. The lumen method developed and illustrated by formula [40] below:

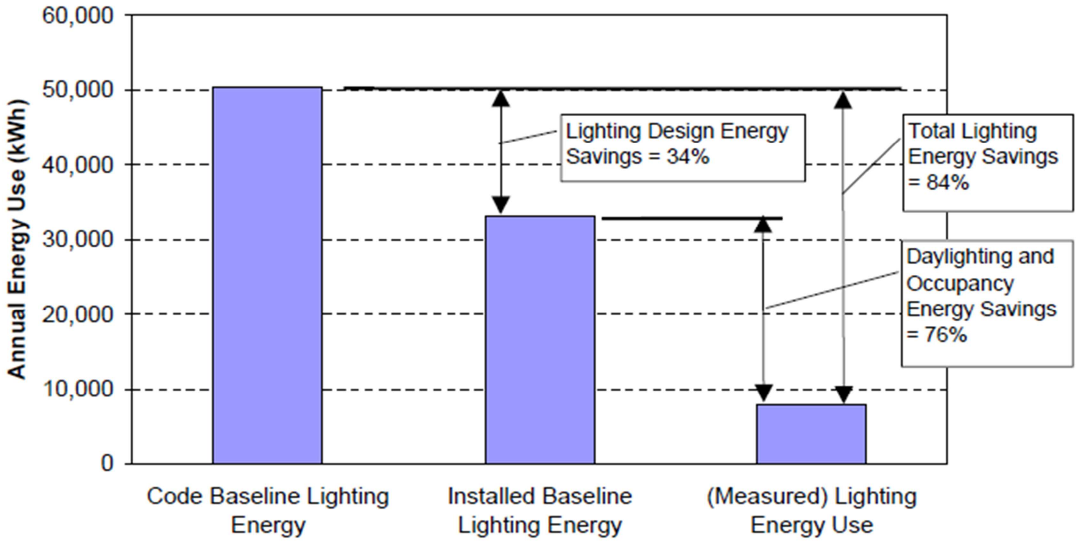
$$N = \frac{F1\ x\ A}{Lu\ x\ L1\ x\ L2\ x\ Cu} \quad \ldots\ (4.2.3.2)$$

Where: N - number of lamps required, F1 - required footcandle level at the task, A - area of room (ft^2), Lu - lumen output per lamp, Cu - Coefficient of utilization, L1 - lamp depreciation factor, L2 - luminaire dirt depreciation factor.

The methodology for calculating energy cost savings from the reduction of operating time for lighting systems, assuming 100 hours a month, can be achieved by multiplying lamps energy by number of lamps divided by (1000) to convert to kW and multiplied by energy cost ($/kWh).

Lighting design energy savings is the difference between the code baseline lighting energy and the installed baseline lighting energy. For a percentage savings, this metric can be calculated as the difference between the code baseline - lighting power density (LPD); which is the lighting power divided by the lighted floor area and the Installed LPD. This metric will be negative if the Installed LPD is greater than the code baseline LPD. Lighting energy cost savings percentage is illustrated in Figure 4.2, and energy calculation example for a simple office building is summarized in Table 4.3.

Figure 4.2: Lighting Energy Cost Savings [102]



Source: DOE - Lighting energy performance

Table 4.3: Example of Lighting Energy Cost Calculation for a Small Office

Space	Fixture Type	Fixtures Quantity	Power per Fixture (W)	Total Fixture Power (kW)	Operating Hours per year	Annual Power Use (kWh)
Admin Building	4 Lamp, T8- Flrs.	4	115	0.46	4380	2,014.8
Office 1	2 Lamp, T8, 8' Flrs.	20	112	2.24	4380	9,811.2
Office 2	2 Lamp, T8, 8' HO	16	160	2.56	4380	11,212.8
Office 3	4 Lamp, T5, 28W	10	126	2.26	4380	9,898.8

Office 4	6 Lamp T8, 4' Flrs.	10	220	2.2	4380	9,636
Conference Room	30W, LED	20	30	0.6	5000	3000
Bathrooms	23W screw in CFLs	8	23	0.184	4400	809.6
Storage room	4 Lamp T8, F32	2	115	0.3	4400	1320
Kitchen	3 Lamp, T5 F28	2	96	0.192	4400	844.8
Parking Lot	400W HID	10	455	4.55	4745	21,589.8
Total Building (kWh/yr)						70,137.8

Source: Author

4.2.4 HVAC System

The Heating, ventilating and air conditioning (HVAC) system for a facility is the system of motors, ducts, fans, controls and heat exchange units which delivers heated or cooled air to various parts of the facility. The purpose of the HVAC system is to add or remove heat and moisture and remove undesirable air components from the facility in order to maintain the desired environmental conditions for people, products and/or equipment. Providing acceptable indoor air quality is a critical function of the HVAC system, and air movement to remove odors, dust, pollen, etc., is necessary for comfort and health. It may also be necessary to meet unusual requirements such as those in a laboratory or a clean room.

The HVAC system is responsible for a significant portion of the energy use and energy cost in commercial buildings, such as those found in a WWTP [103].

The energy efficiency rating for furnaces and boilers is specified in terms of the ratio of the output energy supplied to the input energy provided. The efficiency is shown in equation (4.2.4.1) below:

Efficiency (%) = $\frac{Heat\ Output}{Heat\ Input}$ .... (4.2.4.1)

The efficiency of air conditioners is usually measured in terms of their efficiency ratios (EER), or their seasonal energy efficiency ratios (SEER). They are specified as:

EER or SEER = $\frac{Btu\ of\ cooling}{Watt-hours\ of\ electric\ energy\ input}$ .... (4.2.4.2)

The EER value is measured at a single temperature for the outside air, while the SEER involves a weighted average of the EERs over a typical season with a range of outside temperatures. Air conditioning units SEER can reach 18 or greater, but most units have SEERs around 12 -14.

Chiller efficiency is usually measured in terms of a coefficient of performance (COP) which is expressed as:

COP = $\frac{Heat\ absorbed\ by\ the\ Evaporator}{Heat\ rejected\ by\ the\ condenser-Heat\ absorbed\ by\ the\ evaporator}$ ...... (4.2.4.3)

Chiller efficiencies may also be expressed as EERs, where

EER = COP x 3,412 (Btu /Wh) ....(4.2.4.4)

If an air conditioner heat capacity or tonnage is known, then electric load is estimated as:

Electric Load = $\frac{Cooling\ capacity\ (Ton)}{EER}$ (Btu/kWh).. (4.2.4.5)

4.2.5 Environmental Systems

WWTPs, as is the case with most industrial and commercial institutions are required by local, state and federal regulatory authorities to comply with regulations pertaining to emissions and other discharges to the environment. This includes compliance with rules concerning the treatment of activated sludge, tertiary treatment, wastewater purification for non-potable water reuse, water sustainability, clarification and oil and / or solids removal. Many pollution control systems can provide the right compliance solutions through the application of a variety of approved and well-known physical/chemical, adsorption/absorption systems for the removal of contaminants that might be emitted or disposed of to the environment during wastewater treatment processes.

Environmental treatment systems implemented in a WWTP could include air stripping, adsorption/absorption processes, activated carbon filtration, the several options of in-situ remediation for contaminated soils and air abatement technologies.

4.3 Sustainable Biological Processes

Means [94], states that most wastewater treatment facilities can significantly reduce their energy costs by up to 30% or more through energy efficiency measures and treatment process modifications. However, Hoppock, D.C., et.al [95], states that through optimized aeration and improved pumping alone, wastewater treatment plants could save 547 to 1,057 million kWh annually, reducing overall energy use in the wastewater sector by 3% to 6%. Stillwell, et.al, [88] in their wastewater treatment process modifications case study, included anaerobic digestion with biogas utilization and biosolids incineration with electricity generation. Analysis provides a top-level estimate of energy savings within the wastewater sector in the United States via these two process modifications. First, examined potential energy recovery from anaerobic digestion with biogas utilization on a national scale. This case study, briefly discussed below, estimates the state of Texas produces and consumes more electricity than any other state in the nation, which is the reason to choose Texas as a test-bed for analysis of energy recovery from biosolids incineration with electricity generation. These energy recovery strategies could help offset the electricity consumption of the wastewater sector and represent possible areas for sustainable energy policy implementation. The analysis considers energy consumption and potential savings only; the economics of energy recovery from wastewater treatment, while highly relevant, is reserved for a separate analysis. Energy recovery at wastewater treatment plants represents an important policy lever for sustainability.

Sludge is usually treated to form biosolids using some form of digestion. Sludge digestion and the associated solids processing operations constitute the second largest use of electricity in wastewater treatment [104]. As a rule of thumb, anaerobic digestion produces about 35 m^3 of gas per day per person in the service area, which has a typical heating value of approximately 6.2 kWh/ m^3 [119].

Anaerobic Digestion with Biogas utilization:

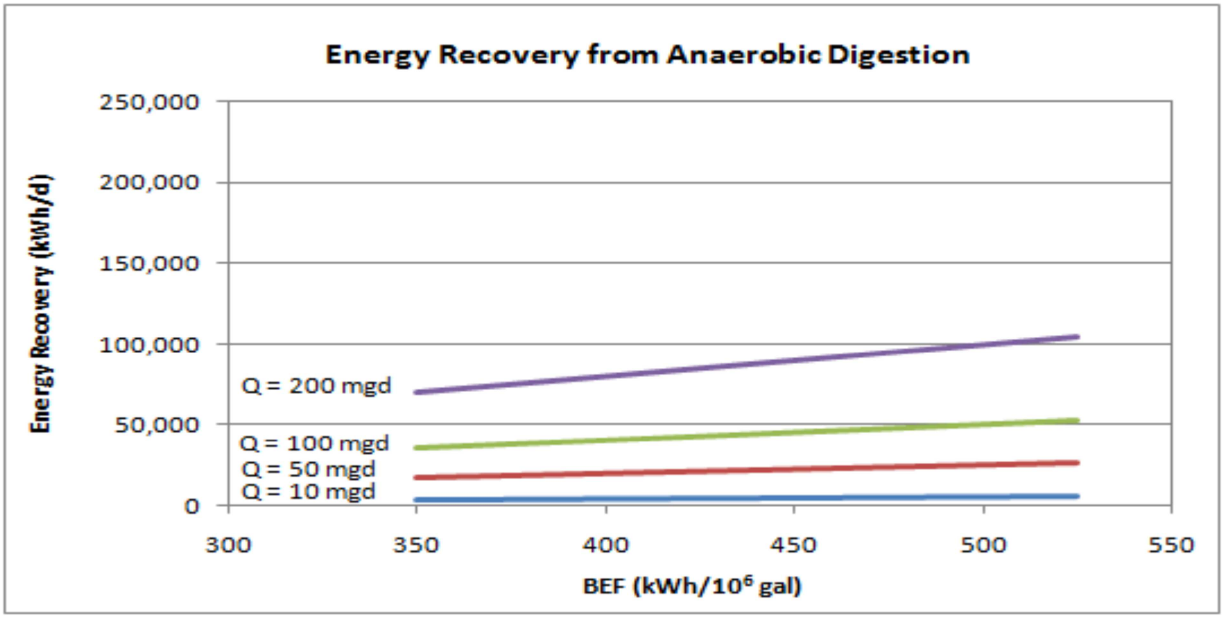
Analysis of energy recovery potential for wastewater treatment plants using anaerobic digestion with biogas utilization was based on CWNS data and biogas energy factors reported by Burton and EPRI [96][73]. Potential energy recovery was calculated using equation:

$$ER_{anaerobic} = Q \times BEF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3.1)$$

Where: $ER_{anaerobic}$ - energy recovery from anaerobic digestion (kWh/d), Q -flow rate (MGD), and BEF - biogas energy factor (kWh/10^6 gal). Reported biogas energy factors range from 350 to 525 (kWh/MG) or (0.0925 to 0.139 kWh/ m^3).

Research from Burton and EPRI reveals that 350 (kWh) of electricity are produced from each 1 (MG) of WW treated. Figure 4.3, shows the variance of potential energy recovery (kWh/d) from anaerobic digestion with biogas utilization with the biogas energy factors, BEF (kWh/10^6 gal), and increases with increasing wastewater flow.

Figure 4.3: Energy Recovery from Anaerobic Digestion



Source: Stillwell, Hoppock and Webber, Texas-Austin and Duke Universities, 2010

Biosolids Incineration with Electricity Generation

Analysis of energy recovery for WWTP using biosolids incineration with electricity generation was based on CWNS data, typical wastewater dry solids content, heating values of biosolids and heat rates for steam electric power plants [M&E, CWNS 2004, Masters, and G.M.]. Potential energy recovery was calculated using the following equation:

$$ER_{incineration} = \frac{Q \ x \ Cs \ x \ HV}{HR} \quad \text{...} \ (4.3.2)$$

Where: $ER_{incineration}$ - energy recovery from biosolids incineration (kWh/d), Q - wastewater flow rate (MGD), Cs - wastewater dry solids content (kg/10^6 gal), HV - solids heating value (kJ/kg), and HR - steam electric heat rate (kJ/kWh). However, sources did not specify whether HV represents lower or upper heating value, but this heating value does account for residual moisture present in biosolids, dewatered to 28% solids or greater [M&E, 4th edition]. Potential energy recovery calculated using equation (4.3.2) varies with the range in biosolids heating values reported in Table 4.4.

Table 4.4: Biosolids Heating Values

Factor	Equation Term	Reported Value	Units
Wastewater dry solids contents	*Cs*	680 -1,020	Kg/10^6 Gal
Biosolids heating value (digested biosoilds)	*HV**	9,000 – 14,000	kJ/kg
Steam electric heat rate	*HR***	10,550	kJ/kWh

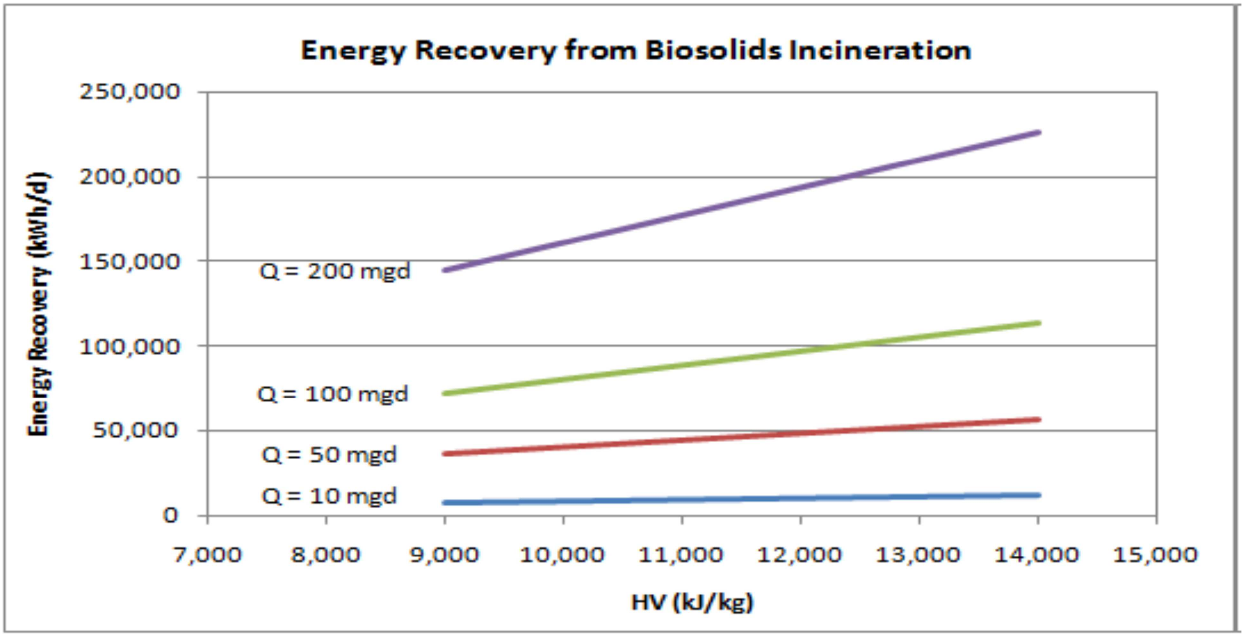
Source: Stillwell, Hoppock and Webber, Texas-Austin and Duke Universities, 2010

*Source did not specify high heating versus low heating value

** Heat rate similar to that of a coal-fired power plant due to the solid fuel nature of biosolids and associated air pollution control equipment

Figure 4.4: Potential energy recovery from biosolids incineration varies with the biosolids heating value, HV, and increases with increasing wastewater flow.

Figure 4.4: Energy Recovery from Biosolids Incineration



Source: Stillwell, Hoppock and Webber, Texas-Austin and Duke Universities, 2010

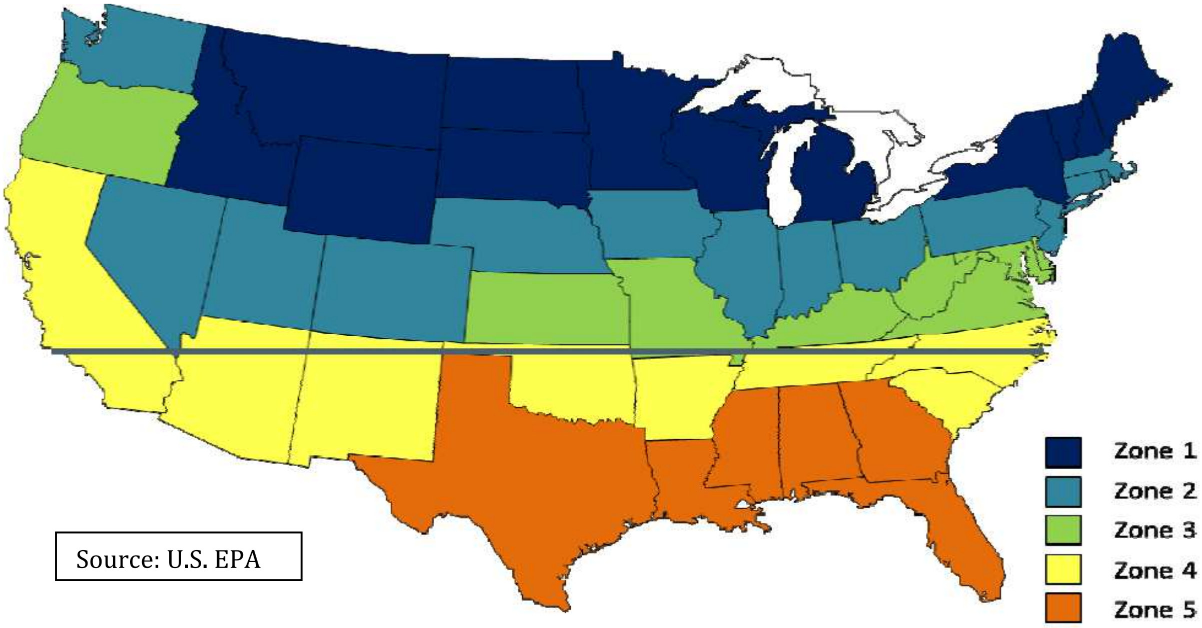
Most wastewater treatment plants with multiple hearth or fluidized bed furnaces use incineration as a means of biosolids disposal only and not for electricity generation. Thus this incineration represents an opportunity to generate electricity via steam cycle.

As discussed in sub-chapter 1.7, WWTP system boundaries should be defined and delineated for an energy and emission inventory estimation project. Boundaries will enable sequestering of all energy consumption and generation resources and processes.

Thermal energy requirements for anaerobic digesters as EPA [96] states, climate is the most important factor determining digester heating requirements. When ambient air and sludge temperatures are low, it takes more energy to heat the digesters.

Methodology used to determine these requirements has utilized the U. S. five different climate zones based on cooling and heating degree days, Figure 4.5, (EIA) [105].

Figure 4.5: U.S. Climate Zones



Source: U.S. EPA

Zone 1 – Cold climate with more than 7,000 heating degree days

Zone 2 – Cold/moderate climate with 5,500 to 7,000 heating degree days

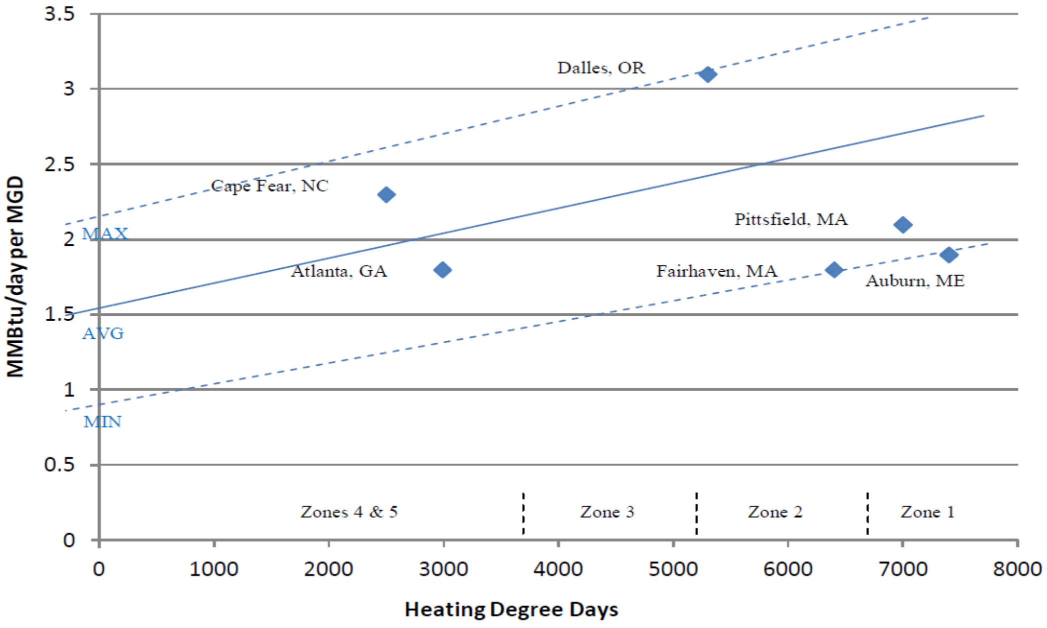
Zone 3 – Moderate/mixed climate with 4,000 to 5,500 heating degree days

Zone 4 – Warm/hot climate with fewer than 4,000 heating degree days and fewer than 2,000 cooling degree days

Zone 5 – Hot climate with fewer than 4,000 heating degree days and more than 2,000 cooling degree days

Recent feasibility studies and technical papers data from various anaerobic digester gas projects were examined to determine how digester heating requirements correlate to climate [157]. These feasibility analyses and technical papers assessed digester gas projects in the following locations: Georgia (Zone 5), North Carolina (Zone 4), Oregon (Zone 3), Massachusetts (Zone 2), and Maine (Zone 1). With minimum and maximum bounds for the energy requirements, the average value for MMBtu/day/MGD was determined in Figure 4.6 below [157].

Figure 4.6: Thermal Energy Requirements for Anaerobic Digesters by Heating Degree Days



Source: H. Scott 2011, CDM 2009, Fishman, Carollo, Brown and Caldwell, and SEA consultants

Many other references detailed boundaries according to activity requirement, of which. Monteith et.al, [92], referring less on energy discussion and more on process emissions, concluded that GHGs emissions are generated by liquid treatment processes, by solids treatment processes and by the combustion of biogas and fossil fuels on-site for energy generation. GHGs also may be produced because of solids disposal (transportation and degradation of solids off-site), off-site energy production, off-site chemicals production and even from the degradation of constituents remaining in the treated water, all of which was captured by the proposal of this dissertation.

The quantity and distribution of GHG produced will depend on the characteristics of the incoming wastewater, the required treated water criteria, and the on-site processes used.

Since this research is targeting energy and emissions of a new facility in the design phase in which detailed flow information and data are not readily available, flows may be assessed from population estimates and appropriate per-capita and design-flow factors. Similarly, in the absence of actual plant-specific data, influent characteristics, standard per-capita BOD, suspended solids, and nitrogen and phosphorus-design loadings, the pre-established data in Table 4.5 can be used, and the concentrations estimated accordingly [79].

Table 4.5: Per-Capita Loading Factors Used in Greenhouse-Gas Estimation

Loading Parameter	Factor
Flow	480 L/d (127 gal/d)
Five day biochemical oxygen demand	0.0817 kg/d (0.18 lb/d)
Total suspended solids	0.0908 kg/d (0.20 lb/d)

Total Kjeldahl nitrogen	0.0123 kg/d (0.027 lb/d)
Total phosphorus	0.0036 kg/d (0.008 lb/d)

Source: M&E, 1991

4.3.1 Estimation of Biologically Generated Greenhouse Gases

Aerobic basin/Liquid treatment: When primary sludge is mixed with waste activated sludge or trickling filter humus and the combination is aerobically digested, there will be both oxidation of the organic matter in the primary sludge and endogenous oxidation of the cell mass produced from the biological oxidation and from the activated sludge or filter humus. The generalized biochemical equation for the aerobic digestion of primary sludge solids is [8]:

$$\text{Organic matter} + O_2 \xrightarrow[\text{microbes}]{\text{aerobic}} \text{New cells} + \text{Energy for cells} + CO_2 + \text{end products} \; \ldots\ldots \; (4.3.3)$$

Furthermore, Monteith et al. estimate aerobic basin CO_2 as combined from endogenous decay and BOD oxidation. A fraction of the carbon incorporated to biomass under aeration (M&E) is

$$V\ K_{id}\ X \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.3.4)$$

Where: V = aerobic reactor volume (m^3), Kd = Biomass endogenous decay coefficient (d^{-1}) and X = Biomass concentration in aerobic reactor (g VSS/m^3) and, is converted to CO_2 via endogenous respiration. Assuming that the biomass can be represented by the formula $C_5H_7O_2N$ (Rittmann and McCarty, 2001 and Hoover & Forges, 1952, WEF Engineering Management), the CO_2 emissions arising from endogenous decay can be estimated from equation (4.3.5):

$C_5H_7O_2N + 5\ O_2 \rightarrow 5\ CO_2 + 2\ H_2O + NH_3$ .... (4.3.5)

The relationship reveals that 5 moles of CO_2 are released for every mole of biomass respired. The gram molecular weights of the biomass ($C_5H_7N_2O$) and CO_2 are 113 and 44, respectively, giving rise to a conversion factor of 1.947 kg CO_2/kg biomass respired endogenously.

Carbon dioxide from BOD oxidation however, represents the carbon not incorporated to biomass and converted to CO_2 under aerobic conditions. Estimating the CO_2 produced from this process is done indirectly from the oxygen requirement. Assuming that soluble BOD can be expressed in chemical form, by the expression $C_{10}H_{19}O_3N$ (Rittmann and McCarty, 2001), the equation for oxidation of BOD to produce energy for growth is

$2\ C_{10}H_{19}O_3N + 25\ O_2 \rightarrow 20\ CO_2 + 16\ H_2O + 2\ NH_3$.. (4.3.6)

This equation predicts that, for every mole of oxygen consumed, 0.8 moles of CO_2 are released. The gram molecular weights of oxygen and CO_2 are 32 and 44 grams, respectively, leading to a conversion ratio of 1.1 kg CO_2/kg O_2. This discussion concludes that aeration basin total:

$$CO_{2\ \text{aeration basin}} = CO_{2\ \text{endogenous}} + CO_{2\ \text{BOD}}$$

Anaerobic Digestion:

This process employs microbes that thrive in an environment in which there is no molecular oxygen and there is a substantial amount of organic matter. The organic material is a food source for the microbes, and they convert it into oxidized materials, new cells, energy for their life processes and some gaseous end products, such as methane and carbon dioxide. The generalized equation for an anaerobic action is [8]:

$$\text{Organic matter} + \text{Combined } O_2 \xrightarrow[\text{microbes}]{\text{anaerobic}} \text{New cells} + \underset{\text{for cells}}{\text{Energy}} + CH_4 + CO_2 + \underset{\text{products}}{\text{Other end}} \quad \text{.................} \ (4.3.7)$$

GHG emissions are also generated during solids treatment. Solids production sources in a treatment plant are plant operations dependent, and they are combined from summing the solids removed from screening, grit removal, primary treatment clarifiers and the biological treatment processes, and secondary sedimentation. Other processes per [79] (M & E, 4th edition) used for thickening, digesting, conditioning and dewatering of solids produced from primary and secondary settling tanks also constitute sources of solids.

Stabilization of wastewater solids and biosolids can be accomplished either by aerobic or anaerobic digestion. Aerobic digestion may be used to treat waste activated sludge or mixtures of it, trickling filter or primary sludge and waste sludge from extended aeration plants. It is employed in plant sizes of less than 5 (MGD), and in the late 1990s, in larger treatment plants with capacities up to 50 (MGD), (WEF). Anaerobic digestion in major applications can be found in the stabilization of concentrated sludge produced from the treatment of municipal and industrial wastewater. Because of the emphasis on energy conservation and recovery, and the desirability of obtaining beneficial use of wastewater biosolids, anaerobic digestion continues to be the dominant process for stabilizing sludge. Furthermore, anaerobic digestion of municipal wastewater sludge can, in many cases, produce sufficient digester gas to meet most of the energy needs for plant operation. Total gas production is usually estimated from the percentage of volatile solids reduction. Typical values vary from 12 to 18 (ft^3/lb) of volatile solids destroyed [79].

If the composition of waste is known, and neglecting the amount of constituent used for cell synthesis, a relationship, first proposed by Buswell & Boruff (1932) and subsequently extended by Sykes (2000), can be used to estimate the amounts of methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and the hydrogen sulfide (H_2S) that will be produced under anaerobic conditions. Using the formula (Cv Hw Ox Ny Sz) for waste composition, the expected mole fractions of methane, carbon dioxide and hydrogen sulfide are given by the three following expressions, respectively:

$$f_{CO2} = \frac{4v - w + 2x - 5y + 2z}{8\,(v - y + z)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.3.8)$$

$$f_{CH4} = \frac{4v + w - 2x - 5y + 2z}{8\,(v - y + z)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3.9)$$

$$f_{H2S} = \frac{z}{8\,(v - y + z)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3.10)$$

As stated above, aerobic wastewater treatment systems produce primarily CO2, whereas anaerobic systems produce a mixture of CH4 and CO2. Furthermore, a study by RTI International, submitted to EPA [164], introduced equations (4.3.11) and (4.3.12) providing a general means of estimating the CO_2 and CH_4 emissions directly from any type of wastewater treatment process assuming all organic carbon removed from the wastewater is converted to either CO_2, CH_4, or new biomass.

$$CO_2 = 10^{-6} \times Q_{ww} \times OD \times Eff_{OD} \times CF_{CO2} \times [(1-MCF_{ww} \times BG_{CH4})\ (1-Y)] \ldots\ldots\ldots\ldots\ (4.3.11)$$

$$CH_4 = 10^{-6} \times Q_{ww} \times OD \times Eff_{OD} \times CF_{CH4} \times [(MCF_{ww} \times BG_{CH4})\ (1-Y)] \ldots\ldots\ldots\ldots\ (4.3.12)$$

where: CO2 = CO2 emission rate (Mg CO_2/hr), CH_4 = CH_4 emission rate (Mg CH_4/hr), 10^{-6} = Units conversion factor (Mg/g), Qww = Wastewater influent flow rate (m^3/hr), OD = Oxygen demand of influent wastewater to the biological treatment unit determined as either BOD5 or COD (mg/L

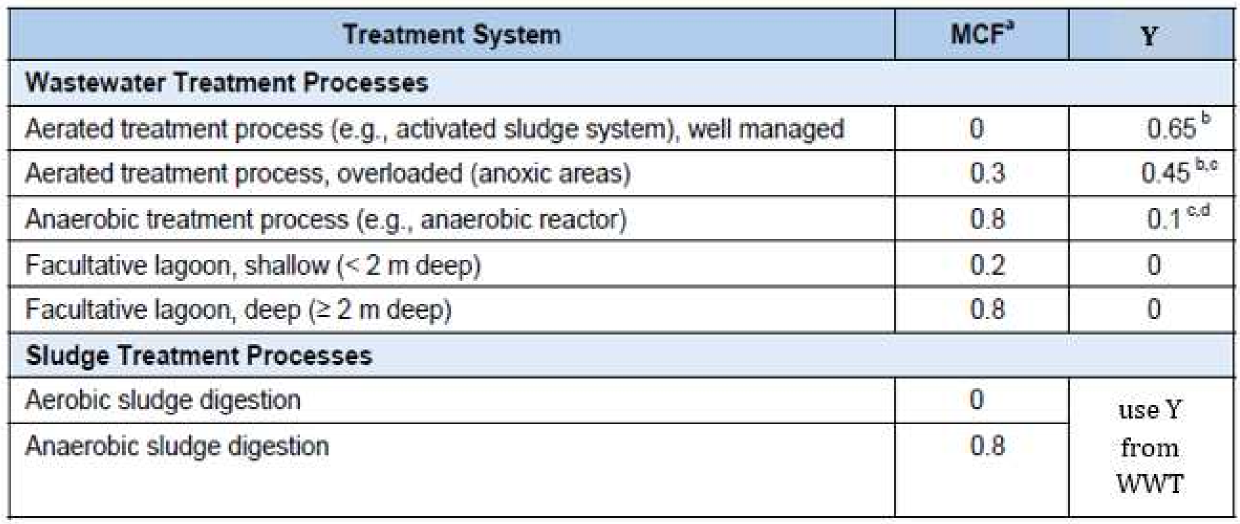
= g/m^3), Eff_{OD} = Oxygen demand removal efficiency of the biological treatment unit, CF_{CO_2} = Conversion factor for maximum CO_2 generation per unit of oxygen demand = 44/32 = 1.375 g CO_2/ g oxygen demand, CF_{CH_4} = Conversion factor for maximum CH_4 generation per unit of oxygen demand = 16/32 = 0.5 g CH_4/ g oxygen demand, MCF_{WW} = methane correction factor for wastewater treatment unit, indicating the fraction of the influent oxygen demand that is converted anaerobically in the wastewater treatment unit (see Table 4.6), BG_{CH_4} = Fraction of carbon as CH_4 in generated biogas (default is 0.65), Y = Biomass yield (g C converted to biomass/g C consumed in the wastewater treatment process).

The biomass yield, Y, can be calculated using Equation (4.3.13). When the biomass generation rate cannot be assessed, default values for the biomass yield provided in (Table - 4.6) should be used.

$$Y = \frac{Qs\ x\ MLVSSs\ x\ CFs}{Qww\ x\ OD\ x\ Eff_{OD}\ x\ CFc} \text{ .... } (4.3.13)$$

Where: Y = Biomass yield (g C converted to biomass/g C consumed in the wastewater treatment process), Q_S = Waste sludge stream flow rate (m^3/hr), Q_{WW} = Wastewater influent flow rate (m^3/hr), MLVSSS = Mixed liquor volatile suspended solids concentration of the waste sludge stream (mg/L = g/m^3), OD = Oxygen demand of influent wastewater to the biological treatment unit determined as either BOD5 or COD (mg/L = g/m^3), Eff_{OD} = Oxygen demand removal efficiency of the biological treatment unit, CF_S = Correction factor for carbon content of the biomass (i.e., $MLVSS_S$) = 0.53 g C/g MLVSS (default), CF_C = Conversion factor for maximum C consumption per unit of oxygen demand = 12/32 = 0.375 g C/ g oxygen demand.

Table 4.6: Default Values of Methane Correction Factors and Biomass Yield



Treatment System	MCF[a]	Y
Wastewater Treatment Processes		
Aerated treatment process (e.g., activated sludge system), well managed	0	0.65 [b]
Aerated treatment process, overloaded (anoxic areas)	0.3	0.45 [b,c]
Anaerobic treatment process (e.g., anaerobic reactor)	0.8	0.1 [c,d]
Facultative lagoon, shallow (< 2 m deep)	0.2	0
Facultative lagoon, deep (≥ 2 m deep)	0.8	0
Sludge Treatment Processes		
Aerobic sludge digestion	0	use Y from WWT
Anaerobic sludge digestion	0.8	

[a] Source: IPCC (2006).

[b] Source: Choubert et al. (2009), Muller et al. (2003), and Munz (2008); Y reported in g-COD in produced biomass/g- COD consumed; equivalent to Y in g-C in produced biomass/g-C consumed when using default CF_C in Equation [4.3.13]

[c] Source: Ammary (2004); Y reported in g-VSS produced/g-COD degraded; converted to in Y g-C in produced biomass/g-C consumed using default CF_S and CF_C in Equation [4.3.13] as Y = Y reported × (CF_S / CF_C).

[d] Source: Low and Chase (1999); Y reported in g-VSS produced/g-COD degraded; converted to Y in g-C in produced biomass/g-C consumed using default CF_S and CF_C in Equation [4.3.13] as Y = Y reported × (CF_S / CF_C).

If the sludge generated from the wastewater treatment unit is digested on site, then there will be additional CO_2 and CH_4 emissions at the facility. Equations [4.3.14] and [4.3.15] provide a method for estimating CO_2 and CH_4 from the digested biological solids for all sludge digesters:

$$CO_2 = 10^{-6} \times Q_s \times MLVSS \times CF_s \times (44/12) \times (1 - MCF_s \times BG_{CH4}) \quad \text{....................} \ (4.3.14)$$

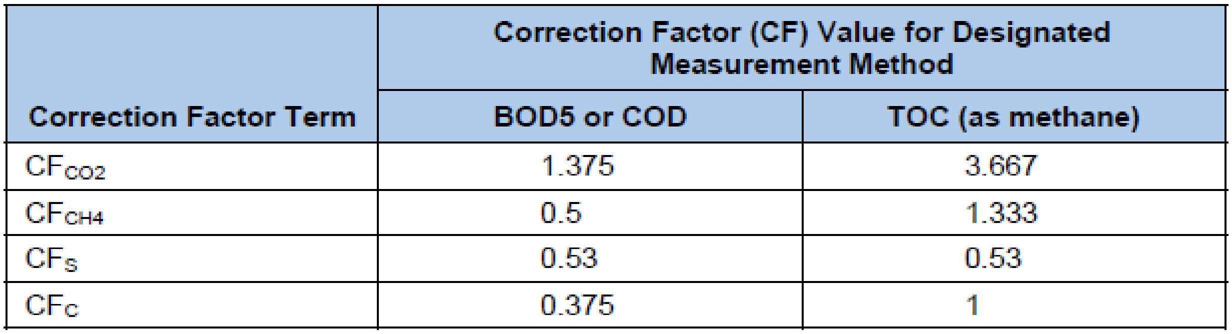
$$CH_4 = 10^{-6} \times Q_s \times MLVSS \times CF_s \times (44/12) \times (1 - MCF_s \times BG_{CH4}) \quad \text{....................} \ (4.3.15)$$

Where: CO_2 = Emissions of CO_2 (Mg CO_2/hr), CH_4 = Emissions of CH_4 (Mg CH_4/hr), 10-6 = Units conversion factor (Mg/g), Q_S = Waste sludge stream flow rate (m^3/hr), MLVSS = Mixed liquor volatile suspended solids concentration of the waste sludge stream (mg/L = g/m^3), CF_S =

Correction factor for carbon content of the biomass (i.e., MLVSSS) = 0.53 g C/g MLVSS (default), MCF_S = methane correction factor for sludge digestion, indicating the fraction of the treated sludge that is converted anaerobically (see Table 3-1), BG_{CH4} = Fraction of carbon as CH_4 in generated biogas (default is 0.65).

Above equations should be corrected using Table 4.7, if TOC concentration is to be used, where TOC and Eff_{TOC} terms would replace the terms OD and Eff_{OD} , respectively.

Table 4.7: Correction Factors for Listed Equations for Different Measurement Method



Correction Factor Term	Correction Factor (CF) Value for Designated Measurement Method	
	BOD5 or COD	TOC (as methane)
CF_{CO2}	1.375	3.667
CF_{CH4}	0.5	1.333
CF_S	0.53	0.53
CF_C	0.375	1

Source: RTI International [164]

Estimating N_2O emissions: Nitrous oxide (N_2O) is an oxide of nitrogen that is not part of the NO_x subset of oxides of nitrogen. N_2O is a greenhouse gas, the emissions of which are contributing toward global climate change; NOx is not a GHG. N_2O should not be confused with NO_X [23].

Wastewater treatment plants may also be a source of N_2O emissions. The amount of nitrogen present in the influent wastewater will determine the N_2O generation potential [164]. The treatment process (whether aerobic, anaerobic, or a combination of aerobic and anaerobic) will also affect the magnitude of the N_2O emissions. During aerobic treatment, ammonia (NH_3^+) or organic nitrogen is biologically oxidized to nitrites (NO_2^-) and nitrates (NO_3^-) by autotrophic bacteria through a process called nitrification. NO_2^- and NO_3^- can then be converted to nitrogen gas (N_2) under anoxic conditions (i.e., where dissolved oxygen is absent) by heterotrophic bacteria through a process called denitrification. N_2O is a byproduct of the nitrification process and an intermediate product of the denitrification process.

The amount of nitrogen in the wastewater influent is the principal factor in determining the extent of the N_2O generation potential in wastewater treatment plants (WWTPs). Total Kjeldahl Nitrogn (TKN) is the commonly monitored parameter. TKN is the sum of organic nitrogen and free ammonia (NH_4^+ and NH_3) in the waste or wastewater. Equation [4.3.16] presents a methodology to estimate N_2O emissions for both aerobic and anaerobic processes using an average value for the percent of influent TKN emitted as N_2O from Chandran (2010):

$$N_2O_{WWTP} = Q_i \times TKN_i \times EF_{N2O} \times EF_{N2O} \times \frac{44}{28} \times 10^{-6} \quad \text{.......................................} \quad (4.3.16)$$

where: N_2O_{WWTP} = N_2O emissions generated from WWTP process (Mg N_2O/hr), Q_i = Wastewater influent flow rate (m^3/hr), TKNi = Amount of TKN in the influent (mg/L = g/m^3), EF_{N2O} = N_2O emission factor (g N emitted as N_2O per g TKN in influent), = 0.0050 g N emitted as N_2O/g TKN (Chandran, 2010), 44/28 = Molecular weight conversion, g N_2O per g N emitted as N_2O, 10^{-6} = Units conversion factor (Mg/g).

Nitrous oxide (N_2O) is an oxide of nitrogen that is not part of the NO_x subset of oxides of nitrogen. N_2O is a greenhouse gas, the emissions of which are contributing toward global climate change; NO_x is not a GHG. N_2O should not be confused with NO_X [23].

4.4 Advanced and Emerging Technologies

As a consequence of rising energy demand and costs, many wastewater facilities have developed energy management strategies and implemented energy conservation measures

(ECMs) to reduce their energy consumption and costs as well as reduce their carbon footprint and associated greenhouse gas emissions [57].

Many energy conservation measures are established and essential measures relating to efficient pumping systems including pumps, drives and motors. In addition, established ECMs include fine bubble diffuser systems that increase the oxygen transfer efficiency (OTE), thereby decreasing energy demand. Established aeration equipment includes highly efficient turbo blowers which use friction-free bearing designs coupled with the use of high efficiency motors and integral speed control to achieve high energy efficiency. Established reactor mixing systems include hyperbolic mixers which use a stirrer located close to the bottom of a tank to promote complete mixing.

EPA 2013 paper on wastewater treatment and in-plant wet weather management [57] focuses on the advances in ECMs used at wastewater facilities, particularly those that have been developed and implemented since 2008. EPA establishes five categories of development regarding emerging wastewater technologies, summarized as:

Established – Technologies that have been used at more than 1 percent (150) of U.S. treatment facilities or have been available and widely used for more than five years.

Innovative – Technologies that have been implemented at full scale for less than five years, or have some degree of initial use (i.e., implemented in more than three but less than 1 percent [150] of US treatment facilities).

Emerging - Adaptive Use – Some wastewater treatment processes have been established for years, but their use has not been static. In some cases, an established technology may have been modified or adapted resulting in an emerging technology.

Research – Technologies in the development stage and/or have been tested at a Laboratory or bench scale only.

A comprehensive energy savings opportunities, efficiency and conservation measures and options, other than the advanced, applicable to water and wastewater networks are available below in a general list incorporating common energy savings and some advanced measures already found in WWTPs: [97].

- Variable frequency drives for applications with variable loads (aeration system, various wastewater pumps, etc.)
- Automatic continuous dissolved oxygen (DO) control
- Fine bubble diffusers for aeration systems
- High efficiency pumps and blowers
- Premium efficiency motors
- Low-pressure ultraviolet (UV) disinfection lamp - systems
- Retrofitting pneumatic pumps with electrical pumps
- Air compressor with variable frequency drive
- Gravity belt thickening of sludge
- Rotary and screw-type sludge dewatering
- Use of anaerobic digestion in place of aerobic digestion of sludge
- Solar-powered water circulators
- Supervisory control and data acquisition (SCADA) system for monitoring and controlling the demand and energy usage of the plant
- Recovering biogas from anaerobic digesters for in-plant electricity and heat production

- Flow equalization for demand and energy cost control

As confirmed by many case studies and research institutions of which some are discussed above, aeration is the most energy demanding out of all WWTP processes as shown in Figure 4.1. Also it is important to recognize that the purpose of aeration is two-fold: 1) to supply the required oxygen to the metabolizing microorganisms and 2) to provide mixing so that the microorganisms come into intimate contact with the dissolved and suspended organic matter [106]. The two most common aeration systems are subsurface and mechanical. In a subsurface system, air is introduced by diffusers or other devices submerged in the wastewater. A mechanical system agitates the wastewater by various means (e.g., propellers, blades, or brushes) to introduce air from the atmosphere.

Fine pore diffusion is a subsurface 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). Smaller bubbles result in more bubble surface area per unit volume and greater OTE.

In the past, various diffusion devices have been classified based on their OTE as either fine bubble or coarse bubble. Since it is difficult to clearly demarcate or define between fine and coarse bubbles, diffused aeration systems (DAS) have been classified based on the physical characteristics of the equipment. Diffused aeration systems can be classified into three categories:

- Porous (fine bubble): fine pore diffusers come in various shapes and sizes such as discs, tubes, domes and plates.

- Nonporous (coarse bubble) diffusers: The common types of nonporous diffusers are fixed orifices (perforated piping, spargers, and slotted tubes); valved orifices; and static tubes. The bubble size of these diffusers is larger than the porous diffusers, thus lowering the OTE
- Other diffusion devices: These include jet aerators (which discharge a mixture of air and liquid through a nozzle near the tank bottom); aspirators (mounted at the basin surface to supply a mixture of air and water); and U tubes (where compressed air is discharged into the down leg of a deep vertical shaft).

Chapter 4 Conclusions:

In a wastewater treatment plant, energy is consumed -- and could be produced as well, by implementing appropriate process design and equipment models. Also, energy could be conserved and optimized by means of using advanced WWT equipment available in today's market. While this chapter analyzed the energy consumed by major equipment and processes, it has also confirmed the possibility of in-plant energy generation from anaerobic treatment methane utilization and described several methodologies for estimating GHG emissions from biological processes. Many case studies found in literature show how the implementation of advanced technologies can lead to a tangible energy savings to offset the monthly energy bill of a plant.

CHAPTER 5.0

OVERVIEW OF EMISSIONS FACTORS AND GLOBAL WARMING POTENTIAL

The EPA, [107] and [108], define the emissions factor as "a numerical value that represents the quantity of pollutant released to the atmosphere with an activity associated with the release of that pollutant". These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance or duration of the activity emitting the pollutant. For example, a pound (lb) of sulfur dioxide per million of british thermal units (BTUs) of heat input, or kilogram of particulate emitted per megagram of coal burned. Emissions factors (EF) are used to estimate GHG or other constituents emanating to the atmosphere from an activity, when direct monitoring devices of gases are not available or possible, therefore, estimation of energy for a new site design and deriving site or process specific emission factors is needed.

The foundation of this research is defining the emission sources of a WWTP in the design phase, identified in plant boundaries as discussed in chapter 1, sec 1.7 and illustrated on Figure [1.3] - flow diagram for energy and GHG emission generation processes. The discussion in this chapter involves the emission factors for various fuels, processes and operations embodied in the identified wastewater boundaries, their formulas and the methodologies of the estimations. As mentioned earlier, wastewater plant energy resources are grouped, in this work, into: 1) Plant imported energy, 2) Pre-combustion energy, 3) In-plant energy produced, and how they pertain to GHG emissions.

Global warming gases reduction has a close relationship with the abatement potential of six greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) [23]. It is confirmed throughout the library of literature examined by this work that the main GHGs emitted from or attributed to WWTP emissions are mainly the first three: CO_2, CH_4 and N_2O listed above.

The concept of a global warming potential (GWP) was developed to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. The definition of a GWP for a particular GHG is the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specified time period (EPA, 2011). Because different gases have different GWPs, carbon dioxide equivalents represent GHGs in terms of their GWP. This allows emissions of different GHGs to be compared with one another.

There are two major approaches to determining emissions; 1) estimation - based on emission factors (EF) and 2) based on measurement - actual monitoring of emissions at the sources [109]. The latter approach, surely, is relevant to plants/generators emitting flue gases/GHGs through a stack. However, in the case of wastewater treatment in which emissions are released directly from some processes and operations to the atmosphere, this approach is not practical, and determining emissions of GHGs generation will be based commonly on the use of emissions factors (EF) found through estimation by the few known calculation methodologies, from established EFs for specific sources or industries or listed EFs for local and regional geographic locations.

This study [109], concluded that emission factors are often the method of choice for reporting GHG emissions, due to the nature of the reduction targets and trading schemes in operation. Emission factors are particularly useful for preparing emission inventories, as they provide values which can be applied to models and spreadsheets to calculate emissions from a large number of sources without exhaustive testing at point of emission. The emission factor-based methodology, estimates GHG emissions by multiplying a level of activity data by an emission factor. Activity data is a quantified measure of an activity, such as electricity consumption, and emission factors convert activity data into emission values.

$$\text{Activity Data x Emission Factor} = CO_2 \text{ Emissions} \quad \text{……………………………………………………} \quad (5.1)$$

While converting other GHGs such as CH_4 and N_2O to CO_2 equivalents can be made using GWP potentials: CO_2e = GHG mass emission x GWP, and the relationship between gigagrams (Gg) of a gas and teragrams of CO_2 equivalents (Tg CO_2e) can be expressed as follows:

$$Tg\ CO_2e = (Gg \text{ of gas}) \text{ x } (GWP) \text{ x } \left(\frac{\text{Tg}}{1000\text{ Gg}}\right) \quad \text{……………………………………………………} \quad (5.2)$$

Price and others (2002) reviewed the different CO_2 emission factors that have been used to estimate emissions from the electricity generating units by the climate action registry. Three methodologies below were developed and applied by many entities, including Berkeley Lab for calculating California electricity emissions, and identified by the GLPF project [1]:

1. Public data sources - using data from the EIA, historical data from power plant generation and fuel consumption, etc.
2. Elfin model - simulating plant operations and emissions based on data sets for six electricity utility service territories
3. Load duration curve methodology - based on more complex plant operation algorithms

Placing the same basic data into the different methods produced results that were in general agreement, given the total CO_2 emissions for California for 1999 as 29.0, 26.1 and 29.5 metric ton of carbon (mT C) , respectively. However, closer analysis indicated that the three methodologies' data could differ significantly on more specific data, such as seasonal changes in emission factors, in which the difference between the results could be almost 20%. Price and others concluded that a hybrid methodology could give the best results. A paper by Afsah and Aller (2010) [110] discusses the often significant discrepancies in CO_2 emission estimates produced around the world by different organizations and methodologies. They described the current systems as inadequately standardized and that there is no way to verify results. They concluded that many governments could go years claiming emissions reductions, merely by changing methodologies for measurement. Greater attention, standardization, empirical testing and third party audit of estimation methodologies is necessary to create a CO_2 emissions reporting infrastructure that is able to support verification of impacts from efforts to reduce overall CO_2 emissions at the national and global level.

Determination of emissions factors and CO_2 emissions:

1) Estimating EF using mass emission rate: This method can be used when combustion gases are released to the atmosphere via a stack. Average mass concentration in the flue gas would commonly be obtained from continuous emission monitoring (CEM) data at the study plant or from manual monitoring [109]. The value for volume can be obtained from gas flow monitoring devices but, for large sources the flow rate is considered to be uniform. Site specific flows for each fuel, may be estimated based on the actual fuel compositions used during the year. Assuming coal is the fuel:

$$EF = \frac{m}{A}\text{; (Ton CO2 / MMBTU)} \quad \ldots\ldots \quad (5.3)$$

EF: emission factor, m: mass emission rate (ton/unit time), A - value of activity data (tons of fuel).

To find the mass emission rate (total mass / defined time period), the following can be used:

$$m = [C] \times V; \quad \ldots\ldots \quad (5.4)$$

V - volumetric flow rate (amount of flue gas over time), [C] - average mass concentration (as measured in flue gas).

2) Estimating EF using stoichiometric equations and oxidation factor or percent oxidized: When fossil fuel combustion occurs, a small amount of carbon remains as ash and soot that is not converted to greenhouse gases. Oxidation factors measure the percentage of carbon that is actually oxidized when combustion occurs. The oxidation factor is used to calculate the amount of the fuel that is contributing to greenhouse gas emissions. The intergovernmental panel on climate change (IPCC) guidelines for calculating emissions inventories require that an oxidation factor be applied to the carbon content to account for a small portion of the fuel that is not oxidized into CO_2. For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains unoxidized).

Also IPCC (2006) states that consumption data in the U.S. Inventory are presented using higher heating values (HHV) rather than the lower heating values (LHV) reflected in the IPCC emission inventory methodology. This convention is followed because data obtained from EIA are based on HHV. Of note, however, is that EIA renewable energy statistics are often published using LHV. The difference between the two conventions relates to the treatment of the heat energy that is consumed in the process of evaporating the water contained in the fuel.

EPA for Ap-42 (1993) stated that emission factors facilitate estimation of emissions from various sources of air pollution. And in most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e. a population average). The EPA general equation for emission estimation is:

$E = A \times EF \times (1 - ER/100)$ .... (5.5)

Where: E = emissions, A = activity rate, EF = emission factor, and ER = overall emission reduction efficiency %. ER is further defined as the product of the control device destruction or removal efficiency and the capture of the control system.

3) Emissions using fuel heat content: Carbon dioxide emissions can be determined by multiplying heat content times the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12).

$CO_{2\ \text{emissions}}$ = Fuel Energy x Carbon Content Coefficient x Fraction Oxidized x (44/12)..(5.6)

In the case of natural gas:

$CO_{2\ \text{Therm}}$ = HHV x Carbon Coefficient x Fraction Oxidized % x $\frac{CO2}{C}$ MW Ratio

Where: HHV is the high heating value, carbon coefficient for N.G. = 14.47, $\frac{CO2}{C} = \frac{44}{12} = 3.67$

The Intergovernmental Panel on Climate Change (IPCC) guidelines for calculating emissions inventories require that an oxidation factor be applied to the carbon content to account for a small portion of the fuel that is not oxidized into CO_2. For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains unoxidized).

While it is important expressing emission factors in the same measurement units as the activity data used in the calculation worksheets, it is also important to document and justify the choice of emission factors used in the estimation of GHG inventory [111].

Site-specific emission factors – This is the most accurate option, but would generally only apply to large industrial customers who have a direct supply and transmission contract with a specific electricity, heat, and/or steam supplier in the vicinity. In this case, the emission factor should be based on the actual fuel fired and the technology employed by the electricity, heat, and/or steam supplier.

Regional/power pool emission factors – If site-specific emissions factors are not available, use a generic regional or power pool emissions factor that has been published by the government in the country where the facility is located. Government statistics may be aggregated by power pool region or state. For example, the USEPA's eGRID9 provides aggregated data for regions and sub-regions of the power grid, as well as information for every power plant and generating company in the U.S. information on eGRID subregion emission factors is provided in the worksheet "EFs Electricity U.S. Region." The Canadian GHG Challenge Registry publishes provincial emission factors in the Registry Guide 10. Regional power pool data is preferable to state data, as transmission and distribution grids often cover multiple states. Power pool data more accurately reflects the generation mix for a region.

National average emission factors – If regional or power pool emission factors are not available, the use of an appropriate generic national average factor for the entire country's grid is recommended.

In general, choices of emission factors for practical use can be the standard IPCC, or life cycle assessment (LCA) emission factors [112]: 1) Using standard EF in line with the IPCC 2006 principles, which covers all CO_2 emissions that occur due to energy consumption within the territory of the local authority, either directly due to fuel combustion within the local authority or indirectly via fuel combustion associated with electricity and heat/cold usage within this area.

The standard EFs are based on the carbon content of each fuel, like in national GHG inventories in the context of the UNFCCC, and the Kyoto protocol. In this approach, CO_2 is the most important GHG , and the emissions of CH_4 and N_2O do not need to be calculated, as well as CO_2 from biomass/biofuels and the certified green electricity are considered to be zero.

2) Using LCA, which take into consideration the overall life cycle of the emissions of the final combustion, but also all emissions of the supply chain. It includes emissions from exploitation, transport and processing (e.g. refinery) steps in addition to the final combustion, and the emissions from the use of biomass/biofuels, and from certified green electricity are considered higher than zero.

Conclusion of Chapter 5:

The standards of this research work will preferably apply emission factors estimations for equipment and processes using design specific data where possible and available. Other EFs will be taken from sources implying IPCC, EIA or USEPA standards.

CHAPTER 6.0
METHODOLOGIES FOR CALCULATING PLANT ENERGY AND EMISSIONS FACTORS

Emissions factors discussion in this chapter is organized per plant energy groups identified previously in chapter 4.0 as: Plant imported energy group, Plant pre-combusted energy group, and In-plant energy produced group.

6.1 Plant Imported Energy Group

These are energy sources imported to the plant directly from production utility or through supplier or marketer. They comprise the major types of fuels used in a WWTP and largest part of plant's energy cost, as a percentage of the annual budget. This group of energy includes electricity and natural gas, and some other lesser used fuels.

6.1.1 Electricity Production (kilowatt-hour) [14], [18], [19]

In order to estimate the CO_2 attributed to electricity use in a plant, it is important to decide which emission factor is to be used in the calculation. For instance: the Greenhouse Gas Equivalencies Calculator uses the Emissions & Generation Resource Integrated Database (eGRID) U.S. annual non-baseload CO_2 output emission rate to convert reductions of kilowatt-hours into avoided units of carbon dioxide emissions. Most users of the Equivalencies Calculator who seek equivalencies for electricity-related emissions want to know equivalencies for emissions reductions from energy efficiency or renewable energy programs. These programs are not generally assumed to affect baseload emissions (the emissions from power plants that run all the time), but rather non-baseload generation (power plants that are brought online as necessary to meet demand). Electricity emission factor (updated November 2012):

$$\mathbf{7.0555 \times 10^{-4}\ metric\ tons\ CO_2 / kWh}, \quad (6.1.1.1)$$

This calculation does not include any greenhouse gases other than CO_2, and does not include line losses. Table 6.1 shows grid losses estimates. Individual subregion non-baseload emissions rates are also available on eGRID Web site, Table 6.2.

Table 6.1: eGRID2012, Year 2009 Grid Gross Loss (%)

Power Grid	Grid Gross Loss
Eastern	5.82
Western	8.21
ERCOT	7.99
Alaska	5.84
Hawaii	7.81
U. S.	6.5

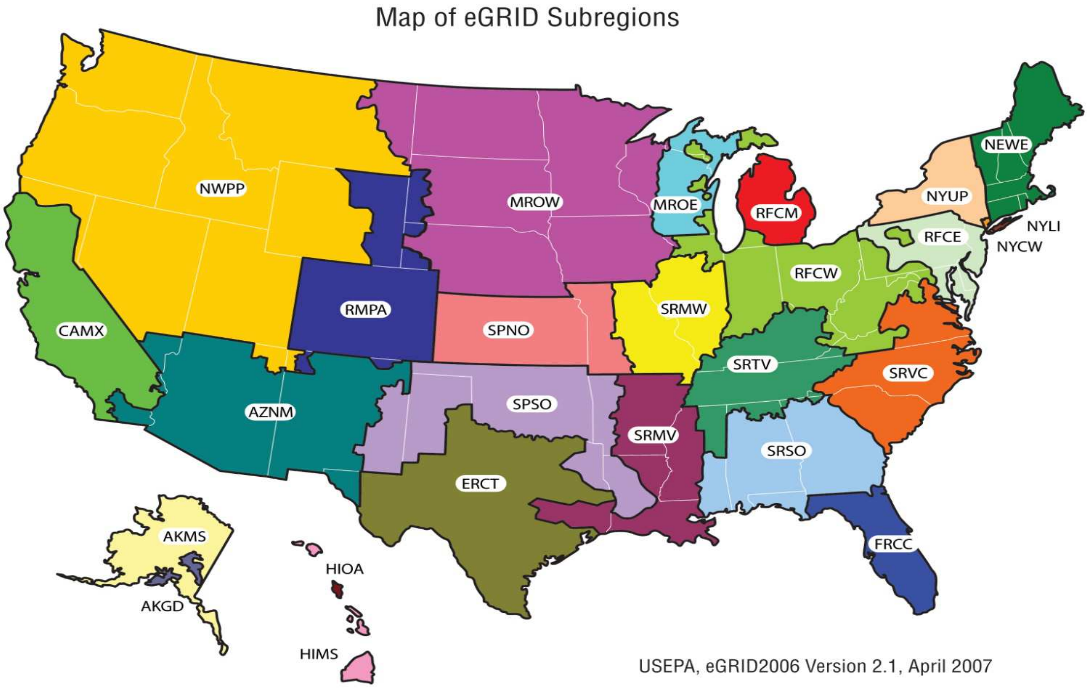
Source: U.S. EPA - eGRID

In addition to CO_2, electric power plants also emit some CH_4, and N_2O GHG emissions. CH_4 and N_2O emissions are reported in pounds and are estimated by multiplying the fuel specific heat input in MMBtu by appropriate EF from Table [6.2]of EPA's Final Mandatory Reporting of Greenhouse Gases Rule (EPA, 2009). Nitrous oxide (N_2O) is an oxide of nitrogen that is not part of the NOx subset of oxides of nitrogen.

In the U.S., electricity is generated in many different ways, with a wide variation in environmental impact. Electricity generation from the combustion of fossil fuels contributes toward unhealthy air quality, acid rain and global climate change.

Many electricity customers can choose their provider of electricity or can purchase green power from their utility. To estimate indirect GHG emissions from electricity, the Power Profiler or eGRID subregion annual output emission rates as a default emission factor can be used. This procedure includes determining the power grid region based on zip code and electric utility (which can be found at power profiler), utilizing Figure 6.1 and Table 6.2 below to determine regional emission factors.

Figure 6.1 eGRID Subregion Map for the U.S.A.


Map of eGRID Subregions

USEPA, eGRID2006 Version 2.1, April 2007

Table 6.2: eGRID2012 Version 1.0 (Year 2009) Data

eGRID subregion name	eGRID subregion acronym	Subregion annual CO_2 output emission rate (lb./Mwah)	Subregion annual CH_4 output emission rate (lbs./MWh)	Subregion annual N_2O output emission rate (lb/MWh)
SRNAME	SUBRGN	SRCO2RTA	SRCH4RTA	SRN2ORTA
NPCC NYC/Westchester	NYCW	610.6687	0.0238	0.0028
ASCC Miscellaneous	AKMS	521.2619	0.0218	0.0043
WECC California	CAMX	658.6846	0.0289	0.0062
NPCC Upstate NY	NYUP	497.9185	0.0159	0.0068
ASCC Alaska Grid	AKGD	1280.8582	0.0277	0.0077
SERC Mississippi Valley	SRMV	1002.4119	0.0194	0.0107
NPCC Long Island	NYLI	1347.9882	0.0969	0.0124

WECC Northwest	NWPP	819.2079	0.0153	0.0125
ERCOT All	ERCT	1181.7273	0.0167	0.0131
FRCC All	FRCC	1176.6065	0.0392	0.0135
HICC Miscellaneous	HIMS	1351.6625	0.0724	0.0138
NPCC New England	NEWE	728.4087	0.0757	0.0139
RFC East	RFCE	947.4237	0.0268	0.0150
WECC Southwest	AZNM	1191.3503	0.0191	0.0156
SERC Virginia/Carolina	SRVC	1035.8686	0.0215	0.0174
SERC South	SRSO	1325.6842	0.0223	0.0208
SPP South	SPSO	1599.0168	0.0232	0.0218
HICC Oahu	HIOA	1593.3483	0.1017	0.0220
SERC Tennessee Valley	SRTV	1357.7107	0.0173	0.0221
RFC West	RFCW	1520.5931	0.0181	0.0251
MRO East	MROE	1591.6518	0.0240	0.0270
WECC Rockies	RMPA	1824.5125	0.0222	0.0272
MRO West	MROW	1628.6032	0.0288	0.0278
RFC Michigan	RFCM	1659.4568	0.0314	0.0279
SPP North	SPNO	1815.7573	0.0210	0.0289
SERC Midwest	SRMW	1749.7530	0.0196	0.0290

Source: eGRID web site

Subregion name for Michigan State for instance, in the eGRID Web data is RFC Michigan, and the pertaining CO_2, CH_4 and N_2O emissions are as shown in columns above.

6.1.2 Natural Gas Fuel (Therm) [18] [19]

Carbon dioxide emissions per therm (1 therm = 100,000 BTUs) are determined by multiplying heat content times the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to carbon (44/12). And, the stoichiometric equation for the combustion of mainly methane containing natural gas is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad \ldots\ldots\ldots\ldots \quad (6.1.2.1)$$

The average heat content of natural gas is 0.1 MMBtu per therm (EPA 2012). The average carbon coefficient of natural gas is 14.47 kg carbon per MMBtu (EPA 2012). The fraction oxidized to CO_2 is 100 percent (IPCC 2006).

This equivalency represents the CO_2 for natural gas burned as a fuel, not natural gas released to the atmosphere. Direct CH_4 emissions released to the atmosphere (without burning) are about 21 times more powerful than CO_2 in terms of their warming effect on the atmosphere. And the calculation for natural gas CO_2e is as follows:

0.1 MMBtu/1 therm × 14.47 kg C/MMBtu × 44 g CO_2/12 g C × 1 metric ton/1,000 kg = **0.005306 metric tons CO_2/therm** ……………………………………………………. (6.1.2.2)

6.1.3 Liquefied Petroleum Gas (LPG) [14]

Liquefied petroleum gas (LPG or LP-gas) consists of propane, propylene, butane, and butylenes; the product used for domestic heating is composed primarily of propane. This gas, obtained mostly from gas wells (but also, to a lesser extent, as a refinery by-product) is stored as a liquid under moderate pressures. There are three grades of LPG available as heating fuels: commercial-grade propane, engine fuel-grade propane (also known as HD-5 propane), and commercial-grade butane. In addition, there are high-purity grades of LPG available for laboratory work and for use as aerosol propellants. Specifications for the various LPG grades are available from the American Society for Testing and Materials and the Gas Processors Association. A typical heating value for commercial grade propane and HD-5 propane is 90,500 British thermal units per gallon (Btu/gal), after vaporization; for commercial-grade butane, the value is 97,400 Btu/gal (Report on revisions to AP-42) [113]. Emission factors for butane and propane specific for boiler combustion are shown in Table 6.3.

Table 6.3: Propane and Butane Emission Factors for Boilers

	Butane Emission Factor (lb/10^3 gal)	Propane emission factor (lb/10^3 gal)
GHG	Industrial Boilers	Industrial Boilers
CO_2	14,000	12,500
N_2O	0.9	0.9
CH_4	0.2	0.2

Adopted from EPA AP-42

The emission factor reference calculation above was based on propane cylinders for home use, however, same methodology can be generalized for propane fuel.

Propane is a 3-carbon alkane with molecular formula C_3H_8, is normally found as a gas, but compressible to a transportable liquid. It is a byproduct of natural gas processing and oil refining. It is widely used as a fuel for engines, forklifts and oxy-gas torches all of which can be found in a WWTP. When combusted, propane follows the common hydrocarbon properties producing CO_2 and H_2O:

$C_3H_8 + 5\,O_2 \longrightarrow 4\,H_2O + 3\,CO_2$ + Energy .... (6.1.3.1)

Propane is 81.7 percent carbon (EPA 2012). Fraction oxidized is 100 percent (IPCC 2006).

Carbon dioxide emissions per pound of propane were determined by multiplying the weight of propane in a cylinder times the carbon content percentage times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12). Propane cylinders vary with respect to size; for the purpose of this equivalency calculation, a typical cylinder for home use was assumed to contain 18 pounds of propane, and the calculation for natural gas CO_2e is as follows:

18 pounds propane/cylinder × 0.817 pound C/pound propane × 0.4536 kilograms/pound × 44 kg CO_2/12 kg C × 1 metric ton/1,000 kg =

0.024 metric tons CO_2/cylinder .... (6.1.3.2)

6.1.4 Gasoline, Diesel and Biodiesel:

These fuels are considered imported when stored on plant's premises. They are common fuels used in WWTPs, sometimes with non-stationary equipment, or used periodically during plants rehabilitation and construction activities. Emission factors for such a type of fuels are found in Tables 10.1, 10.3 and 10.4 listed in Appendix [A].

Industrial applications of both gasoline and diesel internal combustion (IC) engines such as aerial lifts, forklifts, mobile refrigeration units, generators, pumps, industrial sweepers/scrubbers, material handling equipment (such as conveyors) and portable drilling equipment. The three primary fuels for reciprocating IC engines are gasoline, diesel fuel oil (No.2), and natural gas. Gasoline is used primarily for mobile and portable engines. Diesel fuel oil is the most versatile fuel and is used in IC engines of all sizes. The rated power of these engines covers a rather substantial range, up to 250 horsepower (hp) for gasoline engines and up to 600 hp for diesel engines, (EPA 1996).

6.1.5 Alternative/Renewable Fuels:

Ethanol is a renewable fuel made from various plant materials collectively known as "biomass." More than 95% of U.S. gasoline contains ethanol in a low-level blend to oxygenate the fuel and reduce air pollution [123].

Ethanol is also available as E85—a high-level ethanol blend. This alternative fuel can be used in flexible fuel vehicles—a vehicle type that has an internal combustion engine and runs on either E85 or gasoline.

There are several steps involved in making ethanol available as a vehicle fuel:

- Biomass feedstocks are grown, collected and transported to an ethanol production facility
- Feedstocks are made into ethanol at a production facility and transported to a blender/fuel supplier
- Ethanol is mixed with gasoline by the blender/fuel supplier and distributed to fueling stations.

Researchers agree ethanol could substantially offset nation's petroleum use. In fact, studies have estimated that ethanol and other biofuels could replace 30% or more of U.S. gasoline demand by 2030. The use of ethanol is required by the federal Renewable Fuel Standard (RFS).

Ethanol (CH_3CH_2OH) is a clear, colorless liquid. Also known as ethyl alcohol, grain alcohol, and EtOH, the molecules in this fuel contain a hydroxyl group (-OH) bonded to a carbon atom. Ethanol is made of the same chemical compound regardless of whether it is produced from starch- and sugar-based feedstocks, such as corn grain (as it primarily is in the U.S.), sugar cane (as it primarily is in Brazil) or from cellulosic feedstocks (which are dedicated energy crops, such as wood chips or crop residues).

Ethanol has a higher octane number than gasoline, providing premium blending properties. Minimum octane number requirements prevent engine knocking and ensure drivability. Low-level ethanol blends generally have a higher octane rating than unleaded gasoline. Low-octane gasoline is blended with 10% ethanol to attain the standard 87 octane requirement. Ethanol is also the main component in E85. A gallon of ethanol contains less energy than a gallon of pure gasoline. The amount of energy difference varies depending on the blend. A gallon of pure ethanol (E100) contains 34% less energy than a gallon of gasoline.

Ethanol Energy Balance

Ethanol is primarily produced from the starch in corn grain in the U.S. Some studies suggest that corn-based ethanol has a negative energy balance, meaning it takes more energy to produce the fuel than the amount of energy the fuel provides. However, recent studies using updated data about corn production methods demonstrate a positive energy balance for corn ethanol.

Cellulosic ethanol, which is produced from non-food based feedstocks, is expected to improve the energy balance of ethanol, because non-food-based feedstocks are anticipated to require less fossil fuel energy to produce ethanol. Biomass used to power the process of converting non-food-based feedstocks into cellulosic ethanol is also expected to reduce the amount of fossil fuel energy used in production. Another potential benefit of cellulosic ethanol is that it produces lower levels of GHG emissions.

Methanol

Methanol (CH_3OH), also known as wood alcohol, is an alternative fuel under the energy policy act (EPACT) of 1992. As an engine fuel, methanol has chemical and physical fuel properties similar to ethanol. Methanol use in vehicles has declined dramatically since the early 1990s, and automakers no longer manufacture methanol vehicles (DOE- EE&RE) [36]. Wilson and Burgh [114], say methanol has been and still is, used for motor fuel especially in certain classes of automobile racing. It has never been accepted as a general purpose fuel, primarily because of its lower energy density relative to gasoline. Methanol contains only about half of the combustion energy of gasoline by weight. In addition, methanol attacks some common automotive fuel system materials. It is also somewhat toxic and burns with an almost invisible flame –a safety consideration.

Methanol is methane with one hydrogen molecule replaced by a hydroxyl radical (OH). This fuel is generally produced by steam-reforming natural gas to create a synthesis gas. Feeding this synthesis gas into a reactor with a catalyst produces methanol and water vapor. Various feedstocks can produce methanol, but natural gas is currently the most economical.

Conclusion: Methanol is used only in special cases such as for racing cars, while ethanol is pumped in most of gas stations and its use is increasing over time. And, as concluded by Michael Wang of Argonne National Laboratory; compared to gasoline, any type of ethanol fuel substantially helps reduce fossil energy and petroleum use. Ethanol produced from corn can achieve moderate reductions in GHG emissions, while that produced from cellulosic plants, such as grass and weeds, can achieve much greater energy and GHG benefits.

Emissions factors for ethanol and methanol are listed, between others, in Appendix [A], and some key fuels densities are listed in Table 6.4 below [114]:

Table 6.4: Energy Densities for Key Renewable and fossil fuels

Fuel	Energy Density (BTU/Gal, HHV)
Methanol	65,840
Ethanol	87,543
Gasoline	122,350
Diesel Fuel (D2)	146,650
Biodiesel (typical B100)	127,700
Biodiesel (typical B20)	143,000

Adopted from Wilson & Burgh

6.2 Pre-Combustion Energy Sources Group

This group is comprised of any energy consumed outside WWT plants for the production of other products some of which are used for the WWTP operations or services. Such materials could include gasoline and other fuels used for transporting employees or cargo to the plant, water delivery on tankers, chemicals production for treatment processes and the like.

6.2.1 Gasoline Fuel (gallons) (EPA 2012, and IPCC 2006[14], [18], [19])

To obtain the number of grams of CO_2 emitted per gallon of gasoline combusted, the heat content of the fuel per gallon is multiplied by the kg CO_2 per heat content of the fuel. The average heat content per gallon of gasoline is 0.125 MMBtu/gallon and the average emissions per heat content of gasoline is 71.35 kg CO_2/MMBtu. (EPA 2010)

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

0.125 MMBtu/gallon * 71.35 kg CO_2/MMBtu * 1 metric ton/1,000 kg =

$8.92*10^{-3}$ metric tons CO_2/gallon of gasoline .... (6.2.1.1)

6.2.2 Passenger Vehicles Fuel Consumption per Year [14], [17].

Passenger vehicles are defined as 2-axle 4-tire vehicles, including passenger cars, vans, pickup trucks, and sport/utility vehicles. In 2010, the weighted average combined fuel economy of cars and light trucks combined was 21.6 miles per gallon (FHWA 2012). The average vehicle miles traveled in 2010 was 11,489 miles per year. In 2010, the ratio of carbon dioxide emissions to total greenhouse gas emissions (including carbon dioxide, methane and nitrous oxide, all expressed as carbon dioxide equivalents) for passenger vehicles was 0.985 (EPA 2012).

The amount of carbon dioxide emitted per gallon of motor gasoline burned is 8.92×10^{-3} metric tons, as calculated in the (gasoline consumption / gallons) section.

To determine annual greenhouse gas emissions per passenger vehicle, the following methodology was used: vehicle miles traveled (VMT) was divided by average gas mileage to determine gallons of gasoline consumed per vehicle per year. Gallons of gasoline consumed were multiplied by carbon dioxide per gallon of gasoline to determine carbon dioxide emitted per vehicle per year. Carbon dioxide emissions were then divided by the ratio of carbon dioxide emissions to total vehicle greenhouse gas emissions to account for vehicle methane and nitrous oxide emissions. Due to rounding, performing the calculations given in the equations below may not return the exact results shown:

8.92×10^{-3} metric tons CO_2/gallon gasoline × 11,489 VMT $_{\text{car/truck average}}$ × 1/21.6 miles per gallon $_{\text{car/truck average}}$ × 1 CO_2, CH_4, and N_2O/0.985 CO_2 =

4.8 metric tons CO_2e /vehicle/year .... (6.2.2.1)

6.2.3 Energy Consumption from Transporting Water, Sludge or Personnel [22]

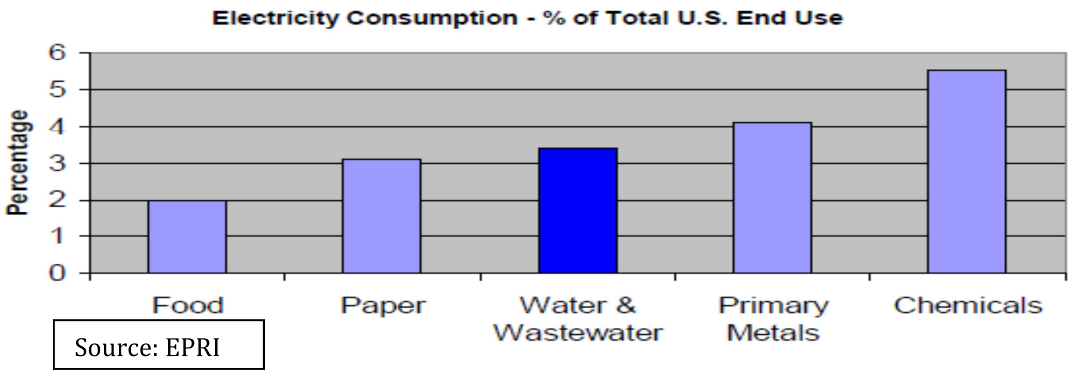
Emission factors for CO_2, CH_4 and N_2O emitted from a range of fuels used in transportation can be found in Table 10.1 - Default factors for calculating CO_2 emission factors from fossil fuel combustion, and Table 10.4 – Default CO_2 emissions factors and HHV for various fuels types. Tables are listed in Appendix [A]. CH4 and N2O emissions factors for highway vehicles are available from the same sources. Calculating the emissions pertaining to this activity can be adopted from passenger vehicles methodology VMT, discussed above.

6.2.4 Energy Demand from Water Use

Water is supplied to treatment plants by local water utility companies and sometimes hauled to plants by tanker transportation services. Fresh water is heavily used in wastewater treatment plants for several purposes including, but not limited to, plant cleaning, hot water/steam production, HVAC units operations and others.

The water and wastewater industry as a whole is a significant energy-consuming segment in the U.S. In the year 2000, approximately 123.45 billion kWh were used to move and treat water and wastewater, which represented about 3.4% of all U.S. end use electricity consumption, Figure 6.2 below [30]. This places water and wastewater as the third largest industrial end use segment for electricity, behind chemicals and primary metals.

Figure 6.2: Electricity Consumption by Major U.S. Industries



Source: EPRI

NREL, states that energy requirement [154] is fundamentally tied to the physical layout of the water supply system. The power needed to lift ground water can be expressed as:

$$W = Q \times \rho \times H \quad \text{.......} \quad (6.2.4.1)$$

Where

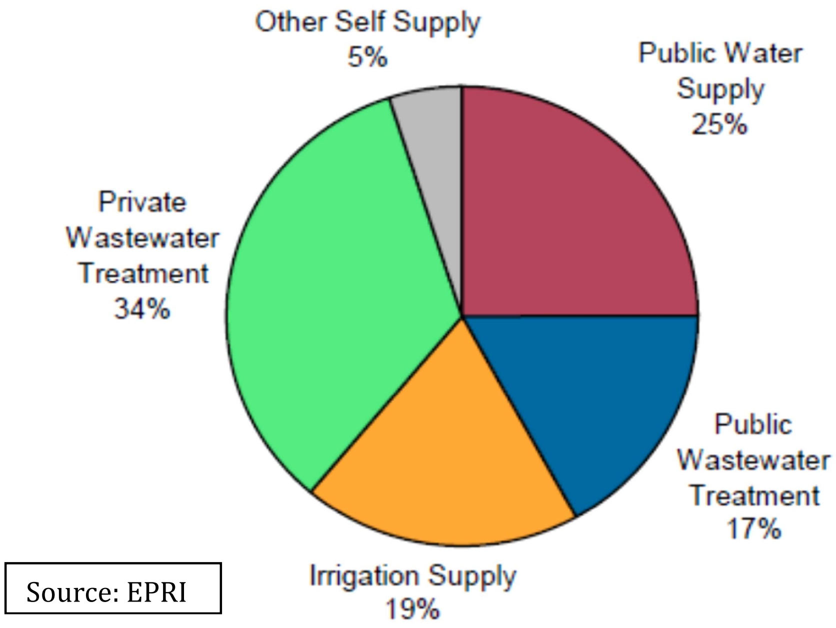
W = the power needed, Q = the water flow rate, ρ = water density and H = the head. For pumping water through pipes, the equation is the same, except that the total head, H, is the sum of both the gravity head and the head loss due to pipe friction.

Wilkinson defines the energy intensity of water as "the embodied energy, the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location" [116]. Based on this definition, he has estimated the average energy requirement for blended (local and imported) supplies for a municipal utility in California to be as high as 2,439 kWh per acre-foot (AF). At one AF per 325,851 gallons, this translates into about 1 kWh for each 134 gallons produced. A 1996 study by the Electric Power Research Institute (EPRI) by Franklin Burton estimates the national energy use by water systems at 75 billion kWh, which at the time represented three percent of total national electricity demand (Burton 1996).

Because of the universal need for water, the water industry can be broadly defined to include [30]: 1) Public water supply utilities – includes both municipal water utilities and privately owned water utilities, 2) Public wastewater treatment facilities – includes municipal facilities and other treatment plants serving the general public, 3) Private wastewater treatment facilities – includes privately owned facilities that treat wastewater from isolated industrial and commercial sources, 4) Irrigation supply for agriculture, and 5) Self-supply consumers – includes industrial, commercial, and residential consumers who have access to their own supplies of water.

Total U.S. water industry energy consumption for the year 2000 is detailed in Figure 6.3. Of the total consumption, about 51.6 billion kWh (42%) was attributed to water and wastewater facility operations serving the general public; public water supply utilities consumed about 30.6 billion kWh and public wastewater facilities consumed the other 21 billion kWh. Private wastewater treatment facilities consumed about 42 billion kWh (34%), agricultural irrigation consumed about 23.6 billion kWh (19%), and other self-supply consumed about 6.2 billion kWh (5%).

Figure 6.3: Electricity Consumption - Contribution for U.S. Water & Wastewater



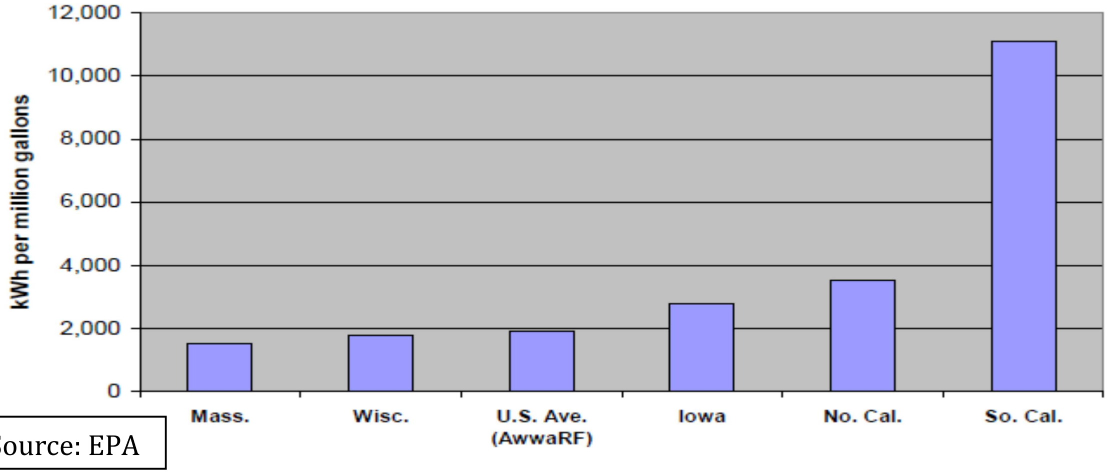
Source: EPRI

The USEPA stated an even higher consumption rate for water and wastewater utilities in 2008 of 75 billion kWh. It was further estimated that water and wastewater utilities spend more than $4 billion per year on energy to pump, treat, deliver, collect, and clean water. This report focuses on freshwater conveying, treatment, and end-use technologies within the public water supply and agricultural irrigation sectors that offer significant energy savings potential [115].

Energy Intensity of Public Water Supply

The energy intensity related to the public supply of water can be quantified in terms of kWh per million gallons (kWh/MG). The energy intensity of water will vary by region (Figure 6.4) as well as by the water sources and treatment technologies employed; often all three will be interdependent. Example water energy intensities for various regions in the U.S. are shown in the Table 6.5 below:

Figure 6.4: Average Energy Intensity for Water Supply (kWh/MG) [115]

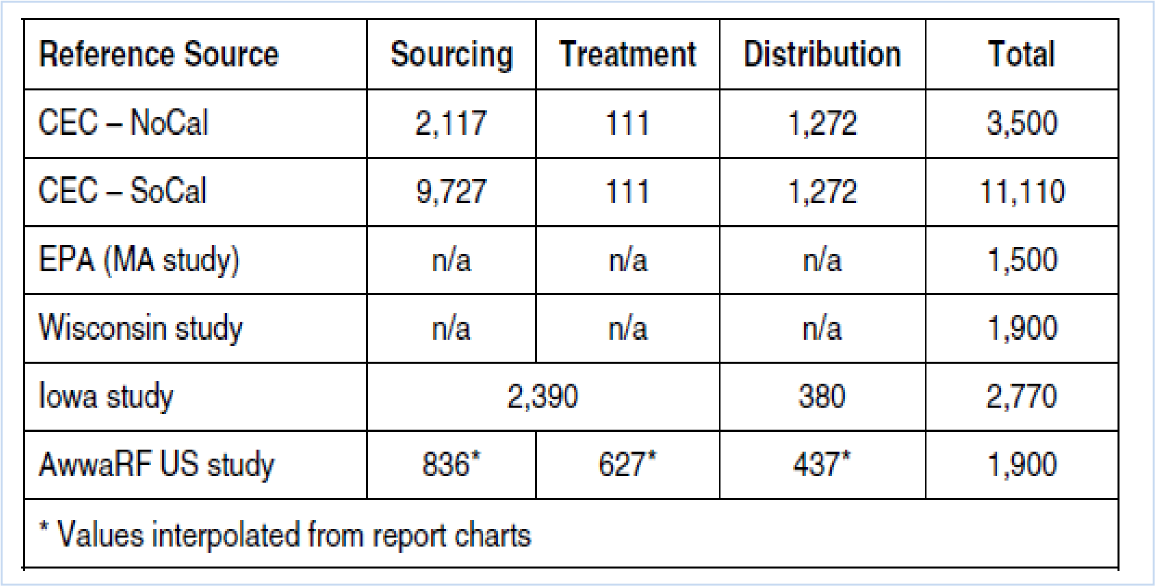


Source: EPA

Electricity Use in Public Water Supply

The energy intensity of public water supply, see Table 6.7 below, is a combination of the energy required to convey the raw source water to the treatment facility, the energy used to treat the water to potable standards and the energy needed to distribute the water to end users. Currently, pumping accounts for about 85% of energy consumption with 15% needed for other treatment requirements [30], and table source [32].

Table 6.5: Average Energy Intensity of Public Water Supply for Different Sites (kWh/MG)



Reference Source	Sourcing	Treatment	Distribution	Total
CEC – NoCal	2,117	111	1,272	3,500
CEC – SoCal	9,727	111	1,272	11,110
EPA (MA study)	n/a	n/a	n/a	1,500
Wisconsin study	n/a	n/a	n/a	1,900
Iowa study	2,390		380	2,770
AwwaRF US study	836*	627*	437*	1,900
* Values interpolated from report charts				

Source: E. Means and Mcguire

According to the U.S. Geological Survey (USGS), public water supply utilities provided 43.3 billion gallons per day (BGD) on average in 2000. Based upon a total energy consumption value of 30.6 billion kWh for public water supply utilities for the same year, the aggregate level estimate for U.S. public water supply energy intensity is about 1,936 kWh/MG, which is very close to the average AwwaRF value in Table [6.6] above [32].

Conclusion: the case studies discussion above, summarized in Table [6.6] shows that water energy intensity can be different from one system to another, and per Robert Wilkinson [116] definition; energy intensity is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location. It is clear that water energy intensity is location dependent.

6.2.5 Energy associated with the use of chemical products

Many chemicals are used in wastewater treatment processes such as in the coagulation of sizable wastewater suspended solids concentrations. These chemicals could include aluminum sulfates, iron salts and lime. In addition to coagulating colloidal and suspended solids, they remove substantial amount of the phosphorus from wastewater.

Other chemicals are used in the disinfection processes of treated wastewater. These could include chlorine, sodium hypochlorite (bleach, $Na(OCl)_2$), ultra violet (UV), ozone and peroxide. Below is a discussion of the energy consumed in the production of some of the most used chemicals in the U.S. treatment systems.

Lime Production (IPCC Source Category 2A2) [25]

Lime is an important manufactured product with many industrial, chemical, and environmental applications. Its major uses are in steel making, flue gas desulfurization (FGD systems at coal-fired electric power plants, construction, and water purification). For U.S. operations, the term “lime” actually refers to a variety of chemical compounds. These include calcium oxide (CaO), or high-calcium quicklime; calcium hydroxide ($Ca(OH)_2$), or hydrated lime; dolomite quicklime ([CaO•MgO]); and dolomitic hydrate ([Ca $(OH)_2$•MgO]) or ([$Ca(OH)_2$•Mg $(OH)_2$]).

Lime production in the United States—including Puerto Rico—was reported to be 15,781 thousand metric tons in 2009 (USGS 2010). This production resulted in estimated CO_2 emissions of 11.2 Tg CO_2e.

Methodology: During the calcination stage of lime production, CO_2 is given off as a gas and normally exits the system with the stack gas. To calculate emissions, the amounts of high-calcium and dolomitic lime produced were multiplied by their respective emission factors. The emission factor is the product of a constant reflecting the mass of CO_2 released per unit of lime and the average calcium plus magnesium oxide (CaO + MgO) content for lime (95 percent for both types of lime) (IPCC 2006). The emission factors were calculated as follows:

For high-calcium lime:

[(44.01 g/mole CO_2) ÷ (56.08 g/mole CaO)] × (0.9500 CaO/lime) = 0.7455 g CO_2/g lime .... (6.2.5.1)

For dolomitic lime:

[(88.02 g/mole CO_2) ÷ (96.39 g/mole CaO)] × (0.9500 CaO/lime) = 0.8675 g CO_2/g lime .... (6.2.5.2)

Production was adjusted to remove the mass of chemically combined water found in hydrated lime, determined according to the molecular weight ratios of H_2O to ($Ca(OH)_2$ and [$Ca(OH)_2$•Mg(OH)2]) (IPCC 2000).

Energy consumption of chlorine and sodium hypochlorite disinfection [26]

Although Ultraviolet, (UV) disinfection of wastewater is becoming more common, the majority of wastewater plants still use chlorine gas or chlorine compounds for disinfection. One of the objectives of the PG&E [26] benchmarking project is to measure and compare the energy consumption of UV disinfection at different plants. Since chlorine compounds are still the dominant wastewater disinfection processes, it is interesting to also compare their energy intensity with UV. After disinfection, chlorine residuals persist in the effluent. Most states will not allow the use of chlorination alone for pristine receiving waters because of its effects on aquatic species. To minimize these effects, chlorinated wastewater must often be dechlorinated.

Chlorine Disinfection

Chlorine is manufactured by an energy intensive electrochemical process. The energy required to produce chlorine is approximately 1.5 (kWh/lb) of chlorine. The chlorine dosage for disinfection will vary based on chlorine demand, wastewater characteristics, and discharge requirements. The chlorine dosage usually ranges from 5 to 20 mg/l and the chlorine required to disinfect 1MG of wastewater using various chlorine dosages can be calculated using the following equation:

lbs Cl_2/MG = (mg/l) Cl_2 x 10^{-3} (g/mg) x 3.785 (L/G) x10^6 (G/MG) x 1/454 (g/lb) ……………………………………………………………………………………………… (6.2.5.3)

The energy consumption to produce the required chlorine gas is:

KWh/MG = lbs Cl_2/MG x 1.5 (kWh/lb) Cl_2 …………………………………………………………… (6.2.5.4)

Table 6.6 below shows the pounds of chlorine and the energy required to generate the chlorine to disinfect one million gallons of wastewater at various chlorine dosages.

Table 6.6: Chlorine Production Energy at Various Cl_2 Dosages

Cl_2 Dose	Lb Cl_2/MG	kWh/MG
20 mg/l	166.8	250.2
10mg/l	83.4	125.1
5mg/l	41.7	62.6

Source: PG&E /SBW Consulting

Carbon Dioxide (CO_2) is generated in both diaphragm and mercury cells Cl_2 production processes by oxidation of the granite anode [159]. Analysis of one blow-gas stream before treatment reveals the CO_2 production rate average in four test runs to be about 4,050 (lb CO_2 / 100 tons Cl_2 produces). Since less graphite is consumed in mercury cells, CO_2 generated in mercury cell plants is correspondingly lower and has been calculated to be about 2,000 (lb / 100 tons Cl_2)

Sodium Hypochlorite Disinfection

Similar to chlorine, sodium hypochlorite is produced by an energy intensive electrochemical process. The energy to produce sodium hypochlorite is approximately 2.5 (kWh/lb) of sodium hypochlorite. This energy consumption figure is based on production of sodium hypochlorite at a concentration of 10 g/l from a brine feed of 30 g/l of sodium chloride. It is based on a bi-polar electrolysis cell suitable for on-site generation.

The relationship between (lbs) of chlorine gas and (lbs) of sodium hypochlorite is:

$$Cl_2 + H_2O \text{ ---- } HOCl + HCl \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6.2.5.5)$$

The equation for calculating the pounds of hypochlorite to disinfect 1 MG at various chlorine dosages is as follows:

$$\text{lbs NaOCl/MG} = (\text{mg/l})\ Cl2 \times 10^{-3}\ (\text{g/mg}) \times 3.785\ (\text{l/G}) \times 10^{6}\ (\text{G/MG}) \times 1/454\ (\text{g/lb}) \times 1.05 \ldots\ldots\ldots\ldots \quad (6.2.5.6)$$

And the equation for calculating the energy consumption to produce the sodium hypochlorite is:

$$\text{KWh/MG} = \text{lb NaOCl / MG} \times 2.5\ (\text{kWh/ lb})\ \text{NaOCl} \quad \ldots\ldots\ldots\ldots \quad (6.2.5.7)$$

Table 6.7 below shows the pounds of chlorine, the pounds of equivalent sodium hypochlorite and the energy required to generate the hypochlorite to disinfect one million gallons of wastewater at various chlorine dosages.

Table 6.7: NaOCl Production Energy at Various Cl_2 Dosages

Cl2 Dose	Lb Cl2/MG	Lb NaOCl	kWh/MG
20 mg/l	166.8 17	175.16	437.8
10 mg/l	83.4	87.57	218.9
5 mg/l	41.7	43.8	109.5

Source: PG&E /SBW Consulting

Secondary Energy Consumption

There is obviously secondary energy consumption in the production, handling and shipping of chlorine and sodium hypochlorite. Chlorine for example is compressed, liquefied, and shipped by rail, truck, or barge. Sodium Hypochlorite is usually transported by tanker truck in relatively dilute form. Sodium hypochlorite also decomposes during storage and transport. The quantification of these secondary energy debits is complex, subject to local conditions, and beyond the scope of this analysis. However, the calculated energy consumption for both chlorine and sodium hypochlorite should be considered as minimum values.

Comparison with UV

The energy consumption for chlorine and sodium hypochlorite disinfection at a dose of 20mg/l (250.2 kWh/MG for Cl2, and 437.8 kWh/MG for hypochlorite) is well within the range of UV disinfection with low pressure mercury lamps at a plant 259 (kWh/MG). Even at a chlorine dose of 10mg/l, there is published data for low pressure UV systems that are comparable with the energy consumption of chlorine and sodium hypochlorite. UV disinfection with medium pressure mercury lamps at a plant (1000 kWh/MG) is considerably above even hypochlorite disinfection at a dose of 20mg/l. However, published data for medium pressure UV systems is in the range of hypochlorite disinfection at high chlorine dosages.

Conclusions on a global energy basis, low pressure Hg UV is competitive with chlorine/hypochlorite disinfection and dechlorination. Medium pressure Hg UV, however, is more energy intensive than chlorine disinfection, but competitive with hypochlorite at high dosages.

6.3 In-Plant Energy Production - Processes of Energy Recovery and Reuse

Numerous opportunities are available to wastewater treatment facilities (WWTF) for energy production, these may include, but not be limited to, combined heat and power processes (CHP), waste heat recovery, methane from digesters and sludge and in-plant use of alternative and renewable energy, which are discussed below.

6.3.1 Combined Heat & Power (CHP): [117]

Combined heat and power (CHP) is a highly efficient method of providing power and useful thermal energy (heating or cooling) at the point of use with a single fuel source. By employing waste heat recovery technology to capture a significant portion of the heat created as a by-product of fuel use, CHP systems typically achieve total system efficiencies of 60% to 80% percent. An industrial or commercial entity can use CHP to produce electricity and thermal energy instead of obtaining electricity from the grid or producing thermal energy in an on-site furnace or boiler. In this way, CHP can provide significant energy efficiency, cost savings, and environmental benefits compared to the combination of grid-supplied electricity and on-site boiler use (referred to as separate heat and power or SHP).

CHP plays important roles both in efficiently meeting U.S. energy needs and in reducing the environmental impact of power generation. Currently, CHP systems represent approximately 8% of the electric generating capacity in the United States [118].

The 2008 CWNS identified 1,351 WWTFs greater than 1 MGD that have anaerobic digesters but that do not utilize CHP, representing 15,795 MGD of wastewater flow, and using the results developed within the technical potential analysis stating that 1 MGD of influent flow can produce 26 kW of electric capacity and 2.4 MMBtu/day of thermal energy, these 1,351 WWTFs could produce approximately 411 MW of electric capacity and 37,908 MMBtu/day of thermal energy if they all installed and operated CHP. The following Table 6.8 estimates CHP benefits and values of energy and consequently CO_2 emissions reduction owing to the implication of CHP systems in a plant. [119]

Table 6.8: Potential CO_2 Emissions Displaced with CHP at WWTF

Input / Output	Value
Electric potential at WWTFs with anaerobic digesters	411 MW
Total annual electric production (assumes year-round operation)	3,602,826 MWh
Adjusted all-fossil average CO_2 emissions factors	1,860.14 lb CO_2/MWh
Total displaced CO_2 emissions	3,350,880 tons CO_2/year or 3,040,726 metric tons CO_2/year
Equivalent number of passenger vehicles	596,052

Source: EPA, Opportunities for CHP at WWTFs

Benefits resulting from a CHP system include:

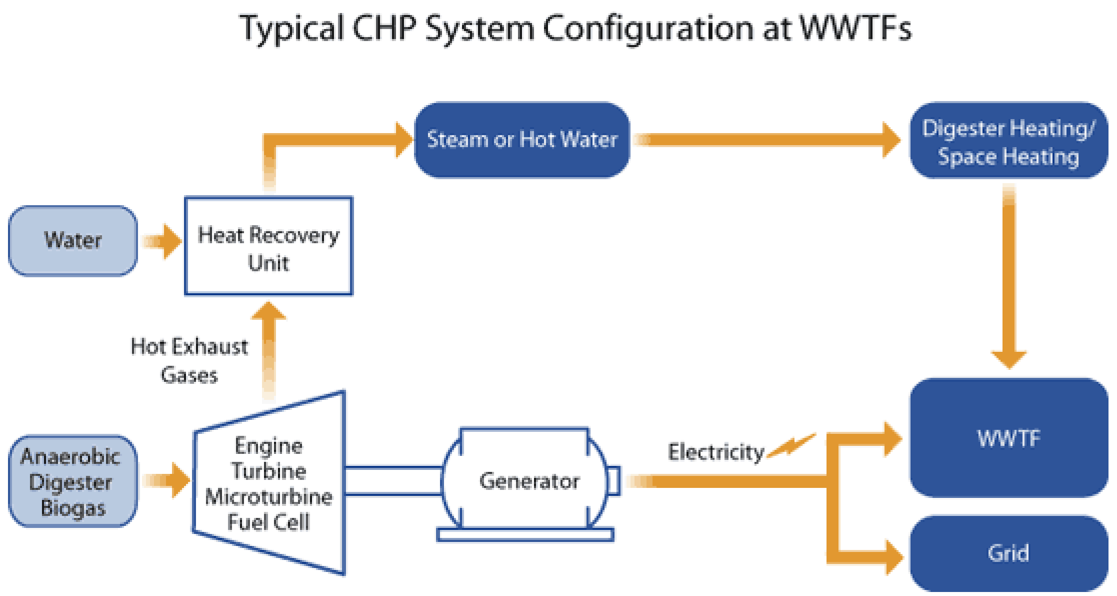
1) Efficiency benefits**:** CHP requires less fuel than SHP to produce a given energy output, and because electricity is generated at the point of use, transmission and distribution

losses that occur when electricity travels over power lines from central power plants are displaced. 2) Reliability benefits**:** CHP can be designed to provide high-quality electricity and thermal energy on site without relying on the electric grid, decreasing the impact of outages and improving power quality for sensitive equipment. 3) Environmental benefits**:** Because less fuel is burned to produce each unit of energy output, CHP reduces emissions of greenhouse gases (GHG) and other air pollutants. 4) Economic benefits**:** Because of its efficiency benefits, CHP can help facilities save money on energy. Also, CHP can provide a hedge against fluctuations in electricity costs.

In the most common type of CHP system, known as a topping cycle (see Figure 6.4), fuel is used by a prime mover (reciprocating engines, gas turbine, microturbine to drive a generator to produce electricity, and the otherwise-wasted heat from the prime mover is recovered to provide useful thermal energy. Examples of the two most common topping cycle CHP configurations are:

1. A reciprocating engine or gas turbine burns fuel to generate electricity and a heat recovery unit captures heat from the exhaust and cooling system. The recovered heat is converted into useful thermal energy, usually in the form of steam or hot water.
2. A steam turbine uses high-pressure steam from a fired boiler to drive a generator producing electricity. Low-pressure steam extracted from or exiting the steam turbine is used for industrial processes, space heating or cooling, domestic hot water or for other purposes.

Fig 6.5: Typical Reciprocating Engine/Gas Turbine CHP configuration (Topping Cycle)



Source: Basic Information. U.S. EPA Combined Heat and Power Partnership. December 6, 2012

This figure [34] shows a gas turbine or internal combustion engine-based CHP system that is typically used in WWT facilities. Methane gas from the anaerobic digester is combusted to generate electricity for onsite use or to be exported to the power grid. Simultaneously, heat is recovered using heat recovery steam generator (HRSG) that produces steam or hot water for process application or space heating.

In another type of CHP system, known as a bottoming cycle, fuel is used for the purpose of providing thermal energy in an industrial process, such as a furnace, and heat from the process that would otherwise be wasted is used to generate power.

Engineering Data for Energy Generated by CHP – Rule of Thumbs [34], [36]

- A typical WWTF processes 100 gallons per day of wastewater for every person served

- Approximately 1.0 cubic foot (ft^3) of digester gas can be produced by an anaerobic digester per person per day. This volume of gas can provide approximately 2.2 watts of power generation
- The heating value of the biogas produced by anaerobic digesters is approximately 600 British thermal units per cubic foot (Btu/ft^3) [34], 60 percent that of natural gas (1000 Btu per cubic foot, but with maximum digestion and proper cleanup can be increased to as much as 95%) [36]
- For every 4.5 million gallons per day processed by a WWTF with anaerobic digestion, the generated biogas can produce approximately 100 kilowatts (kW) of electricity and 12.5 million Btu (MMBtu) of thermal energy
- A typical WWTP facility processes 1 million gallons per day (MGD) of wastewater for every 10,000 in population served
- Anaerobic digesters are generally used when wastewater flow is greater than 5 MGD.
- For each MGD processed by a plant with anaerobic digesters, the available biogas can generate up to 35 kW

Methodology for calculating CHP fuel use and CO_2 emissions reduction, as well as displaced grid electricity and the consequent CO_2 emissions reduction is summarized below. The project example is adapted from the same EPA reference [117]

Key points in calculating fuels and CO2 emissions savings of a CHP:

- To calculate the fuel and CO_2 emissions savings of a CHP system, both electric and thermal outputs of the CHP system must be accounted for

- The CHP system's thermal output displaces the fuel normally consumed in and emissions emitted from on-site thermal generation in a boiler or other equipment, and the power output displaces the fuel consumed and emissions from grid electricity
- To quantify the fuel and CO_2 emissions savings of a CHP system, the fuel use of and emissions released from the CHP system are subtracted from the fuel use and emissions that would normally occur without the system (i.e., using SHP)
- A key factor in estimating the fuel and CO_2 emissions savings for CHP is determining the heat rate and emissions factor of the displaced grid electricity. EPA's Emissions & Generation Resource Integrated Database (eGRID) is recommended source for these factors, See Appendix A.

A detailed example for CHP calculation methodology is illustrated step-by-step below to ease calculation methodology: The CHP system uses a combustion turbine of 5,000 kW operating 7,500 hours/year. The system provides only heating using natural gas. The CHP electric generating efficiency is 29%, 11,806 (Btu/kWh) - HHV or 10,684 (Btu/kWh) - LHV. The power to heat ratio reflects only the thermal production of the generating unit (i.e. combustion turbine), and it's estimated to be 62%. This data helps calculate the thermal energy produced by the CHP system that replaces thermal energy formerly produced by an onsite boiler using a 1,028 (Btu/ft3) HHV natural gas fuel, with a CO_2 emission rate of 116.9 (lb/MMBtu) and a generating thermal efficiency of 80%.

<u>Required formulas:</u>

Calculating Fuel Savings from CHP

$$FS = (FT+FG)-FCHP \quad \text{..........} \quad (1)$$

Where:

FS = Total Fuel Savings (Btu)

FT = Fuel Use from Displaced On-site Thermal Production (Btu)

FG = Fuel Use from Displaced Grid Electricity (Btu)

FCHP = Fuel Used by the CHP System (Btu)

Step 1: Calculate FT and FG using Equations 3 and 6, respectively.

Step 2: Calculate FCHP through direct measurement or using Equations 8, 9 or 10.

Step 3: Calculate FS.

Calculating CO2 Savings from CHP

$$CS = (CT+CG)-CCHP \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

CS = Total CO_2 Emissions Savings (lbs CO2)

CT = CO_2 Emissions from Displaced On-site Thermal Production (lbs CO2)

CG = CO_2 Emissions from Displaced Grid Electricity (lbs CO2)

CCHP = CO_2 Emissions from the CHP System (lbs CO2)

Step 1: Calculate CT and CG using Equation 4 and Equation 7, respectively.

Step 2: Calculate CCHP using Equation 11.

Step 3: Calculate CS.

To obtain total fuel savings (FS) and total CO_2 emissions savings (CS), the following calculation sequence is applied to determine A) FT, FG, CT, CG, and then B) CCHP and FCHP.

A) Calculating FT, CT, FG and CG

3) Fuel Use from Displaced On-site Thermal Energy Production:

FT = CHPT / ŋT.. (3)

257,964 MMus/yr. = 206,371 MMus/yr. / 80%

Where:

F_T = Fuel Use from Displaced On-site Thermal Production (Btu)

CHP_T = CHP System Thermal Output (Btu)

ŋT = Thermal Equipment Efficiency (%)

4) CO2 Emissions from Displaced On-site Thermal Production:

CT = FT *EFF .... (4)

30,155,992 lbs CO2 = 257,964 MMBtu/yr * 116.9 lb CO2/MMBtu

Where:

C_T = CO_2 emissions from displaced on-site thermal production (lbs CO2)

F_T = Thermal Fuel Savings (Btu)

EFF = Fuel Specific Emissions Factor (lbs CO_2/MMBtu)

Note: tables for fuels emission factors and HHV are available in Appendix [A]

5**) Displaced Grid Electricity from CHP:**

EG = CHPE / (1-LT&D) .... (5)

39,817.4 MWh/year = 37,500 MWh/year / (1 – 5.82%)

Where:

EG = Displaced Grid Electricity from CHP (kWh)

CHPE = CHP System Electricity Output (kWh)

LT&D = Transmission and Distribution Losses (%)

6) Fuel Use from Displaced Grid Electricity:

FG =EG *HRG .... (6)

380,909 MMBtu/year = 39,817.4 MWh/year * 9,566 Btu/kWh / 1000

Where:

FG = Fuel Use from Displaced Grid Electricity (Btu)

EG = Displaced Grid Electricity from CHP (kWh)

HRG = Grid Electricity Heat Rate (Btu/kWh)

7) CO_2 Emissions from Displaced Grid Electricity:

CG = EG *EFG .... (7)

67,211,771,200 lbs CO2 = 39,817.4 MWh/year * 1,688 lb CO2/kWh * 1000

Where:

CG = CO2 Emissions from Displaced Grid Electricity (lbs)

EG = Displaced Grid Electricity from CHP (kWh)

EFG = Grid Electricity Emissions Factor (CO2 lb/kWh)

B) <u>Calculating CCHP and FCHP</u>

Estimating Fuel Use (FCHP) and CO2 Emissions (CCHP) of the CHP System

The energy content of the fuel consumed by the CHP system (FCHP) can be determined through several methods. Direct measurement is the first option, it produces the most accurate results, but direct measurement is not an option for the case of a new WWTP design phase, the options below might be used:

1) Converting the fuel volume into an energy value (Btu equivalent) using a fuel-specific energy density using Equation 8.
2) Converting the fuel weight into an energy value (Btu equivalent) using a fuel-specific energy density (mass basis) using Equation 9.

3) Applying the electrical efficiency of the CHP system to the CHP system’s electric output using Equation 10.

8) Calculating Energy Content of the Fuel Used by CHP from the Fuel Volume

$$F_{CHP} = VF*EDF \quad \ldots\ldots\ldots\ldots \quad (8)$$

Where:

FCHP = Fuel Used by the CHP System (Btu)

VF = Volume of CHP Fuel Used (cubic foot, gallon, etc.)

EDF = Energy Density of CHP Fuel (Btu/cubic foot, Btu/gallon, etc.)

Step 1: Measure or estimate VF.

Step 2: Select the appropriate value of EDF.

Step 3: Calculate FCHP.

9) Calculating Energy Content of the Fuel Used by CHP from the Fuel Weight

$$F_{CHP} = WF*EDF \quad \ldots\ldots\ldots\ldots \quad (9)$$

FCHP = Fuel Used by the CHP System (Btu)

WF = Weight of CHP Fuel Used (lbs)

EDF = Energy Density of CHP Fuel – Mass Basis (Btu/lb)

Step 1: Measure or estimate WF.

Step 2: Select the appropriate EDF. In order to be used here, the values in Table 6.11 below must be converted to a mass basis using the fuel-specific density.

Step 3: Calculate FCHP.

10) Energy Content of the Fuel Used by CHP from the CHP Electric Output

$$F_{CHP} = (CHPE / EECHP) * 3412 \quad \ldots\ldots\ldots\ldots \quad (10)$$

FCHP = Fuel Used by the CHP System (Btu)

CHPE = CHP System Electricity Output (kWh)

EECHP = Electrical Efficiency of the CHP System (percentage in decimal form)

3412 = Conversion factor between kWh and Btu

Step 1: Measure or estimate CHPE.

Step 2: Determine EECHP. (This value should account for parasitic losses, and is usually available in a product specification sheet provided by the manufacturer of the equipment.) **Step 3**: Calculate FCHP.

Table 6.9: Selected Fuel-Specific Energy and CO_2 Emissions Factors

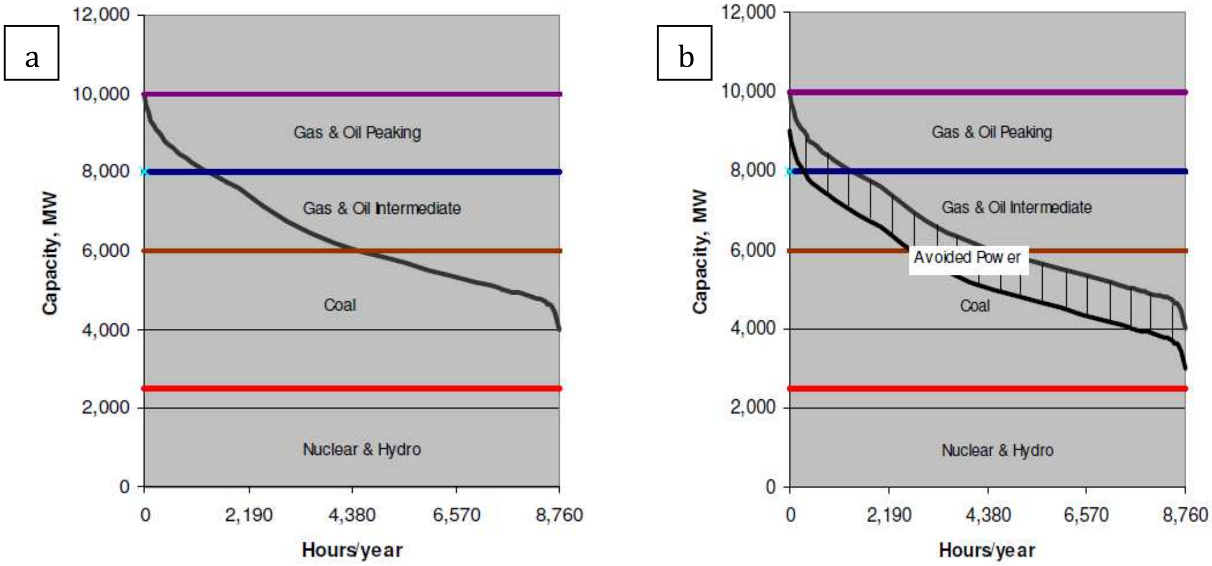
Fuel Type	Energy Density	CO_2 Emissions Factor
Natural Gas	1,028 Btu/scf	116.9 lb/MMBtu
Distillate Fuel Oil #2	138,000 Btu/gallon	163.19 lb/MMBtu
Residential Fuel Oil #6	150,000 Btu/gallon	165.6 lb/MMBtu
Coal (Anthracite)	12,545 Btu/lb	228.3 lb/MMBtu
Coal (Bituminous)	12,465 Btu/lb	205.9 lb/MMBtu
Coal (Subbituminous)	8,625 Btu/lb	213.9 lb/MMBtu
Coal (Lignite)	7,105 Btu/lb	212.5 lb/MMBtu
Coal (Mixed-Industrial Sector)	11,175 Btu/lb	207.1 lb/MMBtu

Source: 40 CFR Part 98, Mandatory Greenhouse Gas Reporting

Impact of CHP Addition to a Generation System [117]

A relatively simple load duration curve analysis can be used to show the impact of CHP additions, using eGRID data. The load duration curve analysis presented here first introduces a typical load duration curve, and then shows how the addition of CHP affects the resources dispatched. Figure 6.6 a) and b) show effect of CHP on the duration curve.

Figure 6.6: a) Hypothetical Power System Load Duration Curve and Dispatch Order and b) Marginal Displaced Generation due to 1,000 MW of CHP

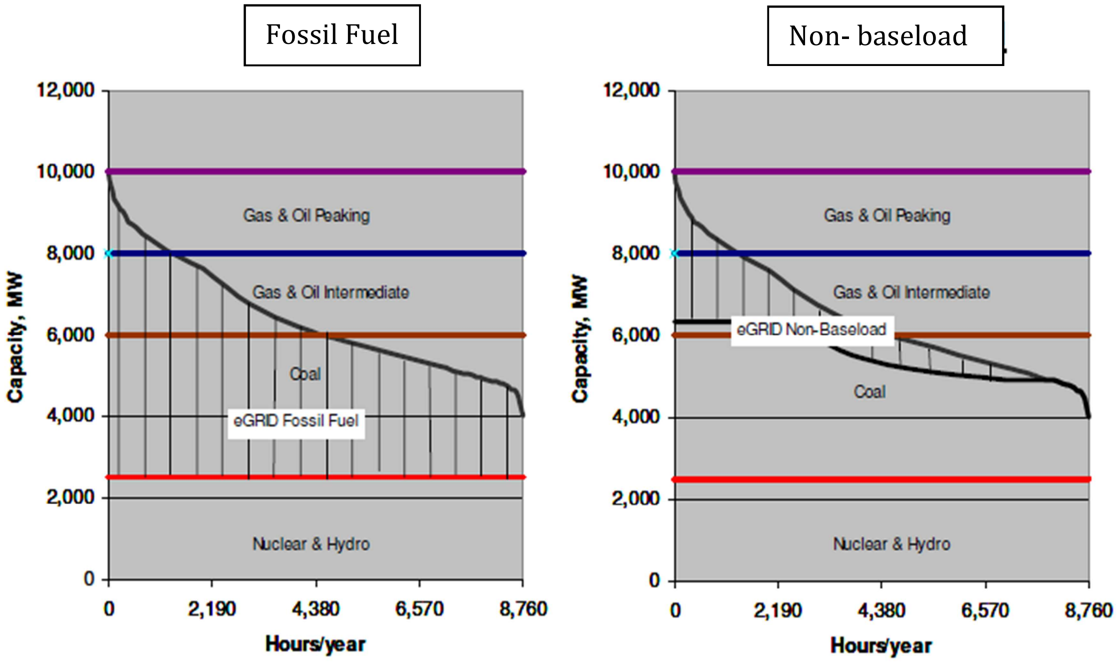


Source: EPA, Aug. 2012

Demand for electricity varies widely over the year, and different types and sizes of generators are used to meet the varying load as it occurs. A load duration curve represents the electric demand in MW for a specific region or subregion for each of the yearly 8,760 hours.

Figure [6.7] below presents a typical load duration curve for a hypothetical PCA. Hourly demand levels are ordered from highest to lowest. In this example, the graph shows that the highest hourly electric demand is 10,000 MW and the demand for the next highest hour is about 9,800 MW. The minimum demand is 4,000 MW, meaning that every hour of the year had at least this much demand. In a competitive electric market, the generators are dispatched based on their bid price into the market. Generators with low variable costs will be dispatched first, and will therefore operate many hours per year (i.e., serve as baseload generators).

Figure 6.7: Fossil Fuel and Non-baseload Comparison



Source: EPA, August 2012

6.3.2 Waste Heat Recovery in a WWT Facility

There are several heat recovery opportunities in an industrial plant, including WWT facilities. These opportunities could include compressed air waste heat recovery, the application of a condensing economizer for heating boiler makeup water, waste heat recovery from coffee roasters, waste heat recovery from chemical reactor exhaust to preheat combustion air and steam boiler blowdown heat recovery, etc. [41].

The heat recovery potential depends on the nature of process, operational strategy, type of equipment installed and availability of a suitable heat recovery sink. Based on practical observations, major waste heat recovery processes available to a WWTP could include the utilization of waste heat from compressors and boilers/steam processes, discussed below.

Heat Recovery from Compressors:

Compressors are huge energy consumers; it is estimated that 8 horsepower from an energy source is needed to generate 1 horsepower of compressed air. For this reason alone, utilizing energy wasted from this operation is worth the investment. A quick calculation method for air cooled compressors could be performed by converting the electric usage of the compressor to horsepower, and to BTUs using the heat load relation:

$$\textit{Heat Load (MMBtu)} = \frac{kWh}{0.746} \times 2{,}545\, \frac{Btu}{HP} \div 10^{6} \quad \ldots\ldots \quad (6.3.2.1)$$

Then, the resulting amount of heat would have to be multiplied by an average saving percentage of 0.75 - 0.80 to determine amount of actual heat recovered. However, detailed calculation process for closest accuracy would have looked like the following equation, using compressor information, which is adopted from a U.S. DOE calculator:

$$\textit{Btu/year} = 2{,}545\, \frac{\mathbf{Btu}}{\mathbf{HP}} \times \textit{HP} \times \textit{Annual Operating Hours} \times \textit{Load Factor} \times \textit{Compressor Capacity} \times$$

$$\frac{\textbf{Heat Exchanger Efficiency}}{\textbf{Unit Heater Efficiency}} \quad \ldots\ldots \quad (6.3.2.2)$$

Example of data needed to complete calculation is summarized and introduced in Table 6.10.

Table 6.10: Calculation Data and Results of a Heat Recovery System

Data	Example Value
Horsepower	50
Annual operating Hours	4,125
Load Factor	80%
Compressor Capacity	70%
Eff. of Heat exchanger	79%
Eff. of space Heating	80%
BTU / Year	290,273,156.25
CCF / Year	2,903
MCF / Year	290

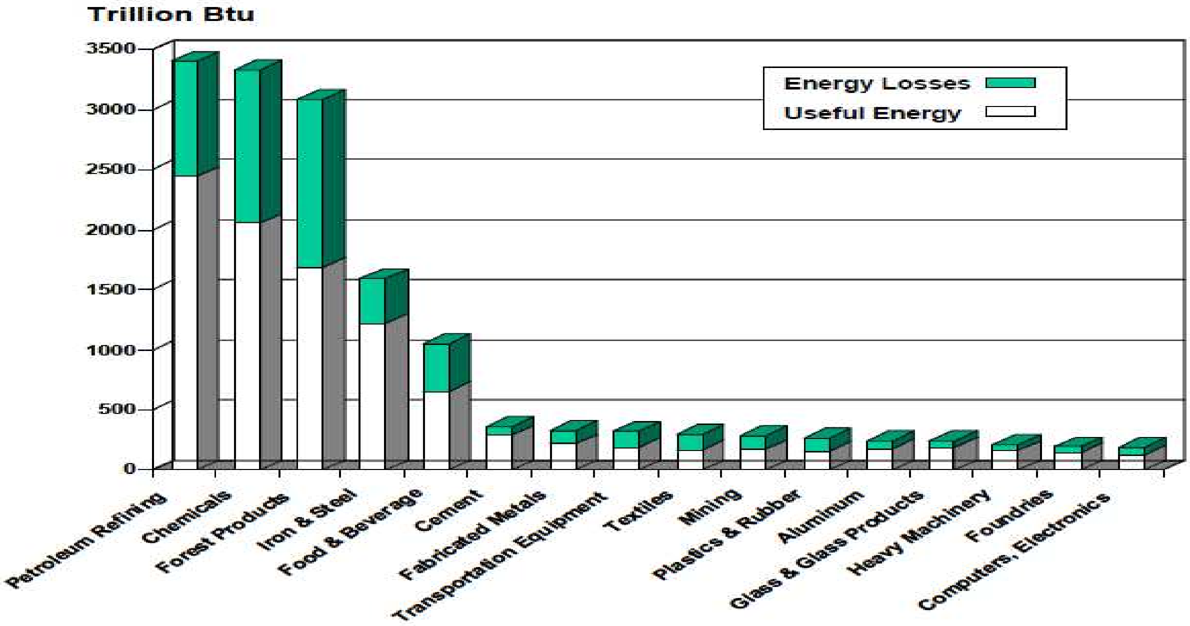
Source: DOE

Heat recovery from Boilers:

Heat recovery may be obtained from heat accompanying exhaust of gases to the atmosphere or contained in the water blown down from boilers, which is the main waste energy recovery method that can be found in WWTPs. Nevertheless, these systems have several advantages and disadvantages [IE 2004]:

Advantages of heat recovery systems will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process, reducing pollution, since less flue gases of high temperature are emitted, and reducing equipment size and associated auxiliaries. Disadvantages though, include the capital cost to implement a waste heat recovery system. It is necessary to put a cost to the heat being offset and the quality of heat which is often of low quality-low temperature. Figure 6.8 below, shows a comparison between used energy and the energy loss for several types of industries

Figure 6.8: Industrial Systems Energy Use and Loss [121]



Source: DOE

Boiler BLowdown:

The boiler blowdown process involves the periodic or continuous removal of water from a boiler to remove and control accumulated total suspended and dissolved solids (TDS). During the process, water is discharged from the boiler to avoid the negative impacts of dissolved solids or impurities on boiler efficiency and maintenance. However, boiler blowdown wastes energy because the blown down liquid is at about the same temperature as the steam produced. Minimizing the boiler blowdown rate can substantially reduce energy losses [122] and also reduce makeup water and chemical treatment costs. Blowdown rates typically range from 4% to 8% of boiler feed water flow rate, but can be as high as 10% when makeup water has a high solids content. Much of this heat can be recovered by routing the blown down liquid through a heat exchanger that preheats the boiler's makeup water [123]. The continuous boiler blowdown also can be routed to a flash tank where the higher pressure, for instant, 300 (psig), is reduced to a lower pressure of approximately 55 psig. Flash steam is produced in the pressure reduction process and piped into any low-pressure steam demand. This operation has a reasonable fuel cost savings. Additional energy can be recovered from the contaminated condensate exiting the flash vessel. The condensate dissipates energy that could be utilized to preheat makeup water.

Energy savings from minimizing boiler blowdowns:

Additional savings can be achieved by using automatic blowdown surface control systems, which optimize surface blowdown by regulating water volume discharged in relation to amount of dissolved solids present [124].

The methodology for calculating boiler blowdown reduction require the determination of makeup water savings, by deducting final feedwater from initial (lb/hr) - which can reduce blowdown from 8% to 6%. Then, from enthalpy difference of boiler water and makeup feed water at their perspective temperatures, the thermal energy savings can be determined (Btu/lb). Finally, annual fuel savings is estimated multiplying makeup water saved (lb/hr) by operating hours/year by thermal energy saving (Btu/year), divided by boiler efficiency and by 10^6 to get energy savings per (MMBtu). For cost savings, multiply by ($/MMBtu). In summary:

$$\mathit{Annual\ Fuel\ Savings} = \frac{\frac{lb}{hr}\ x\ 8760\frac{hr}{year}\ x\ \frac{Btu}{lb}\ x\ \$/MMBtu}{eff\ x\ 1MM\ x\ Btu/MMBtu} = \$ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6.3.2.3)$$

Heat recovery from Boiler Blowdown: [123]

Heat can be recovered from boiler blowdown by using a heat exchanger to preheat boiler makeup water. Any boiler with continuous blowdown exceeding 5% of the steam rate is a good candidate for the introduction of blowdown waste heat recovery. Larger energy savings occur with high-pressure boilers. Best energy/heat savings can be maintained by continuous blowdown systems (lb/hr), to avoid the buildup of high concentrations of dissolved solids.

The methodology for calculating the energy savings includes the estimation of blowdown ratio percentage, using these formulae:

$$\mathit{Blowdown\ Ratio\ \%} = \frac{blowdown\ rate\ (\frac{lb}{hr})}{blowdown\ rate + boiler\ steam\ production\ (\frac{lb}{hr})} \ldots\ldots\ (6.3.2.4)$$

Then, heat recovery can be found using Table 6.11, which calculates the potential for heat recovery from boiler blowdown in (MMBtu/hr). Recoverable heat is located at the intersection of the blowdown ratio percent and corresponding boiler operating pressure (psig). And, since the table was based on a steam production rate of 100,000 (lb/hr) and 60^oF makeup water, annual savings can be correlated the following way:

Annual Energy Savings (MMBtu) = R*ecovered Heat (MMBtu/hr)* x

$$\frac{boiler\ production\left(\frac{lb}{hr}\right)}{100{,}000\left(\frac{lb}{hr}\right)}\ \text{X}\ \frac{\text{operating}\frac{\text{hours}}{\text{year}}\left(\frac{hr}{yr}\right)}{boiler\ efficiency} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6.3.2.5)$$

Table 6.11: Recoverable Heat from Boiler Blowdown

Blowdown Rate, % Boiler Feed water	Heat Recovered, Million Btu per hour (MMBtu/hr)				
	Steam Pressure, psig				
	50	100	150	250	300
2	0.45	0.5	0.55	0.65	0.65
4	0.9	1.0	1.1	1.3	1.3
6	1.3	1.5	1.7	1.9	2.0
8	1.7	2.0	2.2	2.6	2.7
10	2.2	2.5	2.8	3.2	3.3
20	4.4	5.0	5.6	6.4	6.6

Source: DOE- EERE- Office of Industrial Technologies

Flash Steam:

Blowdown waste heat can be recovered with a heat exchanger, a flash tank, or flash tank in combination with a heat exchanger. Lowering the pressure in a flash tank allows a portion of the blowdown to be converted into low-pressure steam. This low-pressure steam is most typically used in deaerators. Drain water from the flash tank is then routed through a heat exchanger. Cooling the blowdown has the additional advantage of helping to comply with local codes limiting the discharge of high-temperature liquids into the sewer system.

When the pressure of saturated condensate is reduced, a portion of the liquid “flashes” to low-pressure steam. Depending on the pressures involved, the flash steam contains approximately 10% to 40% of the energy content of the original condensate. In most cases, including condensate receivers and deaerators, the flashing steam is vented and its energy content lost. However, a heat exchanger can be placed in the vent to recover this energy. The following table indicates the energy content of flash steam at atmospheric pressure.

A methodology introduced by DOE- EERE, [123] for calculating potential energy recovery from flashed steam can be achieved using Table 6.12, which assumes continuous operation, 70 ^{o}F makeup water and condensed steam at 100 ^{o}F. The potential energy recovered from the flashed steam, which is based on 8760 (hours/yr) of annual operation, can be found at the intersection of steam velocity (ft/min) and pipe diameter (inches). The value from the table can be corrected for actual operating hours and boiler efficiency:

Energy Recovered (MMBtu/yr) =

$$\textit{Energy recovered}\left(\frac{MMBtu}{hr}\right) \text{ x } \frac{actual\ hours\ \left(\frac{hr}{yr}\right)}{8{,}760\left(\frac{hr}{yr}\right) x\ eff} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(6.3.2.6)}$$

Normally, calculated annual fuel savings are per vents of device. Often there are several such vents in a steam facility, and the total savings can be significantly larger.

Table 6.12: Energy Recovery Potential of a Vent Condenser

Pipe Diameter (inches)	Energy Content (MMBtu/yr)				
	Steam Velocity (feet/min)				
	200	300	400	500	600
2	90	140	185	230	280
4	370	555	740	925	1,110
6	835	1,250	1,665	2,085	2,500

10	2,315	3,470	4,630	5,875	6,945

Source: DOE- EERE- Office of Industrial Technologies

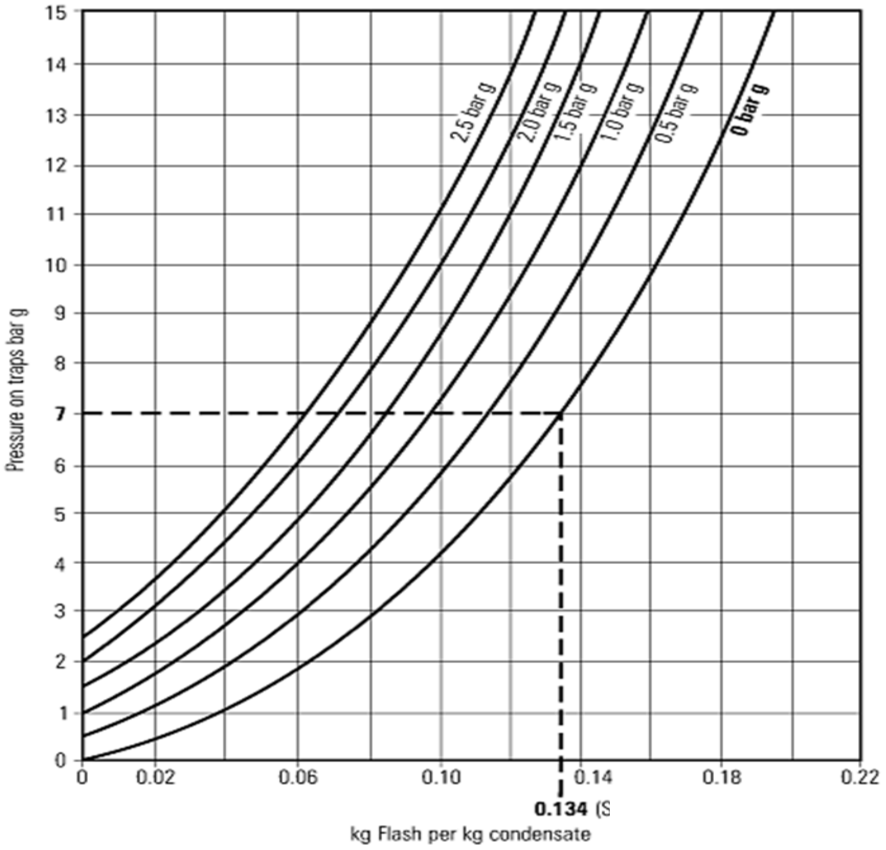
A useful rule of thumb is that every 500 (lb/hr) of recovered flash steam provides 1 gallon per minute of distilled water.

Another method for predicting the amount of generated flash steam by International site for Spirax Sarco [160] is discussed here for the case of a condensate entering a steam trap as saturated water, at a gauge pressure of 7 bars, and a temperature of 170 ^{o}C. The specific amount of heat in the condensate at this pressure is 721 (kJ/kg). After passing through the steam trap, the pressure in the condensate return line is 0 bars. At this pressure, the maximum amount of heat each kilogram of condensate can hold is 419 kJ and the maximum temperature is 100 ^{o}C. There is an excess of 302 kJ of heat which evaporates some of the condensate into steam. This quantity of steam is calculated as: heat needed to generate 1 kg of saturated steam from water at the same temperature, at 0 bars, is 2257 kJ. An amount of 302 kJ can therefore evaporate:

$\frac{302\ kJ}{2257\ kJ}$ = 0.134 kg of steam per kg of condensate, the proportion of flash steam generated therefore equals 13.4% of the initial mass of condensate. If for example, the equipment using steam at 7 bars were condensing 250 kg/hr, then amount of steam flash released by condensate at 0 bars: 0.134 x 250 kg/hr = 33.5 kg/hr of flash steam.

Alternatively the chart in Fig 6.9 can be read directly for the moderate and low pressures encountered in many plants.

Fig 6.9: Flash Steam Graph



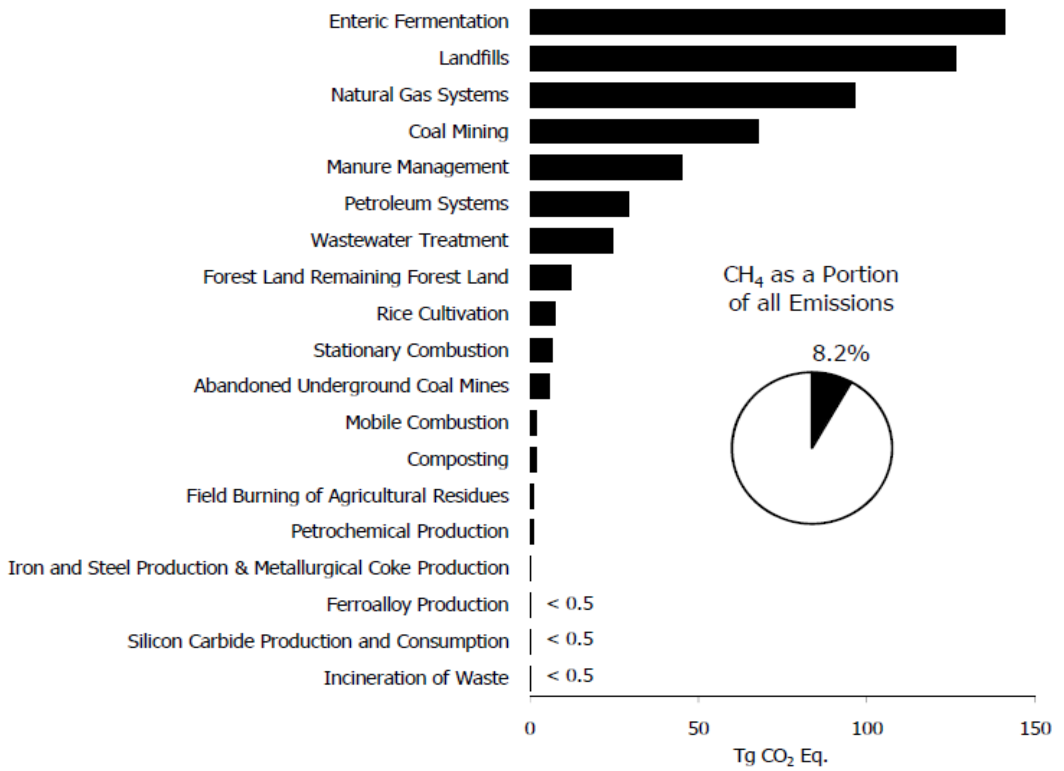
Source: Spiral Serco

6.3.3 **Energy from Methane Production** [10], [39]

Sewage contains 10 times the energy needed to treat it, and it is technically feasible to recover energy from sludge. As renewable energy, it can be used directly in wastewater treatment, reducing the facility's dependency on conventional electricity. The greater the quantity of energy produced by the industry, the more the industry can help reduce emissions of greenhouse gases. Using solids as a resource rather than as waste may help stressed public budgets as well. Wastewater solids must be processed prior to disposal, and solids handling accounts for as much as 30% of a WWTF's costs.

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, where the latter condition produces CH_4. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions. The generation of N_2O may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia and proteins. These compounds are converted to nitrate (NO_3) through the aerobic process of nitrification. Denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into denitrogen gas (N_2). N_2O can be an intermediate product of both processes, but is more often associated with denitrification. Sources of Anthropogenic Methane in the U.S.A. obtained from 2008 Emissions, reported April 2010 [24] are shown in Figure 6.10 below with wastewater methane in the 8th position.

Figure 6.10: Position of Wastewater Methane in the U.S.A.



Source: Bracmort, et.al, Congressional Research Services

In 2009, CH_4 emissions from domestic wastewater treatment were 16.0 Tg CO_2 Eq. (760 Gg). In 2009, CH_4 emissions from industrial wastewater treatment were estimated to be 8.5 Tg CO_2 Eq. (407 Gg). The 2009 emissions of N2O from centralized wastewater treatment processes and from effluent were estimated to be 0.3 Tg CO_2 Eq. (1 Gg) and 4.7 Tg CO_2 Eq. (15.2 Gg), respectively. Total N2O emissions from domestic wastewater were estimated to be 5.0 Tg CO_2 Eq. (16.2 Gg). N2O emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

Methodologies for calculating CH_4 volumes generated within WWTP activities and from technologies associated with CH4 utilization as an energy source were discussed in detail in chapter 4, section 4.3 and as a fuel in section 6.1.2 of this chapter.

6.3.4 Renewable/Alternative Energy

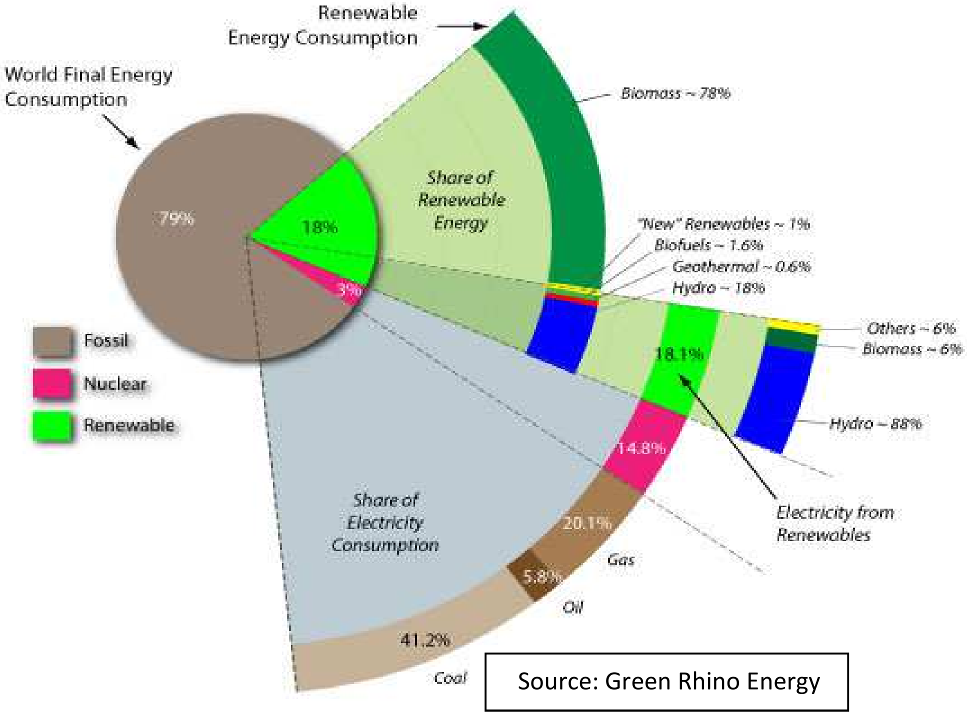
Renewable generation technologies as defined by EPRI and stated by EIA energy statistics include the following energy sources: hydroelectric power, wind, solar photovoltaic (PV), solar thermal, biomass/biofuels, geothermal and emerging ocean energy conversion technologies. Alternately, technologies applicable to WWTPs sites found in practice are mainly solar and wind energies and geothermal/heat pump - increasingly used in recent years as a renewable source of energy for building's heating and cooling. These technologies are chosen for discussion in this research work. In addition, biomass is the main source for energy recovery from WWT processes due to the broad methane production volumes as discussed earlier in chapter 4, section 4.3.

The emissions caused by power generation vary across the country due to many factors, including: how much electricity is generated, the used electricity generation technologies and air pollution control devices used [35]. From 2003 to 2007 the U.S. relied on fossil fuels in the form of coal, natural gas, and petroleum to supply about 85% of its energy needs, while renewable energy such as wind and solar, accounted for about 7% of US energy needs [37].

Electricity generation is dominated by coal-fired power stations that need 2.9 kWh of primary fossil energy for every kWh of electricity generated. I.e. they provide a net loss of 1.9 kWh of fossil energy for every 1kWh electricity. Conversely, renewable energies provide a net saving of fossil energy. Hydro, for instance, uses only 0.01 kWh of fossil energy per kWh of electricity [38].

Most of the energy the world uses does not stem from renewable sources. In fact, only 18% of the world's final energy consumption comes from renewable energy. The majority is divided up by fossil fuels (79%) and nuclear energy (3%). Of the renewable, biomass is by far (78%) the most prominent source, mostly used for heat, followed by hydro energy (18%). So-called "new" sources including wind and solar account for around 1% of world's renewable energy use Figure 6.11 below.

Figure 6.11: Uses & Sources of Renewable Energy



Source: Green Rhino Energy

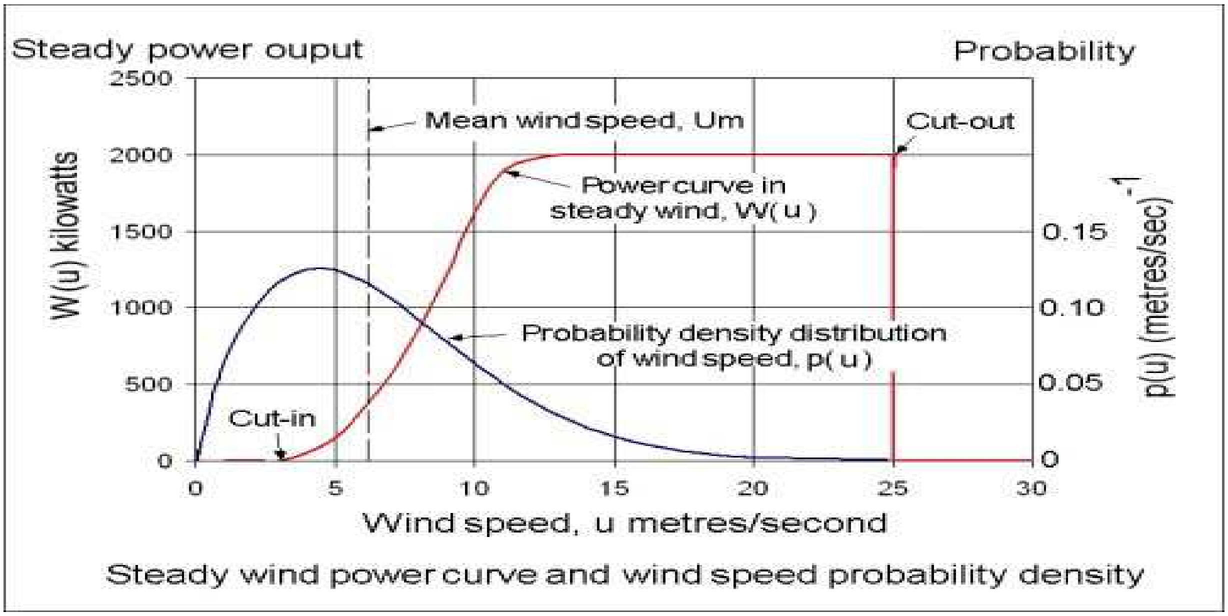
6.3.5 Renewable Energy from Wind Power

Innovations in all areas of energy supply and energy consumption are among the most effective tools to fight the negative consequences of climate change. Renewable energy technologies such as wind power and solar energy allow us to substantially reduce greenhouse gases by increasing energy efficiency and saving energy, leading to a sustainable use of resources. Clean energy such as wind power utilization provide environmental and energy sustainable advantages.

Wind Power Curve Analysis

A power curve shows the power output of a wind turbine system over the operational range of wind speeds. Figure 6.12 (PelaFLow Consulting) below shows a power output curve *W(u)* in a steady wind of speed *u*. Also shown is the probability density distribution *p(u)* for a particular mean speed U_m of 6 meters/second.

Figure 6.12: Power Output Curve, for a Vestas 90 meter, 2 megawatt Turbine



Source: PelaFlow Consulting

The power output in watts or kilowatts is shown on the vertical axis and the wind speed in meters per second or miles per hour is shown on the horizontal axis. Due to the non-linear variation of power with steady wind speed, the mean power obtained over time in a variable wind with a mean velocity U_m is not the same as the power obtained in a steady wind of the same speed.

The theoretical available power in the wind as expressed by de Vries [125]

$$P_{wind} = \frac{1}{2}\rho V^3 A \ldots\ldots\ldots\ldots \quad (6.3.5.1)$$

Where:

P_{wind}= wind power in watts, ρ = air density in kg/m^3, V= wind speed in m/s,

A = swept area of the rotor in m^{2,} ($A = \pi r^2$)

To be noted that the density of air decreases with temperature and altitude and that the major factor in power generation is wind velocity.

Actual available power can be expressed as: [126]

$$P_{actual} = \frac{1}{2} \eta \, \rho \, V^3 A \quad \ldots\ldots \quad (6.3.5.2)$$

Where

η = efficiency of the windmill (in general less than 0.4, or 40%)

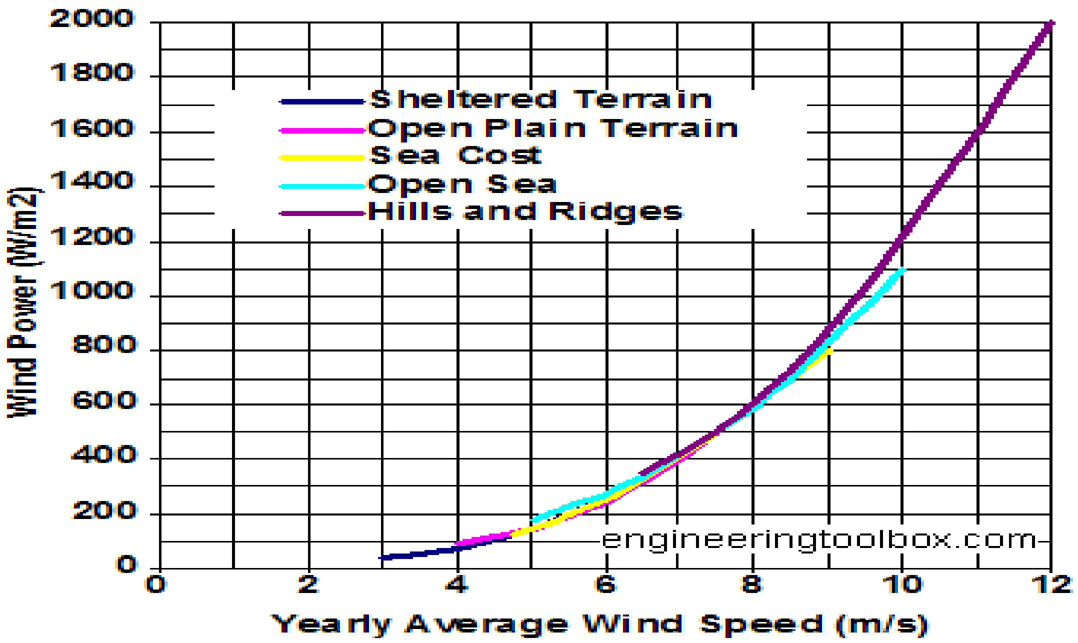
The methodology to determine available energy output from a wind turbine can be found by multiplying formerly calculated wind power resources from equation (6.3.5.2) above by efficiency and annual operating hours, or using graph in Figure 6.13 [126] below, to obtain wind power. Wind power can be obtained by intersecting a known average wind velocity with graph's curve for the specific location at sheltered or open location, sea cost or open sea, or hills and ridges.

Last step is to multiply wind power by wind turbine efficiency and annual operating hours, as illustrated in equation (6.3.5.3.):

Energy $_{wind\ turbine}$ *(kWh/m^2-yr) =*

$P_{wind\ power}$ *(W/m^2)/1000 x Turbine Eff % x Operating Time (hr/year)* .... (6.3.5.3)

Figure 6.13: Available wind resources as a function of yearly average wind velocity and different typical terrains



Source: Engineering Tool Box

Equations 6.3.5.2 and 6.3.5.3 will show that power of the wind (MW) so much larger than the rated power of the turbine generator (MW) caused by the effect of the Betz Limit, and inefficiencies in the system.

Albert Betz, is a physicist who in 1919 concluded that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit or Betz' Law. This limit has nothing to do with inefficiencies in the generator, but in the very nature of wind turbines themselves.

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). Once the engineering requirements of a wind turbine; strength and durability in particular are also factored the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time other inefficiencies are accounted for in a complete wind turbine system - e.g. the generator, bearings, power transmission and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity.

Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted.

The power output of a wind generator is proportional to the area swept by the rotor - i.e. if swept area is doubled, the power output will also double. And, the power output of a wind generator is proportional to the cube of the wind speed; i.e. if wind speed doubled, the power output will increase by a factor of eight (2 x 2 x 2).

The ratio of how much power a wind turbine can extract from wind at a certain speed is called power coefficient (Cp) [125], which is determined by dividing the turbine power output at a certain wind speed by the total power in wind at that speed. This approach neglects mechanical and electrical losses in the turbine system and results in a conservative value for Cp.

$$Cp = \frac{P_{turbine\ Output}}{P_{wind}} \qquad (6.3.5.4)$$

Solving for wind power unknowns [127] is generalized in formula as shown in Table 6.13 below.

$$P = 0.5 \times \rho \times A \times Cp \times V^3 \times Ng \times Nb \qquad (6.3.5.5)$$

Table 6.13: Formula for Predicting Unknown Parameters of Wind Power

$P = 0.5 \times \rho \times A \times Cp \times V^3 \times Ng \times Nb$	Solve for wind power.
$\rho = \frac{P}{0.5 \times A \times Cp \times V^3 \times Ng \times Nb}$	Solve for air density.

$A = \frac{P}{0.5 \times \rho \times Cp \times V^3 \times Ng \times Nb}$	Solve for swept area of the rotor, propeller or blades.
$Cp = \frac{P}{0.5 \times \rho \times A \times V^3 \times Ng \times Nb}$	Solve for coefficient of performance.
$V = \left(\frac{P}{0.5 \times \rho \times A \times Cp \times Ng \times Nb} \right)^{1/3}$	Solve for wind speed.
$Ng = \frac{P}{0.5 \times \rho \times A \times Cp \times V^3 \times Nb}$	Solve for generator or alternator efficiency.
$Nb = \frac{P}{0.5 \times \rho \times A \times Cp \times V^3 \times Ng}$	Solve for gear box bearing efficiency.

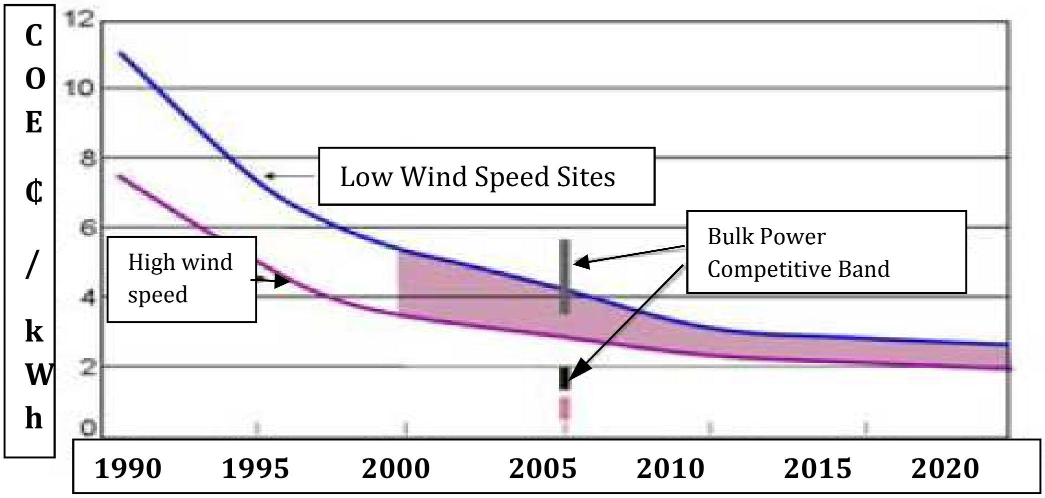
Where:

Symbol	Description	Typical values
ρ	air density	1.2 kg/m^3 (sea level)
Cp	performance coefficient	0.35 is typical 0.56 is the theoretical maximum known as the Betz limit.
Ng	generator efficiency	50 percent to 80 percent.
Nb	gearbox	95 percent

Source: AJ Design – Online Science Mathematics Engineering Software

Flowers, Nordstrom of NREL [128], in Figure 6.14 predict cost of wind energy from 1990 to 2020, comparing low wind and high wind speed sites.

Figure 6.14: Wind Cost of Energy

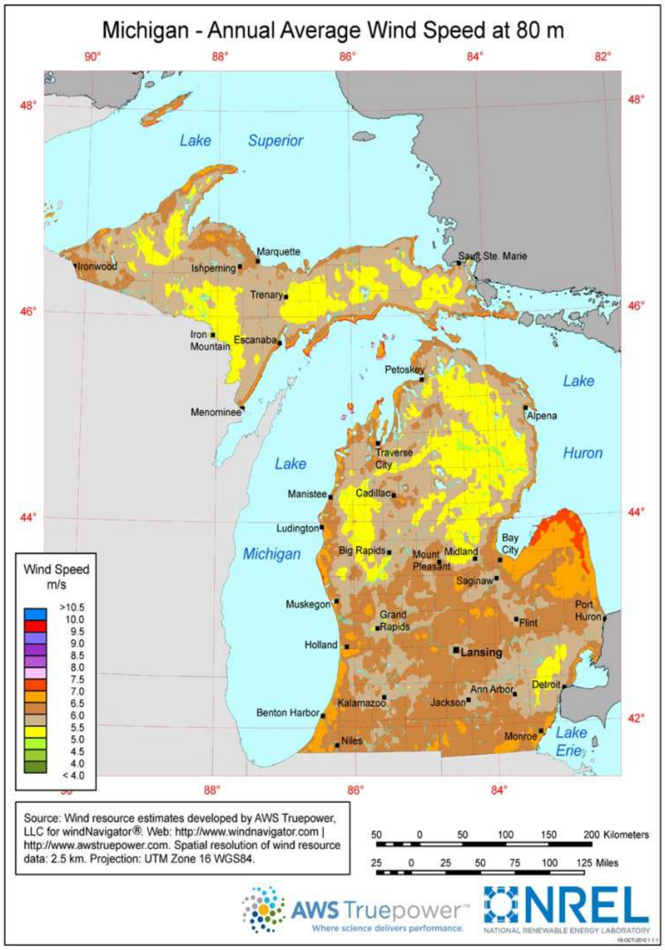


Source: Flowers and Nordstorm, NREL

The Department of Energy's Wind Program and the National Renewable Energy Laboratory (NREL) has published a wind resource map for the state of Michigan. The wind resource map shows the predicted mean annual wind speeds at a height of 80-meters, Figure 6.15. Areas with annual average wind speeds around 6.5 meters/second and greater at 80-meter height are generally considered to have suitable wind resource for wind development. According to the NREL wind resource map of Michigan, [129] for instant, Wayne State University is not suited for wind power as it has an annual average wind speed of only about 5.5 meters/second at a height of 80 meters.

The actual wind speed at a site is also greatly influenced by the local topography and nearby obstacles such as trees or other building structures. Not only do these obstacles reduce wind speed and its consistency, they may cause wind direction to shift erratically. All these factors make the task of estimating wind resources difficult. Inaccurate estimates of wind speed ultimately lead to false performance expectations.

Figure 6.15: Wind Speed for the State of Michigan



6.3.6 Renewable Energy from Solar

Locating appropriate sitting for a site solar energy system is the first step in the design of a system, followed by determining available options for solar power generation at the site. A feasible options for locating photovoltaic (PV) arrays might include the roof of the plant buildings or on the ground.

Once the PV locations that make the best use of space and performance at the site are determined, capacity and savings values using the national renewable energy laboratory (NREL) PVWATTS AC energy and cost savings calculator, can be determined. This calculator is a tool that determines the EPBB design factor and calculates annual kWh output for an individual system based on the orientation and tilt of the panels, the square footage of the panels and the site location.

The solar generation design estimation might assume fairly standard modules with an output of 230 watts. Higher output modules are available, but are manufactured by a limited number of companies. Modules by a single manufacturer have output as high as 320 watts.

Conceptual Design Components:

Modules: PV modules are available in many sizes and outputs depending on the manufacturer and model. Sizing and module outputs will vary depending on the exact specifications of the equipment used. The output of the module is size dependent which will be used as the basis for capacity estimate. However, higher and lower performance modules are available (~180 to 320 watts). Higher performance modules may reduce the number of modules or increase the capacity of the system, but cost will also be higher.

Inverters: As with PV modules there are a variety of options for inverter technology. The most common configuration is to minimize the number of components by installing larger inverters sized to the configuration of the modules.

An optional approach is micro-inverters. This is a distributed architecture, in which maximum power point tracking (MPPT) is done in a panel level. In this architecture an MPP tracker is connected to each PV panel and tracks its individual maximum power point, independently of other panels. Then, it is only responsible for DC-AC conversion, which makes it more efficient and reliable than traditional one. The panel-level MPP tracker may also act as an inverter, or more precisely - micro-inverter, performing both the MPPT and DC-AC conversion at the panel level. If standard inverters were assumed in the calculation, then updating to micro-inverters, just like high performance modules, will increase output but also increase costs.

Design Factors:

Include orientation, tilt, and shading each have a large effect on the output of a PV system design.

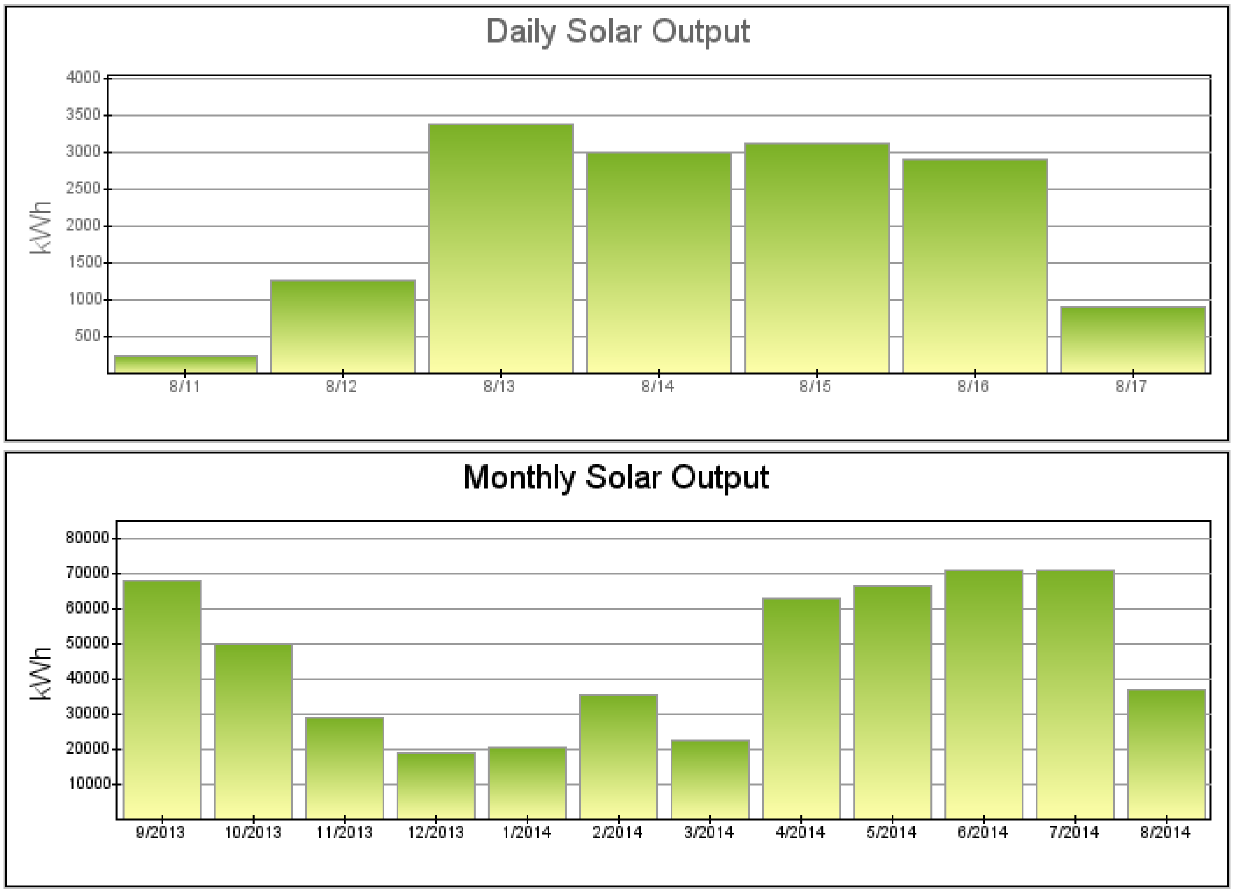
Orientation: The orientation to true south affects the amount of sunlight that will hit the solar panels. The further the panels are oriented away from true south the worse they will perform. The impact is not linear and higher tilt systems are more impacted by deviations on southern orientation. Arrays are typically aligned with the building orientation for aesthetic (and some cost) reasons. A good analysis should consider a panel layout orientation, for instant at 180 degrees (south) and the angle degree (compass direction) orientations that align with the buildings.

Tilt: The tilt of a system also has an impact on system performance. Panels are typically mounted flat onto the roof for roofs with some pitch (> 4:12). For flat roof installation, panels are put on tilt up mounting kits that hold the panels at anywhere from 5-25+ degrees; the amount of tilt depends on several mounting and structural variables.

Shading: Solar photovoltaic are particularly sensitive to shading. This is due in part to the way they are wired in series to boost the voltage to achieve acceptable performance in a normal electrical service. Sitting away from elements that cast shadows is important.

DTE energy, a major utility company in the state of Michigan has a company – owned solar energy projects in southeastern Michigan. The power currently produced by one of the many sites includes General Motors (GM) - Detroit/Hamtramck assembly plant. The installations at this site approximately are comprised of a 516 kW – DC solar photovoltaic array system on 264,000 square feet (6.06 acres) with 3,904 Sharp rigid thin film PV modules, ground mount installed ballast and racking and equipped with two – 250 kW inverters. Life time energy produced until August 17, 2014 is 1,302,510 (kWh), avoiding 1,238 metric Tons CO2, based on emission factor of 7.18×10^{-4} (m Tons CO_2/kWh - eGRID, 2007 version 1.1). Figure 6.16 below shows an August day power output and a summary of an annual electric production.

Figure 6.16: A Real-Time Electrical Output Graph for GM - Detroit/Hamtramck Assembly Plant Solar System



Source: DTE energy – Solar Current

6.3.7 Geothermal Heat Pump

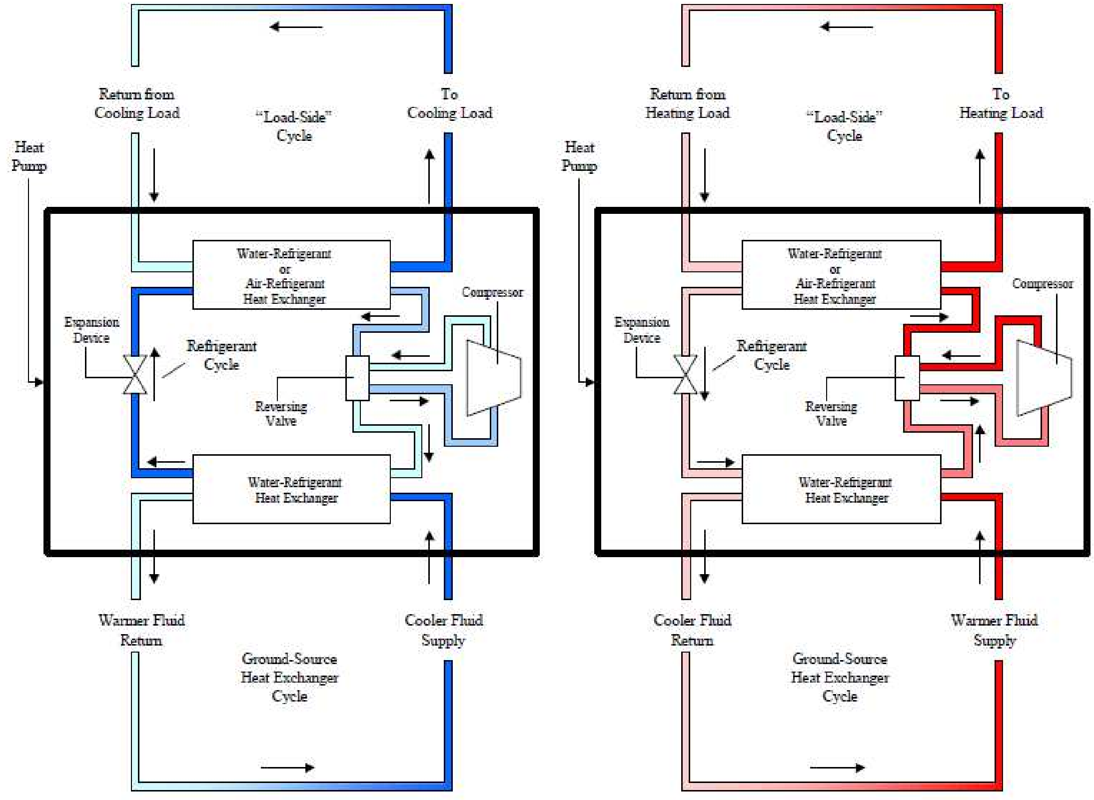
A geothermal heat pump, also known as a ground source heat pump (GSHP), is a central heating and/or cooling system that pumps heat to or from the ground using the earth, groundwater or surface water as a heat source in the winter or a heat sink in the summer. These systems take advantage of the moderate temperatures in the ground (usually between 50°F and 60°F) to boost efficiency and reduce the operational costs of heating and cooling systems.

Space heating and cooling in a geothermal system are provided by a system of water source heat pumps. A water source heat pump (WSHP) is a self-contained, water-cooled, packaged heating and cooling unit, with a reversible refrigerant cycle. Its components are typically enclosed in a common casing, and include a tube-in-tube heat exchanger, a heating/cooling coil, a compressor, a fan, a reversing valve and controls

GSHP systems consist of three loops or cycles as illustrated in Figure 6.17 [161]. The first loop is on the load side and is either an air/water loop or a water/water loop, depending on the application. The second loop is the refrigerant loop inside a WSHP. Thermodynamically, there is no difference between the well-known vapor-compression refrigeration cycle and the heat pump cycle; both systems absorb heat at a low temperature level and reject it to a higher temperature level. The difference between the two systems is that a refrigeration application is only concerned with the low temperature effect produced at the evaporator, while a heat pump may be concerned with both the cooling effect produced at the evaporator as well as the heating effect produced at the condenser. In these dual-mode GSHP systems, a reversing valve is used to switch between heating and cooling modes by reversing the refrigerant flow direction.

The third loop in the system is the ground loop in which water or an antifreeze solution exchanges heat with the refrigerant and the earth.

Figure 6.17: Cycles in a GSHP system in (a) cooling mode and (b) heating mode.



(a) **(b)**

Source: Advances in modelling GSHP Systems

Exploiting the near constant temperature of the earth throughout the seasons, these ground loops provide the needed source of both heat rejection and supply for proper operation of the WSHP units. Installed as either deep-bore vertical loops or shallow horizontal loops as in Figure 6.18, each loop is typically sized for one ton of installed heat pump capacity. The ground source loop is pumped through a condenser water loop to the heat exchanger of each WSHP.

Figure 6.18: Horizontal Ground Source Heat Pump Loop

Source: Geothermal Website Images

The efficiency of distributed WSHP systems typically operates at a coefficient of performance (COP) of 2-3 (for every kW of electrical energy consumed, 2-3 kW of cooling/heating capacity is generated).

Energy saved by installing geothermal systems can be calculated in a similar manner as discussed in HVAC Systems, subchapter 4.2.4. Table 6.14 below compares existing standard equipment energy consumption with an updated geothermal system. The energy savings in (kWh) is calculated by aggregating both systems energy for total number of equipment used and taking the delta difference. The known heating tonnage of equipment are converted to heat energy units (Btu) divided by SEER efficiency rating and multiplied by the operating hours per year to obtain energy (kWh) for both systems. Subtracting the two produce the energy saved.

Table 6.14: Energy Savings Calculation from Using Geothermal Systems

Parameter	Current Conventional System Data	Geothermal System Data	
Total tons	120.5	91	
Btu Input	12000	12000	
Total Btu Input	1446000	1092000	
Utility Factor	45%	45%	
Calculated Annual Operating Hours	4440	4440	
Total Btu Used	2889108000	2181816000	
SEER Rating	8.5	18.4	Energy Saved (kWh)

kWh	339895.06	118576.96	221318.10

Source: Author

6.3.8 <u>Waste Recycling Instead of Landfilling</u>: EPA (2012) [130]

To develop the conversion factor for recycling rather than landfilling waste, emission factors from EPA's WASTE Reduction Model (WARM) were used (EPA 2012). These emission factors were developed following a life-cycle assessment methodology using estimation techniques developed for national inventories of greenhouse gas emissions. According to WARM, the net emission reduction from recycling mixed recyclables (e.g., paper, metals, and plastics), compared with a baseline in which the materials are landfilled, is 0.73 metric tons of carbon equivalents per short ton. This factor was then converted to metric tons of carbon dioxide equivalent by multiplying by 44/12, the molecular weight ratio of carbon dioxide to carbon.

0.73 metric tons of carbon equivalent/ton × 44 g CO_2/12 g C =

2.67 m. tons CO_2 equivalent /ton of waste recycled instead of landfilled

<u>Conclusion of Chapter 6</u>: Table 6.15 lists energy trilogy emissions factors and their units obtained by methodologies discussed in chapter's subsections above. The table lists electric power CO_2 and specifically CO_2e emission factors embedding CO_2, CH_4 and N_2O gases. The energy units of systems pertaining to in-plant energy production are also listed, while calculation formulae can be found in the prospective subsections.

Table 6.15: Summary of the Energy Trilogy - Energy and Emissions Factors

Imported Energy Group	**CO_2 Emissions per Unit Energy or Volume**	**Pre-combusted Energy Group**	**CO_2 Emissions per Unit Energy or Volume**	**In-Plant Energy Group**	**Energy Savings or CO2 Emission**
Electricity	7.0555×10^{-4} (mTonCO2e/ kWh) 7.3206624×10^{-4} (mTonCO_2/kWh)	Gasoline	8.92×10^{-3} (metric Ton/gal)	CHP	kWh or mmBtu
Natural Gas	5.31×10^{-3} (mT CO_2/therm)	Trucks: Gasoline Diesel	 8.92×10^{-3} (mT/gal) 1.0×10^{-2} (mT/gal)	Compressors Heat recovery	mmBtu, or kWh
Propane Butane	5.59×10^{-3} (mT/gal) 6.58×10^{-3} (mT/gal)	Passenger Vehicles – Gasoline	8.92×10^{-3} (metric Ton/gal)	boiler blowdown Heat recovery	mmBtu
Gasoline Diesel	8.92×10^{-3} (mT/gal) 1.0×10^{-2} (mT/gal)	Water Production	1,900 (kWh/MG) 1.34 (mTCO2/MG)	Flash Steam	mmBtu
Ethanol 85 Methanol 85 Biodiesel 20	1.3×10^{-3} (mT/gal) 4.8×10^{-3} (mT/gal) 8.1×10^{-3} (mT/gal)	Lime Chlorine Sod. Hypochl. UV	7.4×10^{-4} mTCO_2/kg 0.176 mTCO_2/MG 0.309 mTCO_2/MG 0.182 mTCO_2/MG	Wind Power Solar Power Geothermal Waste Recycled	kWh kWh, Btu kWh 2.67 mT CO_2/Ton

Source: Author

CHAPTER 7.0

INTEGRATION THROUGH ENERGY TRILOGY MODEL - CONCLUSIONS

7.1 Model Structure

In this research, a detailed discussion of wastewater treatment energy systems, operations and equipment and their calculation equations and default data has been reviewed, and pertaining emissions factors calculation methodologies and their published sources have been provided. This research and review provide the fundamental data requirements to be used in the model for determining the energy consumption at a WWTP design phase. The equations and parameters to be used in the model may be tabulated below in Tables [7.1, 7.2 and 7.3]. The tables are structured based on the energy trilogy sources, with reference to their number and location throughout the chapters discussed previously. The model presented is the first step in estimating a plant's systems energy requirements, and will be followed by the second step, the calculation tool which will provide users with flexibility for varying processes or equipment options to compare impact on resulting plant's design energy demand values and to determine the best process/energy fit.

Table 7.1: Energy Source Group – Calculation Data for Plant Imported Energy

Source of Energy/Fuel	Energy Calculation Equations		Published Energy and Source	E. F. Equations		Published E.F. and Source
	Eq. No.	Pg. No.		Eq. No.	Pg. No.	
Electricity Usage						
Chemical Usage						
Gasoline						
Diesel, Biodiesel						
LNG (Propane/Butane)						
Natural Gas						
Altrn./Renewable Fuels						

Source: Author

Table 7.2: Energy Source Group - Calculation Data for Pre-Combusted Energy

Source of Energy/Fuel	**Energy Calculation Equations**		**Published Energy and Source**	**Emission Factors Equations (EF)**		**Published EF and Source**
	Eq. No.	**Pg. No.**		**Eq. No.**	**Pg. No.**	
Gasoline Fuel						
Passenger Vehicle Fuel						
Transporting Water, etc.						
Water for indoor Cleaning						
Water Demand for plant operations						
Chemical Products Use						
Electric Cars						
Natural Gas Transport						

Source: Author

Table 7.3: Energy Source Group – Calculation Data for In-Plant Energy Produced

Source of Energy/Fuel	**Energy Equations**		**Published Energy and Source**	**Emission Factors Equations (EF)**		**Published EF and Source**
	Eq. No.	**Pg. No.**		**Eq. No.**	**Pg. No.**	
Combined Heat and Power (CHP)						
Waste Heat Recovery form Compressors						
Heat Recovery from Boilers						
Heat Recovery from Boilers Blowdown						
Energy from Minimizing Blowdown						
Energy from Methane (anaerobic Digestion)						
Biosolids Incineration with Electricity Generation						
Energy from Wind Power						
Energy from Solar Heat						
Geothermal						

Source: Author

7.2 Model Mathematical Derivation

Balancing net energy consumption from the operational activities of WWTP can be generalized using the formulae:

Net Energy Consumed = *(Energy Used or Demand – Energy Generated)*………….. (7.1)

This equation can be written in another form to specify the terminology of the energy trilogy groups, yielding the generalized WWTP-new design net energy equation:

Net Energy Consumed = *[(Plant Imported Energy + Pre-Combusted Energy) – In-Plant Generated Energy]*……………………………………………………………………………………. (7.2)

Substituting the information from the three model tables (7.1, 7.2 and 7.3) for the energy source groups identified by this research work, based on subchapters of chapter six, this equation can be expressed:

$$\textit{Net Energy Consumed} = \sum(E6.1.1 + E6.1.2 + E6.1.3 + \cdots E6.1.n) + \sum(E6.2.1 + E6.2.2 + E6.2.3 + \cdots E6.2.n) - \sum(E6.3.1 + E6.3.2 + E6.3.3 + \ldots + E6.3.n)] \ldots\ldots\ldots\ldots (7.3)$$

Where: E: energy, and the number represent the energy source specific subchapter.

Since the ultimate target of this research is to estimate the carbon dioxide emissions (CO_2e), the use of equation (5.1) to derive CO_2 emissions is appropriate:

Activity Data x Emission Factor = CO_2 Emissions;

Where: the activity data represent fuel consumption in units of mass, volume or flow, and the emissions factors are the product of Tons CO_2 emitted per unit of mass, volume or energy. Then using equation (5.3) and rearranging to produce:

EF x A = Em (Ton CO_2)

EF: emission factor (the weight of the GHG or the unit weight or the volume or duration of activity), for the instance of electricity; (Tons CO_2 /kWh), Em: emissions mass rate (Ton CO_2), A:

value of activity data (e.g. fuel consumed, material input, throughput, or production output) in tons of fuel. For the sake of this dissertation, “W” is more appropriate to symbolize the activity value than “A”, and the equation can be rewritten:

$$CO_{2\ \mathrm{emissions}} = EF \times W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.4$$

Furthermore, equation 7.3 can be expanded to express the carbon dioxide equivalent (CO_2) for calculating any GHG other than CO_2, by multiplying the appropriate global warming potential (GWP) value provided in Table 2.4 (comparison of 100-year GWPs). These values are needed to convert emissions of CH_4 and N_2O to CO_2 equivalents as follows:

$$CO_2e = GHG_i \times GWP_{i.} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.5$$

And the sum of all GHGs present in the individual fuel can be presented as:

$$CO_2e = \sum_{i=1}^{n} GHGi \ x \ GWPi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.6$$

Where: CO_2e = Emissions in carbon dioxide equivalents (tons); $GHGi$ = Emissions of GHG “i” (tons); $GWPi$ = GWP of GHG “i”; n = Number of GHG emitted from the source.

By substituting relevant energy sources of each group from equation (7.3), with the inclusion of equation 7.5 for each GHG present in the individual fuel and using the summation notation mathematical approach, the expanded model equation for CO_2e becomes:

$$CO_2e = \sum [(EF1_{ijk} \times W1_{ijk} \times GWP1_{ijk} + EF2_{ijk} \times W2_{ijk} \times GWP2_{ijk} \ldots{+}\, EFn_{ijk} \times Wn_{ijk} \times GWPn_{ijk}) + \sum (EF11_{ijk} \times W11_{ijk} \times GWP11_{ijk} + EF22_{ijk} \times W22_{ijk} \times GWP22_{ijk} \ldots{+}\, EFnn_{ijk} \times Wnn_{ijk} \times GWPnn_{ijk})] - \sum (EF111_{ijk} \times W111_{ijk} \times GWP111_{ijk} + EF222_{ijk} \times W222_{ijk} \times GWP222_{ijk} \ldots{+}\, EFnnn_{ijk} \times Wnnn_{ijk} \times GWPnnn_{ijk}] \ldots\ldots\ldots\ldots\ldots 7.7$$

Where: EF1, W1, GWP1 to EFn, Wn, GWPn = imported energy group,

EF11, W11, WGP11 to EFnn, Wnn, GWPnn = pre-combusted energy group, EF111, W111, GWP111 to EFnnn, Wnnn, GWPnnn = in-plant energy group,

Where: EF1ijk.....EFnijk = emission factors for each of i = CO_2, j = CH_4 and k = N_2O (if included) for the applicable energy activity for the summation variables 1 to n; where: W1ijk......W1nijk = mass or volume of fuel source for the applicable energy type for the summation variables 1 to n; where: GWP1ijk.... WGPnijk = Global warming potential of CO_2, CH_4 and N_2O for the summation variables 1 to n. This goes same way for pre-combusted and in-plant energy groups.

If n is any positive integer and (a1, a2…. an) and (b1, b2….bn) are sets of real numbers, then: [155]

$\sum_{i=1}^{n}(ai + bi\ ) = \sum_{i=1}^{n} ai + \sum_{i=1}^{n} bi$; and

$\sum_{i=1}^{n}(\ ai - bi) = \sum_{i=1}^{n} ai - \sum_{i=1}^{n} bi$;

And, if the summation for: imported energy group = ai, pre-combusted energy =bi, and in-plant produced energy = ci, then model mathematical form can be simplified as:

$CO_2e = \sum_{i=1}^{n}(ai \ldots an) + \sum_{i=1}^{n}(bi \ldots bn) - \sum_{i=1}^{n}(ci \ldots cn)$

CHAPTER 8.0

CALCULATION TOOL DESIGN - SUSTAINABILITY DRIVER

GHG calculation guidance documents that are intended either for developing national inventories, such as the IPCC 2006 guidelines, or for quantifying emissions from a specific source e.g. a boiler, are a good source for adapting an existing or for starting up a new tool.

Developing a new tool will take longer, as some national quantification methods may be too broad to produce the level of quantification certainty needed [132]. Therefore, the task of developing a greenhouse gas calculation tool for a wastewater treatment plant in the design phase adapted by this research work, provides a short-cut approach for wastewater facility designers to estimate net energy requirements and to quantify greenhouse gas inventory. Material identified in Chapters 4, 5 and 6 of this research introduced methodologies for estimating wastewater energy consumption processes, resources for positive energy generation from standardized sources, emission factors of different fuels and the use of the energy trilogy balance to determine a plant's net total energy needs and potential GHG production. This research work also provides energy guidance during the rehabilitation of existing plants, recommends a wide range of energy calculation reference formulae and provides comparison capability to evaluate emissions using diverse technologies. Nevertheless, emission data are available for common emission sources, such as fossil fuels, and site-specific source data can lead to a more precise estimation of emissions from WWTP defined boundaries. The compilation of a wide range of information pertaining to WWTP site-specific priorities by this research tool represents unprecedented management and engineering control that helps produce energy use reduction and GHG emissions production.

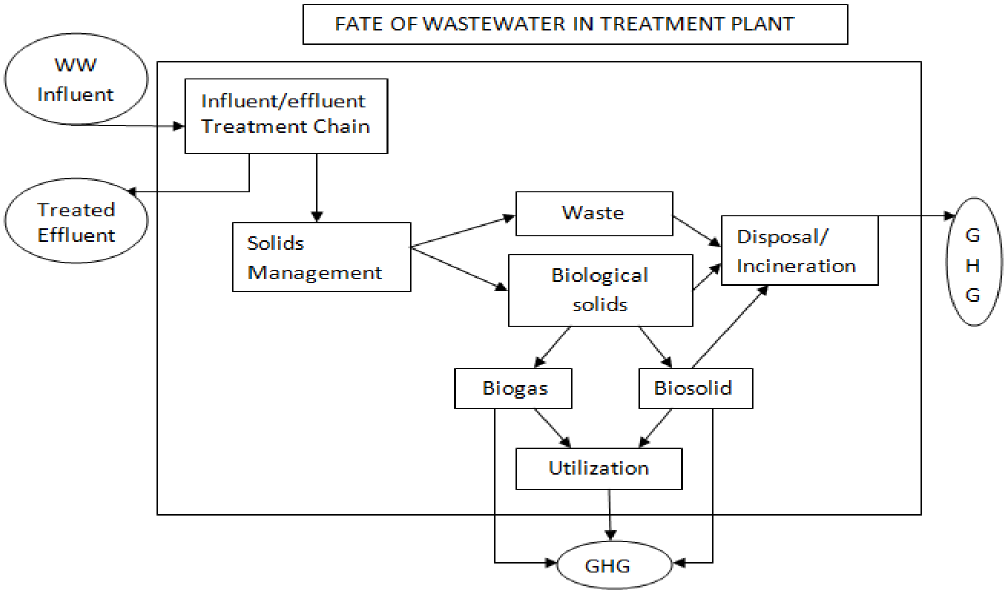
The tool is designed to include wastewater treatment processes extracted from literature, such as Metcalf & Eddie, WEF, other references and personal experience. The tool is composed of listing treatment levels and stages per process type -- biological, physical and chemical -- of a WWTP and the equipment used within. A designer can pick and choose types of processes and equipment for the proposed plant, based on the level of treatment desired. From here, a designer can run the tool, entering choices for several different options to allocate the best fit of processes and equipment for the lowest net energy requirement for the proposed plant design.

As defined by many references found in the tools library, measuring emissions, regardless of the purpose or whether emissions calculations were for a project or for an entire region, the general steps involved in measuring carbon emissions are the same [132]. Based on this fact, the energy trilogy tool is no different, except in being highly data - and process-detail intensive "energy generator-to-effluent discharge," and its construction was based on the following steps:

1. Defining project boundaries:

This is the first step in quantifying GHG emissions, and includes defining the processes that are considered as emissions sources in the total CO_2e inventory. The institutional boundaries set up for this tool consider all energy points involved with wastewater arriving to a WWTP entrance at the inflow structure, through treatment processes and the final stage of treated effluent discharge to a receiving body of water or to a utilization project -- as illustrated in Fig [8.1] -- which describes the fate of wastewater from entrance to exit in a wastewater treatment facility. Plant physical boarders are not limited to boundaries definition. These boundaries also include any in-plant energy-producing sources and all other sources of energy consumed outside the plant boarders involved in generating materials for consumption at the plant at a later phase.

Figure 8.1: Fate of Wastewater in a Treatment Plant



Source: Author

This tool is recording, in its boundaries, three gases: CO_2, CH_4 and N_2O. Mainly these three GHGs are consistently required for water and wastewater reporting in various regulations and per many national and international agencies.

2. Defining relevant GHG sources:

This research defined all wastewater treatment plant energy sources, and relevant GHG emitters and listed them in three major groups as graphed in Figure 1.3, sub-chapter 1.7 and summarized in Table 3.1, chapter 3. This included, as mentioned earlier, the plant imported energy group, plant pre-combusted energy group and In-plant energy produced group. The three groups include energy sources causing GHG generation, generally called direct and indirect emissions embedded within the definition of plant energy boundaries. The sources – can be from combusting fuels, burning natural gas, using chemicals and importing water; from stationary sources, such as pumps, boilers and anaerobic digesters, or from mobile sources such as generators, forklifts and other modes of transportation.

The research defined major gases from treatment plants affecting the global warming to be at a least, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2). These gases are specifically included when indirect emissions from purchased electricity and transportation sources were part of the boundaries.

3. <u>Calculating emissions:</u>

Since this tool is allocating emissions using non-measurable methodologies for nonexistent plants , emissions are determined by calculating the amounts of activities for each process and variety of equipment involved in that process per unit mass or volume, and then converting GHGs to a CO_2e value, based on their emissions factors and global warming potential.

4. <u>Verification of emissions calculation:</u>

Unlike potential projects emissions that are merely based on professional judgments for energy inventory, fuel consumptions and emissions estimation are needed to be verified by an accredited verification body [131]; and emissions inventory calculations, for the purpose of this research, will be verified by comparing them to net energy use and emissions production from reliable baseline studies found in literature, as discussed in chapter (9).

8.1 Tool Structure

Based on the discussion above, a model quantifying CO_2e emissions from a WWTP should be organized in a way that is process and equipment comprehensive, technology rich and easy to understand. Data for calculating emissions can be collected from fuel vendors, utility suppliers, previous experience, material safety data sheets (MSDS), organizational and governmental websites, billing and measurements from identical plants, operation logs and other sources. However, this research reference has compiled major WWTP-used operations and technologies to be handy for a designer to choose from, and has made available emissions estimation methods or information to assess a site-specific, location or regional data.

This tool sets up the spreadsheet data based on treatment processes and equipment and/or potential GHG emitting material included within a process, all of which are included in one, comprehensive spreadsheet called "Master Spreadsheet." Using this tool, CO_2 emissions can be evaluated using more than one quantifying approach; for instance, the use of fuel emissions factors calculation methodologies, default values from locational sources or a mixed approach. This could help compare CO_2e emissions of different data sources.

Many resources, such as USEPA, IPCC, UNFCC, peer-reviewed papers and academic articles and other resources provide guidance and a basis for default and industry specific emissions factors (EF). In our approach, site-specific estimated EFs are preferable, wherever possible. Treatment processes could be different from one plant to another, owing to differences in the chemical and biological composition of wastewater and the impact of operations in use, causing EFs to have different values. Accordingly, because of its importance, the EFs topic is detailed in chapter 5.0 of this work. A Greenhouse EF can be defined as metric tons of CO_2e per production unit (kWh, MMBtu). Since the EFs are of diversified origin and so are the units used, conversion factors are available from reliable academic sources.

8.2 Energy and Emissions Calculation

The tool spreadsheets are prepared in Excel format, and are composed of five major tables:

1) <u>Master Table Spreadsheet - Plant Imported Energy</u>:

This spreadsheet includes three major columns:

a) Plant Operations and Processes Energy Use Sources: constituents of all wastewater treatment levels, processes and operations. These are WWTP sources of energy consumption from which a designer can choose appropriate processes and equipment for the desired treatment level.

b) Energy Inventory, Activity or Matrix: includes two sub-columns; one for "electric energy use (kWh)" subdivided into columns for variety of electricity consuming equipment, and a second column for other fuels and energy sources.

c) Total CO_2 Emissions from Plant Imported Energy: includes columns for calculated CO_2 emissions from the energy groups columns described in (a and b), and a column for the total CO_2 generated from plant "imported energy group".

2. <u>Pre-combusted Energy Source Spreadsheet</u>:

This spreadsheet is comprised of three columns:

a) Pre-combustion Energy Source – Imports column: Includes activities such as imported water, vehicle fuels and non-process use chemicals, etc.

b) Fuel Types column: subdivided into columns for variety of fuels might be found in use at this category, such as kWh, natural gas and LPG.

c) CO_2e column: is divided into columns per the individual CO_2e fuel generator.

3. <u>In-Plant Energy Produced Spreadsheet</u>:

This spreadsheet is composed of three columns:

a) Renewable/Alternative Energy Technology column: this column lists the types of renewable energy and other energy recovery sources could be adopted by a plant.

b) Type of Energy Generated column: includes types of energy that could be generated by an in-plant sources, such as kWh, steam, etc.

c) CO_2e column: is divided into columns per the individual fuel producing CO_2e, but to be deducted from total.

4. <u>Advanced Technologies Spreadsheet</u>:

   The information for this spreadsheet is listed and discussed in detail in subchapter (4.4) and should have been part of the “master spreadsheet,” but was isolated into separate spreadsheet to offer the opportunity for comparison to base measures mainly found in the master spreadsheet.

5. <u>Formula and calculation Design Spreadsheet</u>:

   This spreadsheet will generate the required information assigned by this research work, which includes energy consumption by activity, total energy, CO_2e by activity and plant total.

In this spreadsheet’s first column, the activities or technologies are listed followed by the appropriate formulae for energy calculation, unit of energy, EF formulae or default value, EF units, units conversion, GWP and, finally, the calculated CO_2e for the activity.

Data generated from this spreadsheet are linked to spreadsheets discussed above for information storage and later utilization for the production of comparison tables and graphs.

CHAPTER 9
ADOPTING A BASELINE STUDY FOR VERIFICATION

Baseline measurements refer to the analysis of existing energy bills and operating data to identify the current level of consumption, peak energy usage and costs for an existing water/wastewater facility, process or a system. Baseline measurements are made before implementing any energy conservation management system (ECM), so the positive effect of each ECM can be measured [87] (WEF, MOP 32, 2012).

9.1 Plant Energy Baseline Study

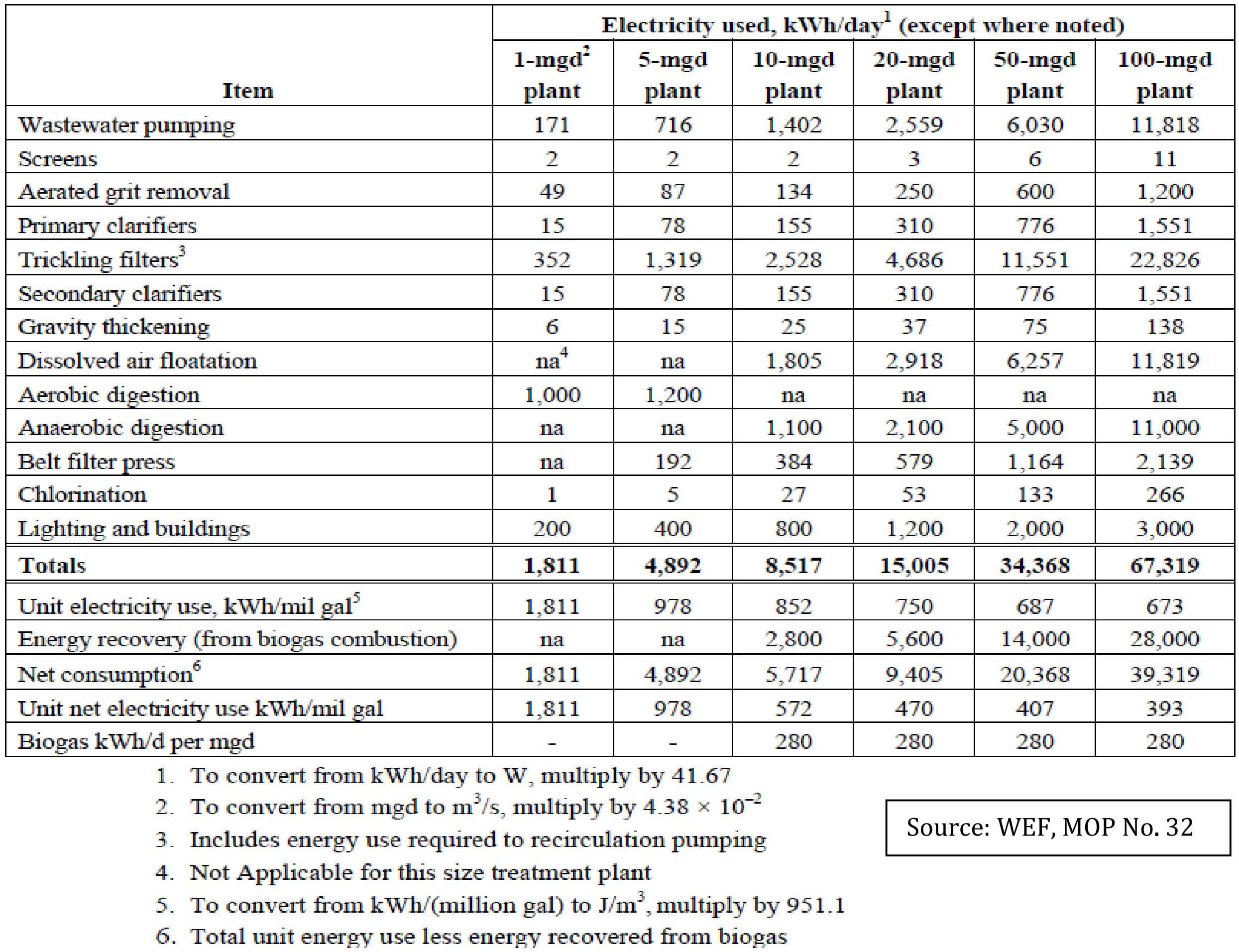
WEF has presented and retained in the 2009 edition of the manual of practice four tables that have served as a guide to computing energy consumption in WWTPs. Estimates of electricity used in each WWTP unit process was presented by Burton, F.L. and EPRI [133] for four categories of plants: trickling filters, activated sludge, advanced wastewater treatment with nitrification and advanced WWTP without nitrification. These tables have been used by wastewater plants to establish baseline conditions, and continued access to this data was determined to be beneficial. Therefore, these tables have been retained for continuous use.

Since the actual energy used will vary at each WWTP, the energy usage in these tables should be adjusted accordingly, taking into consideration site-specific conditions and differences in treatment processes such as: odor control, intermediate pumping, high-purity oxygen, biological nutrient removal, membrane processes, ultraviolet disinfection, water reuse pump stations, gravity belt or drum thickening and centrifuge dewatering. The power consumed by the other processes is affected by a number of variables, and information should be requested from the vendor and engineers to establish the proper level of energy intensity.

If it is determined that savings associated with some improvements may not justify on site monitoring and mathematical computations, models may be used to determine pre-savings and post-savings, based on spot measurements and rules of thumb used in the industry.

Up to this point, we conclude that the four treatment tables can be used as a baseline representing major categories of WWTPs, for comparison with the results of this research mathematical model and its proposed tool, discussed in chapters 7 and 8, respectively. The expected model results will obviously be higher than the baseline tables, due to including the adjustments mentioned above and because of the data intensive master spreadsheet table for process equipment. Below are the four WWTP category Tables 9.1. A, B, C and D

Table 9.1A: Energy Requirements - Trickling Filter Treatment Plant



Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Wastewater pumping	171	716	1,402	2,559	6,030	11,818
Screens	2	2	2	3	6	11
Aerated grit removal	49	87	134	250	600	1,200
Primary clarifiers	15	78	155	310	776	1,551
Trickling filters[3]	352	1,319	2,528	4,686	11,551	22,826
Secondary clarifiers	15	78	155	310	776	1,551
Gravity thickening	6	15	25	37	75	138
Dissolved air floatation	na[4]	na	1,805	2,918	6,257	11,819
Aerobic digestion	1,000	1,200	na	na	na	na
Anaerobic digestion	na	na	1,100	2,100	5,000	11,000
Belt filter press	na	192	384	579	1,164	2,139
Chlorination	1	5	27	53	133	266
Lighting and buildings	200	400	800	1,200	2,000	3,000
Totals	**1,811**	**4,892**	**8,517**	**15,005**	**34,368**	**67,319**
Unit electricity use, kWh/mil gal[5]	1,811	978	852	750	687	673
Energy recovery (from biogas combustion)	na	na	2,800	5,600	14,000	28,000
Net consumption[6]	1,811	4,892	5,717	9,405	20,368	39,319
Unit net electricity use kWh/mil gal	1,811	978	572	470	407	393
Biogas kWh/d per mgd	-	-	280	280	280	280

1. To convert from kWh/day to W, multiply by 41.67
2. To convert from mgd to m^3/s, multiply by 4.38×10^{-2}
3. Includes energy use required to recirculation pumping
4. Not Applicable for this size treatment plant
5. To convert from kWh/(million gal) to J/m^3, multiply by 951.1
6. Total unit energy use less energy recovered from biogas

Source: WEF, MOP No. 32

Table 9.1B: Energy Requirements - Activated Sludge Treatment Plant

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Wastewater pumping	171	716	1,402	2,559	6,030	11,818
Screens	2	2	2	3	6	11
Aerated grit removal	49	87	134	250	600	1,200
Primary clarifiers	15	78	155	310	776	1,551
Aeration (diffused air)	532	2,660	5,320	10,640	26,600	53,200

Table 9.1B: *Continued*

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Return sludge pumping	45	213	423	724	1,627	3,131
Secondary clarifiers	15	78	155	310	776	1,551
Gravity thickening	6	15	25	37	75	138
Dissolved air floatation	na[3]	na	1,805	2,918	6,257	11,819
Aerobic digestion	1,200	2,400	na	na	na	na
Anaerobic digestion	na	na	1,400	2,700	6,500	13,000
Belt filter press	na	192	384	579	1,164	2,139
Chlorination	1	5	27	53	133	266
Lighting and buildings	200	400	800	1,200	2,000	3,000
Totals	**2,236**	**6,846**	**12,032**	**22,283**	**52,544**	**102,824**
Unit electricity use, kWh/mil gal[4]	2,236	1,369	1,203	1,114	1,051	1,028
Energy recovery (from biogas combustion)	na	na	3,500	7,000	17,500	35,000
Net consumption[5]	2,236	6,779	8,532	15,283	35,044	67,824
Unit Net electricity use kWh/mil gal	2,236	1,356	853	764	701	678
Biogas kWh/d per mgd			350	350	350	350

1. To convert from kWh/day to W, multiply by 41.67
2. To convert from mgd to m^3/s, multiply by 4.38×10^{-2}
3. Not Applicable for this size treatment plant
4. To convert from kWh/(million gal) to J/m^3, multiply by 951.1
5. Total unit energy use less energy recovered from biogas

Source: WEF, MOP No. 32

Table 9.1 C: Energy Requirements - Advanced Treatment Plant without Nitrification

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Wastewater pumping	171	716	1,402	2,559	6,030	11,818
Screens	2	2	2	3	6	11
Aerated grit removal	49	87	134	250	600	1,200
Primary clarifiers	15	78	155	310	776	1,551
Aeration (diffused air)	532	2,660	5,320	10,640	26,600	53,200
Return sludge pumping	45	213	423	724	1,627	3,131
Secondary clarifiers	15	78	155	310	776	1,551
Chemical addition	80	290	552	954	2,187	4,159
Filter feed pumping	143	445	822	1,645	3,440	6,712
Filtration	137	247	385	709	1,679	3,295
Gravity thickening	6	15	25	37	75	138
Dissolved air floatation	na[3]	na	2,022	3,268	7,008	13,273
Aerobic digestion	1,200	2,400	na	na	na	na
Anaerobic digestion	na	na	1,400	2,700	6,500	13,000
Belt filter press	na	228	457	689	1,385	2,545

Table 9.1C: *Continued*

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Chlorination	1	5	27	53	133	266
Lighting and buildings	200	400	800	1,200	2,000	3,000
Totals	**2,596**	**7,864**	**14,081**	**26,051**	**60,822**	**118,814**
Unit electricity use, kWh/mil gal[4]	2,596	1,573	1,408	1,303	1,216	1,188
Energy recovery (from biogas combustion)	na	na	3,500	7000	17,500	35,000
Net consumption[5]	2,596	7,964	10,581	19,051	43,322	83,814
Unit net electricity use kWh/mil gal	2,596	1,573	1,058	953	866	838
Biogas kWh/d per mgd			350	350	350	350

1. To convert from kWh/day to W, multiply by 41.67
2. To convert from mgd to m^3/s, multiply by 4.38×10^{-2}
3. Not Applicable for this size treatment plant
4. To convert from kWh/(million gal) to J/m^3, multiply by 951.1
5. Total unit energy use less energy recovered from biogas

Source: WEF, MOP No. 32

Table 9.1 D: Energy Requirements - Advanced Treatment Plant with Nitrification

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Wastewater pumping	171	716	1,402	2,559	6,030	11,818
Screens	2	2	2	3	6	11
Aerated grit removal	49	87	134	250	600	1,200
Primary clarifiers	15	78	155	310	776	1,551
Aeration (diffused air)	532	2,660	5,320	10,640	26,600	53,200
Biological nitrification	346	1,724	3,446	6,818	16,936	33,800
Return sludge pumping	54	256	508	869	1,952	3,757
Secondary clarifiers	15	78	155	310	776	1,551
Chemical addition	80	290	552	954	2,187	4,159
Filter feed pumping	143	445	822	1,645	3,440	6,712
Filtration	137	247	385	709	1,679	3,295
Gravity thickening	6	15	25	37	75	138
Dissolved air floatation	na[3]	na	2,022	3,268	7,008	13,273
Aerobic digestion	1,200	2,400	na	na	na	na
Anaerobic digestion	na	na	1,700	3,200	7,800	15,600
Belt filter press	na	228	457	689	1,385	2,545
Chlorination	1	5	27	53	133	266
Lighting and buildings	200	400	800	1,200	2,000	3,000

Table 9.1 D: *Continued*

Item	Electricity used, kWh/day[1] (except where noted)					
	1-mgd[2] plant	5-mgd plant	10-mgd plant	20-mgd plant	50-mgd plant	100-mgd plant
Totals	**2,951**	**9,631**	**17,912**	**33,514**	**79,383**	**155,540**
Unit electricity use, kWh/mil gal[4]	2,951	1,926	1,791	1,676	1,588	1,558
Energy recovery (from biogas combustion)	na	na	3,500	7,000	17,500	35,000
Net consumption[5]	2,951	9,631	14,412	26,514	61,883	120,540
Unit net electricity use kWh/mil gal	2,951	1,926	1,441	1,326	1,238	1,208
Biogas kWh/d per mgd	-	-	350	350	350	350

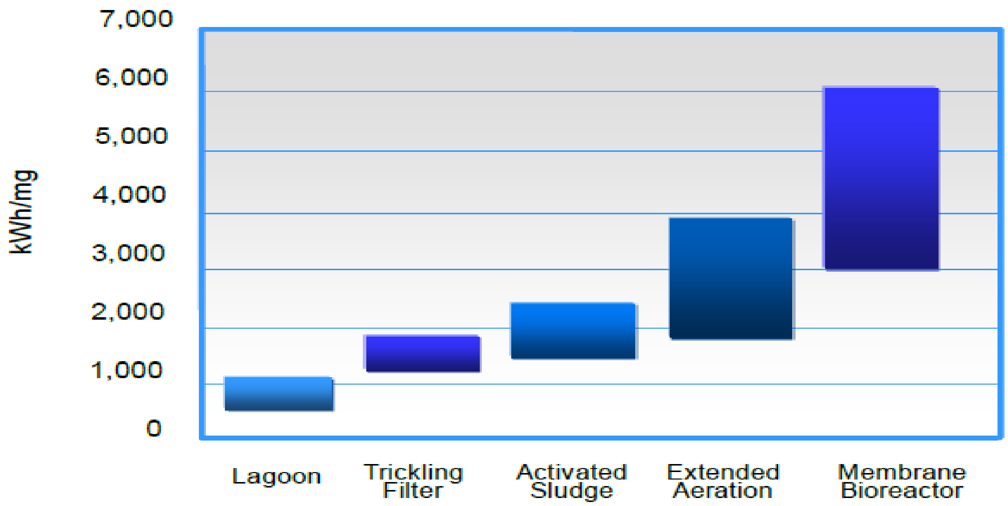
Source: WEF, MOP No. 32

1. To convert from kWh/day to W, multiply by 41.67
2. To convert from MGD to m3/s, multiply by 4.38 × 10–2
3. Not Applicable for this size treatment plant
4. To convert from kWh/ (million gal) to J/m3, multiply by 951.1
5. Total unit energy use less energy recovered from biogas

In regard to plant energy, intensity results of the model in kilowatt-hour per million gallon (kWh/MG) can be compared with benchmarking results from published typical uses of energy at other WWTPs of equal or similar capacities and flow rates.

Designers [162] must select appropriate treatment processes to meet or exceed effluent requirements, but must also be aware that different processes consume different quantities of power. Figure 9.1, provides general guidance on the power requirements of different treatment processes for facilities greater than 1 MGD. Designers and decision-makers need to plan for possible more stringent future effluent requirements; at the same time, they need to consider optimizing operational costs. Balancing these two opposing interests can be a challenge.

Figure 9.1: Typical Treatment Process Power Requirement



Source: WERF, CH2M Hill

Conclusions can be drawn from the summary Table [9.2] of the energy consumptions for the four treatment levels, which is extracted from the tables above; that the energy consumption is decreasing with the increase of influent flow rate, and that energy use by different levels of treatment are different, with advanced level treatments being the highest consumers. Also, these consumption levels represent benchmarks for the different types of WWTFs process levels.

Table 9.2: Average Unit Total Electrical Consumption, kWh/d.

Treatment Type	Wastewater Influent Rate (MGD)					
	1-MGD	5-MGD	10-MGD	20-MGD	50- MGD	100-MGD
Trickling Filters	1,811	978	852	750	687	673
Activated Sludge	2,236	1369	1203	1114	1051	1028
Advanced w/o Nitrification	2,596	1573	1408	1303	1216	1188
Advanced with Nitrification	2951	1926	1791	1676	1588	1558

Source: Compiled by Author

9.2 Energy Baseline Equipment and Processes

For municipal wastewater treatment plants, a new construction energy efficiency study was conducted by BASE Energy, Inc. for PG & E, a utility company that serves 480 WWTFs. The objective of this study was to determine a baseline for analysis of energy efficiency measures in WWTPs [97]. The baseline development incorporated a survey of WWTPs within specific service territories and the literature review. The survey aimed to identify, among other things, the technologies that have traditionally been used, the energy efficient technologies and the proposed calculation methods for energy savings, based on identified baselines. Table [9.3] below, represents a summary of the technology findings.

Table 9.3: Baseline and Energy Efficiency Measures for Various WWT Technologies

Technology	Baseline	Sample Energy Efficiency
	Type of Energy Efficiency Measures	
Aerators (Blowers)	Coarse-Bubble Diffuser	Fine Pore Diffuser
	Inlet/Discharge Vane or No Control	Variable Frequency Drive Control
	Multi-stage Centrifugal blowers	Single-stage Centrifugal Blower with VFD Control
	Fan System Assessment Tool (FSAT) Achievable Efficiency or Average Efficiency from Manufacturers' Data	High Efficiency Blower with Efficiency Better than Achievable/ Average efficiency
Mechanical Aerators	Constant Speed Motor	VFD Control Based on O_2 Content
Air compressors	Rotary Screw Compressors with Load/No-load Control	Air Compressor with VFD Control
Dissolved Oxygen System	Manual Control	Automatic Control
Hydraulic - Driven Systems	Hydraulic Water or Oil Driven Systems	Electrical-Driven Systems
Motors	1992 Epact Standard Efficiency Motors	Motor Efficiency is Higher than Epact Efficacy Standards
Pumps	Throttle, Bypass or No Control	VFD Control
	Hydraulic Institute (HI) Achievable Efficiency	Pump with Efficiency Better than (HI)
	Pneumatic	Electrical-Driven
Sludge Dewatering	Centrifuge	Screw Press
Sludge Thickening	Centrifuge Thickening system	Gravity Belt Thickening
UV Radiation Disinfection	Medium-pressure UV System	Low-pressure UV System
Sludge Treatment Process	Aerobic Treatment System	Anaerobic Treatment System

Source: PG & E / Base Energy, Inc.

Another procedure specific to the wastewater industry described by Monteith et al. (2005), of which some portions were discussed in sub-chapter 3.2, was evaluated using full-scale data from 16 WWTPs in Canada and was applied to plants in all Canadian provinces. For aerobic processes primarily used in North America, the authors determined that the principle GHG emitted from municipal WWTPs was carbon dioxide (WEF 2009).

9.3 Measurement and Verification Protocol

Measurement and verification (M&V) is based on the establishment of an initial baseline by measurements or other means, and then conducting follow up measurement or other accounting. M&V strategies are described in the international performance measurement and verification protocol (IPMVP): EVO - efficiency valuation organization - issued in 2012 in its M&V on Concepts and Options for Determining Energy and Water Savings - Volume 1, [135].

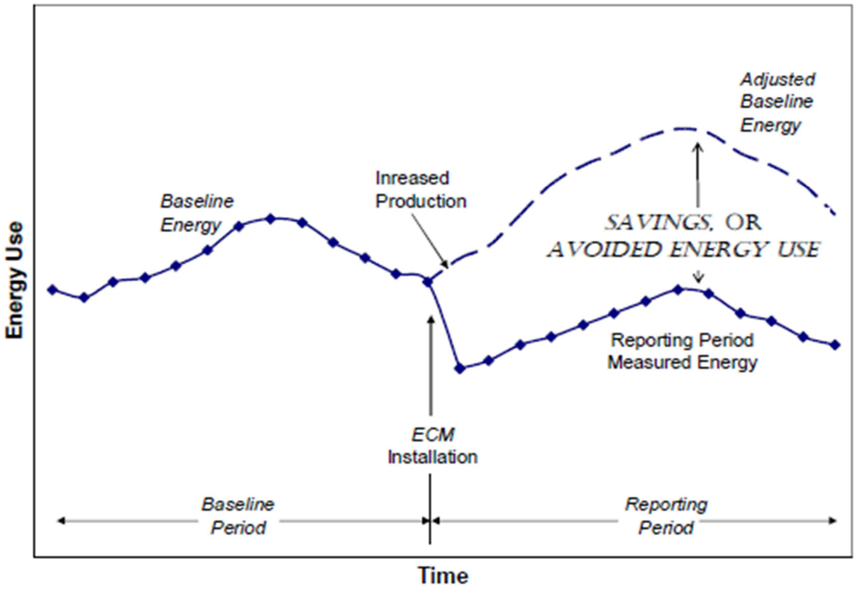
IPMVP states that energy savings cannot be directly measured, since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions.

The baseline for an existing facility project is usually the performance of the facility or system prior to modification. This baseline physically exists and can be measured before changes are implemented. In new construction, the baseline usually hypothetical and is defined based on code, regulation, common practice or documented performance of similar facilities. In either case, the baseline model must be capable of accommodating changes in operating parameters and conditions so that “adjustments” can be made.

Savings = (*Baseline-Period Use* or Demand - *Reporting-Period Use* or Demand)
± Adjustments.. (9.3.1)

The "adjustments" term in this general equation is used to re-state the use or demand of the baseline and reporting periods under a common set of conditions. This adjustments term distinguishes proper savings reports from a simple comparison of cost or usage before and after implementation of an energy conservation measure (ECM). As an example of savings determination process, Figure [9.2] shows the energy-usage history of an industrial boiler before and after the addition of an energy conservation measure (ECM) to recover heat from its flue gases. At about the same time as the ECM installation, plant production also increased.

Figure 9.2: Comparing Measured Energy Use or Demand [135]



Source: IPMVP

IPMVP provides four options for determining savings (A, B, C and D). If it is decided to determine savings at the whole facility level, option C or D may be favored. However if only the performance of the ECM itself is of concern, a retrofit-isolation technique may be more suitable (option A, B or D). Options are summarized in Table 9.4.

Table 9.4: The four Options for Determining Energy Savings [135]

Method A: Retrofit Isolation of Key Parameters
Measure only the key part of the energy computation, (only responsible for a load reduction or only reduction of operating hours, but not both). Savings are determined by field measurement of the key performance parameter(s) which define the energy use of the ECM's affected system(s).
Method B: Retrofit Isolation of All Parameters

Measure all energy factors in the savings calculation (controls for automatic dimmed lighting and control of operating periods). Savings are determined by field measurement of the energy use of the ECM-affected system.
Method C: Whole Facility Meter Analysis
Need both baseline and reporting period data. Savings are determined by measuring energy use at the whole facility or sub-facility level.
Method D: Calibrated Simulation
When there is no meter (or facility) in the baseline, baseline data can be 'manufactured' under controlled circumstances. Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. The model is closely calibrated with data collected for each ECM.

Source: IPMVP

<u>Conclusion:</u> Table 9.4 above, suggests that options C and D are applicable to use for a new WWTP design in which the energy evaluation baseline comparison approach is needed. However, option D is the appropriate approach if: 1) no baseline energy data exists; 2) a situation exists to be used for a new construction or; 3) in our case, estimating the new WWTP design - energy quantification. And since the WEF tables introduced in sub-chapter 9.1 served as a guide to computing energy consumption in WWTPs for electricity for four categories of plants, used by plants to establish a baseline conditions, and was determined to be beneficial, then WEF tables can create a practical replica of the simulation model suggested by option D for the verification of research model and the proposed tool energy calculation results. This comparison will determine how close the research tool results are to the WEF table models for the same treatment levels. Also, other design additions can be evaluated as "adjustments" to define the effect of using advanced, alternative or renewable technologies in a specific design compared with baseline technologies. This approach represents an adequate methodology to measure performance of a proposed WWTP design.

9.4 Comparative Study

The objective of this dissertation was, in addition to other goals, to develop a model to assist designers of WWTP in determining energy requirements and then compare options of equipment and processes during the design or plant rehabilitation phases. As this work is completed and appropriate data on WWTP operations, processes and the technical engineering tools were collected and embedded in the dissertation, it is imperative to validate the data.

A study that was supported by the water environment research (WEF) was taken as a baseline benchmark, discussed and its results in (kWh) electricity are listed in tables for the four levels of wastewater treatment in sub-chapter 9.1 above. An energy compilation from an independent/third party WWTP (other than WEF) study was needed to be surveyed, audited and its energy-use resources to be estimated, based on the energy formulae, supporting tables and statements derived throughout this dissertation.

A detailed survey (Appendix B) was prepared and sent to several WWTPs in the state of Michigan. However, the only complete response and cooperation came from the City of Warren WWTP, located at 32360 Warkop Avenue, Warren, Michigan 48093.

To fulfill the needs of the detailed and lengthy survey submitted to the plant, several meetings were held with plant representative who offered copies of all audits completed by consulting engineering firms in recent years at the plant.

Great efforts were made to reduce the audits data for motors and lighting. The main goal was to estimate the energy consumption from electromechanical and environmental processes in order to compare with applicable WEF study treatment plant results.

9.5 About Warren WWTP

The City of Warren WWTP receives and treats sanitary and industrial flows for a service area of approximately 34 square miles. The plant has a pumping capacity of 206 MGD, an average design flow capacity of 36 MGD, average actual daily flow rate of 22.4 (MGD) with annual operating days of 365, and a maximum sustained flow capacity through the plant of 60 MGD. During storms, flow greater than 60 MGD (due to Infiltration and Inflow) is diverted to a 50 million gallon retention basin (flow equalization) where it is stored until the storm has passed and then it is treated.

The treatment process at the Warren WWTP consists of mechanical screening, pumping, grit removal, primary settling, activated sludge with single stage nitrification, phosphorus removal using metal salt (ferric chloride) precipitation, secondary settling, rapid sand filtration, disinfection by ultra violet light, and dechlorination of basin overflow during heavy rain events using sodium bisulfite.

Solids removed from the process include grit, screenings, and settled sludge. Grit and screenings are disposed of in landfills. Excess activated sludge is blended on a batch basis with primary sludge thickened via a gravity belt thickener, and dewatered with belt filter presses.

The resulting sludge cake is incinerated using a multiple hearth sludge incinerator. Also, sludge cake conveying equipment is in place to facilitate cake transport and disposal in the event the incinerator is out of service for any reason.

Odor control units are employed to treat the exhaust from the wet well, grit chamber/splitting box, and to treat incinerator stack emissions and exhaust from the belt filter press room. Two odor control units are spray mist towers utilizing sodium hydroxide and sodium hypochlorite for odor treatment and the third odor control unit employs activated carbon.

The WWTP and Nine Mile Pumping Station are both powered by two separate DTE Energy electric lines and are backed up with separate generators at both locations.

9.6 Comparison, Results and Conclusions

The comparison was made based on the reduced data from Warren plant, modifying and arranging per the audit's sequence of WEF equipment and processes as much as possible to achieve clear comparison. WEF results are found in Table 9.1 D: Energy Requirements - Advanced Treatment Plant with Nitrification. Table 9.6 and its graphic representation on chart (Figure 9.3) summarize the findings of the comparison study of the two plants' electrical energy.

Table 9.5: Comparison of Electrical Energy Requirements for Warren WWTP and WEF Study for a 20 MGD Advanced treatment with Nitrification

Process:	Electricity Used, kWh/day	
	20 – MGD - WEF	22.4 – MGD - Warren
Wastewater Pumping	2,559	2,994
Screens	3	6.4
Aerated Grit Removal	250	209
Primary Clarifiers	310	282
Primary Treatment	-	265
Aeration	10,640	10575
Dissolved Air Floatation	3268	-
Biological Nitrification	6,818	8,263
Return Sludge Pumping	869	856
Secondary Clarifiers	310	282
Chemical Addition	954	136.5
Filter Feed Pumping	1,645	-
Filtration	709	-
Sand Filtration	-	6,735
Gravity Thickening	37	-
Aerobic Digestion	-	-
Anaerobic Digestion	3,200	-
Belt Filter Press	689	712
Disinfection, Chlorination vs.	53	5800

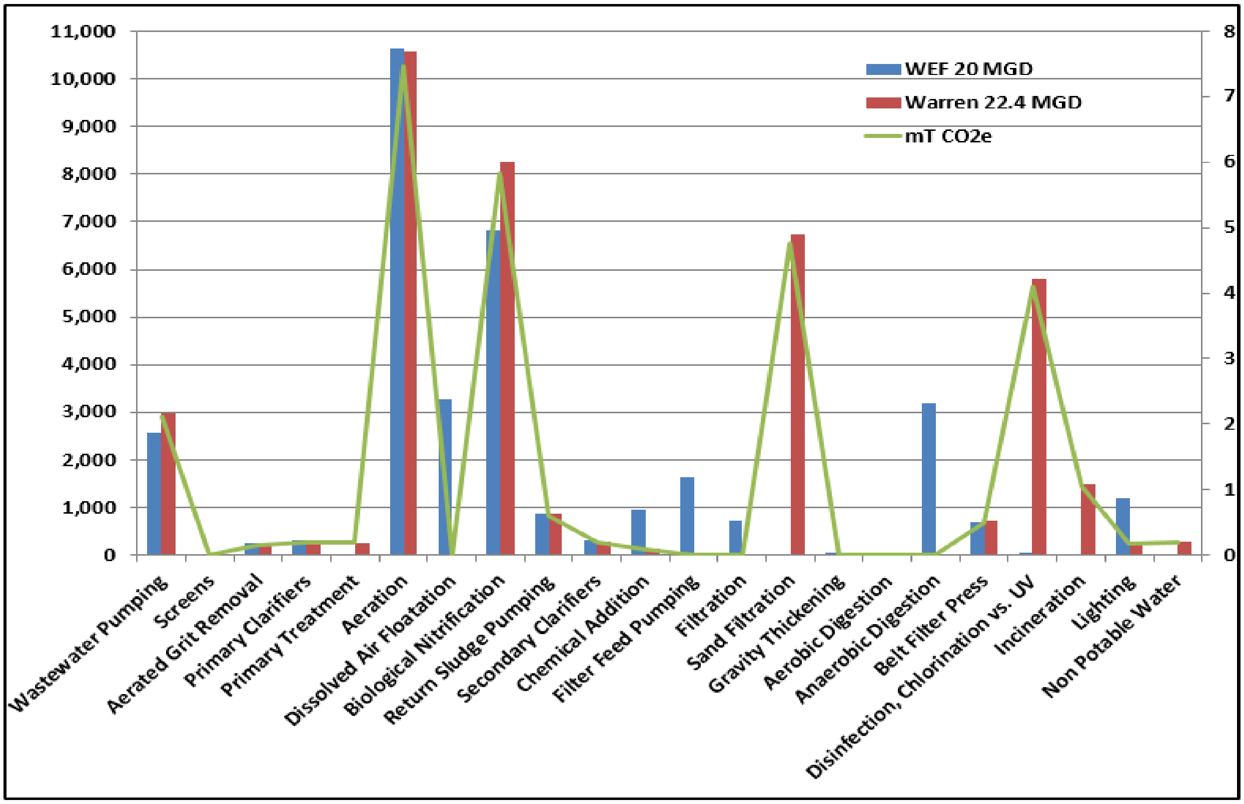
UV		
Incineration	-	1,483
Lighting	1,200	260
Non Potable Water		282
Total	33,514	39,141
Billing kWh/Day, Averaged over 4 years		40,935
Energy Intensity (kWh/MGD)	1,676	1,747
Daily CO2e from kWh		27.6

Source: Author

Notes:

1. UV is calculated using Table 6.8, page 124, for UV and hypochlorite comparison at 10 (mg/l) Chlorine.
2. Energy of equipment are calculated using formulas and lighting tables from Chapter 4 for motors, pumps, compressors, fans, etc.

Figure 9.3: Graph for the Comparison Results Exploring the Daily CO_2 Emissions



Source: Author

Conclusions:

1. Results of the comparison study show that the deviation between the energy use at Warren WWTP and the WEF former study is about 14%. This result assumes, taking all auditing

and surveys data misalignment, that energy estimation methodologies and model derived in this work are dependable and can be a good source for the next phase of producing a tool calculator specific for WWTPs.

2. However, this study provides comprehensive accounting for all sources of energy, rather than merely electric or other source of energy, as is the case with most of the models and tools encountered. Table 9.6 below summarizes the results of other energy sources not encountered in the WEF study, such as the natural gas, an important source of imported energy, and Table 9.7 estimates the pre-combusted energy group including water, chemicals, etc. Data source are listed in Appendix C and estimations in Appendix D.

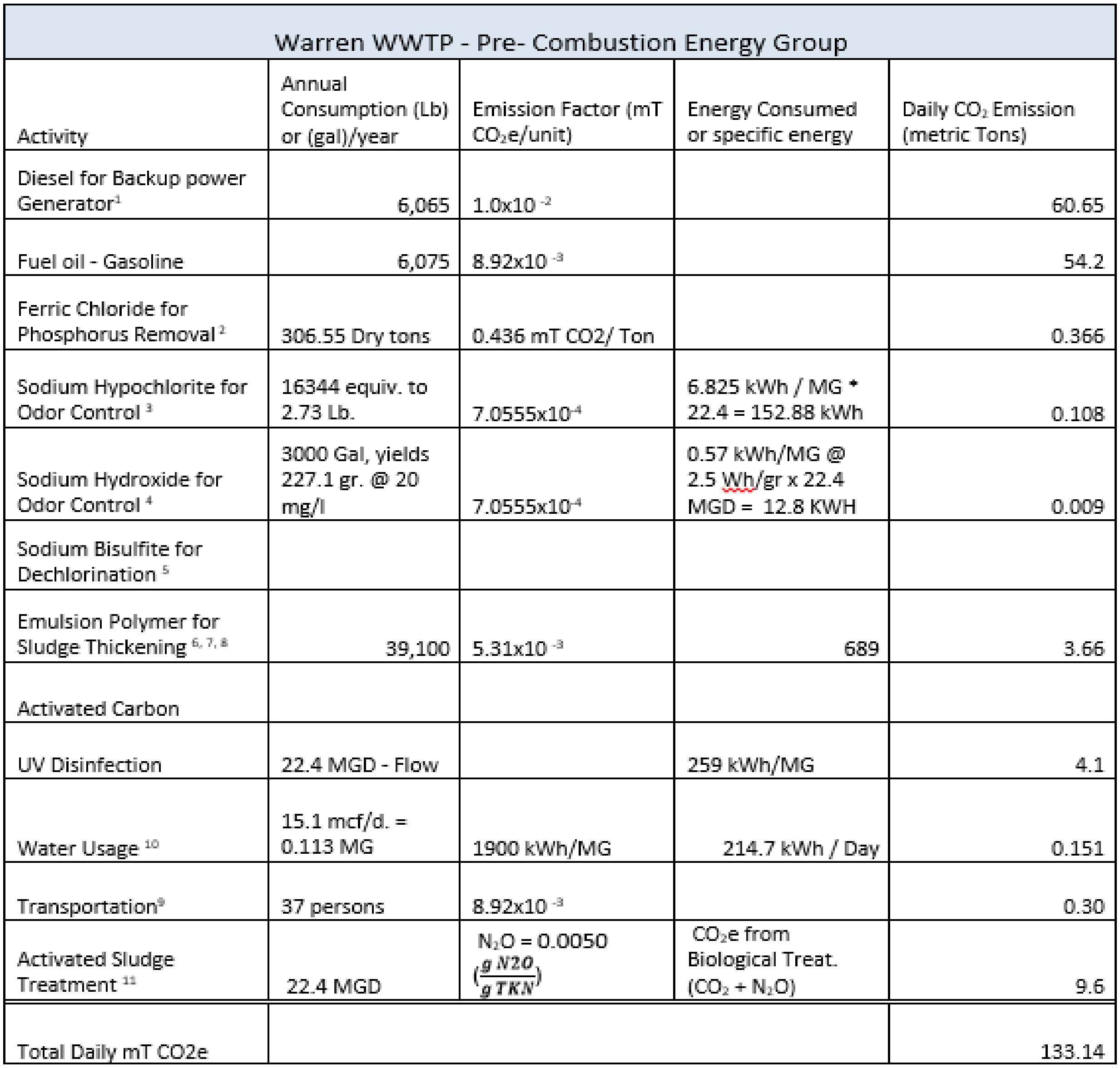
3. Electricity used at Warren equates to 27.6 (m T CO_2e/ day), while combined tables 9.6 and 9.7 (natural gas and the pre-combusted group) equate to 151.14 (m T CO_2e / day). This 5.5-fold increase of GHG is often overlooked partially or completely by other models.

<u>Table 9.6: Warren WWTP Natural Gas Consumption and Daily Emissions</u>

Warren WWTP Natural Gas Consumption - Imported Energy Group						
Activity	Annual Natural Gas (MCF)[1]	Daily Average (MCF)	Annual N. Gas (Therm)[2]	Emissons Factor	Annual Emissions	Daily mTCO2e
Incinerator	102,100	279.73	1,027,677	5.31×10^{-3}	5,457	15
Boilers and Others	20,683	56.67	208,183	5.31×10^{-3}	1,105	3
Total / Annual (MCF)	122,783	336.39	1,235,860	5.31×10^{-3}	6,562	18
1. Based on 2012 plant natural gas bills, 2. Conversion of (10.0654) Therm/MCF is averaged from 2012 bills						

Source: Author

Table 9.7: Pre-Combusted Energy Group Including Chemicals, Fuels and Water



Warren WWTP - Pre- Combustion Energy Group

Activity	Annual Consumption (Lb) or (gal)/year	Emission Factor (mT CO_2e/unit)	Energy Consumed or specific energy	Daily CO_2 Emission (metric Tons)
Diesel for Backup power Generator[1]	6,065	$1.0x10^{-2}$		60.65
Fuel oil - Gasoline	6,075	$8.92x10^{-3}$		54.2
Ferric Chloride for Phosphorus Removal[2]	306.55 Dry tons	0.436 mT CO2/ Ton		0.366
Sodium Hypochlorite for Odor Control[3]	16344 equiv. to 2.73 Lb.	$7.0555x10^{-4}$	6.825 kWh / MG * 22.4 = 152.88 kWh	0.108
Sodium Hydroxide for Odor Control[4]	3000 Gal, yields 227.1 gr. @ 20 mg/l	$7.0555x10^{-4}$	0.57 kWh/MG @ 2.5 Wh/gr x 22.4 MGD = 12.8 KWH	0.009
Sodium Bisulfite for Dechlorination[5]				
Emulsion Polymer for Sludge Thickening[6, 7, 8]	39,100	$5.31x10^{-3}$	689	3.66
Activated Carbon				
UV Disinfection	22.4 MGD - Flow		259 kWh/MG	4.1
Water Usage[10]	15.1 mcf/d. = 0.113 MG	1900 kWh/MG	214.7 kWh / Day	0.151
Transportation[9]	37 persons	$8.92x10^{-3}$		0.30
Activated Sludge Treatment[11]	22.4 MGD	$N_2O = 0.0050$ $(\frac{g\ N2O}{g\ TKN})$	CO_2e from Biological Treat. ($CO_2 + N_2O$)	9.6
Total Daily mT CO2e				133.14

1, 2, Diesel volumes in gallons and Ferric Chloride in dry tons are averaged from 2009/2010 data, and ferric chloride emission factor obtained from Sydney Water Board 1993

3, 4, 5 and 6 volumes are from 2010 data.

7, Emulsion polymer energy factor of 1762 (BTU/Lb) from manufacturer

8, Polymer is assumed to be produced by natural gas, therefore N.G. emission factor is used for calculation. 39,100 Lb x 1762 (Btu/Lb)/100,000 Btu/therm = 689 therms x 5.31 x 10 -3 (Ton CO2/Therm) = 3.66 Tons CO_2

9, Transportation is calculated using equation from subpart 6.2.2

10, Water volumes are obtained from 2013 utility bills

11, Calculation of CO2e generated from activated sludge process is based on reference [164]

Source: Author

APPENDIX A
EMISSIONS FACTORS

Table 10.1 U.S. Default Factors for Calculating CO_2 Emissions from Fossil Fuel Combustion and biomass combustion (Climate registry, released January 2, 2013)

Fuel Type	Heat Content	Carbon Content (Per Unit Energy)	Fraction Oxidized	CO_2 Emission Factor (Per Unit Energy)	CO_2 Emission Factor (Per Unit Mass or Volume)
Coal and Coke	**MMBtu / Short ton**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO_2 / Short ton**
Anthracite	25.09	28.24	1	103.54	2597.82
Bituminous	24.93	25.47	1	93.40	2328.46
Subbituminous	17.25	26.46	1	97.02	1673.60
Lignite	14.21	26.28	1	96.36	1369.28
Coke	24.80	27.83	1	102.04	2530.59
Mixed Electric Utility/electric power	19.73	25.74	1	94.38	1862.12
Unspecified Residential/Com*	22.05	26.00	1	95.33	2102.03
Mixed commercial sector	21.39	25.98	1	95.26	2037.61
Mixed industrial coking	26.28	25.54	1	93.65	2461.12
Mixed industrial sector	22.35	25.61	1	93.91	2098.89
Natural Gas	**Btu/scf**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO2/scf**
Pipeline (US weighted average)	1028	14.47	1	53.02	0.0545
Greater than 1000 Btu	>1000	14.47	1	53.06	Varies
975 to 1000	975-1,000	14.73*	1	54.01*	Varies
1000 to 1025	1,000 – 1,025	14.43	1	52.91*	Varies
1025-1035	1025-1035	14.45	1	52.98*	Varies
1025 to 1050	1,025 – 1,050	14.47*	1	53.06*	Varies
1050 to 1075	1,050 – 1,075	14.58*	1	53.46*	Varies
1075 to 1100	1,075 – 1,100	14.65*	1	53.72*	Varies
Greater than 1100	> 1,110	14.92*	1	54.71*	Varies
Petroleum Products	**MMBtu / gallon**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
Distillate Fuel Oil No. 1	0.139	19.98	1	73.25	10.18
Distillate Fuel Oil No. 2	0.138	20.17	1	73.96	10.21
Distillate Fuel Oil No. 4	0.146	20.47	1	75.04	10.96
Residual Fuel 5 No. 5	0.140	19.89	1	72.93	10.21

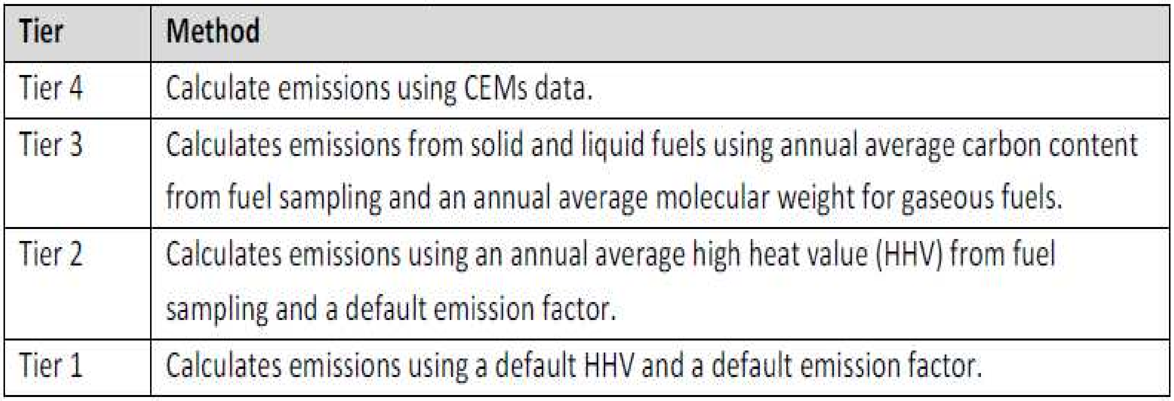
Residual Fuel 5 No. 6	0.150	20.48	1	75.10	11.27
Still Gas	0.143	18.20	1	66.72	9.54
Kerosene	0.135	20.51	1	75.20	10.15
LPG	0.092	17.18	1	62.98	5.79
Propane	0.091	16.76	1	61.46	5.59
Ethane	0.096	17.08	1	62.64	6.01
Propylene	0.091	17.99	1	65.95	6.00
Ethylene	0.100	18.39	1	67.43	6.74
Isobutene	0.097	17.70	1	64.91	6.30
Isobutylene	0.103	18.47	1	67.74	6.98
Butane	0.101	17.77	1	65.15	6.58
Butylenes	0.103	18.47	1	67.73	6.98
Naphtha (<401d F)	0.125	18.55	1	68.02	8.50
Natural Gasoline	0.110	18.23	1	66.83	7.35
Other oil (>401 d F)	0.139	20.79	1	76.22	10.59
Pentanes Plus	0.110	19.10	1	70.02	7.70
Petrochemical Feedstocks	0.129	19.36	1	70.97	9.16
Petroleum Coke	0.143	27.93	1	102.41	14.64
Special Naphtha	0.125	19.73	1	72.34	9.04
Unfinished Oils	0.139	20.32	1	74.49	10.35
Heavy Gas Oils	0.148	20.43	1	74.92	11.09
Lubricants	0.144	20.26	1	74.27	10.69
Motor Gasoline	0.125	19.15	1	70.22	8.78
Aviation Gasoline	0.120	18.89	1	69.25	8.31
Kerosene Type Jet Fuel	0.135	19.70	1	72.22	9.75
Asphalt and Road Oil	0.158	20.55	1	75.36	11.91
Crude Oil	0.138	20.32	1	74.49	10.28
Waxes*	0.132	19.81	1	72.64	9.58
Fossil Fuel-derived Fuels (gaseous)	**MMBtu/scoff**	**kg C / MMBtu**		**g CO2/MMBtu**	**g CO2/short ton**
Acetylene***	0.00147	n/a	1	0.0716	n/a
Fossil Fuel-derived Fuels (solid)	**MMBtu/short ton**	**kg C / MMBtu**		**kg CO2/MMBtu**	**kg CO2/short ton**
Municipal Solid Waste	9.95	24.74	1	90.7	902.47
Tires	26.87	23.45	1	85.97	2310.01
Fossil Fuel-derived Fuels (gaseous)	**MMBtu/scf**	**kg C / MMBtu**		**kg CO2/MMBtu**	**kg CO2 / scf**
Blast Furnace Gas	0.000092	n/a	1	274.32	0.0252
Coke Oven Gas	0.000599	n/a	1	46.85	0.0281

Biomass Fuels-Solid	**MMBtu/short ton**	**kg C / MMBtu**		**kg CO2/MMBtu**	**kg CO2/short ton**
Wood and Wood Residuals	15.38	25.58	1	93.80	1442.64
Agricultural Byproducts	8.25	32.23	1	118.17	974.90
Peat	8.00	30.50	1	111.84	894.72
Solid Byproducts	25.83	28.78	1	105.51	2725.32
Kraft Black Liquor (NA hardwood)**	11.98	25.75	1	94.41	1131.03
Kraft Black Liquor (NA softwood)**	12.24	25.94	1	95.13	1164.39
Biomass Fuels-Gaseous	**MMBtu/scf**	**kg C / MMBtu**		**kg CO2 / MMBtu**	**kg CO2 / scf**
Biogas (captured methane)	0.000841	14.20	1	52.07	0.0438
Landfill Gas (50% CH4/50%Co2)**	0.0005025	14.20	1	52.07	0.0262
Wastewater Treatment Biogas**	Varies	14.20	1	52.07	Varies
Biomass Fuels - Liquid	**MMBtu/gallon**	**kg C / MMBtu**		**kg CO2 / MMBtu**	**kg CO2/gallon**
Ethanol (100%)	0.084	18.67	1	68.44	5.75
Biodiesel (100%)	0.128	20.14	1	73.84	9.45
Rendered Animal Fat	0.125	19.38	1	71.06	8.88
Vegetable Oil	0.120	22.24	1	81.55	9.79
Geothermal	**MMBtu/gallon**	**kg C / MMBtu**		**kg CO2 / MMBtu**	**kg CO2/MMBtu**
Geothermal*	n/a	2.05		n/a	n/a

Source: Heat Content and Default Emission factors are from EPA Final Mandatory Reporting of Greenhouse Gases Rule Table C-1. Carbon Content derived using the heat content and default emission factor. Except those marked with * are from US Inventory of Greenhouse Gas Emissions and Sinks 2004-2007 (2009) and **EPA Climate Leaders Technical Guidance (2008) Table B-2 and *** derived from the API Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry (2009) Table 3-8.

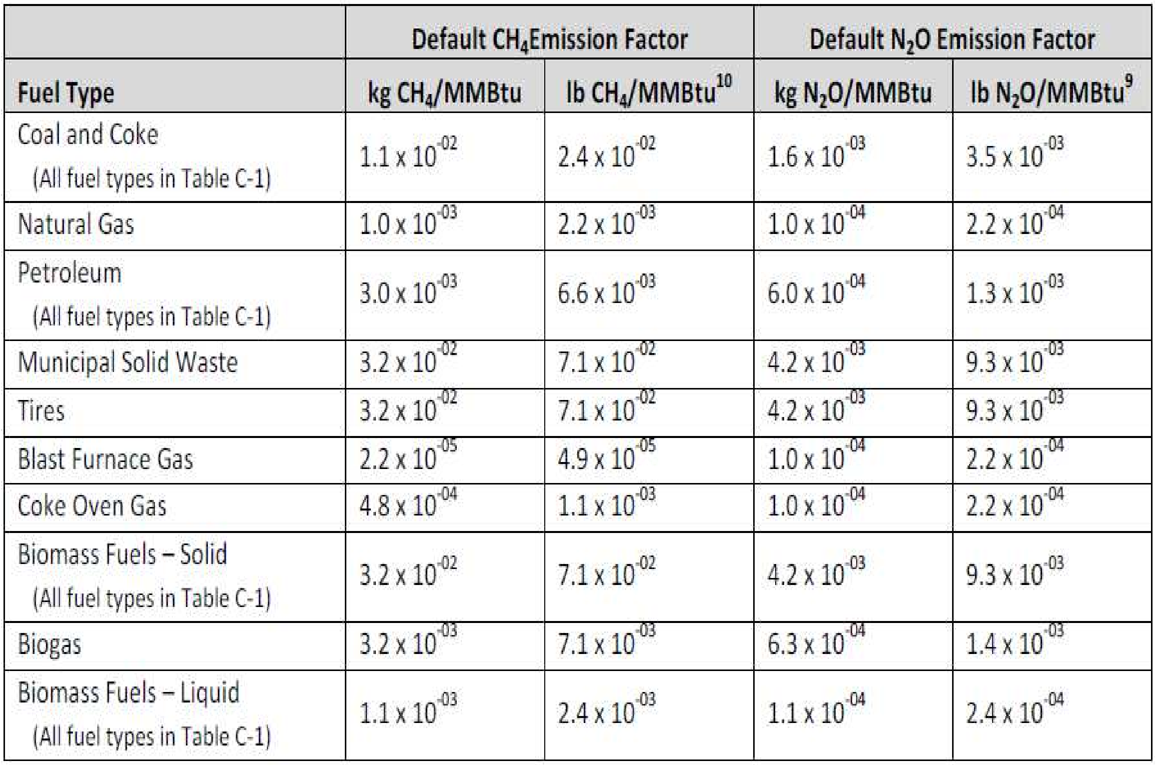
CO_2, N_2O and CH_4 are all emitted from the combustion of fossil fuels from stationary sources. CO_2 is formed from the oxidation of the fuel carbon, CH_4 is a production of incomplete combustion, and N_2O is formed by oxygen-nitrogen reactions. In 40 CFR 98 subpart C four methods (called Tiers) for calculating actual GHG emissions from stationary fossil fuel combustion sources as introduced by "Estimation of GHG Emissions Recommended for Stationary Source Categories Iowa DNR". Last updated 9/9/2013:

Table 10.2: 40 CFR 98 Subpart C Tiers



Tier	Method
Tier 4	Calculate emissions using CEMs data.
Tier 3	Calculates emissions from solid and liquid fuels using annual average carbon content from fuel sampling and an annual average molecular weight for gaseous fuels.
Tier 2	Calculates emissions using an annual average high heat value (HHV) from fuel sampling and a default emission factor.
Tier 1	Calculates emissions using a default HHV and a default emission factor.

Table 10.3: Default CH_4 and N_2O Emissions Factors for Various Types of Fuels



	Default CH_4 Emission Factor		Default N_2O Emission Factor	
Fuel Type	**kg CH_4/MMBtu**	**lb CH_4/MMBtu[10]**	**kg N_2O/MMBtu**	**lb N_2O/MMBtu[9]**
Coal and Coke (All fuel types in Table C-1)	1.1×10^{-02}	2.4×10^{-02}	1.6×10^{-03}	3.5×10^{-03}
Natural Gas	1.0×10^{-03}	2.2×10^{-03}	1.0×10^{-04}	2.2×10^{-04}
Petroleum (All fuel types in Table C-1)	3.0×10^{-03}	6.6×10^{-03}	6.0×10^{-04}	1.3×10^{-03}
Municipal Solid Waste	3.2×10^{-02}	7.1×10^{-02}	4.2×10^{-03}	9.3×10^{-03}
Tires	3.2×10^{-02}	7.1×10^{-02}	4.2×10^{-03}	9.3×10^{-03}
Blast Furnace Gas	2.2×10^{-05}	4.9×10^{-05}	1.0×10^{-04}	2.2×10^{-04}
Coke Oven Gas	4.8×10^{-04}	1.1×10^{-03}	1.0×10^{-04}	2.2×10^{-04}
Biomass Fuels – Solid (All fuel types in Table C-1)	3.2×10^{-02}	7.1×10^{-02}	4.2×10^{-03}	9.3×10^{-03}
Biogas	3.2×10^{-03}	7.1×10^{-03}	6.3×10^{-04}	1.4×10^{-03}
Biomass Fuels – Liquid (All fuel types in Table C-1)	1.1×10^{-03}	2.4×10^{-03}	1.1×10^{-04}	2.4×10^{-04}

Table 10.4: Default CO_2 Emissions Factors and High Heating Values for Various Fuels Types

Fuel Type	Default High Heat Value (HHV)	Default CO_2 emission factor	
Coal and Coke	MMBtu/ton[4]	kg CO_2/MMBtu	lb CO_2/MMBtu[5]
Anthracite	25.09	103.54	228.27
Bituminous	24.93	93.40	205.91
Subbituminous	17.25	97.02	213.89
Lignite	14.21	96.36	212.44
Coke	24.80	102.04	224.96
Mixed (Commercial sector)	21.39	95.26	210.01
Mixed (Industrial coking)	26.28	93.65	206.46
Mixed (Industrial sector)	22.35	93.91	207.04
Mixed (Electric Power sector)	19.73	94.38	208.07
Natural Gas	MMBtu/scf	kg CO_2/MMBtu	lb CO_2/MMBtu
(Weighted U.S. Average)	1.028×10^{-3}	53.02	116.89
Petroleum Products	MMBtu/gallon	kg CO_2/MMBtu	lb CO_2/MMBtu
Distillate Oil No. 1	0.139	73.25	161.49
Distillate Oil No. 2	0.138	73.96	163.05
Distillate Oil No. 4	0.146	75.04	165.43
Residual Fuel Oil No. 5	0.140	72.93	160.78
Residual Fuel Oil No. 6	0.150	75.10	165.57
Used Oil	0.135	74.00	163.14
Kerosene	0.135	75.20	165.79
Liquefied petroleum gases (LPG)	0.092	62.98	138.85
Propane	0.091	61.46	135.50
Propylene	0.091	65.95	145.39
Ethane	0.069	62.64	138.10
Ethanol	0.084	68.44	150.88
Ethylene	0.100	67.43	148.66
Isobutane	0.097	64.91	143.10
Isobutylene	0.103	67.74	149.34
Butane	0.101	65.15	143.63
Butylene	0.103	67.73	149.32
Naphtha (<401 deg F)	0.125	68.02	149.96
Natural Gasoline	0.110	66.83	147.33

Municipal Solid Waste (MSW)	9.95[7]	90.7	199.96
Tires	26.87	85.97	189.53
Plastics	38.00	75.00	165.35
Petroleum Coke	30.00	102.41	225.78
Other fuels - gaseous	MMBtu/scf	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu
Blast Furnace Gas	0.092×10^{-3}	274.32	604.77
Coke Oven Gas	0.599×10^{-3}	46.85	103.29
Propane Gas	2.516×10^{-3}	61.46	135.50
Fuel Gas[7]	1.388×10^{-3}	59.00	130.07
Biomass fuels - solid	MMBtu/ton[8]	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu
Wood and Wood Residuals	15.38	93.80	206.79
Agricultural Byproducts	8.25	118.17	260.52
Peat	8.00	111.84	246.56
Solid Byproducts	25.83	105.51	232.61
Biomass Fuels - gaseous	MMBtu/scf	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu
Biogas (Captured methane)	0.841×10^{-3}	52.07	114.79
Biomass Fuels - liquid	MMBtu/gallon	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu
Ethanol	0.084	68.44	150.88
Biodiesel	0.128	73.84	162.79
Rendered Animal Fat	0.125	71.06	156.66
Vegetable Oil	0.120	81.55	179.79

Petroleum Products	**MMBtu/gallon**	**kg CO$_2$/MMBtu**	**lb CO$_2$/MMBtu**
Other Oil (>401 deg F)	0.139	76.22	168.04
Pentanes Plus	0.110	70.02	154.37
Petrochemical Feedstocks	0.129	70.97	156.46
Petroleum Coke	0.143	102.41	225.78
Special Naphtha	0.125	72.34	159.48
Unfinished Oils	0.139	74.49	164.22
Heavy Gas Oils	0.148	74.92	165.17
Lubricants	0.144	74.27	163.74
Motor Gasoline	0.125	70.22	154.81
Aviation Gasoline	0.120	69.25	152.67
Kerosene-Type Jet Fuel	0.135	72.22	159.22
Asphalt and Road Oil	0.158	75.36	166.14
Crude Oil	0.138	74.49	164.22
Other fuels - solid	MMBtu/ ton[6]	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu
Municipal Solid Waste (MSW)	9.95[7]	90.7	199.96
Tires	26.87	85.97	189.53
Plastics	38.00	75.00	165.35
Petroleum Coke	30.00	102.41	225.78
Other fuels - gaseous	MMBtu/scf	kg CO$_2$/MMBtu	lb CO$_2$/MMBtu

APPENDIX B

ENERGY, EQUIPMENT AND PROCESS INVENTORY SURVEY FOR WWTPs

Source: Author

Phase I - General Information:

WWTP Name:
WWTP Address:
Name and Title of Authorized:
WWTP Design Flow Rate (MGD);
WWTP Average Actual Daily Flow Rate (MGD)
WWTP Average Annual Operating days / hours:
Population Served by WWTP:
Wastewater Chemical Formula, if known:

Flow Characteristics:

BOD5	(lb/day)
TSS	(lb/day)
Total Kjeldahl Nitrogen	(lb/Day)

Treatment Process Level or Type: (Please check appropriate cell)

1. Trickling Filter Treatment Plant
2. Activated Sludge Treatment plan
3. Advanced Treatment plant without Nitrification
4. Advanced Treatment plant with nitrification
5. Please Attach copy of any plant energy audit that was done in the last five years or before any major change to plant
6. Your comments to improve this survey are highly appreciated.

Phase 2 - Technical Data:

1. Fill in all but only data pertaining to your WWTP in the Spreadsheet below
2. Only actual operating equipment are needed. Do not include standby equipment
3. For environmental and treatment chemicals, please supply the annual consumption amounts
4. If you have ant greenhouse Gas Calculation done before, please attach to your survey response
5. Please attach on separate paper any source of energy consumption; electric, natural gas and other fuels or renewable energy if that doesn't fit or not included in table below
6. Don't need to total at the colored lines

Plant Operations and Processes Energy Use Sources	Energy Inventory, Activity or Matrix																				
	Electric Energy Use (kWh)															Chemicals Consumed (Lb), (Gal) per	Natural Gas (MCF) per year	Gasoline (Gal) / year	Diesel (Gal) / year	Butane/ Propane (Gal) / year	mmBtu - Renewable or Other Sources
	Pumps (HP)	Pumps Number	% efficiency % load	Other Motors (HP)	Motors Number	% efficiency % load	Lighting (kW)	HVAC (kW)	Others (kWh)	Environ. Equipment (kW)	Auxiliary Equipment (kW)	Portable Compr. Air (kW)	Comp Air from Plant (kW)	kWh - Renewable or Other Sources	Annual Operating Hours						
Inflow Structure/Total:																					
WW Pumping - Influent																					
WW Pumping - Sludge/debris																					
Preliminary Treatment/Total																					
Screens, all Types																					
Coarse Solids Reducers																					
Aerated Grit Removal:																					
Aeration Equipment																					
Grit-Removal & Collector Equipment's																					
Grit Separators and Washers																					
Grit Pumping																					
Grit Disposal Equipment																					
Flow Equalization:																					
Pumping In and Out																					
Mixing Equipment																					
Aeration Equipment																					
Auxiliary Equipment and Processes:																					
Motors																					
Wet-weather Flows Pumping																					
Water Heating and Cooling																					
Air Handling Units (AHUs)																					
Lighting																					
Odor control																					
Primary Treatment/Total																					
Sedimentation Tank Motors																					
Sedimentation Tank Pumps																					
Primary Clarifiers Motors																					
Primary Clarifiers Pumps																					
Sludge Collection System																					
Sludge Pumping																					
Auxiliary Equipment, Motors and Injectors																					
Advanced Primary Treatment:																					
Chemical Precipitation																					
Secondary Treatment/Total																					
Biological Processes - Aerobic Digestion																					
Activated-Sludge Process:																					
Secondary Clarifiers Motors																					
Secondary Clarifiers Pumps																					
Aeration Tanks Pumps																					
Aeration Tanks Motors																					

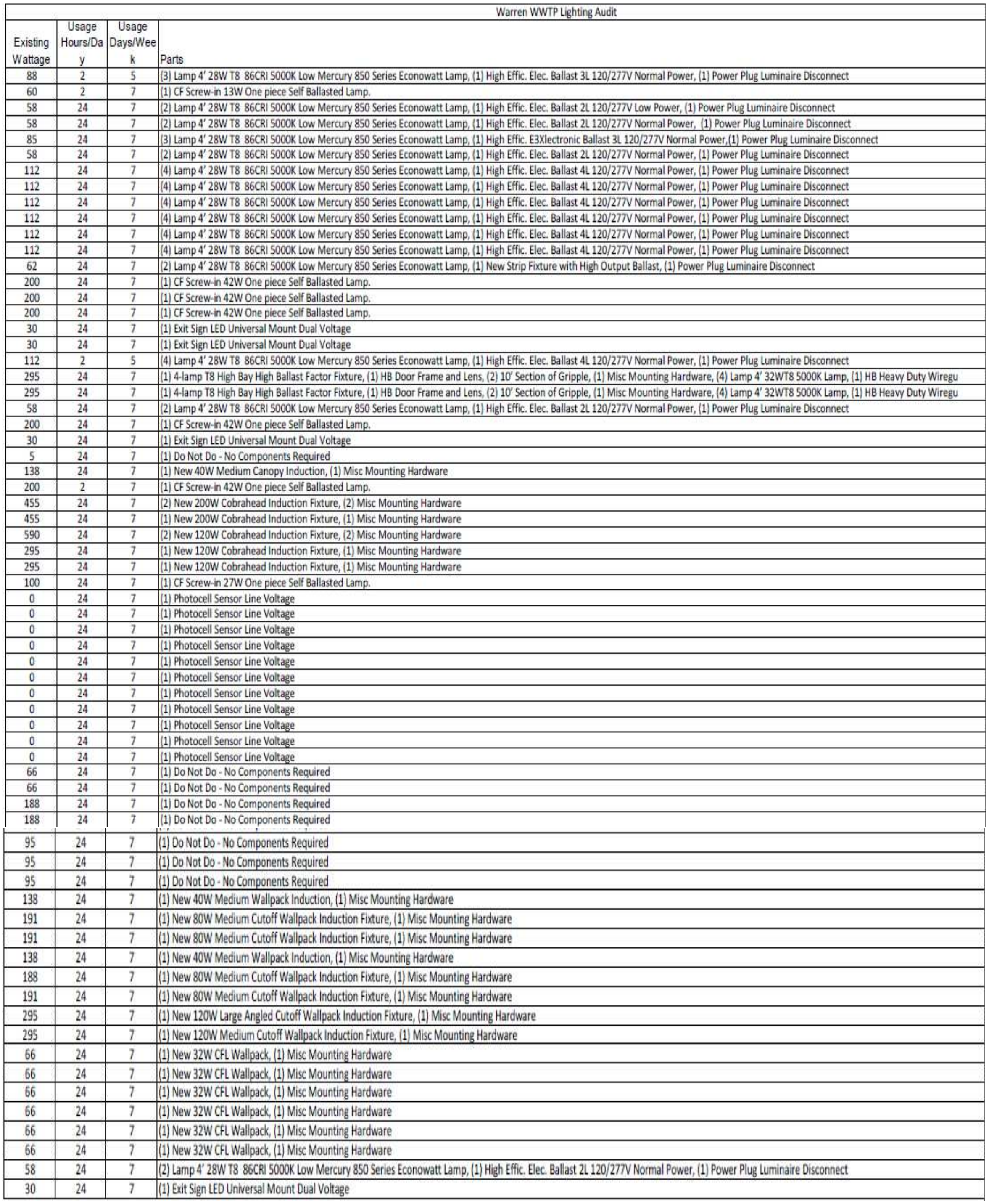
Settling Tanks/Solids Separation																					
Sludge Collection System																					
Waste Sludge Pumps																					
Return Activated Sludge Pumps																					
Other Items																					
Internal Recycle Pumps																					
Auxiliary Equipment, Motors and Injectors																					
Effluent Pumps to Next Treatment																					
Aerated Lagoons:																					
Settling Pond																					
Trickling Filters:																					
Recycle Pumps																					
Water Distributers																					
Rotating Biological Contactors:																					
RBC Drive Motors																					
RBC Air Input																					
Settling Tanks Pumps																					
Aeration Systems:																					
Air Blower Motors																					
Mixtures Motors																					
Compressed Air/Diffused Aeration																					
Low-Speed Turbines																					
Motorized Technologies																					
High Purity Oxygen																					
Biological Processes - Anaerobic Digestion																					
Mixing by Gas Recirculation, Pumping, or Draft-Tube																					
Sludge In-Pumping																					
Sludge Out-Pumping																					
Heating																					
Ventilation/Gas Extraction																					
Motors																					
Anaerobic Covered Lagoon																					
Anaerobic Membrane Separation																					
Chemical Processes:																					
Precipitation: Alum, Aluminum Chloride																					
Precipitation: Ca (OH)$_2$ Lime																					
Dolomitic Lime																					
Neutralization: Cao, CaCO$_3$																					
Neutralization: NaOH, HCL, H$_2$SO$_4$																					
FeCl$_3$ Iron Compounds																					
Chemicals for nitrification, Denitrification																					
Chemicals for phosphorus removal; metal salts,																					
Storage:																					
Motors																					

Dosing Pumps																					
Feed pumps																					
Mixers																					
Compressed Air																					
Tank Shaker																					
Advanced /Tertiary Treatment with or without Nitrification																					
Technology Motors																					
Technology Pumping																					
Technology Air																					
Technology Chemicals																					
Backwash Pumping																					
Disinfection:																					
Chlorination, Chlorine Compounds																					
UV																					
Ozone																					
Solids:																					
Solids Treatment																					
Solids Pumping																					
Solids Thickeners:																					
Sludge and Biosolids Dewatering:																					
Others																					
Compressed Air																					
Electricity																					
Ventilators																					
Odor Controls:																					
Activated Carbon, NaOH , HCL																					
Electricity																					
Pumps or Vacuums																					
Auxiliary Stations/Total																					
Chlorination Building;																					
Dosing Pumps																					
Electrical equipment's, Lighting																					
Workshops:																					
Electrical Machines																					
Natural gas /propane																					
Effluent Discharge pumping																					
Plant Buildings:																					
Lighting (interior, exterior,)																					
Office Equipment and Appliances																					
HVAC																					
In-plant Street Lighting																					
Miscellaneous/ Total:																					
Groundwater Pumping																					
Energy for Recycling																					

APPENDIX – C

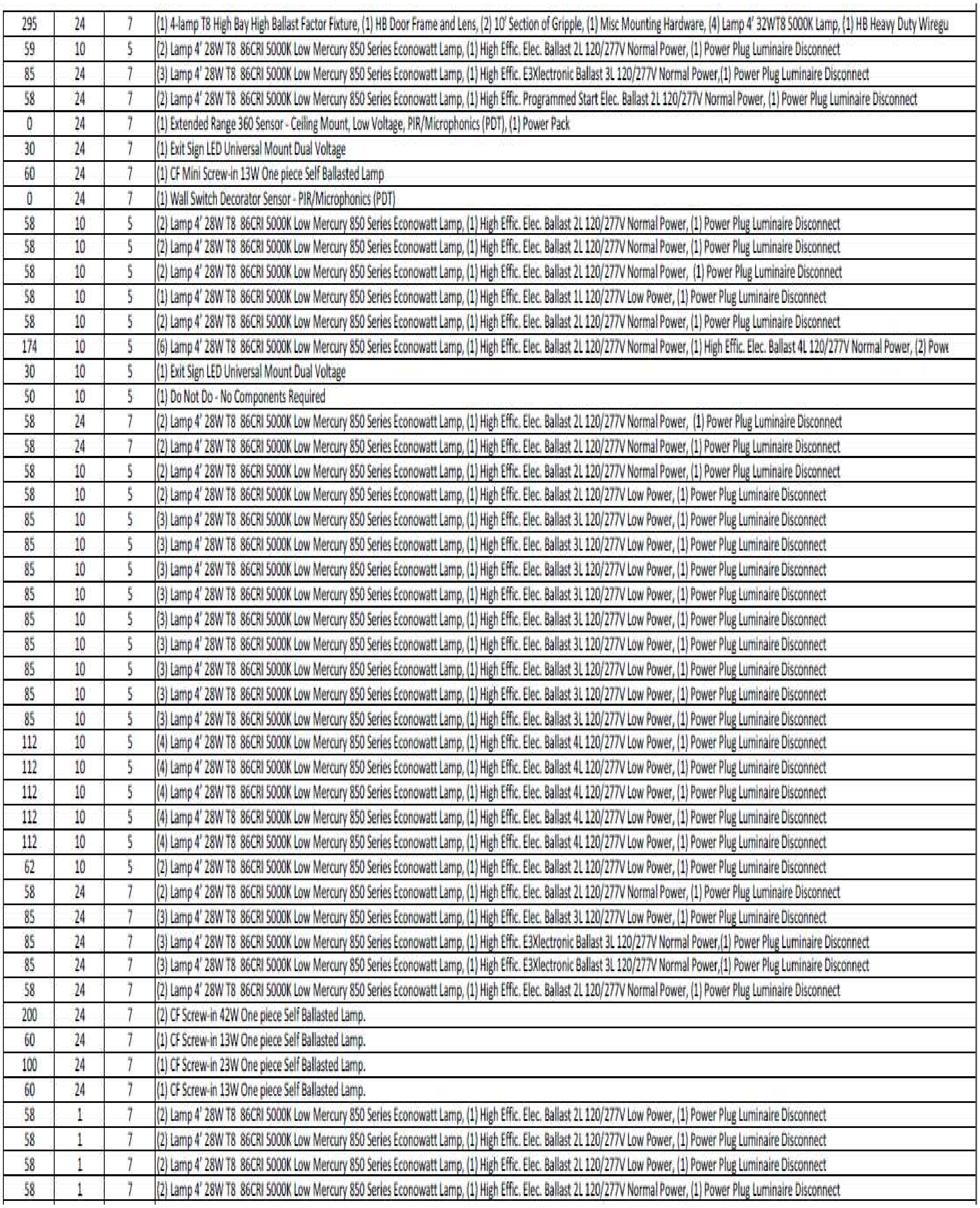
AUDITS AND OTHER DATA

1 - Warren WWTP – Lighting Audit- Source: Warren WWTP for all the audits

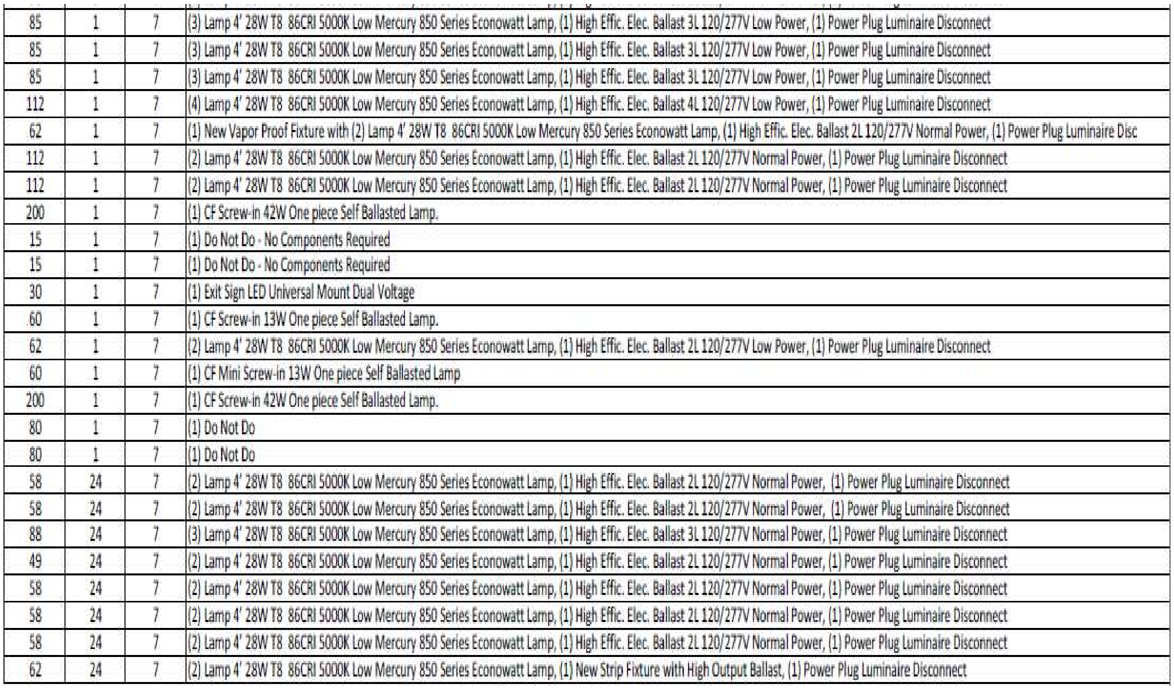


Warren WWTP Lighting Audit

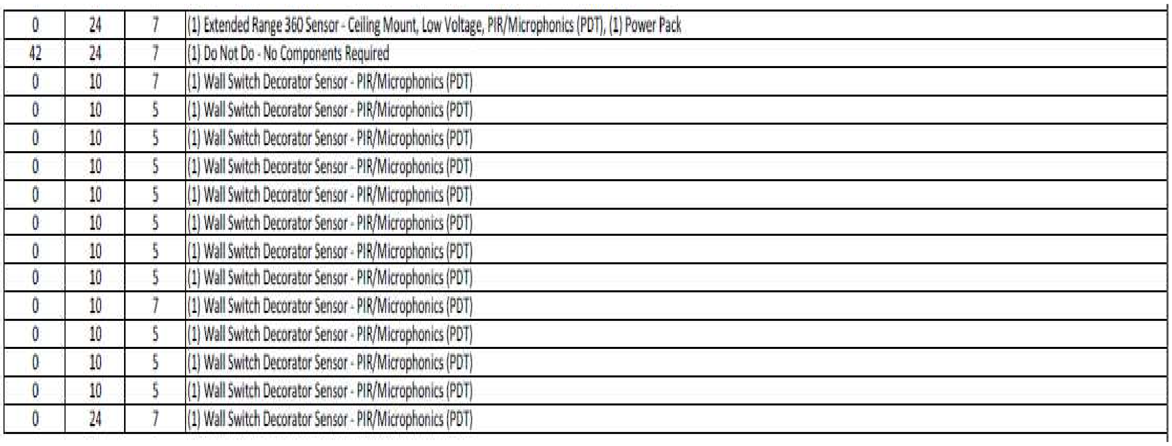
Existing Wattage	Usage Hours/Day	Usage Days/Week	Parts
88	2	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
60	2	7	(1) CF Screw-in 13W One piece Self Ballasted Lamp.
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
85	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. E3Xlectronic Ballast 3L 120/277V Normal Power,(1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
62	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New Strip Fixture with High Output Ballast, (1) Power Plug Luminaire Disconnect
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage
112	2	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
295	24	7	(1) 4-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10' Section of Gripple, (1) Misc Mounting Hardware, (4) Lamp 4' 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
295	24	7	(1) 4-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10' Section of Gripple, (1) Misc Mounting Hardware, (4) Lamp 4' 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage
5	24	7	(1) Do Not Do - No Components Required
138	24	7	(1) New 40W Medium Canopy Induction, (1) Misc Mounting Hardware
200	2	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
455	24	7	(2) New 200W Cobrahead Induction Fixture, (2) Misc Mounting Hardware
455	24	7	(1) New 200W Cobrahead Induction Fixture, (1) Misc Mounting Hardware
590	24	7	(2) New 120W Cobrahead Induction Fixture, (2) Misc Mounting Hardware
295	24	7	(1) New 120W Cobrahead Induction Fixture, (1) Misc Mounting Hardware
295	24	7	(1) New 120W Cobrahead Induction Fixture, (1) Misc Mounting Hardware
100	24	7	(1) CF Screw-in 27W One piece Self Ballasted Lamp.
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
0	24	7	(1) Photocell Sensor Line Voltage
66	24	7	(1) Do Not Do - No Components Required
66	24	7	(1) Do Not Do - No Components Required
188	24	7	(1) Do Not Do - No Components Required
188	24	7	(1) Do Not Do - No Components Required
95	24	7	(1) Do Not Do - No Components Required
95	24	7	(1) Do Not Do - No Components Required
95	24	7	(1) Do Not Do - No Components Required
138	24	7	(1) New 40W Medium Wallpack Induction, (1) Misc Mounting Hardware
191	24	7	(1) New 80W Medium Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
191	24	7	(1) New 80W Medium Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
138	24	7	(1) New 40W Medium Wallpack Induction, (1) Misc Mounting Hardware
188	24	7	(1) New 80W Medium Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
191	24	7	(1) New 80W Medium Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
295	24	7	(1) New 120W Large Angled Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
295	24	7	(1) New 120W Medium Cutoff Wallpack Induction Fixture, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
66	24	7	(1) New 32W CFL Wallpack, (1) Misc Mounting Hardware
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage



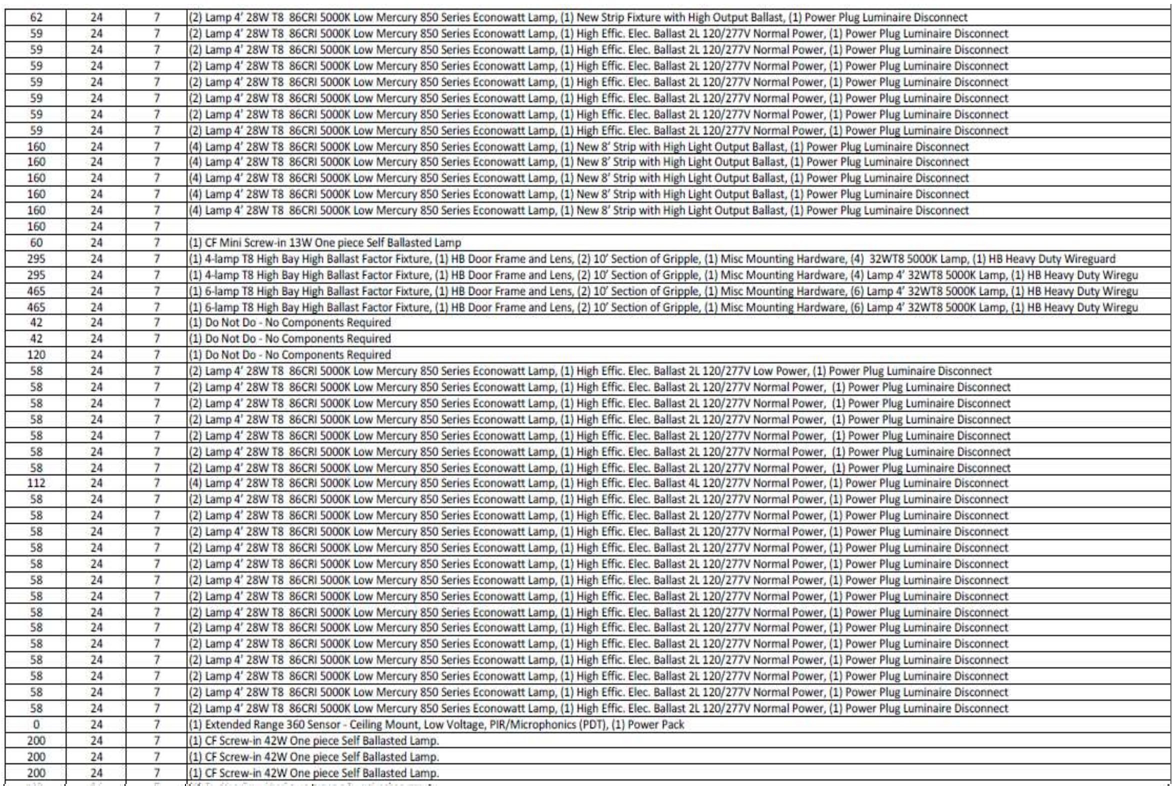
295	24	7	(1) 4-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10' Section of Gripple, (1) Misc Mounting Hardware, (4) Lamp 4' 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
59	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
85	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. E3Xlectronic Ballast 3L 120/277V Normal Power,(1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Programmed Start Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
0	24	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage
60	24	7	(1) CF Mini Screw-in 13W One piece Self Ballasted Lamp
0	24	7	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	10	5	(1) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 1L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
174	10	5	(6) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (2) Powe
30	10	5	(1) Exit Sign LED Universal Mount Dual Voltage
50	10	5	(1) Do Not Do - No Components Required
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	10	5	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	10	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	10	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	10	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	10	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	10	5	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
62	10	5	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
85	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. E3Xlectronic Ballast 3L 120/277V Normal Power,(1) Power Plug Luminaire Disconnect
85	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. E3Xlectronic Ballast 3L 120/277V Normal Power,(1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
200	24	7	(2) CF Screw-in 42W One piece Self Ballasted Lamp.
60	24	7	(1) CF Screw-in 13W One piece Self Ballasted Lamp.
100	24	7	(1) CF Screw-in 23W One piece Self Ballasted Lamp.
60	24	7	(1) CF Screw-in 13W One piece Self Ballasted Lamp.
58	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect



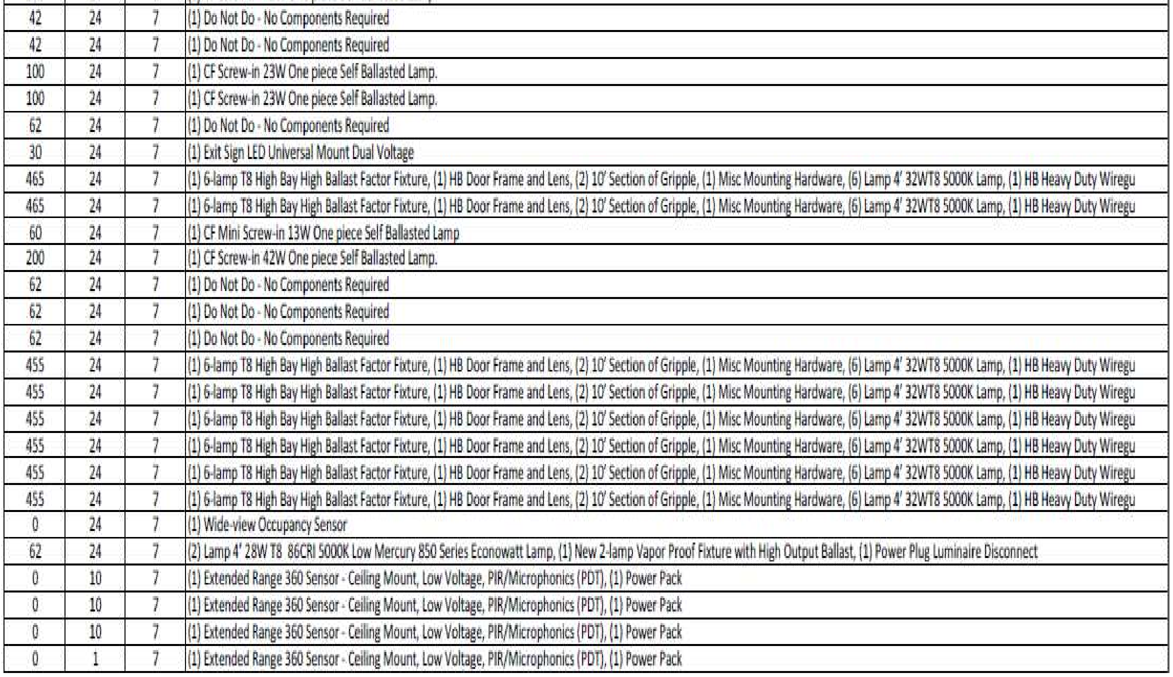
85	1	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	1	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
85	1	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
112	1	7	(4) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
62	1	7	(1) New Vapor Proof Fixture with (2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disc
112	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
200	1	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
15	1	7	(1) Do Not Do - No Components Required
15	1	7	(1) Do Not Do - No Components Required
30	1	7	(1) Exit Sign LED Universal Mount Dual Voltage
60	1	7	(1) CF Screw-in 13W One piece Self Ballasted Lamp.
62	1	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
60	1	7	(1) CF Mini Screw-in 13W One piece Self Ballasted Lamp
200	1	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
80	1	7	(1) Do Not Do
80	1	7	(1) Do Not Do
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
88	24	7	(3) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 3L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
49	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
62	24	7	(2) Lamp 4' 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New Strip Fixture with High Output Ballast, (1) Power Plug Luminaire Disconnect



0	24	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
42	24	7	(1) Do Not Do - No Components Required
0	10	7	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	7	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	10	5	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)
0	24	7	(1) Wall Switch Decorator Sensor - PIR/Microphonics (PDT)

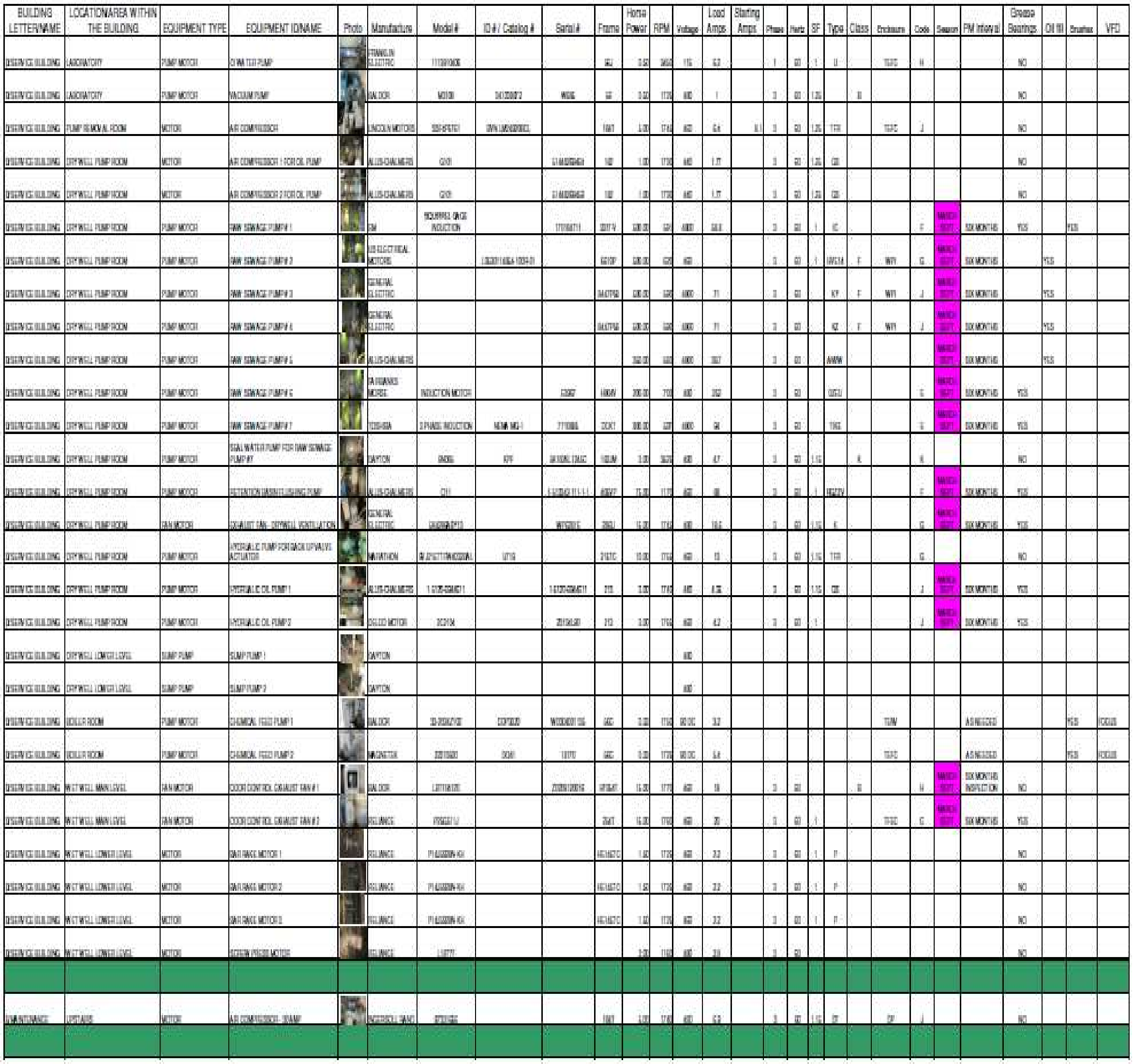


62	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New Strip Fixture with High Output Ballast, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
59	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
160	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 8’ Strip with High Light Output Ballast, (1) Power Plug Luminaire Disconnect
160	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 8’ Strip with High Light Output Ballast, (1) Power Plug Luminaire Disconnect
160	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 8’ Strip with High Light Output Ballast, (1) Power Plug Luminaire Disconnect
160	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 8’ Strip with High Light Output Ballast, (1) Power Plug Luminaire Disconnect
160	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 8’ Strip with High Light Output Ballast, (1) Power Plug Luminaire Disconnect
160	24	7	
60	24	7	(1) CF Mini Screw-in 13W One piece Self Ballasted Lamp
295	24	7	(1) 4-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (4) 32WT8 5000K Lamp, (1) HB Heavy Duty Wireguard
295	24	7	(1) 4-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (4) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
465	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
465	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
42	24	7	(1) Do Not Do - No Components Required
42	24	7	(1) Do Not Do - No Components Required
120	24	7	(1) Do Not Do - No Components Required
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Low Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
112	24	7	(4) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 4L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
58	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) High Effic. Elec. Ballast 2L 120/277V Normal Power, (1) Power Plug Luminaire Disconnect
0	24	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.

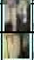


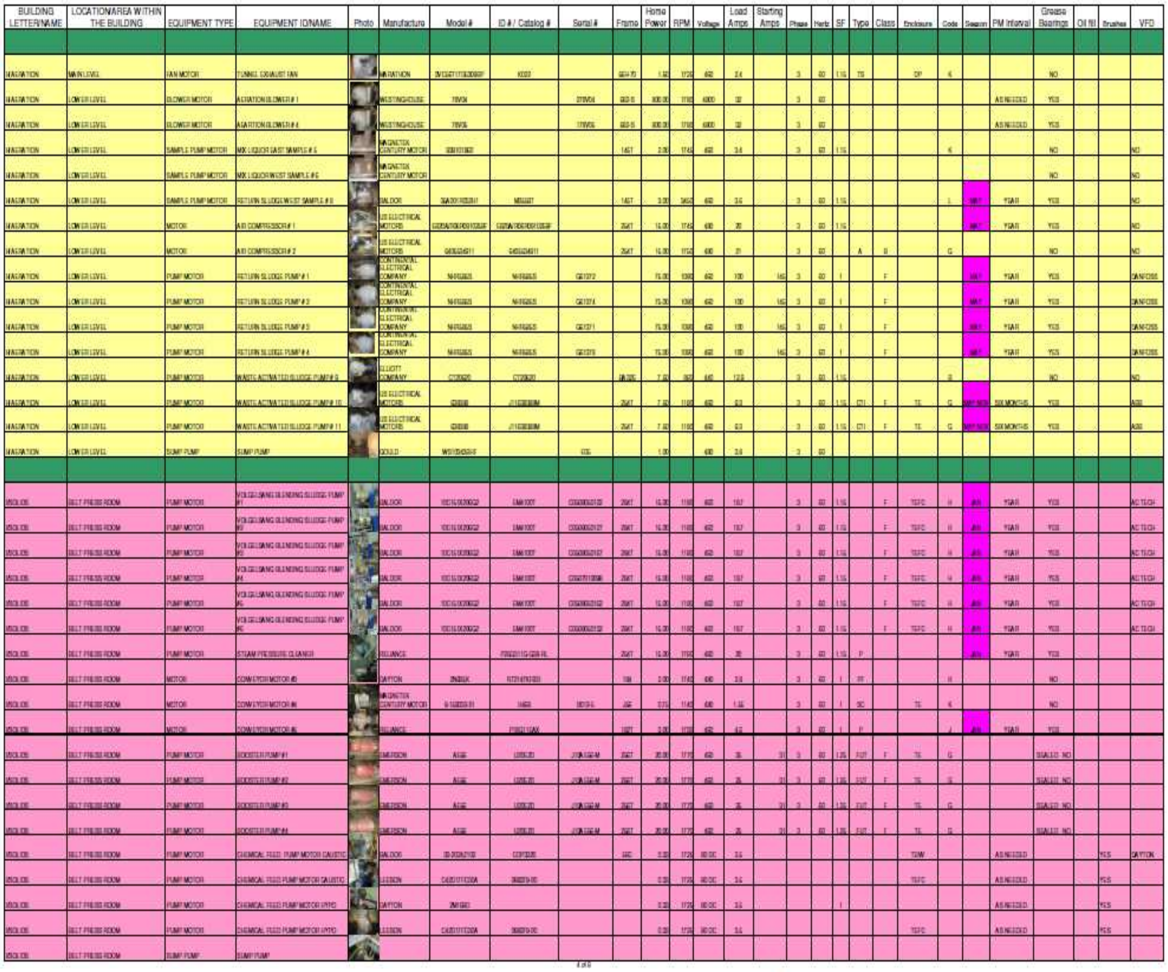
42	24	7	(1) Do Not Do - No Components Required
42	24	7	(1) Do Not Do - No Components Required
100	24	7	(1) CF Screw-in 23W One piece Self Ballasted Lamp.
100	24	7	(1) CF Screw-in 23W One piece Self Ballasted Lamp.
62	24	7	(1) Do Not Do - No Components Required
30	24	7	(1) Exit Sign LED Universal Mount Dual Voltage
465	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
465	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
60	24	7	(1) CF Mini Screw-in 13W One piece Self Ballasted Lamp
200	24	7	(1) CF Screw-in 42W One piece Self Ballasted Lamp.
62	24	7	(1) Do Not Do - No Components Required
62	24	7	(1) Do Not Do - No Components Required
62	24	7	(1) Do Not Do - No Components Required
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
455	24	7	(1) 6-lamp T8 High Bay High Ballast Factor Fixture, (1) HB Door Frame and Lens, (2) 10’ Section of Gripple, (1) Misc Mounting Hardware, (6) Lamp 4’ 32WT8 5000K Lamp, (1) HB Heavy Duty Wiregu
0	24	7	(1) Wide-view Occupancy Sensor
62	24	7	(2) Lamp 4’ 28W T8 86CRI 5000K Low Mercury 850 Series Econowatt Lamp, (1) New 2-lamp Vapor Proof Fixture with High Output Ballast, (1) Power Plug Luminaire Disconnect
0	10	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
0	10	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
0	10	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack
0	1	7	(1) Extended Range 360 Sensor - Ceiling Mount, Low Voltage, PIR/Microphonics (PDT), (1) Power Pack

2 – Warren WWTP - Motor Inventory Survey



BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Photo	Manufacture	Model #	ID # / Catalog #	Serial #	Frame	Horse Power	RPM	Voltage	Load Amps	Starting Amps	Phase	Hertz	SF	Type	Class	Enclosure	Code	Season	PM Interval	Grease Bearings	Oil fill	Brushes	VFD
H-GENERATOR BUILDING	GENERATOR AREA	DIESEL MOTOR	DIESEL GENERATOR MOTOR		GENERAL MOTORS	16-645-E4	[illegible]	71-01-1136		2100KW	900	4000			3	60				DIESEL		JUNE	YEAR CONTRACTED				
H-GENERATOR BUILDING	GENERATOR AREA	MOTOR	AIR COMPRESSOR AC		GENERAL ELECTRIC	5K213AK213	INDUCTION	MC	213TS	7.50	1750	460	11		3	60	1.15	K			H			NO			
H-GENERATOR BUILDING	GENERATOR AREA	MOTOR	AIR COMPRESSOR DC		GENERAL ELECTRIC	5CD152XA001A001	CD258AT	AC-1-85		10.00	3500	[illegible]	72.6							DPFG	D			NO			
H-GENERATOR BUILDING	GENERATOR AREA	FAN MOTOR	COOLING FAN EAST 1		US ELECTRICAL MOTORS			[illegible]	254T	15.00	1800	460	18.6		3	60	1	T			F	JUNE	YEAR	YES			
H-GENERATOR BUILDING	GENERATOR AREA	FAN MOTOR	COOLING FAN WEST 2		US ELECTRICAL MOTORS	R-1724-03-275			254T	15.00	1760	460	21		3	60	1					JUNE	YEAR	YES			
H-GENERATOR BUILDING	GENERATOR AREA	FAN MOTOR	EXHAUST FAN		DAYTON	6K631	[illegible]		56HZ	1.00	1725	460	1.7	2.3	3	60	1.15			DP	K			NO			
H-GENERATOR BUILDING	GENERATOR AREA	PUMP MOTOR	OIL RECIRCULATION PUMP		DELCO MOTOR	T3F14		C71	143T	1.00	1150	460	2		3	60	1.15				K	JUNE DEC	SIX MONTHS INSPECTION	NO			
H-GENERATOR BUILDING	GENERATOR AREA	PUMP MOTOR	DIESEL FUEL PUMP		DELCO MOTOR	JA61101A		F-55	56C	0.75	1745	460	1.3		3	60	1				L			NO			
H-GENERATOR BUILDING	OUTSIDE	DIESEL MOTOR	DIESEL GENERATOR MOTOR		CUMMINS ENGINE	KTA38-G2	100-36T	[illegible]		85.00										DIESEL		APRIL	YEAR CONTRACTED				
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	WEMCO PUMP		EMERSON	[illegible]	[illegible]		286T	25.00	1175	460	34.8	35.5	3	60	1.15	TEF		TE	G	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY GRINDER 1		NORD	132MA	[illegible]			11.00	1735	460	14.6	14.6	3	60								NO			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY GRINDER 2		NORD	132MA	[illegible]			11.00	1735	460	14.6	14.6	3	60								NO			
G-PRIMARY	PRIMARY TUNNEL AREA	SAMPLE PUMP MOTOR	PRIMARY EFFLUENT EAST SAMPLE PUMP		DAYTON	[illegible]			56HZ	1.00	1745	460	3.6	3.7	3	60	1.15							NO			
G-PRIMARY	PRIMARY TUNNEL AREA	SAMPLE PUMP MOTOR	PRIMARY EFFLUENT WEST SAMPLE PUMP		BALDOR	[illegible]	[illegible]		145TC	2.00	1725	460	3.1		3	60	1.15		B	TE	K	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY WATER PUMP		DAYTON	[illegible]			182JM	3.00	3450	460	4.3	3.3	3	60	1.15		F	TE	H	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	MOTOR	COMPRESSOR 1		BALDOR	[illegible]	[illegible]		215T	10.00	1750	460	14.7		3	60	1.15		B	TEFC	J	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY SLUDGE PUMP 1		BALDOR	[illegible]	[illegible]		254T	7.50	1185	460	10.7		3	60	1.15		F	TEFC	J	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY SLUDGE PUMP 2		BALDOR	[illegible]	[illegible]		254T	7.50	1185	460	10.7		3	60	1.15		F	TEFC	J	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TUNNEL AREA	PUMP MOTOR	PRIMARY SLUDGE PUMP 3		BALDOR	[illegible]	[illegible]		254T	7.50	1185	460	10.7		3	60	1.15		F	TEFC	J	MAY NOV	SIX MONTHS	YES			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	SCUM COLLECTOR SKIMMER 1 & 2		SEW EURODRIVE	[illegible]	[illegible]		????	0.75	1800	460	1.45		3	60	1		F	TEFC	H			NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	SCUM COLLECTOR SKIMMER 3 & 4		SEW EURODRIVE	[illegible]	[illegible]		????	0.75	1800	460	1.45		3	60	1		F	TEFC	H			NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	SCUM COLLECTOR SKIMMER 5 & 6		SEW EURODRIVE	[illegible]	[illegible]		????	0.75	1800	460	1.45		3	60	1		F	TEFC	H			NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	SCUM COLLECTOR SKIMMER 7 & 8		SEW EURODRIVE	[illegible]	[illegible]		????	0.75	1800	460	1.45		3	60	1		F	TEFC	H			NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	SCUM MIXER		EMERSON	[illegible]	[illegible]		143T	1.00	1755	460	1.5		3	60	1.4	ELT	F	TEFNA	L	MAY NOV	SIX MONTHS INSPECTION	NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 1 & # 2 SLUDGE COLLECTOR DRIVE		RELIANCE		[illegible]		[illegible]	1.00	1725	460	1.8		3	60	1.15	F					AS NEEDED	YES			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 3 & # 4 SLUDGE COLLECTOR DRIVE		WESTINGHOUSE	ABMV		1770B3A	182	1.00	1745	460	1.7		3	60								NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 5 & # 6 SLUDGE COLLECTOR DRIVE		BALDOR		[illegible]		182	1.00	1725	460	1.5		3	60				TE			AS NEEDED	YES			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 7 & # 8 SLUDGE COLLECTOR DRIVE		WESTINGHOUSE			1770B3A	182	1.00	1745	460	1.7		3	60								NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 1 HELICOID		ALLIS CHALMERS	1-5131-08417-1-1		1-5131-08417-1-1	182	1.00	1735	460	1.8		3	60	1.15	DK						NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 2 HELICOID		ALLIS CHALMERS	1-5131-08417-1-1		1-5131-08417-1-1	182	1.00	1735	460	1.8		3	60	1.15	DK						NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 3 HELICOID		DAYTON	[illegible]	[illegible]		182	1.00	1725	460	1.7		3	60	1.15			TEFC				NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 4 HELICOID		MAGNETEK CENTURY MOTOR	[illegible]	[illegible]		182	1.00	1745	460	1.5		3	60					J		AS NEEDED	YES			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 5 HELICOID		DELCO MOTOR	[illegible]		[illegible]	182	1.00	1745	460	1.56		3	60	1			TE	L		AS NEEDED	YES			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 6 HELICOID		WESTINGHOUSE			1770B3A	182	1.00	1745	460	1.7		3	60								NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 7 HELICOID		ALLIS CHALMERS	1-5131-08417-1-E		1-5131-08417-1-E	182	1.00	1735	460	1.8		3	60	1.15	DK						NO			
G-PRIMARY	PRIMARY TANK AREA OUTSIDE	MOTOR	PRIMARY CLARIFIER # 8 HELICOID		ALLIS CHALMERS	1-5131-08417-1-E		1-5131-08417-1-E	182	1.00	1735	460	1.8		3	60	1.15	DK						NO			

BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Photo	Manufacture	Model #	ID # / Catalog #	Serial #	Frame	Horse Power	RPM	Voltage	Load Amps	Starting Amps	Phase	Hertz	SF	Type	Class	Enclosure	Code	Season	PM Interval	Grease Bearings	Oil fill	Brushes	VFD
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	POLYMER FEED PUMP 1		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	POLYMER FEED PUMP 2		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	POLYMER FEED PUMP 3		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	POLYMER FEED PUMP 4		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	FERRIC FEED PUMP 1		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	FERRIC FEED PUMP 2		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	PUMP MOTOR	FERRIC FEED PUMP 3		DAYTON	2M168				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	FOCUS 3
I-SOLIDS	POLYMER STORAGE AREA	MOTOR	POLYMER TANK MIXER 1		LOUIS ALLIS / LIGHTIN	[illegible]	DD3 1107G-1		182	1.00	1750	460	1.6		3	60		CTXC		CTXC	K						
I-SOLIDS	POLYMER STORAGE AREA	MOTOR	POLYMER TANK MIXER 2		LOUIS ALLIS / LIGHTIN	[illegible]	DD3 1107G-1		182	1.00	1750	460	1.6		3	60		CTXC		CTXC	K						
I-SOLIDS	AIR COMPRESSOR ROOM	SYSTEM	AIR COMPRESSOR # 1		INGERSOLL RAND	SSR UP6-40-125		[illegible]			3730	460			3	60											
I-SOLIDS	AIR COMPRESSOR ROOM	SYSTEM	AIR COMPRESSOR # 2		INGERSOLL RAND	SSR UP6-40-125		[illegible]			3730	460			3	60											
I-SOLIDS	AIR COMPRESSOR ROOM	SYSTEM	AIR COMPRESSOR # 3		INGERSOLL RAND	SSR UP6-30-125		[illegible]			4640	460			3	60											
I-SOLIDS	DECANT TUNNEL	PUMP MOTOR	VOLGELSANG SLUDGE TRANSFER PUMP #1		BALDOR	[illegible]	[illegible]		254T	7.50	1180	460	10.7		3	60	1.15		F	TEFC	J	JAN	YEAR	YES			
I-SOLIDS	DECANT TUNNEL	PUMP MOTOR	VOLGELSANG SLUDGE TRANSFER PUMP #2		BALDOR	[illegible]	[illegible]		254T	7.50	1180	460	10.7		3	60	1.15		F	TEFC	J	JAN	YEAR	YES			
I-SOLIDS	DECANT TUNNEL	PUMP MOTOR	VOLGELSANG SLUDGE TRANSFER PUMP #3		BALDOR	[illegible]	[illegible]		254T	7.50	1180	460	10.7		3	60	1.15		F	TEFC	J	JAN	YEAR	YES			
I-SOLIDS	DECANT TUNNEL	PUMP MOTOR	DECANT PUMP		BALDOR	[illegible]	[illegible]		254T	15.00	1760	460	18.4		3	60	1.15		F		J	JAN	YEAR	YES			
I-SOLIDS	DECANT TUNNEL	MOTOR	HELICOID # 1		SEW EURODRIVE	DFT100L5A	[illegible]		????	3.00	1720	460Y	4.3		3	60	1			TEFC				NO			
I-SOLIDS	DECANT TUNNEL	MOTOR	HELICOID # 2		SEW EURODRIVE	DFT100L5A	[illegible]		????	3.00	1720	460Y	4.3		3	60	1			TEFC				NO			
I-SOLIDS	DECANT TUNNEL	MOTOR	HELICOID # 4		SEW EURODRIVE	DFT100L5A	[illegible]		????	3.00	1720	460Y	4.3		3	60	1			TEFC				NO			
I-SOLIDS	DECANT TUNNEL	MOTOR	HELICOID # 5		SEW EURODRIVE	DFT100L5A	[illegible]		????	3.00	1720	460Y	4.3		3	60	1			TEFC				NO			
I-SOLIDS	DECANT TUNNEL	SUMP PUMP	SUMP PUMP									110			3	60								NO			
I-SOLIDS	BLENDING TANK ROOF	MOTOR	MIXER - BLENDING TANK #1		EMERSON	[illegible]	[illegible]		182TC	3.00	1740	460	3.8		3	60	1	ELT	F	ELT	K	APRIL OCT	SIX MONTHS INSPECTION	NO			
I-SOLIDS	BLENDING TANK ROOF	MOTOR	MIXER - BLENDING TANK #2		EMERSON	[illegible]	[illegible]	[illegible]	182TC	3.00	1740	460	3.8		3	60	1	ELT	F	ELT	K	APRIL OCT	SIX MONTHS INSPECTION	NO			
I-SOLIDS	BLENDING TANK ROOF	MOTOR	MIXER - BLENDING TANK #3		EMERSON	[illegible]	[illegible]		182TC	3.00	1740	460	3.8		3	60	1	ELT	F	ELT	K	APRIL OCT	SIX MONTHS INSPECTION	NO			



BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Photo	Manufacture	Model #	ID # / Catalog #	Serial #	Frame	Horse Power	RPM	Voltage	Load Amps	Starting Amps	Phase	Hertz	SF	Type	Class	Enclosure	Code	Season	PM Interval	Grease Bearings	Oil fill	Brushes	VFD
H AERATION	MAIN LEVEL	FAN MOTOR	TUNNEL EXHAUST FAN		MARATHON	[illegible]	K022		[illegible]	1.50	1720	460	2.4		3	60	1.15	TS		DP	K			NO			
H AERATION	LOWER LEVEL	BLOWER MOTOR	AERATION BLOWER # 1		WESTINGHOUSE	78V34		2T8V04	503-S	300.00	1780	4000	32		3	60							AS NEEDED	YES			
H AERATION	LOWER LEVEL	BLOWER MOTOR	AERATION BLOWER # 4		WESTINGHOUSE	78V35		1T8V05	503-S	300.00	1780	4000	32		3	60							AS NEEDED	YES			
H AERATION	LOWER LEVEL	SAMPLE PUMP MOTOR	MIX LIQUOR EAST SAMPLE # 5		MAGNETEK CENTURY MOTOR	[illegible]			145T	2.00	1745	460	3.4		3	60	1.15				K			NO			NO
H AERATION	LOWER LEVEL	SAMPLE PUMP MOTOR	MIX LIQUOR WEST SAMPLE # 6		MAGNETEK CENTURY MOTOR																			NO			NO
H AERATION	LOWER LEVEL	SAMPLE PUMP MOTOR	RETURN SLUDGE WEST SAMPLE # 8		BALDOR	[illegible]	[illegible]		145T	3.00	3450	460	3.6		3	60	1.15				L	MAY	YEAR	YES			NO
H AERATION	LOWER LEVEL	MOTOR	AIR COMPRESSOR # 1		US ELECTRICAL MOTORS	[illegible]	[illegible]		256T	15.00	1745	460	20		3	60	1.15					MAY	YEAR	YES			NO
H AERATION	LOWER LEVEL	MOTOR	AIR COMPRESSOR # 2		US ELECTRICAL MOTORS	[illegible]	[illegible]		256T	15.00	1752	460	21		3	60		A	B		G			NO			NO
H AERATION	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 1		CONTINENTAL ELECTRICAL COMPANY	[illegible]	[illegible]	GE1372		75.00	1000	460	100	165	3	60	1		F			MAY	YEAR	YES			DANFOSS
H AERATION	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 2		CONTINENTAL ELECTRICAL COMPANY	[illegible]	[illegible]	GE1374		75.00	1000	460	100	165	3	60	1		F			MAY	YEAR	YES			DANFOSS
H AERATION	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 3		CONTINENTAL ELECTRICAL COMPANY	[illegible]	[illegible]	GE1371		75.00	1000	460	100	165	3	60	1		F			MAY	YEAR	YES			DANFOSS
H AERATION	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 4		CONTINENTAL ELECTRICAL COMPANY	[illegible]	[illegible]	GE1370		75.00	1000	460	100	165	3	60	1		F			MAY	YEAR	YES			DANFOSS
H AERATION	LOWER LEVEL	PUMP MOTOR	WASTE ACTIVATED SLUDGE PUMP # 9		ELLIOTT COMPANY	[illegible]	[illegible]		[illegible]	7.50	[illegible]	440	12.0		3	60	1.15				B			NO			NO
H AERATION	LOWER LEVEL	PUMP MOTOR	WASTE ACTIVATED SLUDGE PUMP # 10		US ELECTRICAL MOTORS	[illegible]	[illegible]		254T	7.50	1180	460	6.3		3	60	1.15	CTI	F	TE	G	MAY NOV	SIX MONTHS	YES			ABB
H AERATION	LOWER LEVEL	PUMP MOTOR	WASTE ACTIVATED SLUDGE PUMP # 11		US ELECTRICAL MOTORS	[illegible]	[illegible]		254T	7.50	1180	460	6.3		3	60	1.15	CTI	F	TE	G	MAY NOV	SIX MONTHS	YES			ABB
H AERATION	LOWER LEVEL	SUMP PUMP	SUMP PUMP		GOULD	[illegible]		[illegible]		1.00		460	2.6		3	60											
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #1		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #2		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #3		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #4		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #5		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	VOLGELSANG BLENDING SLUDGE PUMP #6		BALDOR	[illegible]	[illegible]	[illegible]	256T	15.00	1180	460	18.7		3	60	1.15		F	TEFC	H	JAN	YEAR	YES			AC TECH
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	STEAM PRESSURE CLEANER		RELIANCE		[illegible]		256T	15.00	1760	460	20		3	60	1.15	P				JAN	YEAR	YES			
I SOLIDS	BELT PRESS ROOM	MOTOR	CONVEYOR MOTOR #3		DAYTON	[illegible]	[illegible]		184	2.00	1740	460	3.0		3	60	1	PT			H			NO			
I SOLIDS	BELT PRESS ROOM	MOTOR	CONVEYOR MOTOR #4		MAGNETEK CENTURY MOTOR	[illegible]	[illegible]	[illegible]	56	0.75	1140	460	1.55		3	60	1	SC		TE	K			NO			
I SOLIDS	BELT PRESS ROOM	MOTOR	CONVEYOR MOTOR #5		RELIANCE		[illegible]		182T	2.00	1730	460	4.0		3	60	1	P			J	JAN	YEAR	YES			
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	BOOSTER PUMP #1		EMERSON	[illegible]	[illegible]	[illegible]	256T	30.00	1775	460	35	31	3	60	1.25	FUT	F	TE	G			SEALED NO			
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	BOOSTER PUMP #2		EMERSON	[illegible]	[illegible]	[illegible]	256T	30.00	1775	460	35	31	3	60	1.25	FUT	F	TE	G			SEALED NO			
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	BOOSTER PUMP #3		EMERSON	[illegible]	[illegible]	[illegible]	256T	30.00	1775	460	35	31	3	60	1.25	FUT	F	TE	G			SEALED NO			
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	BOOSTER PUMP #4		EMERSON	[illegible]	[illegible]	[illegible]	256T	30.00	1775	460	35	31	3	60	1.25	FUT	F	TE	G			SEALED NO			
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	CHEMICAL FEED PUMP MOTOR CAUSTIC		BALDOR	[illegible]	[illegible]		56C	0.33	1725	90 DC	3.5							TENV			AS NEEDED			YES	DAYTON
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	CHEMICAL FEED PUMP MOTOR CAUSTIC		LEESON	[illegible]	[illegible]			0.33	1725	90 DC	3.5							TEFC			AS NEEDED			YES	
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	CHEMICAL FEED PUMP MOTOR HYPO		DAYTON	[illegible]				0.33	1725	90 DC	3.5				1						AS NEEDED			YES	
I SOLIDS	BELT PRESS ROOM	PUMP MOTOR	CHEMICAL FEED PUMP MOTOR HYPO		LEESON	[illegible]	[illegible]			0.33	1725	90 DC	3.5							TEFC			AS NEEDED			YES	
I SOLIDS	BELT PRESS ROOM	SUMP PUMP	SUMP PUMP																								

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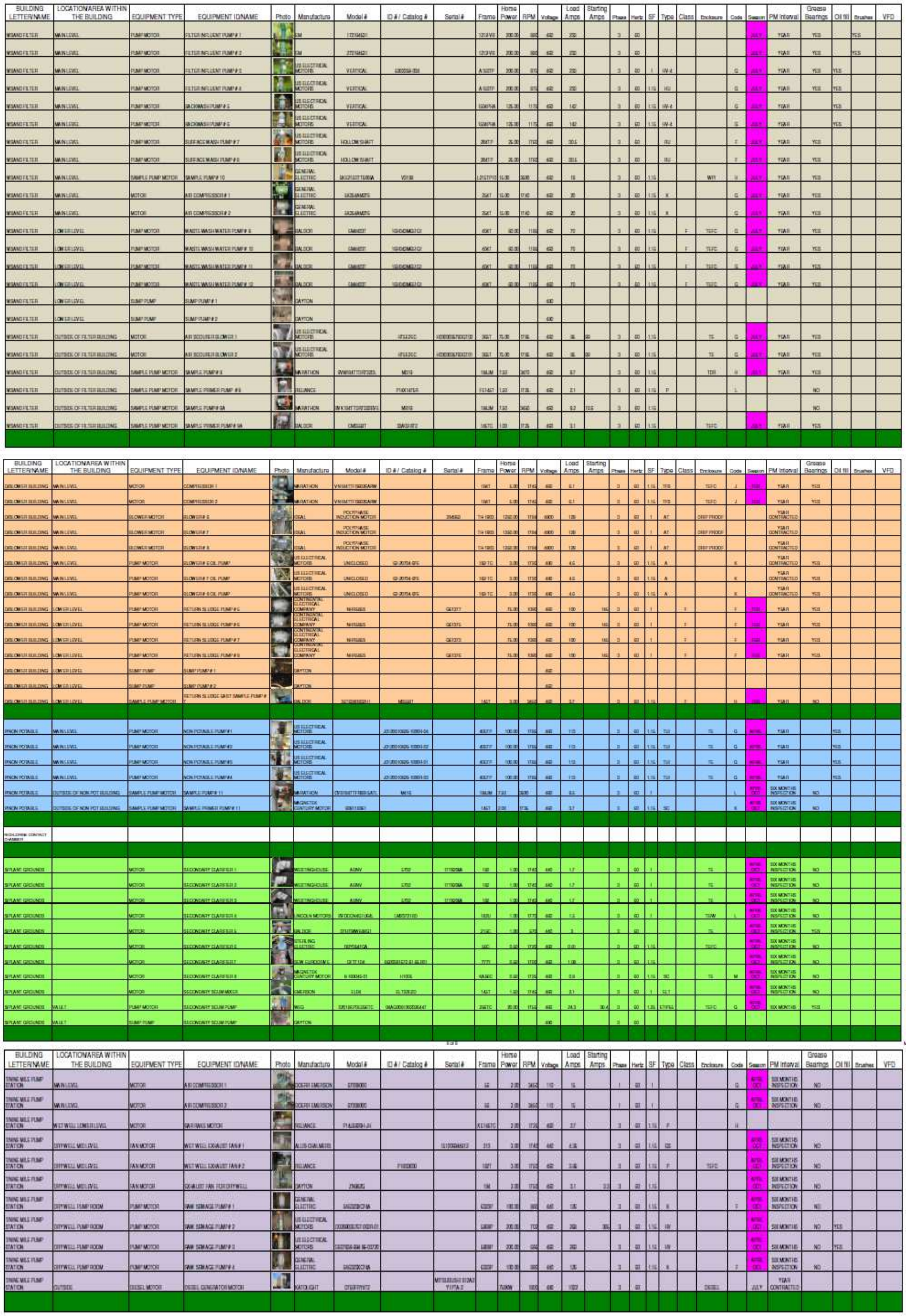
BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Photo	Manufacture	Model #	ID # / Catalog #	Serial #	Frame	Horse Power	RPM	Voltage	Load Amps	Starting Amps	Phase	Hertz	SF	Type	Class	Enclosure	Code	Season	PM Interval	Grease Bearings	Oil fill	Brushes	VFD
J INCINERATOR	LOWER LEVEL	PUMP MOTOR	ASH PUMP EAST 2		BALDOR	[illegible]	[illegible]		324T	40.00	1775	460	47		3	60	1.15		F	TEFC		MAY NOV	SIX MONTHS	YES			
J INCINERATOR	LOWER LEVEL	PUMP MOTOR	ASH PUMP WEST 1		BALDOR	[illegible]	[illegible]		324T	40.00	1775	460	47		3	60	1.15		F	TEFC		MAY NOV	SIX MONTHS	YES			
J INCINERATOR	LOWER LEVEL	BLOWER MOTOR	CENTER SHAFT COOLING AIR BLOWER		BALDOR	[illegible]	[illegible]		284T	15.00	1765	460	18.7		3	60	1.15		F	TEFC		MAY NOV	SIX MONTHS	YES			ABB
J INCINERATOR	LOWER LEVEL	BLOWER MOTOR	SECONDARY COMBUSTION AIR BLOWER		BALDOR	[illegible]	[illegible]		213T	5.00	1160	460	8		3	60	1.1		F	TEFC		MAY NOV	SIX MONTHS	NO			
J INCINERATOR	LOWER LEVEL	BLOWER MOTOR	BACK UP CENTER SHAFT COOLING AIR BLOWER		GENERAL ELECTRIC	[illegible]		[illegible]	[illegible]	25.00	1770	460	31.8		3	60	1	K	F	TEFC		MAY NOV	SIX MONTHS	NO			
J INCINERATOR	LOWER LEVEL	MOTOR	FURNACE CENTER SHAFT DRIVE		BALDOR	[illegible]	[illegible]	[illegible]	284T	25.00	1765	460	28		3	60	1.15		F	TEFC	H	MAY NOV	SIX MONTHS				
J INCINERATOR	LOWER LEVEL	SUMP PUMP	SUMP PUMP									460			3	60											
J INCINERATOR	MAIN LEVEL	BLOWER MOTOR	COMBUSTION AIR BLOWER		BALDOR		[illegible]		324T	40.00	3545	460	44		3	60	1.15		F	TEFC		MAY NOV	SIX MONTHS	YES			ABB
J INCINERATOR	TOP LEVEL	FAN MOTOR	INDUCED DRAFT I.D. FAN		BALDOR	[illegible]	[illegible]	[illegible]	364T	50.00	1780	460	58		3	60	1.15		F	TEFC	G	MAY NOV	SIX MONTHS	YES			ABB
J INCINERATOR	TOP LEVEL	MOTOR	CONVEYOR MOTOR #C		RELIANCE	[illegible]	[illegible]		182TC	5.00	1745	460	6.2		3	60	1.15	P		TEFC	H	MAY NOV	SIX MONTHS	YES			
J INCINERATOR	TOP LEVEL	MOTOR	SCREW PRESS MOTOR																								
J INCINERATOR	OUTSIDE	FAN MOTOR	ODOR CONTROL FAN		BALDOR	[illegible]	[illegible]		286T	30.00	1770	460	37		3	60	1.15		F	TEFC	H	MAY NOV	SIX MONTHS	YES			
J INCINERATOR	OUTSIDE	SAMPLE PUMP MOTOR	RAW SEWAGE SAMPLE PUMP / TOP		DAYTON	[illegible]	[illegible]		145T	3.00	3450	460	3.9	4.4	3	60	1.15			TEFC		MAY NOV	SIX MONTHS INSPECTION	NO			
J INCINERATOR	OUTSIDE	SAMPLE PUMP MOTOR	RAW SEWAGE SAMPLE PUMP / BOTTOM		DAYTON	[illegible]	[illegible]		145T	3.00	3450	460	3.9	4.4	3	60	1.15			TEFC		MAY NOV	SIX MONTHS INSPECTION	NO			
L CHLORINE	CHLORINATOR ROOM	FAN MOTOR	EXHAUST FAN EAST		MAGNETEK	[illegible]	380	[illegible]		0.17	1075	120	2.8		1	60								NO			
L CHLORINE	CHLORINATOR ROOM	FAN MOTOR	EXHAUST FAN WEST		MAGNETEK	[illegible]	380	[illegible]		0.17	1075	120	2.8		1	60								NO			
L CHLORINE	STORAGE ROOM	FAN MOTOR	EXHAUST FAN STORAGE EAST		GENERAL ELECTRIC	[illegible]	H162		56	0.33	1140	120	7		1	60	1				N			NO			
L CHLORINE	STORAGE ROOM	FAN MOTOR	EXHAUST FAN STORAGE WEST		GENERAL ELECTRIC	[illegible]	H162		56	0.33	1140	120	7		1	60	1				N			NO			
L CHLORINE	STORAGE ROOM	MOTOR	AIR COMPRESSOR		DAYTON	[illegible]	304	[illegible]	56	2.00	3450	120	15	15	1	60	1			ODP				NO			
M DECHLORINATION	BISULFITE STORAGE ROOM	SAMPLE PUMP MOTOR	CONTACT SAMPLE PUMP		A.O. SMITH	[illegible]	[illegible]	[illegible]	56J	0.75	3450	115	10.0	18.0	1	60	1.6	UD			L		AS NEEDED			YES	
M DECHLORINATION	BISULFITE STORAGE ROOM	PUMP MOTOR	BISULFITE FEED PUMP # 1		GENERAL ELECTRIC	[illegible]	[illegible]		56	0.33	1725	90 DC	3				1.4						AS NEEDED			YES	
M DECHLORINATION	BISULFITE STORAGE ROOM	PUMP MOTOR	BISULFITE FEED PUMP # 2		DAYTON	[illegible]				0.75	1725	90 DC	8.2				1						AS NEEDED			YES	



BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Manufacture
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	FILTER INFLUENT PUMP # 1	GM
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	FILTER INFLUENT PUMP # 2	GM
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	FILTER INFLUENT PUMP # 3	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	FILTER INFLUENT PUMP # 4	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	BACKWASH PUMP # 5	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	BACKWASH PUMP # 6	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	SURFACE WASH PUMP # 7	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	PUMP MOTOR	SURFACE WASH PUMP # 8	US ELECTRICAL MOTORS
N/SAND FILTER	MAIN LEVEL	SAMPLE PUMP MOTOR	SAMPLE PUMP # 10	GENERAL ELECTRIC
N/SAND FILTER	MAIN LEVEL	MOTOR	AIR COMPRESSOR # 1	GENERAL ELECTRIC
N/SAND FILTER	MAIN LEVEL	MOTOR	AIR COMPRESSOR # 2	GENERAL ELECTRIC
N/SAND FILTER	LOWER LEVEL	PUMP MOTOR	WASTE WASH WATER PUMP # 9	BALDOR
N/SAND FILTER	LOWER LEVEL	PUMP MOTOR	WASTE WASH WATER PUMP # 10	BALDOR
N/SAND FILTER	LOWER LEVEL	PUMP MOTOR	WASTE WASH WATER PUMP # 11	BALDOR
N/SAND FILTER	LOWER LEVEL	PUMP MOTOR	WASTE WASH WATER PUMP # 12	BALDOR
N/SAND FILTER	LOWER LEVEL	SUMP PUMP	SUMP PUMP # 1	DAYTON
N/SAND FILTER	LOWER LEVEL	SUMP PUMP	SUMP PUMP # 2	DAYTON
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	MOTOR	AIR SCOURER BLOWER 1	US ELECTRICAL MOTORS
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	MOTOR	AIR SCOURER BLOWER 2	US ELECTRICAL MOTORS
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	SAMPLE PUMP MOTOR	SAMPLE PUMP # 8	MARATHON
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	SAMPLE PUMP MOTOR	SAMPLE PRIMER PUMP # 8	RELIANCE
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	SAMPLE PUMP MOTOR	SAMPLE PUMP # 8A	MARATHON
N/SAND FILTER	OUTSIDE OF FILTER BUILDING	SAMPLE PUMP MOTOR	SAMPLE PRIMER PUMP # 8A	BALDOR

BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Manufacture
O/BLOWER BUILDING	MAIN LEVEL	MOTOR	COMPRESSOR 1	MARATHON
O/BLOWER BUILDING	MAIN LEVEL	MOTOR	COMPRESSOR 2	MARATHON
O/BLOWER BUILDING	MAIN LEVEL	BLOWER MOTOR	BLOWER # 6	IDEAL
O/BLOWER BUILDING	MAIN LEVEL	BLOWER MOTOR	BLOWER # 7	IDEAL
O/BLOWER BUILDING	MAIN LEVEL	BLOWER MOTOR	BLOWER # 8	IDEAL
O/BLOWER BUILDING	MAIN LEVEL	PUMP MOTOR	BLOWER # 6 OIL PUMP	US ELECTRICAL MOTORS
O/BLOWER BUILDING	MAIN LEVEL	PUMP MOTOR	BLOWER # 7 OIL PUMP	US ELECTRICAL MOTORS
O/BLOWER BUILDING	MAIN LEVEL	PUMP MOTOR	BLOWER # 8 OIL PUMP	US ELECTRICAL MOTORS
O/BLOWER BUILDING	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 5	CONTINENTAL ELECTRICAL COMPANY
O/BLOWER BUILDING	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 6	CONTINENTAL ELECTRICAL COMPANY
O/BLOWER BUILDING	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 7	CONTINENTAL ELECTRICAL COMPANY
O/BLOWER BUILDING	LOWER LEVEL	PUMP MOTOR	RETURN SLUDGE PUMP # 8	CONTINENTAL ELECTRICAL COMPANY
O/BLOWER BUILDING	LOWER LEVEL	SUMP PUMP	SUMP PUMP # 1	DAYTON
O/BLOWER BUILDING	LOWER LEVEL	SUMP PUMP	SUMP PUMP # 2	DAYTON
O/BLOWER BUILDING	LOWER LEVEL	SAMPLE PUMP MOTOR	RETURN SLUDGE EAST SAMPLE PUMP # 7	BALDOR
P/NON POTABLE	MAIN LEVEL	PUMP MOTOR	NON POTABLE PUMP#1	US ELECTRICAL MOTORS
P/NON POTABLE	MAIN LEVEL	PUMP MOTOR	NON POTABLE PUMP#2	US ELECTRICAL MOTORS
P/NON POTABLE	MAIN LEVEL	PUMP MOTOR	NON POTABLE PUMP#3	US ELECTRICAL MOTORS
P/NON POTABLE	MAIN LEVEL	PUMP MOTOR	NON POTABLE PUMP#4	US ELECTRICAL MOTORS
P/NON POTABLE	OUTSIDE OF NON POT BUILDING	SAMPLE PUMP MOTOR	SAMPLE PUMP # 11	MARATHON
P/NON POTABLE	OUTSIDE OF NON POT BUILDING	SAMPLE PUMP MOTOR	SAMPLE PRIMER PUMP # 11	MAGNETEK CENTURY MOTOR
R/CHLORINE CONTACT CHAMBER				
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 1	WESTINGHOUSE
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 2	WESTINGHOUSE
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 3	WESTINGHOUSE
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 4	LINCOLN MOTORS
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 5	BALDOR
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 6	STERLING ELECTRIC
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 7	SEW EURODRIVE
S/PLANT GROUNDS		MOTOR	SECONDARY CLARIFIER 8	MAGNETEK CENTURY MOTOR
S/PLANT GROUNDS		MOTOR	SECONDARY SCUM MIXER	EMERSON
S/PLANT GROUNDS	VAULT	PUMP MOTOR	SECONDARY SCUM PUMP	WEG
S/PLANT GROUNDS	VAULT	SUMP PUMP	SECONDARY SCUM PUMP	DAYTON

BUILDING LETTER/NAME	LOCATION/AREA WITHIN THE BUILDING	EQUIPMENT TYPE	EQUIPMENT ID/NAME	Manufacture
T/NINE MILE PUMP STATION	MAIN LEVEL	MOTOR	AIR COMPRESSOR 1	DOERR EMERSON
T/NINE MILE PUMP STATION	MAIN LEVEL	MOTOR	AIR COMPRESSOR 2	DOERR EMERSON
T/NINE MILE PUMP STATION	WET WELL LOWER LEVEL	MOTOR	BAR RAKE MOTOR	RELIANCE
T/NINE MILE PUMP STATION	DRYWELL MID LEVEL	FAN MOTOR	WET WELL EXHAUST FAN # 1	ALLIS-CHALMERS
T/NINE MILE PUMP STATION	DRYWELL MID LEVEL	FAN MOTOR	WET WELL EXHAUST FAN # 2	RELIANCE
T/NINE MILE PUMP STATION	DRYWELL MID LEVEL	FAN MOTOR	EXHAUST FAN FOR DRYWELL	DAYTON
T/NINE MILE PUMP STATION	DRYWELL PUMP ROOM	PUMP MOTOR	RAW SEWAGE PUMP # 1	GENERAL ELECTRIC
T/NINE MILE PUMP STATION	DRYWELL PUMP ROOM	PUMP MOTOR	RAW SEWAGE PUMP # 2	US ELECTRICAL MOTORS
T/NINE MILE PUMP STATION	DRYWELL PUMP ROOM	PUMP MOTOR	RAW SEWAGE PUMP # 3	US ELECTRICAL MOTORS
T/NINE MILE PUMP STATION	DRYWELL PUMP ROOM	PUMP MOTOR	RAW SEWAGE PUMP # 4	GENERAL ELECTRIC
T/NINE MILE PUMP STATION	OUTSIDE	DIESEL MOTOR	DIESEL GENERATOR MOTOR	KATOLIGHT

3 - WWTP ELECTRIC POWER USAGE

YEAR **2010**

Usage Period		# of Days	KWH/day	Total Charges $	$/KWH	Tot. KWH
12/17/2009	1/19/2010	34	41308	100,580	0.07161	1,404,472
1/20/2010	2/16/2010	28	40354	76,282	0.06751	1,129,912
2/17/2010	3/17/2010	29	40864	89,046	0.07264	1,185,056
3/18/2010	4/20/2010	34	39840	98,074	0.0724	1,354,560
4/21/2010	5/18/2010	28	41280	90,053	0.07791	1,155,840
5/19/2010	6/17/2010	30	39296	90,053	0.07639	1,178,880
6/18/2010	7/19/2010	32	38516	85,628	0.07353	1,232,512
7/20/2010	8/18/2010	30	36736	82,621	0.075	1,102,080
8/19/2010	9/20/2010	33	33911	81,412	0.07061	1,119,063
9/21/2010	10/19/2010	29	36215	76,466	0.07281	1,050,235
10/20/2010	11/16/2010	28	35931	77,197	0.0767	1,006,068
11/17/2010	12/15/2010	29	41313	87,447	0.073	1,198,077
TOT:		**364**	38797	$1,034,859	0.0733	**14,116,755**

YEAR **2011**

Usage Period		# of Days	KWH/day	Total Charges $	$/KWH	
12/16/2010	1/19/2011	35	43529	100,208	0.06577	1,523,515
1/20/2011	2/16/2011	28	41280	90,641	0.07842	1,155,840
2/17/2011	3/20/2011	32	51570	118,017	0.07152	1,650,240
3/21/2011	4/18/2011	29	50052	108,254	0.07458	1,451,508
4/19/2011	5/17/2011	29	51509	111,624	0.07473	1,493,761
5/18/2011	6/19/2011	33	48320	117,917	0.07395	1,594,560
6/20/2011	7/19/2011	30	40000	90,690	0.07558	1,200,000
7/20/2011	8/18/2011	30	42560	99,173	0.07767	1,276,800
8/19/2011	9/20/2011	33	40931	99,852	0.07393	1,350,723
9/21/2011	10/19/2011	29	41412	95,282	0.07934	1,200,948
10/20/2011	11/16/2011	28	39909	91,998	0.07458	1,117,452
11/17/2011	12/15/2011	29	51079	114,697	0.07743	1,481,291
TOT:		**365**	45179	$1,238,353	0.0748	**16,496,638**

Year **2012**

Usage Period		# of Days	KWH/day	Total Charges $	$/KWH	
12/16/2011	1/19/2012	35	45751	130,935	0.08177	1,601,285
1/20/2012	2/19/2012	31	43479	113,881	0.08449	1,347,849
2/20/2012	3/19/2012	29	45815	114,088	0.08587	1,328,635
3/20/2012	4/18/2012	30	40160	106,581	0.08846	1,204,800
4/19/2012	5/17/2012	29	41710	105,640	0.08733	1,209,590
5/18/2012	6/18/2012	32	38100	106,901	0.08768	1,219,200

6/19/2012	7/18/2012	30	36352	98,548	0.09036	1,090,560
7/19/2012	7/23/2012	5	38400	17,417	0.09071	192,000
7/24/2012	8/20/2012	28	37577	99,096	0.09418	1,052,156
8/21/2012	9/18/2012	29	38201	107,372	0.09692	1,107,829
9/19/2012	10/18/2012	30	36384	96,724	0.08861	1,091,520
10/19/2012	11/15/2012	28	37131	91,931	0.08842	1,039,668
11/16/2012	12/16/2012	31	37223	97709	0.08468	1,153,913
TOT:		**367**	39714	$1,286,823	0.0884	**14,639,005**

WWTP ELECTRIC POWER USEAGE

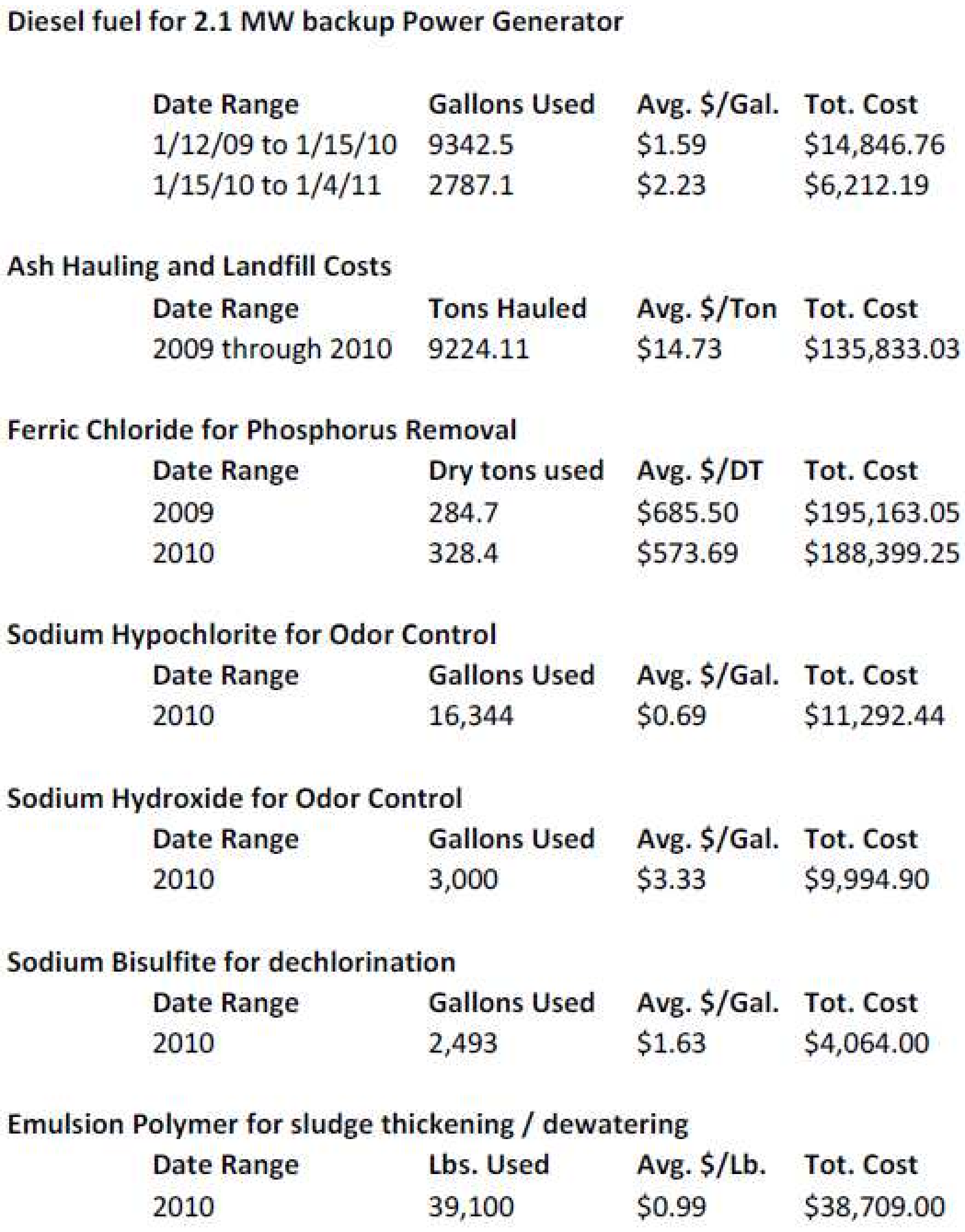
YEAR	**2013**					
Usage Period		**# of Days**	**KWH/day**	**Total Charges $**	**$/KWH**	
12/17/2012	1/17/2013	32	41880	109,900	0.082	1,340,160
1/18/2013	2/18/2013	32	43830	114,301	0.08149	1,402,560
2/19/2013	3/18/2013	28	45703	110,981	0.08673	1,279,684
3/19/2013	4/17/2013	30	44736	115,544	0.08609	1,342,080
4/18/2013	5/19/2013	32	45450	125,793	0.08649	1,454,400
5/20/2013	6/18/2013	30	38784	107,421	0.09232	1,163,520
6/19/2013	7/21/2013	33	38807	108,405	0.08465	1,280,631
7/22/2013	8/20/2013	30	36832	96,307	0.08716	1,104,960
8/21/2013	9/18/2013	29	35686	89,853	0.08682	1,034,894
9/19/2013	10/20/2013	32	33870	91,272	0.08421	1,083,840
10/21/2013	11/17/2013	28	34937	85,824	0.08773	978,236
TOT:		**336**	40047	$1,155,601	0.0860	**13,464,965**
				2013 projected:		**14,617,089**

4 – WARREN WWTP NATURAL GAS USAGE

Year	**2011**		**$**	**$**	**$**	**Total$/**
Month	**MCF**	**MMBTU**	**Transport.**	**Supply**	**Total**	**MCF**
January	11,729	11,870	$11,030	$53,040	$64,070	$5.46
February	10,783	10,934	$10,187	$51,097	$61,284	$5.68
March	11,943	12,062	$11,221	$42,908	$54,129	$4.53
April	11,058	11,124	$10,432	$49,979	$60,411	$5.46
May	9,588	9,636	$9,129	$48,808	$57,937	$6.04
June	8,101	8,166	$7,802	$47,988	$55,790	$6.89
July	7,639	7,692	$7,390	$26,710	$34,100	$4.46
August	8,441	8,509	$8,105	$51,596	$59,701	$7.07
September	7,900	7,971	$7,623	$37,749	$45,372	$5.74
October	3,184	3,200	$3,475	$18,117	$21,592	$6.78

November	5,774	5,797	$5,726	$10,056	$15,782	$2.73
December	11,072	11,138	$10,452	$41,664	$52,116	$4.71
Total	**107,212**	**108,099**	**$102,572**	**$479,712**	**$582,284**	**$65.57**
Avg.	**8,934**	**9,008**	**$8,548**	**$39,976**	**$48,524**	**$5.46**
Year	**2,012**					
January	13,300	13,380	$12,440	$43,956	$56,396	$4.24
February	9,960	10,030	$9,460	$34,653	$44,113	$4.43
March	11,729	11,799	$11,416	$33,467	$44,883	$3.83
April	11,047	11,091	$10,786	$14,267	$25,053	$2.27
May	10,149	10,200	$9,870	$15,610	$25,480	$2.51
June	9,348	9,423	$9,110	$25,952	$35,062	$3.75
July	7,989	8,037	$7,839	$27,673	$35,512	$4.45
August	8,714	8,758	$8,500	$24,883	$33,383	$3.83
September	8,267	8,308	$8,282	$27,725	$36,007	$4.36
October	10,194	10,265	$9,653	$23,105	$32,758	$3.21
November	11,250	11,351	$10,794	$39,616	$50,410	$4.48
December	10,836	10,944	$10,427	$49,408	$59,835	$5.52
Total	**122,783**	**123,587**	**$118,576**	**$360,315**	**$478,891**	**$46.87**
Avg.	**10,232**	**10,299**	**$9,881**	**$30,026**	**$39,908**	**$3.91**
Year	**2,013**					
January	14,370	14,499	$15,222	$48,005	$63,227	$4.40
February	11,190	11,291	$11,800	$36,308	$48,108	$4.30
March	10,091	10,202	$10,864	$44,306	$55,171	$5.47
April	11,035	11,167	$10,607	$46,615	$57,223	$5.19
May	9,341	9,416	$9,085	$38,715	$47,800	$5.12
June	7,283	7,341	$7,213	$44,175	$51,387	$7.06
July	9,020	9,128	$7,930	$34,776	$42,706	$4.73
August	7,389	7,478	$7,309	$33,042	$40,352	$5.46
September	7,200	7,272	$7,194	$28,312	$35,507	$4.93
October	9,446	9,522	$9,181	$33,231	$42,411	$4.49
November			$0			#DIV/0!
December			$0			#DIV/0!
Total	**96,365**	**97,316**	**$96,406**	**$387,485**	**$483,891**	**$51.14**
Avg.	**9,637**	**9,732**	**$8,034**	**$38,749**	**$48,389**	**$5.19**

5 – Process Chemicals and Cost Summary



Diesel fuel for 2.1 MW backup Power Generator

Date Range	Gallons Used	Avg. $/Gal.	Tot. Cost
1/12/09 to 1/15/10	9342.5	$1.59	$14,846.76
1/15/10 to 1/4/11	2787.1	$2.23	$6,212.19

Ash Hauling and Landfill Costs

Date Range	Tons Hauled	Avg. $/Ton	Tot. Cost
2009 through 2010	9224.11	$14.73	$135,833.03

Ferric Chloride for Phosphorus Removal

Date Range	Dry tons used	Avg. $/DT	Tot. Cost
2009	284.7	$685.50	$195,163.05
2010	328.4	$573.69	$188,399.25

Sodium Hypochlorite for Odor Control

Date Range	Gallons Used	Avg. $/Gal.	Tot. Cost
2010	16,344	$0.69	$11,292.44

Sodium Hydroxide for Odor Control

Date Range	Gallons Used	Avg. $/Gal.	Tot. Cost
2010	3,000	$3.33	$9,994.90

Sodium Bisulfite for dechlorination

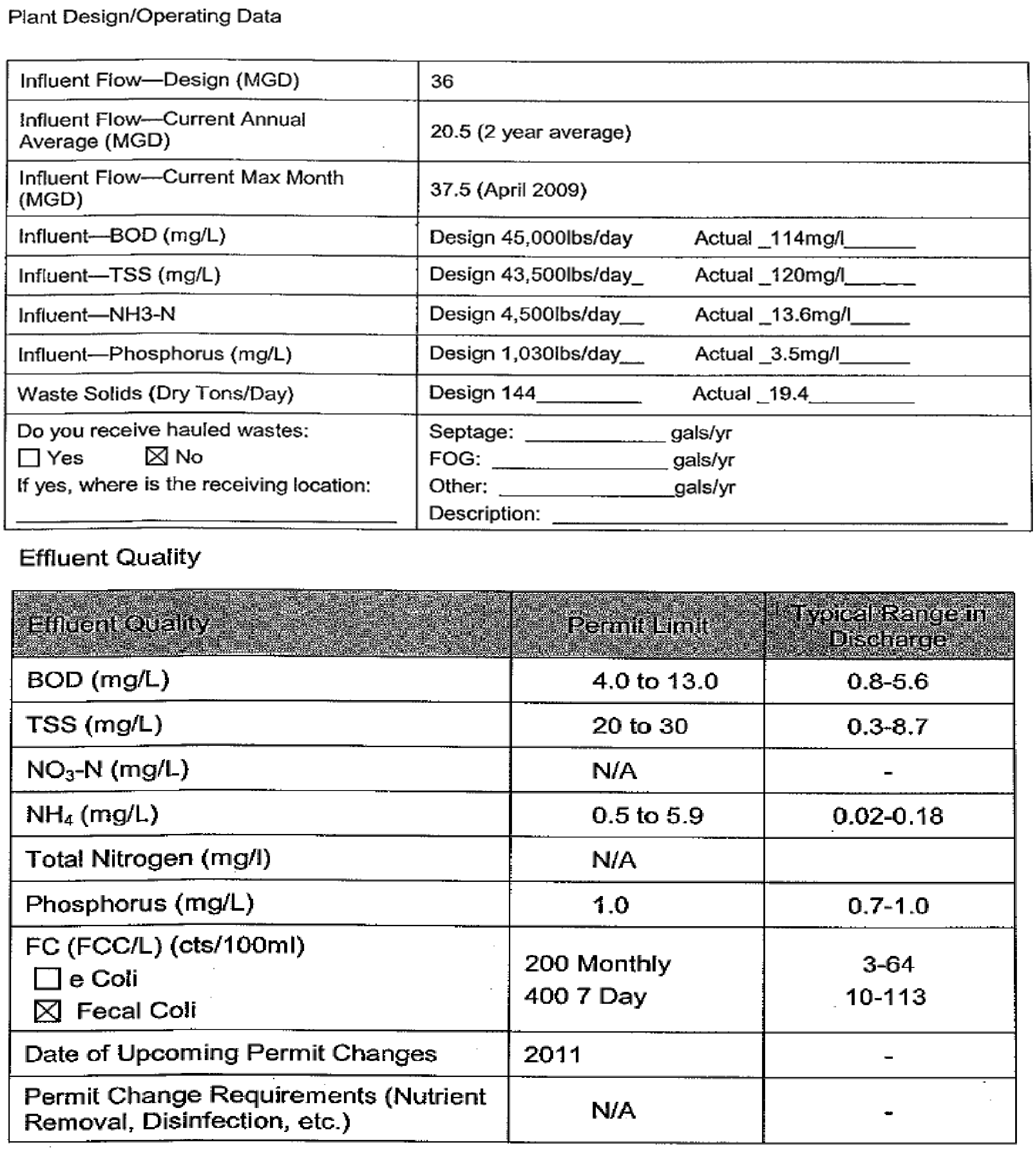
Date Range	Gallons Used	Avg. $/Gal.	Tot. Cost
2010	2,493	$1.63	$4,064.00

Emulsion Polymer for sludge thickening / dewatering

Date Range	Lbs. Used	Avg. $/Lb.	Tot. Cost
2010	39,100	$0.99	$38,709.00

6 – Plant Operating Data

The following plant's data is generated by HRC Consultants using WWTP – Energy Efficiency Opportunity Screening Tool:



Plant Design/Operating Data

Influent Flow—Design (MGD)	36
Influent Flow—Current Annual Average (MGD)	20.5 (2 year average)
Influent Flow—Current Max Month (MGD)	37.5 (April 2009)
Influent—BOD (mg/L)	Design 45,000lbs/day Actual _114mg/l______
Influent—TSS (mg/L)	Design 43,500lbs/day_ Actual _120mg/l_____
Influent—NH3-N	Design 4,500lbs/day__ Actual _13.6mg/l_____
Influent—Phosphorus (mg/L)	Design 1,030lbs/day__ Actual _3.5mg/l______
Waste Solids (Dry Tons/Day)	Design 144________ Actual _19.4_________
Do you receive hauled wastes: ☐ Yes ☒ No If yes, where is the receiving location: ________________________	Septage: ____________ gals/yr FOG: ______________ gals/yr Other: ______________gals/yr Description: ______________________________

Effluent Quality

Effluent Quality	Permit Limit	Typical Range in Discharge
BOD (mg/L)	4.0 to 13.0	0.8-5.6
TSS (mg/L)	20 to 30	0.3-8.7
NO_3-N (mg/L)	N/A	-
NH_4 (mg/L)	0.5 to 5.9	0.02-0.18
Total Nitrogen (mg/l)	N/A	
Phosphorus (mg/L)	1.0	0.7-1.0
FC (FCC/L) (cts/100ml) ☐ e Coli ☒ Fecal Coli	200 Monthly 400 7 Day	3-64 10-113
Date of Upcoming Permit Changes	2011	-
Permit Change Requirements (Nutrient Removal, Disinfection, etc.)	N/A	-

7 - Incineration natural gas consumption:

YEAR	ANNUAL GAS USE (MMCF)	MONTHLY AVG. GAS USE (MMCF)
2013	94.0	7.8
2012	102.1	8.5
2011	90.7	7.6
2010	80.9	6.8

Source: Plant's division director e-mail.

APPENDIX - D

ESTIMATING PRE-COMBUSTED ENERGY FOR WARREN - WWTP

Note: Source of all materials and volumes are from Warren - WWTP data attached in appendix C.

Ultra-violet (U.V.) Disinfection

From dissertation: Comparison with UV, page 124:

259 $\frac{kWh}{MG}$ x 22.4 $\frac{MG}{day}$ = 5,801.6 $\frac{kWh}{day}$ x emission factor

5801.6 x 7.0555 x 10^{-4} $\frac{mTCO2e}{kWh}$ = 4.1 (mTCO$_2$e / day)

Polymer:

- Energy intensity from manufacturer = 1,762 (BTU/Lb)
- Assumption: natural gas is the energy fuel-source
- Polymer consumption = 39,100 (Lb/ day), from plant data
- Natural gas emission factor = 5.31 x 10^{-3} $\frac{mTCO2}{Therm}$

39,100 $\frac{Lb}{day}$ x 1,762 $\frac{BTU}{Lb}$ x 10^{-5} $\frac{BTU}{Therm}$ =

689 x 5.31 x 10^{-3} = 3.66 (mTCO$_2$e / day)

Ferric Chloride:

- Emission factor source: Sydney Water Board
- 306.55 Ton of ferric chloride

0.48 $\frac{TCO2}{Ton\ F.Chl.}$ x 1/1.1 (conversion) = 0.436 (mTCO$_2$e / Ton F. Chl.)

306.55 Ton F. Chl. x 0.436 $\frac{TCO2e}{T\ F.Chl.}$ = 133.65 (mTCO$_2$) / 365 days = 0.366 (mTCO$_2$e/Day)

Sodium Hypochlorite:

- Volume =16,344 (Gal)
- Equation source: Dissertation subpart (6.2.5), Eq. 6.2.5.6, page 123

16,244 Gal x 20 $\frac{mg}{L}$ x 3.785 $\frac{L}{Gal}$ x 10^{-3} $\frac{g}{mg}$ x 1/454 $\frac{Lb}{g}$ x 10^{6} $\frac{Gal}{MG}$ = 2.73 (Lb)

We Need 2.5 $\frac{kWh}{Lb}$ of sodium hypochlorite.

2.73 Lb NaOCl x 2.5 $\frac{kWh}{Lb}$ = 6.825 $\frac{kWh}{MG}$

6.825 $\frac{kWh}{MG}$ x 22.4 MGD = 152.88 (kWh)

Sodium Hydroxide (NaOH):

- NaOH production requires (as reported by Dr. Peter Faguy):

1.85 $\frac{Wh}{g}$ in practice, 2.5 $\frac{Wh}{g}$ Reported

20 $\frac{mg}{L}$ x 3000 Gal x 3.785 $\frac{L}{Gal}$ x 1/454 $\frac{Lb}{g}$ x 10^{-3} $\frac{g}{mg}$ x 10^{6} $\frac{Gal}{MG}$ = 0.50 $\frac{Lb}{MG}$

0.50 $\frac{Lb}{MG}$ x 454 $\frac{g}{Lb}$ = 227.1 $\frac{g}{MG}$

3000 Gal NaOH ,

227.1 g NaOH @ 20 $\frac{mg}{L}$

227.1 $\frac{g}{MG}$ x NaOH x 2.5 $\frac{Wh}{g}$ x 10^{-3} $\frac{kWh}{Wh}$ = 0.57 $\frac{kWh}{MG}$

0.57 $\frac{kWh}{MG}$ x 22.4 MGD = 12.8 (kWh) / day

Water:

- Public water supply energy intensity = 1900 $\frac{kWh}{MG}$, (dissertation Table 6.5, page 118)
- Water consumption from bills for 2013 year: 5,439 $\frac{MCF}{Yr}$ = 15.1 $\frac{MCF}{Day}$

15.1 x 10^{3} $\frac{ft3}{day}$ x 7.481 $\frac{Gal}{ft3}$ x 10^{-6} = 0.113 $\frac{MG}{day}$

0.113 $\frac{MG}{day}$ x 1900 $\frac{kWh}{MG}$ = 214.7 $\frac{kWh}{day}$

Transportation:

- From plant information: employees number = 37
- Assumptions: 7 cars x 5 miles, 10 cars x 7.5 miles, 10 cars x 10 miles, 10 cars x 15 miles.
- using Eq. # 6.2.2.1, page 114 - dissertation

720 mi x 1/21.6 $\frac{Gal}{mi}$ x 8.92 x 10^{-3} $\frac{TCO2e}{Gal\ gasoline}$ x 1/0.985 = 0.30 ($mTCO_2$)

Estimating CO_2 from the Biological Activated Sludge (A.S.) Process:

- Warren - WWTP data obtained from a study prepared by Hubble, Roth and Clarck, consulting engineers (HRC), Michigan.
- Influent BOD_5 (mg/L) = 114 - actual
- Primary treatment BOD_5 = 64 - 72 (median = 68)
- Effluent BOD5 (mg/L) = 0.8 - 5.6 (median = 3.2)
- Average flow rate to A.S. system = 22 (MGD)
- Calculation formula from reference [164] (dissertation, page 85)

$$Q\ ww = 22 \times 10^{6}\ \frac{Gal}{day} \times \frac{1\ m3}{264.2\ Gal} \times \frac{day}{24\ hrs} = 3{,}470\ \frac{m3}{hr}$$

$$\text{A.S. BOD5 reduction efficiency} = \frac{BOD\ in - BOD\ out}{BOD\ in} \times 100\% = \frac{68-3.2}{68} \times 100\% = 95.3\%$$

The A.S. system is assumed to be well-managed due to the high BOD_5 reduction efficiency. For a well-managed A.S. system, the following defaults are taken from Table 4.6 and Table 4.7 (dissertation, page 86 and 87, ref [164]):

$MCFww = 0$

$Y = 0.65$

$CF_{CO2} = 1.375$

$CF_{CH4} = 0.5$

(Dissertation Eq.4.3.11):

$$CO_2 = 10^{-6} \times Q_{ww} \times OD \times Eff_{OD} \times CF_{CO2} \times [(1-MCF_{ww} \times BG_{CH4})(1-\lambda)])$$

$$CO_2 = 10^{-6} \times 3{,}470\ \frac{m3}{hr} \times 68\ \frac{g}{m3} \times 0.953 \times 1.375 \times [\ (1-0)\ (1-0.65)]$$

$$CO_2 = 0.10822\ \frac{Mg\ CO2}{hr}\ \text{(emission rate)}$$

$$CO_2 = 0.10822\ \frac{Mg\ CO2}{hr} \times 24\ \frac{hr}{day} = 2.60\ \frac{Mg\ CO2}{day} = 2.60\ \frac{mTCO2}{day}$$

Since *MCFww* = 0, no CH_4 is generated from the treatment process. Hence, equation for estimating CH_4 yields zero

Estimating N_2O Emissions from Warren WWTP

$$Qi = 22.4\text{ MGD} / 24\text{ hr} = 0.93\ \frac{\boldsymbol{MGal}}{\boldsymbol{hr}} = 0.93 \text{ x } 10^6\ \frac{\boldsymbol{Gal}}{\boldsymbol{hr}} \text{ x } \frac{\mathbf{1}\ \boldsymbol{m3}}{\mathbf{264.2}\ \boldsymbol{Gal}} = 3{,}532.7\ \frac{\boldsymbol{m3}}{\boldsymbol{hr}}$$

Since Warren treatment plant has no measurements for the TKN, and it receives combined wastewater, a TKN of 17 $(\frac{mg}{L})$ is assumed for the plant (M&E 4th edition, table page 191) :

$$17\ (\frac{mg}{L}) \text{ x } (\frac{1000\ L}{m3}) \text{ x } (\frac{1\ g}{1000\ mg}) = 17\ (\frac{g}{m3})$$

$$N_2O_{WWTP} = Q_i \text{ x } TKN_i \text{ x } EF_{N2O} \text{ x } EF_{N2O} \text{ x } \frac{44}{28} \text{ x } 10^{-6}$$ (from dissertation, Eq. 4.3.16, page 88)

$$N_2O_{WWTP} = 3{,}532.7\ \frac{m3}{hr} \text{ x } 17\ \frac{g}{m3} \text{ x } 0.0050\ \frac{g\ N2O}{g\ TKN} \text{ x } \frac{44}{28} \text{ x } 10^{-6}\ \frac{Mg}{g}$$

$$N_2O_{WWTP} = 0.000944\ \frac{Mg\ N2O}{hr}$$

Using global warming potential for N_2O of 310, the hourly N_2O emissions expressed as CO_2e from WWTP yield:

$$CO_2e = 0.000944\ \frac{Mg\ N2O}{hr} \text{ x } 310 = 0.2926\ \frac{Mg\ CO2e}{hr} = 0.2926 \text{ x } 24 = 7.0\ \frac{mTCO2}{day}$$

Note: N_2O emission factor = 0.0050 (g N emitted as N_2O/g TKN), Ref: Chandran, 2010.

Total CO_2e from biological treatment processes = 2.6 + 7.0 = 9.6 $\frac{mTCO2}{day}$

APPENDIX - E

ACRONYMS AND ABBREVIATIONS

ACEEE	American Council for an Energy-Efficient Economy
AF	Acre-Foot
ASTM	American Society for Testing and Materials
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BHP	Brake Horsepower
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
Btu	British Thermal Unit
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CHP	Combined Heat and Power
COD	Chemical oxygen Demand
CO_2e	Carbon Dioxide Equivalent
CWNS	Clean Water Shed Needs Survey - US EPA
DAF	Dissolved Air Floatation
DO	Dissolved Oxygen
DOE	Department of Energy
DSIRE	Database of State Incentives for Renewable and Efficiency
ECM	Energy Conservation Measure
eGRID	U.S. EPA’s Emissions & Generation Resource Integrated Database
EF	Emission Factor
EIA	U.S. Energy Information Administration
EPACT	Energy Policy Act
EPRI	Electric Power Research Institute
ET	Energy Trilogy
FGD	Flue Gas Desulfurization
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
gpm	Gallons per minute
GWP	Global Warming Potential
hp	Horsepower
HRSG	Heat Recovery Steam Generator
ICE	Internal Combustion Engine
I&I	Inflow and infiltration
IPCC	International Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt hour
MG	Million Gallons

M&V	Measurement and Verification
MGD	Million Gallons per Day
$mTCO_2e$	Metric Ton Carbon Dioxide Equivalent
NEMA	National Electrical Manufacturers Association
N_2O	Nitrous Oxide
NYSERDA	New York State Research and Development Authority
PF	Power Factor
PG&E	Pacific Gas and Electric
PLC	Programmable Logic Controller
POTW	Publicly Owned Treatment Works
PSAT	Pump System Assessment Tool
psi	Pounds per Square Inch
psig	Pounds per Square Inch Gauge
RFS	Renewable Fuel Standards
RPM	Revolutions per Minute
SHP	Separate Heat and Power
SRT	Solids Residence Time
TBL	Triple Bottom Line
TCE	Ton Carbon Equivalent
TCEQ	Texas Commission on Environmental Quality
TDH	Total Dynamic Head
TRI	Toxic Release Inventory
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
UV	Ultraviolet Light
UVT	UV transmittance
VFD	Variable Frequency Drive
VMT	Vehicle Miles Travelled
W	Watt
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRF	Water Research Foundation
WSHP	Water Source Heat Pump
WSU	Wayne State University
WWTF	Wastewater Treatment Facility
WWTP	Wastewater Treatment Plant
Y	Biomass Yield

APPENDIX - F

GLOSSARY [52]

ALTERNATIVE (transportation) FUELS -- as defined by the National Energy Policy Act (EPAct) the fuels are: methanol, denatured ethanol and other alcohols, separately or in mixtures of 85 percent by volume or more (or other percentage not less than 70 percent as determined by U.S. Department of Energy rule) with gasoline or other fuels; CNG; LNG; LPG; hydrogen; "coal-derived liquid fuels;" fuels "other than alcohols" derived from "biological materials;" electricity, or any other fuel determined to be "substantially not petroleum" and yielding "substantial energy security benefits and substantial

ANNUAL MAXIMUM DEMAND -- The greatest of all demands of the electrical load which occurred during a prescribed interval in a calendar year.

BARREL - In the petroleum industry, a barrel is 42 U.S. gallons. One barrel of oil has an energy content of 6 million British thermal units. It takes one barrel of oil to make enough gasoline to drive an average car from Los Angeles to San Francisco and back (at 18 miles per gallon over the 700-mile round trip).

BASE LOAD - The lowest level of power production need during a season or year.

CARBON DIOXIDE (CO_2) - A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO_2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO_2 emissions is fossil fuel combustion. CO_2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO_2 have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels. (EPA)

CARBON DIOXIDE EQUIVALENT (CDE). A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents (MMTCDE)" or "million short tons of carbon dioxide equivalents (MSTCDE)" The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP. MMTCDE= (million metric tons of a gas) * (GWP of the gas) For example, the GWP for methane is 24.5. This means that emissions of one million metric tons of methane are equivalent to emissions of 24.5 million metric tons of carbon dioxide. Carbon may also be used as the reference and other greenhouse gases may be converted to carbon equivalents. To convert carbon to carbon dioxide, multiply the carbon by 44/12 (the ratio of the molecular weight of carbon dioxide to carbon). (EPA)

CFCs (CHLOROFLUOROCARBONS or CHLORINATED FLUOROCARBONS) - A family of artificially produced chemicals receiving much attention for their role in stratospheric ozone depletion. On a per molecule basis, these chemicals are several thousand times more effective as greenhouse gases than carbon dioxide. Since they were introduced in the mid-1930s, CFCs have been used as refrigerants, solvents and in the production of foam material. The 1987 Montreal protocol on CFCs seeks to reduce their production by one-half by the year 1998.

CLIMATE CHANGE - Also referred to as 'global climate change'. The term 'climate change' is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, 'climate change' has been used synonymously with the term, 'global warming'; scientists however, tend to use the term in the wider sense to also include natural changes in climate. See also Enhanced Greenhouse Effect. (EPA)

COGENERATION - Cogeneration means the sequential use of energy for the production of electrical and useful thermal energy. The sequence can be thermal use followed by power production or the reverse, subject to the following standards:

(a) At least 5 percent of the cogeneration project's total annual energy output shall be in the form of useful thermal energy.

(b) Where useful thermal energy follows power production, the useful annual power output plus one-half the useful annual thermal energy output equals not less than 42.5 percent of any natural gas and oil energy input.

EFFICIENCY - The ratio of the useful energy delivered by a dynamic system (such as a machine, engine, or motor) to the energy supplied to it over the same period or cycle of operation. The ratio is usually determined under specific test conditions.

EMISSION STANDARD - The maximum amount of a pollutant legally permitted to be discharged from a single source.

ENERGY - The capacity for doing work. Forms of energy include: thermal, mechanical, electrical and chemical. Energy may be transformed from one form into another.

ENERGY EFFICIENCY - Using less energy/electricity to perform the same function. Programs designed to use electricity more efficiently - doing the same with less. For the purpose of this paper, energy efficiency is distinguished from DSM programs in that the latter are utility-sponsored and -financed, while the former is a broader term not limited to any particular sponsor or funding source. "Energy conservation" is a term which has also been used but it has the connotation of doing without in order to save energy rather than using less energy to do the something and so is not used as much today. Many people use these terms interchangeably.

ENHANCED GREENHOUSE EFFECT - The natural greenhouse effect has been enhanced by anthropogenic emissions of greenhouse gases. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCs, HFCs, PFCs, SF6, NF3, and other photochemically important gases caused by human activities such as fossil fuel consumption and adding waste to landfills, trap more infra-red radiation, thereby exerting a warming influence on the climate. See Climate Change and Global WarEPAct - The Energy Policy Act of 1992 addresses a wide variety of energy issues. The legislation creates a new class of power generators, exempt wholesale generators (EWGs), that are exempt from the provisions of the Public Utilities Holding Company Act of 1935 and grants the authority to FERC to order and condition access by eligible parties to the interconnected transmission grid.

FAHRENHEIT -- A temperature scale in which the boiling point of water is 212 degrees and its freezing point is 32 degrees. To convert Fahrenheit to Celsius, subtract 32, multiply by 5, and divide the product by 9. For example: 100 degrees Fahrenheit - 32 = 68; 68 x 5 = 340; 340 / 9 = 37.77 degrees Celsius.

FOSSIL FUEL -- Oil, coal, natural gas or their by-products. Fuel that was formed in the earth in prehistoric times from remains of living-cell organisms.

GIGAWATT (GW) -- One thousand megawatts (1,000 MW) or, one million kilowatts (1,000,000 kW) or one billion watts (1,000,000,000 watts) of electricity. One gigawatt is enough to supply the electric demand of about one million average California homes.

GREENHOUSE EFFECT -- The effect produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent most of the outgoing infra-red radiation from the surface and lower atmosphere from escaping into outer space. This process occurs naturally and has kept the Earth's temperature about 59 degrees F warmer than it would otherwise be. Current life on Earth could not be sustained without the natural greenhouse effect. (EPA). See Global Climate Change.

GRID -- The electric utility companies' transmission and distribution system that links power plants to customers through high power transmission line service (110 kilovolt [kV] to 765 kV); high voltage primary service for industrial applications and street rail and bus systems (23 kV-138 kV); medium voltage primary service for commercial and industrial applications (4 kV to 35); and secondary service for commercial and residential customers (120 v to 480 v). Grid can also refer to the layout of a gas distribution system of a city or town in which pipes are laid in both directions in the streets and connected at intersections.

HEAT CAPACITY - The amount of heat necessary to raise the temperature of a given mass one degree. Heat capacity may be calculated by multiplying the mass by the specific heat.

HEAT RATE - A number that tells how efficient a fuel-burning power plant is. The heat rate equals the Btu content of the fuel input divided by the kilowatt-hours of power output.

HORSEPOWER (HP) - A unit for measuring the rate of doing work. One horsepower equals about three-fourths of a kilowatt (745.7 watts).

KILOVOLT (kV) -- One-thousand volts (1,000). Distribution lines in residential areas usually are 12 kV (12,000 volts).

KILOWATT (kW) -- One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

KILOWATT-HOUR (kWh) -- The most commonly-used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumes 534 kWh in an average month.

LIFE-CYCLE COST - Amount of money necessary to own, operate and maintain a building over its useful life.

LOAD - The amount of electric power supplied to meet one or more end user's needs.

LOAD - An end-use device or an end-use customer that consumes power. Load should not be confused with demand, which is the measure of power that a load receives or requires.

MEGAWATT HOUR (MWh) - One-thousand kilowatt-hours, or an amount of electrical energy that would supply 1,370 typical homes in the Western U.S. for one month. (This is a rounding up to 8,760 kWh/year per home based on an average of 8,549 kWh used per household per year [U.S. DOE EIA, 1997 annual per capita electricity consumption figures]).

RENEWABLE ENERGY -- Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and wood. Although particular geothermal formations can be depleted, the natural heat in the earth is a virtually inexhaustible reserve of potential energy. Renewable resources also include some experimental or less-developed sources such as tidal power, sea currents and ocean thermal gradients.

SOURCE ENERGY - All the energy used in delivering energy to a site, including power generation and transmission and distribution losses, to perform a specific function, such as space conditioning, lighting, or water heating. Approximately three watts (or 10.239 Btu of energy is consumed to deliver one watt of usable electricity.

THERM - One hundred thousand (100,000) British thermal units (1 therm = 100,000 Btu).

UTILITY -- A regulated entity which exhibits the characteristics of a natural monopoly. For the purposes of electric industry restructuring, "utility" refers to the regulated, vertically-integrated electric company. "Transmission utility" refers to the regulated owner/operator of the transmission system only. "Distribution utility" refers to the regulated owner/operator of the distribution system which serves retail customers.

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ABSTRACT

THE ENERGY TRILOGY: AN INTEGRATED SUSTAINABILITY MODEL TO BRIDGE WASTEWATER TREATMENT PLANT ENERGY AND EMISSIONS GAPS

by

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August 2014

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An estimated 4% of national energy consumption is used for drinking water and wastewater services. Despite the awareness and optimization initiatives for energy conservation, energy consumption is on the rise owing to population and urbanization expansion and to commercial and industrial business advancement. The principal concern is since energy consumption grows, the higher will be the energy production demand, leading to an increase in CO_2 footprints and the contribution to global warming potential.

This dissertation is in the area of energy-water nexus, focusing on wastewater treatment plant (WWTP) energy trilogy – the group of three related entities, which includes processes: (1) consuming energy, (2) producing energy, and (3) the resulting - CO_2 equivalents. Detailed and measurable energy information is not readily obtained for wastewater facilities, specifically during facility preliminary design phases. These limitations call for data-intensive research approach on GHG emissions quantification, plant efficiencies and source reduction techniques.

To achieve these goals, this research introduced a model integrating all plant processes and their pertinent energy sources. In a comprehensive and "Energy Source-to-Effluent Discharge" pattern, this model is capable of bridging the gaps of WWTP energy, facilitating plant designers' decision-making for meeting energy assessment, sustainability and the environmental regulatory compliance. Protocols for estimating common emissions sources are available such as for fuels, whereas, site-specific emissions for other sources have to be developed and are captured in this research.

The dissertation objectives were met through an extensive study of the relevant literature, models and tools, originating comprehensive lists of processes and energy sources for WWTPs, locating estimation formulas for each source, identifying site specific emissions factors, and linking the sources in a mathematical model for site specific CO_2 e determination. The model was verified and showed a good agreement with billed and measured data from a base case study. In a next phase, a supplemental computational tool can be created for conducting plant energy design comparisons and plant energy and emissions parameters assessments.

The main conclusions drawn from this research is that current approaches are severely limited, not covering plant's design phase and not fully considering the balance of energy consumed (EC), energy produced (EP) and the resulting CO_2 e emission integration. Finally their results are not representative. This makes reported governmental and institutional national energy consumption figures incomplete and/or misleading, since they are mainly considering energy consumptions from electricity and some fuels or certain processes only.

The distinction of the energy trilogy model over existing approaches is based on the following: (1) the ET energy model is unprecedented, prepared to fit WWTP energy assessment during the design and rehabilitation phases, (2) links the energy trilogy eliminating the need for using several models or tools, (3) removes the need for on-site expensive energy measurements or audits, (4) offers alternatives for energy optimization during plant's life-cycle, and (5) ensures reliable GHG emissions inventory reporting for permitting and regulatory compliance.

AUTOBIOGRAPHICAL STATEMENT

Ph.D. + 31 years of total professional experience:

- 20 years of general and mechanical engineering experience including:

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- 11 years with the environmental, health and safety (EHS) fields consisting of:

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Education and Certification

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Certified Storm Water Manager: Non-Point Source Construction and Industrial Site, MDEQ 2002

Unpublished Papers

- Practical Guide on leaking Underground Storage Tanks, Wayne State University, 1/1993
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