12-2020

The Optimization of Efficiency and Infrastructure for Modern Potable Water Treatment Plants

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THE OPTIMIZATION OF EFFICIENCY AND INFRASTRUCTURE

FOR MODERN POTABLE WATER

TREATMENT PLANTS

A Thesis

by

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Submitted to the Graduate College of
The University of Texas Rio Grande Valley
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING

December 2020

Major Subject: Mechanical Engineering

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ABSTRACT

DeKock, Brent A., The Optimization of Efficiency and Infrastructure for Modern Potable Water Treatment Plants. Master of Science in Engineering (MSE), December 2020, 189 pp., 32 tables, 76 figures, 64 references, and 10 chapters.

The USDOE Industrial Assessment Centers (IACs) is a program that is designed to help small and medium-sized manufacturing facilities reduce their overall costs and improve energy efficiency. This includes improving potable water treatment plants which supply water throughout the country. This thesis covers the process of how IAC branches and water treatment facilities generally operate, as well as several assessment recommendations that have been developed by a branch of the IAC for several water treatment plants based in the Rio Grande Valley of Texas. The steps of the assessment and water treatment process are described, and several cost saving measures that were developed are discussed at length. These include updating lighting equipment, utilizing improved components in various machinery, updating fenestration, using novel evaporation preventing devices and installing renewable energy devices and other energy efficiency measures all showing millions of dollars in potential savings in total.

DEDICATION

The completion of my master's studies would not have been possible without the love and support of my family and friends. My fiancée, soon to be wife and love of my life, Ana Escobedo, has wholeheartedly inspired, motivated and supported me by all means to accomplish this degree, she is truly my muse. My sister and brother-in-law, Courtney and Aaron Stidwell, have provided immense amounts of love and support throughout my life and education and I would not be where I am today without their help and assistance. My parents, Terri and August DeKock, my grandmother, Patricia Wicker, as well as my step-mother and soon to be in-laws, Delia DeKock and Tom and Mary Escobedo, also contributed immeasurable sums of love, encouragement to pursue a higher education, and vast amounts of wisdom and assistance throughout my entire life which have allowed me to become the man I am now. My brother and soon to be brother-in-law, Clay DeKock and Thomas Kelly Escobedo, played integral roles in my development as well and I am truly thankful to have had brothers and friends such as them to help me enjoy the finer things in life. All of my other family and friends, who I wish I could list, that have encouraged me and provided a shoulder to lean on and an ear to complain to, your patience will never be forgotten. My mentors, coworkers and acquaintances who have offered their support and kindness throughout the years and helped me in more ways than I can mention to develop my knowledge and skills so I could reach this goal in my life. Thank you all, words cannot express my deep gratitude for your love, compassion and support over the years, this thesis is dedicated to every one of you and I will do my best to continue to make you all proud.

ACKNOWLEDGEMENTS

I will always be immensely grateful to Dr. Alexander Domijan, chair of my thesis committee, and Mr. Arnold Pedraza, my manager at the IAC, for all of their mentoring and advice, and for giving me a chance to contribute to this great program and learn many valuable engineering and energy management skills. My deep appreciation and admiration goes to Dr. Maysam Pournik and Dr. Mataz Alcoutlabi, both members of my thesis committee, and Dr. Jaime Ramos for their sage like patience, understanding and immeasurable assistance throughout my master's degree and work with the IAC. My sincere thanks to Dr. Robert Jones and Dr. Karen Lozano who encouraged my curiosity and love for materials engineering, their encouragement helped me make my decision to pursue my master's degree. I would also like to thank Dr. Constantine Tarawneh who also encouraged me to pursue a degree in higher education after my bachelor's degree and for showing me that early morning classes can still be thoroughly enjoyable. I also am very grateful to Mr. Jose Sanchez, Ms. Samantha Ramirez and Mr. Gregory Potter for their mentorship, friendship and assistance while working through my degrees. I want to also thank Dr. Arturo Fuentes, Dr. Isaac Choutapalli, Dr. Horacio Vasquez, and Dr. Stephen Crown for helping me reach this goal as well and for teaching me invaluable engineering principles. Finally, I wish to thank all of my teachers growing up and all of the other faculty and staff at UTRGV who have assisted me throughout my entire education, I would not be here without your guidance, support, wisdom and kindness over my lifetime, thank you all from the bottom of my heart.

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CHAPTER I

INTRODUCTION

This aim of this thesis is to describe in full the Industrial Assessment Center's practices and general assessment procedures along with documenting the work they have accomplished in regards to energy savings and waste management with specificity given to three potable water treatment facilities. There are several steps that must be done when assessing facilities with the IAC, and consistency is a must when developing a full report. Recently, a branch of the IAC in Edinburg, Texas at the University of Texas- Rio Grande Valley has made several visits to various water treatment facilities in the RGV and developed numerous energy saving and waste reduction recommendations that have been shown to be viable sources of millions of dollars in potential savings in the coming years for these facilities.

Figure 1: UTRGV IAC Assessment Team during an Assessment

There are many opportunities for improvements in general for modern potable water treatment and this thesis describes some of the research which has been undergone and developed in order to fully understand the potential and offer multiple avenues to not only improve and optimize the energy efficiency of these facilities, but also the infrastructure and processes. These improvements will vault these potable water treatment facilities into the next era of global water treatment with some initial investment that will pay off quickly and last for decades to come. The hope is that these alterations will improve these plants' efficiency, overall revenue, and sustainability so that they may one day be completely energy independent which will lead the charge for nearby facilities to follow suit and improve their own company's procedures and infrastructure using these ideas and recommendations.

The Industrial Assessment Center

In order to fully understand the work that was done for this thesis one must learn about what the Industrial Assessment Center is all about and how the program performs their assessments. The original program was first created in the United States in 1976 under the name of the Energy Analysis and Diagnostic Centers initiative which the government supplemented in response to rising energy costs and the current oil embargo of the time. Its main aim was to focus on helping small and medium sized manufacturing facilities reduce any unnecessary costs and improve energy efficiency. Soon after in 1978, the current program was formed and moved under the guidance of the Department of Energy. The program expanded the scope of their evaluations and assessments to include ineffective production procedures such as excessive waste production and material mismanagement to name a few. Over the next 40 years, the program has expanded even further to cover improvements such as the implementation of smart manufacturing and energy management technologies, the adoption of renewable energy sources to reduce energy grid dependence, and improving cybersecurity awareness. Up to this point thousands of assessments have been performed on a menagerie of manufacturing facilities that range in their focus from food production, vehicle components, specialty products, and utility production to only scratch the surface. These assessments provide recommendations which the facility can choose whether or not to implement which range in savings from a few hundred dollars to hundreds of thousands of dollars a year.

Figure 2: Industrial Assessment Center Logo

The process for providing these assessments ranges, but it usually entails the center director approaching local manufacturing facilities in up to a 150 mile radius of the local IAC branch and asking if they are interested in an energy assessment. These facilities must have energy costs that range from over one hundred thousand to 2.5 million dollars. Once the offer to make an assessment is made then the facility must decide if they wish to go ahead with the assessment or not. If they accept the offer then the facility is asked to provide detailed information about their process and the general layout of their facility, any safety precautions that are mandatory in order for a team to tour the facility, as well a year's worth of any bills they wish the center to analyze as part of their assessment report. Once this information is obtained then a team of students and professors from the local branch may make one or more trips to the facility in order to observe the production process first hand and conduct the assessment. The team will have a student lead, a student safety officer and a professor assigned to mentor and monitor progress of the assessment and final report. The student lead will help organize the assessment tour and assign team members individual work and areas they need to review or observe in operation. The student safety officer is in charge of distributing the proper safety equipment to all members of the assessment team and must ensure all safety protocols are being followed at all times during the plant tour. The members of the team will take detailed notes on their observations while touring the production process in order to fully understand the scope of the recommendations that could be a possibility for the facility. They ask questions about the equipment, personnel, and layout of the facility in order to glean any ideas of ways to improve the processing efficiency. Once the assessment walk-through is complete then the team heads back to the center to discuss their findings and develop a list of recommendations that could be achieved for the facility. These are entirely dependent on the type of facility viewed, but there are certain recommendations which can be suggested for many facilities such as upgrading outdated lighting which is a common issue in many plants for example. Usually an individual student will work on developing each recommendation to fruition under the guidance of the student leader and faculty advisor, but for some larger and more novel recommendations multiple students can work on gathering research and deciphering the best way to approach and resolve the problem.

Figure 3: Full Student Assessment Team and Supervising Professors with Facility Staff

The recommendations must use data that is gathered and evaluated based on the bills provided by the facility so that proper payback time estimations can be found. The evaluation of these bills is a crucial step in the assessment process and plays a key role in almost all recommendations. Energy bills are evaluated based on energy consumption in kilowatt hours and energy demand in kilowatts. These total values for the year of energy bills they provide are then used to create values for the avoided cost of electricity and demand, and the total avoided cost of electricity in dollars per kilowatt hour. Depending on the type of facility there may be other bills such as water and natural gas usage that must be analyzed in a similar manner.

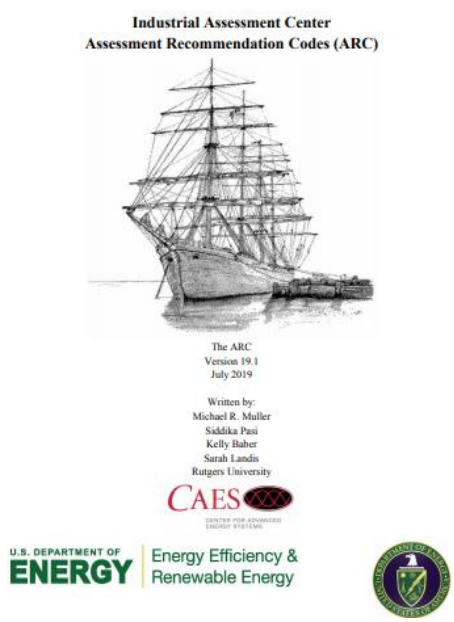
Once the bills are analyzed they can be used to calculate the savings the company could see by implementing the various recommendations that are relevant to the site. The payback times will range, but the IAC focuses on recommendations with payback times that are usually less than ten years since they are more likely to be adopted by the facility in question. All of the information for these recommendations along with the calculations needed to obtain their results is included in the final assessment report in order to show the facility how the results were obtained. The results are listed in an executive summary in the final assessment report and described in subsequent easy to read tables so that the relevant staff can have access to the most crucial pieces of information such as costs to implement, utility savings, total monetary savings per year along with the payback times themselves in a simplified format. Other information is then provided in the report such as the plant and process description, the trends seen in the bills provided, avoided cost information and calculations obtained from the bills, load factor analyses, a list of the major energy consuming equipment and general practices of the staff observed by the team, and an emissions analysis based on the developed recommendations. The recommendations themselves are then listed in full detail along with other energy efficiency measures that may not have been able to be quantified entirely, but have been researched and shown to be possible improvements to the facility in general. Finally, sections on general energy management, cybersecurity and the overall conclusion of the report are included for the facility to peruse.

After the assessment report is complete, it is then sent to the main IAC office located at Rutgers University for revisions and critiques. After several rounds of critiques and corrections are made by the student leader then the report is verified as complete and uploaded to the IAC website making the findings available for the public to view. This finalized report is then submitted to the facility as well so they may review the results. The student leader can then create a presentation based on the findings and present it to the facility’s relevant staff to describe the overall conclusions and savings that are achievable based on the teams results if the staff are interested. After the report is turned into the facility and the presentation is done then the assessment process is nearly complete. After approximately six to twelve months, the local IAC center's director will contact the facility again to find out if any of the recommendations have been implemented successfully or not; the director will then update the online database to reflect these findings.

These are the general steps each branch of the IAC undertakes to successfully develop assessment reports for the facilities they tour. Sometimes multiple tours may be necessary to fully gather all of the necessary data for the recommendations, but sometimes only a single trip is necessary based on the size of the facility. This methodical process has led to hundreds of millions of dollars in energy and material savings at thousands of facilities since the IAC was first founded and will continue to grow in number for years to come. Various report savings and recommendation implementation data can be obtained on the IAC website at https://iac.university/ where one can also find data about the different branches and manufacturing facilities can sign up for an energy evaluation. The steps the IAC undertakes to create a successful assessment report are mentioned in subsequent chapters of this document. The subsequent recommendations this thesis covers are given general descriptions of how their results were obtained; a full list of the equations used for the recommendations is listed in Appendix A.

Energy Management

The IAC's primary goal is to save various facilities money by providing recommendations for them to improve their energy management and efficiency. These recommendations can vary widely from improving various equipment with updated components, to insulating containers to reduce heat loss, updating the fenestration of a facility's building to reduce air conditioning or heating costs, or even installing smart energy controllers to reduce a facility's peak energy demand throughout the day. There have been numerous additions to the recommendations that have been achieved and finalized by various IAC branches in the past, and the list continues to grow each year in the official IAC Assessment Recommendation Code (ARC) List. Ever since the program's birth, energy management has been the primary focus and ensuring the companies they visit are as optimized as possible is a main tenant of each branch. Depending on the facility in question there may be multiple solutions for improving overall energy management, but finding these possible recommendations can be challenging and often takes a keen eye to see the potential for large improvements. Oftentimes, the equipment a facility uses is outdated and utilizes mostly original components, so there are small improvements to the mechanisms which can be suggested that can drastically increase the efficiency of a machine and reduce overall energy consumption. Not only is the equipment generally outdated, but the buildings that comprise most facilities usually have not been brought into the 21st century in terms of general infrastructure.


Industrial Assessment Center
Assessment Recommendation Codes (ARC)

The ARC
Version 19.1
July 2019

Written by:
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Kelly Baber
Sarah Landis
Rutgers University

CAES

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Figure 4: Cover of Official ARC List for 2019

Most facilities try to use cost saving materials when constructing their buildings in order to reduce the initial investment of opening the facility. These materials and equipment soon become outdated and can become detrimental to the facility over time. It is up to the IAC to observe what equipment is currently in use and to find energy saving alternatives and measures that will enhance the facility's sustainability and efficiency.

Lighting is usually the first thing that is observed and studied in nearly all facilities the IAC visits. Most high output facilities that were constructed over the past 50 years usually use primarily fluorescent and incandescent lighting for the interior of their buildings and high pressure sodium or halogen bulbs for the exterior and surrounding grounds. These are usually the standard types of bulbs and fixtures that are observed and can be easily replaced with much higher efficiency LED alternatives. LEDs, or light emitting diodes, are a type of lighting that has seen a huge expansion in applications over the past 10 years. They offer higher directionality of lighting, longer lifespans, increased brightness, and most importantly utilize far less energy than their predecessors. Researchers have been able to develop replacements for nearly all types and styles of lighting including a huge swath of fluorescent light tubes, high intensity high bay bulbs, flood lights, wall packs, Exit sign lighting, parking lot box lights and many more. By replacing either the bulb or the fixture itself with an LED equivalent a company can reduce their lighting energy usage usually by half and significantly reduce their energy bill in the process.

Similarly, a lot of the major processing equipment many facilities utilize also need to be updated to increase their efficiency and output while reducing product loss. For example, many manufacturing facilities use pumps to transfer various liquids throughout their development process. The pumps themselves can be upgraded to be more efficient with various operations such as trimming the impeller blades to better match the desired output, but a major update to a pumps operation is changing how their shafts are sealed. Many pumps today utilize what is known as gland packing to reduce the leakage of liquid around the pump shaft. This method of sealing has been extremely common for decades and has been updated using different gland material technology; it works by applying pressure from the spinning shaft to the outer pump casing which in turn robs the pump of its efficiency through increased friction. The packing must be replaced several times throughout the year to ensure the smallest amount of liquid is lost over time as well. This replacement process can take several hours and needs a trained technician to remove the old packing, and then cut and insert the new packing. This entire process can be circumvented by utilizing mechanical seals, which reduce total liquid losses by as much as 95% and allow the pumps to run more efficiently by reducing the friction between the shaft and pump housing considerably. Another major change to the equipment most facilities use that the IAC suggests is replacing the v-belts used by many different machines in a large variety of plants with cogged v-belts. The classic v-belts are prone to slipping and degrading quickly, they are usually only able to transfer approximately 95% of the energy provided by their attached motor to the final piece of equipment. The cogged belts act as a combination between a gear and a belt that not only increases the machine’s energy efficiency up to approximately 98% in some cases, but also the lifespan of the belt itself. By implementing these upgraded pieces of hardware throughout a facility the energy savings can add up to thousands of dollars over a single year’s usage.

A facility’s fenestration, or the arrangement, layout and style of its doors and windows, also plays a key role in a plant’s overall energy efficiency. Window and door technology has increased drastically in the past 20 years to decrease heat and air transmission while simultaneously decreasing overall energy usage. Many facilities utilize single paned glass windows to allow light transmission into their buildings while also allowing an excessive amount of heat or cold to enter as well. Insulated windows have become cheaper and more energy efficient each year allowing companies to lower their energy bills since cooling costs will be far less while allowing nearly the exact same amount of light to enter their buildings throughout the day. The energy saving potential in having updated windows is immense, but if the cost of total replacement is too high, then a simple high grade window tinting can be applied for a fraction of the cost to reap extensive energy savings. Another simple fix many facilities can gain energy savings from is updating or even just applying weather stripping to the various exterior doors of a facility. This reduces both the exfiltration of cold air to the outside during warmer months and also reduces the infiltration of cold air during colder months. This brings down the demand on the air conditioning unit considerably since it has to work far less to maintain the ambient temperature set by the facility's supervisors. The amount of energy saved by these measures varies on a case by case basis depending on the location of the fenestration on the building itself, the local weather of the region the facility is located, and most importantly the style of updates the facility chooses to implement to the fenestration. These are just a few examples of updates a facility can choose to undergo, but there are many others that can be done depending on the facility itself and their specific needs.

A facility can further reduce energy consumption and the energy demand on its air conditioning units by changing the exterior or makeup of the buildings themselves in numerous ways. This can range from implementing reflective roof paint to reject a large portion of the ultra-violet rays the sun emits, to installing upgraded wall and ceiling insulation, in addition to installing sky lights to reduce the need for indoor lighting throughout the day. Changing the color of a building's roof has been shown to drastically reduce the amount of heat energy a building absorbs. By preventing heat energy from being absorbed a facility further decreases the demand on the air conditioning units to maintain desired temperatures. This also applies to the case of updating the insulation inside the building to make a building more resistant to heat loss or gain. By applying the principles of heat transfer the potential for reduced energy absorption can be plainly seen. By installing skylights in buildings throughout a facility, the need for electrically powered lighting can drastically be reduced and lead to thousands in savings. This not only provides essential lighting to the facility, but also can act as a potential source for heat transfer to occur as well. It can be detrimental at times depending on a facility, but depending on the type of buildings present it can reduce the overall energy consumption of a facility considerably.

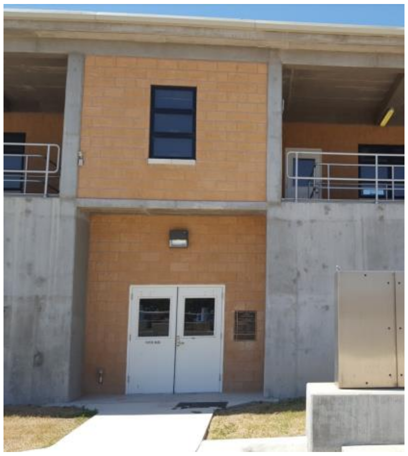

Figure 5: Example of Un-tinted Single-Paned Glass Windows and Outdoor Lighting Left on in the Daytime

Another significant way for facilities to drastically reduce energy consumption and improve their sustainability is by implementing renewable energy sources at their facility. These sources of renewable energy fall in a few main categories which have been successfully implemented at a large number of facilities around the world. They include using solar photo-voltaic (PV) arrays, wind, hydroelectric and steam turbines depending on the type of facility in question. The potential for energy savings is enormous, and after an initial investment, which can be subsidized using tax incentives provided by the U.S. government in most cases, a facility could potentially see savings in the millions over the coming decades based on their own electric bill savings in addition to the potential for the sale or storage of excess electricity. The initial implementation cost may be high, but with a modest loan repayment plan a renewable energy installation can pay for itself in a short number of years depending on the desired output. As the technology for these energy sources advances, prices become lower and outputs become higher and the potential energy savings see increases as well. When implementing these sources along with a battery storage system, a facility can become entirely energy independent and can store any excess energy produced for later use. If a facility has any excess land such as a nearby field or a roof with a large open area it can easily implement a PV solar array. If the facility is located far enough away from any local airports and has the space it can install a wind turbine up to 100 meters tall to harvest immense amounts of wind energy at a fantastic rate. A facility that utilizes pressure reduction valves or is located in a hilly area could very easily install hydroelectric turbines to capture the potential energy which is usually unutilized. Some facilities produce excess heat which can also be utilized to produce steam which is then in turn used to power steam turbines. Other facilities utilize machinery or processes which produce gases that can in turn be used in various forms of turbines before final disposal. These are just a few examples of renewable energy implementations, but there are several other options which can be utilized in order to reduce overall energy costs drastically for many facilities.

Waste Reduction

Waste reduction is another significant facet of total savings that IAC locations try to offer various facilities. There are numerous ways to achieve the reduction of waste in many facilities and these include implementing ways to utilize wasted heat that is usually expelled to the environment, re-using cooled water to remove heat from different equipment, recycling material which would normally be considered as waste, filtering and reusing waste oils, reducing the evaporation of working fluids, or even selling waste to other facilities that could potentially utilize it in their processes. These are but a few ways that waste reduction can be achieved, but again, the implementation of each of these depends entirely on the facility itself and the processes they undergo including the products they create.

Waste heat is a significant source of energy that can be utilized in a number of ways. It can be used to power renewable energy sources like steam turbines, keeping a facility warm in colder winter months to reduce the load on the ambient heating unit, and working in combination with a facility's boilers to heat various materials to working temperatures. These are but a few from a long list of possibilities for waste heat to be reused by a facility, but the number of options are limited only by the ingenuity and ability of a facility to adapt its processes to capture and reuse this often wasted resource. By utilizing this untapped source of energy a plant could potentially see significant reductions in overall energy use since a lot of processes that the heat would be supplementing are either electrically powered or run using fuels such as natural gas.

Reusing water in plants is a type of recommendation that has been gaining adoption in many plants before the IAC even gets to do an assessment. This can be done in a number of ways including using cooled water produced in one part of the plant which would normally be removed as waste water, but instead pumping it to different areas of a plant to remove heat from various pieces of equipment. This decreases the load on the equipment while also increasing its efficiency and longevity since the heat could accumulate over time and damage either components of the machines, or the entire piece of equipment itself. Another way to reuse water in many facilities is by implementing a cooling tower at the location. In some manufacturing processes water is used to cool off parts as they are being created, and cooling towers can then take this warmed water and return it to the proper working temperature with minimal effort. This vastly increases the length of time the water is usable for and allows the company to save money on waste water and water acquisition charges.

Figure 6: Aluminum Waste from Tube Manufacturing Facility in Recycling Bin

Depending on the desired final part to be manufactured there can often be large amounts of wasted material that is removed from the final part while it is being processed. This can include metals such as aluminum, brass, copper and steel, as well as ceramics such as sand and glass. Various types of polymers, both thermoplastics and thermosets, are also widely produced by manufacturing facilities and can create large amounts of waste as the final products are being created. Many of these forms of waste have the opportunity to be recycled either by the company itself by inputting the scraps back into the feedstock, or by shipping it to the supplier for them to recycle in order to obtain better material deals in the future. While the plant operates, there can be other forms of waste which are normally just thrown away and considered as garbage as soon as the desired product is obtained. These include packing plastics, wooden pallets and cardboard boxes to name a few. These forms of waste can often be removed through local recycling companies that will remove the waste free of charge usually, or can even be sold in bulk to different companies such as in the case of wooden pallets. There have been several recommendations made by IAC centers for companies to invest in cardboard compactors which are machines that compress large amounts of cardboard together to reduce overall waste volume. Sometimes local manufacturing facilities can actually purchase the compacted cardboard for use in their own processes or the original company can just save money by reducing their waste volume that would normally cause their trash receptacles to overflow and lead to additional waste disposal charges. Waste collection companies operate by providing removal services that are usually based by the volume of the provided receptacle or the overall volume of waste to be removed on a monthly basis. Since the latter form of this is fairly hard to estimate with varying amounts of waste being produced depending on demand and product availability, the volume of the receptacle is usually the preferred agreement that a company has their waste removed with. By recycling waste or decreasing overall waste material production a company can see huge returns of investment on the various ways they can choose to handle their changes in operation as waste disposal can be a serious source of lost income for many companies.

Figure 7: Waste Container used at a Manufacturing Facility

Many facilities often utilize oils or lubricants in varying degrees to lubricate machines, the working pieces themselves, or the final product they are trying to sell. Oftentimes this oil is removed and separated into a waste disposal tank for later removal by a hazardous waste company. However, if a company implements a filtering system, these oils and lubricants can be reused several times over thus decreasing the amount of waste disposals necessary for the year while also saving money on the lubricant or oil itself. Some manufacturing processes involve using lubricants to cut a piece of metal which subsequently needs to be washed off in order to finalize the creation process. This waste water/oil is then collected in waste barrels or large disposal tanks mentioned above. By implementing a furnace or evaporator to heat this mixture up and evaporate the water from the solution a company can see an immense reduction in overall waste production. Disposal fees for hazardous waste materials such as used oils can be extremely expensive over a year's time, so by decreasing the overall volume of the collection tank inputs the waste disposal company would have to stop by far less often to remove the waste oil.

The unwanted evaporation of liquids during a production process can be a huge source of profit loss for many companies that deal with all manner of liquids in their processing. Certain liquids used in various processes can be drastically altered if too much evaporation is allowed to occur as well. Congealing of the fluid can cause many problems for a company as the fluid may lose its working viscosity and lead to damage to various machines in the process. Depending on the working fluid itself, there can be several ways to mitigate the loss of the liquid through evaporation however. Sometimes cooling the container the fluid is being held in can drastically reduce the amount of evaporation that occurs yearly. Another ideal option includes covering the respective containers which can range from a simple storage tank lid to installing a vast array of shade balls to cover large water reservoirs. These covers can have drastic impacts on the overall productivity for a facility since they can save potential product for sale in the future, keep the manufacturing process running smoothly, and ensure that the liquid they initially purchase does not go to waste. Depending on the type of facility, the savings that can be achieved through reducing evaporation can be hundreds of thousands of dollars a year.

Another way the IAC recommends reducing waste was touched on earlier, in some situations depending on the principle product of a company, the waste products they would normally just get rid of could potentially be bought and used by other facilities for their processes in turn. This includes scrap metal sold to local scrapyards, waste oils sold to manufacturing facilities that require lesser grade oils or lubricants for their operation, cardboard which could be sold for recycling at local companies, or selling wastewater sludge for use in composting or even brick manufacturing. These are just a few of the different arrangements that can be made with other manufacturing facilities in order to mutually benefit both companies while reducing the overall production costs of both.

Potable Water Treatment and Processing

Water treatment for human consumption is a process dating back thousands of years and has evolved over the millennia to provide access to nearly all of human kind from a wide variety of sources. There are a number of ways to achieve potable treated water with today's technology, but for the most part nearly all potable water treatment facilities utilize a similar set of steps that ensures a quality final product. Several chemicals in differing amounts are used throughout most of the world's water treatment facilities, but there are variations to the chemicals used and several substitutes are becoming viable alternatives for future employment. The processes themselves are also being altered slightly or being circumvented entirely by utilizing new technologies or implementing older ideas in new ways to enhance production and reduce costs. There are many standards and tests that are utilized in order to make sure the water that is sent to customers is of top quality and that the present chemicals will not be harmful in their final amounts. The overall water treatment process continues to evolve, but nearly all currently operated plants follow the logical flow of the seven main steps for large scale water treatment. These steps are shown in the figure below and can be achieved through various means but most plants adhere to these main processes since they are proven to achieve a more than sufficient result.

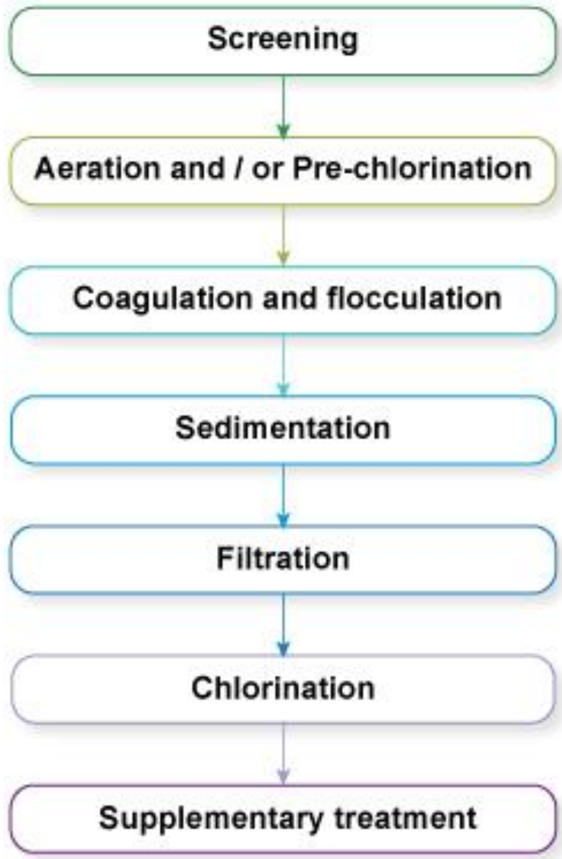

Figure 8: The Seven Main Steps of Large Scale Water Treatment (The Open University, 2017)

Screening consists of using various screens or filters to remove any large floating particulates or suspended solids that are present in the water feedstock. The source of the water itself ranges from rivers, to lakes, to underground or above ground reservoirs, to wells, or even extensive canal systems.

Figure 9: Irrigation Canal Used to Supply Water Treatment Facilities (Knight, 2009)

The material initially removed during the screening process usually includes solids such as twigs, leaves, paper, rags, and even insects in some cases. Any of this debris could potentially obstruct the flow of water into the subsequent areas of the plant or even damage equipment such as the various pumps used throughout the facility. There are usually several coarse and fine screens that are utilized to ensure the largest of the various particulates are removed before further processing.

Figure 10: A Coarse Screen Used to Filter Debris from Raw Water (The Open University, 2017)

Once screening is completed, the water is usually aerated by passing it over an aerator (of which there are many styles) several times in order to agitate the water and add air which in turn helps expel any soluble unwanted gases trapped inside. These gases include carbon dioxide and hydrogen sulfide among others, which usually make the water more acidic and their removal ensures less corrosion occurs in the various equipment of the facility. Other gaseous organic compounds are also expelled that would otherwise alter the taste or smell of the final water product. The organic compounds the aeration process removes include iron or manganese by changing the compounds to their insoluble form through oxidation. Further filtration is usually involved to remove these now insoluble compounds and then the water is prepared for any pre-chlorination treatment the plant deems necessary. Excess algal growth from various water sources can be a serious issue for many plants as the algae can eventually clog up sand filters which are utilized further along the treatment process. Pre-chlorination can be achieved through several means, but many plants employ a combination of chemicals including chlorine dioxide and liquid ammonia to name a few. Chlorine dioxide is a red to yellow-green gas at room temperature that readily dissolves in water, and liquid ammonia is an extremely powerful disinfectant used throughout the world in various processing facilities. This chemical addition further disinfects and cleans the water and oxidizes even more organic compounds the aeration process missed.

After aeration and pre-chlorination are completed, coagulation takes place in which the facility employs chemical coagulants in order to remove fine particles less than 1 µm in size that are still suspended in the water. The coagulants usually have positive ionic electrical charges and are added to the water in order to attract the negatively charged finer particulates. To add the coagulant to the water a rapid mixer and mixing tank are usually involved to quickly disperse the chemicals using a high-speed impeller.

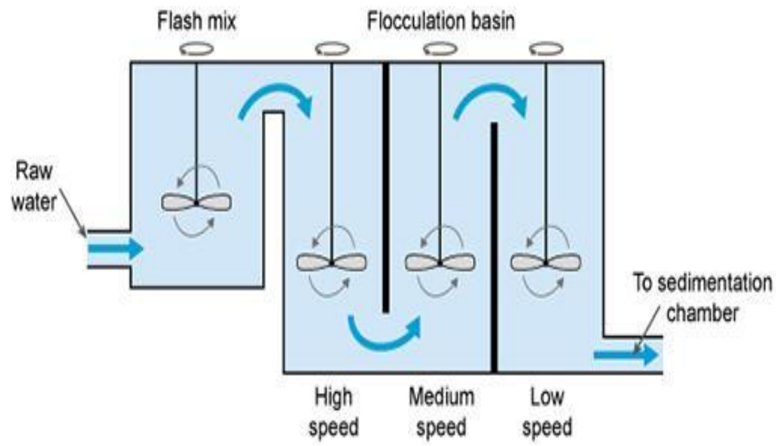

Figure 11: Example of Coagulation–Flocculation Process (The Open University, 2017)

When the electrically charged particles become neutralized, the microscopic particles begin to coalesce forming soft, fluffy particles referred to as ‘flocs’. The two coagulants most often used in the treatment of water are aluminum sulfate and ferric chloride, both of which are classified as metallic salts. Ferric chloride is utilized for odor control, phosphorus removal and hydrogen sulfide minimization. It has high efficiency, effectiveness in clarification, and utility as a sludge dewatering agent. The chemical leaves slight residual color and offers very good turbidity removal. Aluminum sulfate is soluble in water and is mainly used as a coagulating agent in the purification of drinking water and wastewater and also assists in various other manufacturing processes. In water purification, it causes suspended impurities to group into larger particles which then settle at the bottom of the container to then be removed by a track vacuum at the bottom of the clarifier tanks. Flocculation then occurs where the water is gently stirred by paddles in a deep basin and the flocs meet each other to form larger flocs. A special chemical coagulant called a flocculent is added to enhance the process of which there are several such as the organic polymer called polyelectrolyte.

Figure 12: Emptied Flocculation Basin with Exposed Mixing Paddle

The flocculation basin has several compartments with decreasing mixing speeds as the water advances through the chambers. These compartmentalized chambers allow increasingly large flocs to form without being broken apart by the various mixing paddles. This process allows the now fully formed flocs to settle at the bottom of the basins to later be removed.

Figure 13: Filled and Emptied Clarification Basins

After the largest flocs coagulate and settle at the bottom of the flocculation basins, the water is then sent to a series of clarification basins in a process called sedimentation. This process has the water slowly transfer along the long open basins and further cleanse itself of the coagulated material. The remaining particulates gather along the bottom of the tank and the mud-like material is referred to as sludge. The sludge is cleaned from the bottom of the clarifier and flocculation basins and sent to the facility's sludge processing station.

Figure 14: Sludge Pond at a Potable Water Treatment Facility

The processing of sludge varies from facility to facility, but most areas utilize what are known as sludge ponds which utilize the heat from the sun to remove the majority of the liquid from the sludge which is then disposed of in various ways depending on the chemicals used to clean the water. Since most of the chemicals used to process and clean potable water are toxic, most dried sludge is removed from the ponds and shipped to the nearest landfill for final disposal.

Figure 15: Filtering Bed Used at a Potable Water Treatment Facility

The next step in the cleaning process is filtration, where the remaining solids and debris are separated and removed via several filtering beds of sand and gravel. This is the final step to remove all of the remaining microscopic solids and once the filters are full of trapped solids, they are backwashed to cleanse them. In this process, clean water and air is pumped backwards up the filter to dislodge the trapped impurities, and the water carrying the debris (referred to as backwash) is discharged back into the original water source for recycling. After filtration, the water is either sent to a clear well via transfer pumps or to a storage tank where contact time can occur with further chlorination.

Figure 16: Emptied Filtration Transfer Tank

The final chlorination phase is next where the water is further chlorinated to eliminate any remaining pathogenic microorganisms. Chlorine is used in liquid form where it reacts with any pollutants present over a given contact time. Residual chlorine stays in the water after the contact time is over and remains all the way through the distribution system, protecting it from any microbials or other pathogens that might enter it until the water reaches the consumers.

Figure 17: Storage Tank and Transfer Pumps

Some facilities utilize supplementary treatments which usually entail further chemical additions such as fluoride to enrich the water. Finally, the cleaned water is usually held in large storage tanks, sometimes able to hold several million gallons at a time, for easy distribution to customers throughout the region. All of these steps combine to ensure the cleanest water is available to the facility's constituents, but some steps may be combined or removed due to different equipment additions or special chemical treatments that the facility deems as acceptable. The water is continuously tested daily to ensure the final product meets the facility's and the government's strict treatment standards. After confirming the treated water meets the facility's standards, multiple high service pumps are utilized to send the cleaned water to their waiting customers.

Figure 18: High Service Pumps

CHAPTER II

ANALYZING ENERGY BILLS

In order to complete an assessment to its fruition the IAC must first analyze a year's worth of various utility bills provided by the facility, primarily of which are the electricity bills. Natural gas, and water bills can be analyzed in order to better understand the cost breakdowns of each, but the facility itself determines if these are necessary depending on the operations they perform during their day to day processing. The primary focus for every branch of the IAC however are the energy bills since these are almost always the largest bill a facility pays on a monthly basis. Analyzing the bills themselves can be particularly difficult based on what is supplied by the facility undergoing the assessment since utility companies can have drastically different layouts for their bills, but with a consistent and methodical approach an analysis can be completed that gives crucial information as to how much money is spent on electricity consumption and electrical demand. Based on the data obtained from this analysis, the various trends can be used to create figures which show how the costs fluctuate month to month. The various monthly load factors and total avoided cost of electrical energy is also determined from the analysis results and give an actual boiled down total electricity cost based on dollars per kilowatt-hour which can then be used to determine savings in the subsequent recommendations for the facility. Finally, a load factor analysis may be performed which analyzes the overall energy efficiency of the plant itself, and determines the amount of savings that can be obtained by running the facility more efficiently.

Demand and Billing Analysis

In order to begin the demand and billing analysis for the plants electricity consumption, an IAC staff member must have at least a full year of energy bills. These bills range widely stylistically, but a consistent set of information can be obtained after reading through them and differentiating the various charges, fees, and credits which may be present. There are two sets of numbers of primary interest that the IAC needs to construct the data trends and develop the avoided cost and load factor analysis, the overall electrical consumption in kWh and the electrical demand in kW, which are used to find the final estimated rates the company pays for both their consumption and demand. However, all pieces of the bill must be identified such as any extra charges that may be present so that the monthly total shown on the bill can be matched to the analysis correctly. These extra charges can include any miscellaneous customer charges such as transmission or transition charges, congestion charges, distribution charges, nuclear decommissioning charges, late payment fees and any metering charges or taxes the utility company sees fit.

Other pieces of data of particular interest to the billing analysis include if there are special electricity rates for different amounts of consumption, or if the utility company applies what are known as ratchet charges. These ratchet charges are set in place by the utility to ensure consistent amount of money is received from the manufacturing facility month to month. How it works depends on the monthly demand of kW the company requires; when the company reaches a particularly high demand for one month then the utility can use this as a benchmark for the next eleven months (National Grid, 2019). This benchmark allows the utility to charge 50-80% of this high demand if the company does not reach that amount of consumption already. So a company could have one bad month where they use 500 kW for their demand, but the next month they only use 300 kW; some utility companies would then have the ability to charge the customer for 400 kW since their new benchmark is 500 kW and 400 is 80% of that (if 80% was that particular utility company's ratchet percentage). This form of billing can be very detrimental to facilities since one bad day where most of their machines are running at the exact moment for just one fifteen minute interval can cause total peak demand to skyrocket leading to results like the example mentioned above.

The demand charge, mentioned above, is essentially the highest amount of energy in kW that is demanded in a single fifteen minute interval by the company on any given day during the current billing cycle. This is what is commonly referred to as a peak in demand, and can be seen when machines are first started at the same time, or when the majority of them are running together during processing. This can be seen when viewing the 15 minute demand data for a company taken from their smart meter, which is the piece of equipment most utility companies utilize to determine the monthly peak demand. There are still many companies that utilize older meters where the monthly peaks sometimes have to be measured in person. This demand peak is then listed on the electric bill and multiplied by a specified rate to obtain the final demand charge for the month. If the company assessed is supplied by a national electricity provider then they may be subject to ratcheting as mentioned before. The daily peak demand most often occurs at the start of a work day or after a lunch break when the majority of equipment is powered up and when the air conditioning unit is working hardest to maintain the set ambient temperature for the various buildings at a facility. Most often the highest demand for the year can be seen during the summer months for this reason; the hotter the outside air is, the harder the air conditioning system must work to keep the facility cool. Demand can be extremely varied for this reason and is why the IAC always recommends and advises companies to try and pay close attention to how they operate their equipment to decrease their average monthly demand peaks. By timing the powering up of machines in sequential order at different fifteen minute intervals and not all at once a company can see drastic reductions in demand overall. Other options for keeping demand peaks low are installing smart devices known as demand controllers, which help regulate a facility's demand throughout the day.

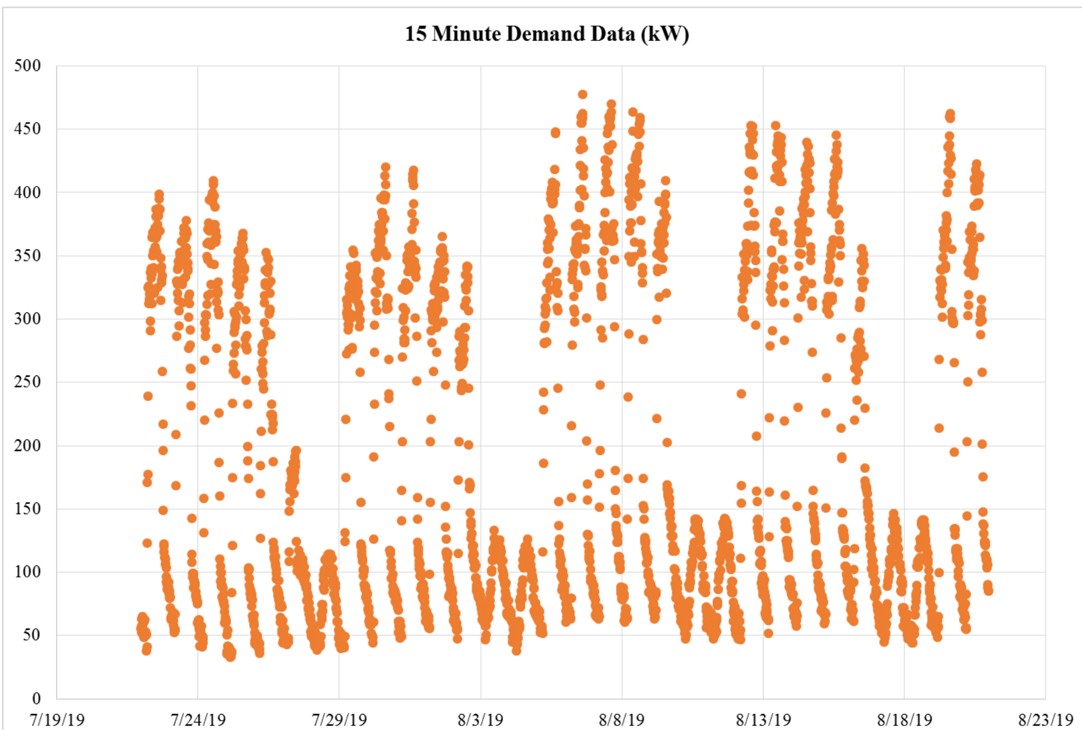

Figure 19: Fifteen Minute Demand Data Taken Using a Smart Meter

Electrical consumption is the other main metric that can be seen in electric bills that indicate the total energy used by the company in a given billing cycle. How this datum works is the electric meter will measure the total electricity used for the entire length of time shown in the bill. The demand mentioned before is used to obtain this information, but instead it is monitored as it adjusts throughout the entire time period instead of just the highest point. This is then multiplied by the total hours in the billing cycle which can range depending on the utility. So if the billing cycle for one month is 30 days, or 720 hours, and the total demand used for the month was 500 kW, then to obtain the electrical consumption for the month one would simply multiply the two together to obtain 360,000 kWh for the month. This total consumption in kWh is then multiplied by a specified rate listed in the electric bill similarly to demand mentioned before, and the total consumption charge is determined. All of the charges mentioned above are then combined to obtain the total energy bill for the company, which can range substantially from month to month depending on a multitude of factors.

Companies that are able to keep relatively consistent peak demands are known to have what is referred to as a high electrical load factor, which can be described as a measure for how energy efficient a plant is actually running month to month. It is determined by taking the total consumption in kWh for a given billing cycle, and dividing it by the product of peak demand for the month and how many hours were in the billing cycle. This provides a value between 0 and 1 which is essentially a percentage that shows how well a company's peak demands match with overall monthly electrical consumption. For a company to be considered reasonably energy efficient this number should be at least 0.75, but the higher this value is the better the facility is running. Their electricity bills will be much lower overall when this value is increased. Unfortunately most companies are not aware of the balance between demand and consumption and what determines their overall electricity charges so it is up to the IAC staff to demonstrate and educate them on how to improve their operation in this regard.

Table 1: Electrical Demand and Billing Analysis for a Potable Water Treatment Plant

Electrical Demand and Billing Analysis													
Sevice Dates: May 2018 - April 2019													
Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total/Avg
From	5/13	6/12	7/15	8/13	9/16	10/15	11/13	12/13	1/14	2/12	3/12	4/11	
To	6/12	7/15	8/13	9/16	10/15	11/13	12/13	1/14	2/12	3/12	4/11	5/13	
Days in Cycle	30	33	29	34	29	29	30	32	29	28	30	32	**365**
Energy Consumption (kWh)	165,888	116,736	128,640	168,576	91,776	78,336	96,384	95,232	81,408	104,832	113,280	132,480	**1,373,568**
First 200 KWH	67,276	59,290	65,894	72,422	55,526	44,698	45,236	43,162	41,932	55,988	45,926	44,928	**642,278**
Next 200 KWH	67,276	57,446	62,746	72,422	36,250	33,638	45,236	43,162	39,476	48,844	45,926	44,928	**597,350**
Over 400 KWH	31,336	0	0	23,732	0	0	5,912	8,908	0	0	21,428	42,624	**133,940**
Billed Demand (kW)	336.38	296.45	329.47	362.11	277.63	223.49	226.18	215.81	209.66	279.94	229.63	224.64	**267.62**
Electrical Load Factor	0.68	0.50	0.56	0.57	0.47	0.50	0.59	0.57	0.56	0.56	0.69	0.77	**0.59**

Costs Associated with Energy Consumption (kWh)													
Energy Costs EC ($)													**Total**
EC (First 200 kWh)	5,903	5,202	5,782	6,354	4,872	3,922	3,969	3,787	3,679	4,912	4,030	3,942	**$56,353**
EC (Next 200 kWh)	4,557	3,891	4,250	4,906	2,456	2,279	3,064	2,924	2,674	3,309	3,111	3,043	**$40,464**
EC (Over 400 kWh)	1,217	0	0	922	0	0	230	346	0	0	832	1,656	**$5,204**
Sum of Consumption Costs ($)	**11,677**	**9,093**	**10,032**	**12,182**	**7,327**	**6,200**	**7,263**	**7,057**	**6,353**	**8,221**	**7,973**	**8,641**	**$102,022**

Costs Associated with Demand													
Demand Costs ($)													**Total**
P.C.R.F	(0.005)	(0.008)	(0.015)	(0.018)	(0.020)	(0.020)	(0.016)	(0.012)	(0.005)	(0.005)	(0.001)	(0.001)	
Demand Charge	1,345.52	1,185.80	1,317.88	1,448.44	1,110.52	893.96	904.72	863.24	838.64	1,119.76	918.52	898.56	**$12,845.56**
PCRF Large Power Charge	(829)	(934)	(1930)	(3034)	(1836)	(1567)	(1542)	(1143)	(407)	(524)	(113)	(132)	**($13,991.42)**
Sum of Demand Costs ($)	**516.08**	**251.91**	**(611.72)**	**(1585.93)**	**(725.00)**	**(672.76)**	**(637.42)**	**(279.54)**	**431.60**	**595.60**	**805.24**	**766.08**	**($1,145.86)**

Costs Independent of Energy & Demand													
Additional Charges ($)													**Total**
Meter Charge	0	0	0	0	0	0	0	0	0	0	0	0	**$0**
Customer Charge	85	85	85	85	85	85	85	85	85	85	85	85	**$1,020**
Sales Taxes	0	0	0	0	0	0	0	0	0	0	0	0	**$0**
Sum of Independent Costs	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**$1,020**
Total Sum of All Costs	**$12,278.56**	**$9,430.41**	**$9,505.23**	**$10,681.23**	**$6,687.43**	**$5,612.68**	**$6,710.55**	**$6,862.36**	**$6,869.82**	**$8,901.68**	**$8,863.29**	**$9,492.43**	**$101,895.67**

Table 1 displays a typical billing analysis that is done for every plant the IAC assesses. The particular set of bills that were used for this analysis originated from a potable water treatment facility in the Rio Grande Valley of Texas and has charges that are based on rates specified by their electricity provider. The data in this figure is used for further analyses for various sections in an assessment report.

Trends in Billing Data

Once the bills are laid out in an easy to understand format showing the changes in charges month to month then IAC staff can construct figures which show the how demand and consumption change throughout the year and how they relate to the bills the company is required to pay. The following figures were constructed based on the data shown in Table 1, and demonstrate how the electrical charges can vary month to month and how demand and consumption are related to the final monthly charges as well as to each other.

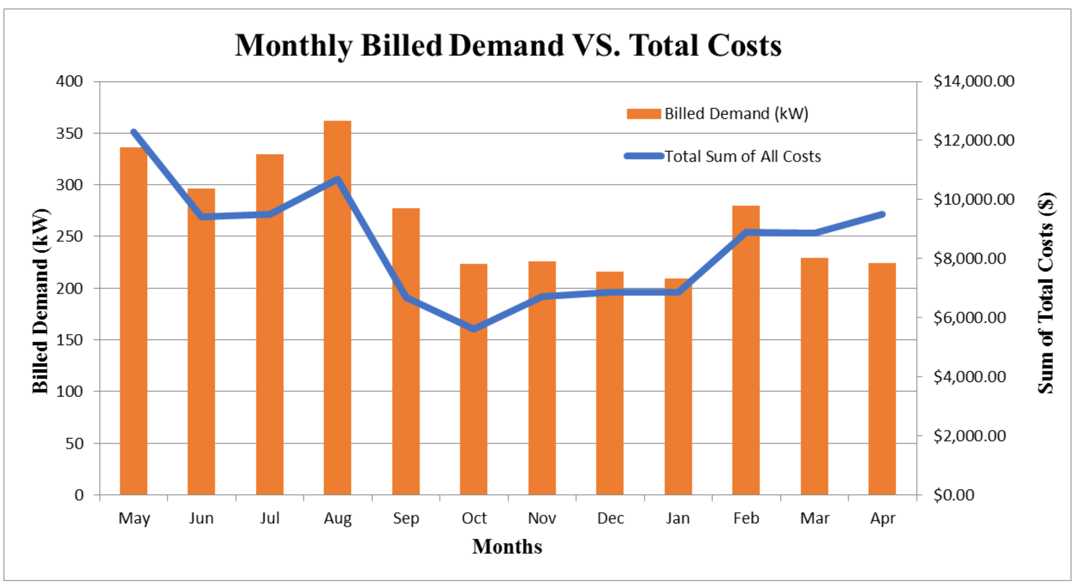

Figure 20: Monthly Billed Demand vs. Total Electricity Costs

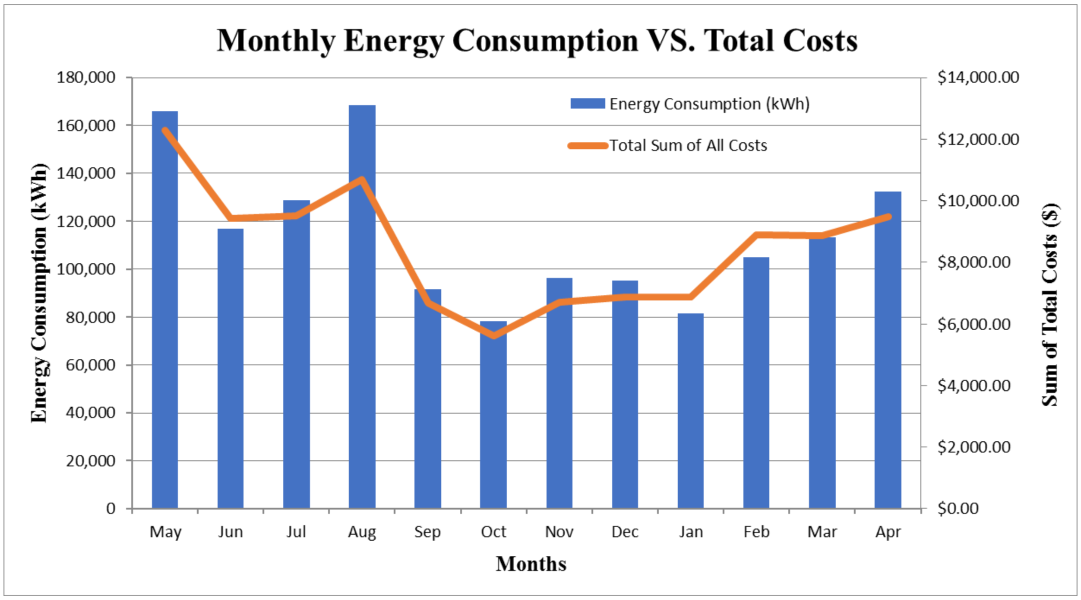

Figure 21: Monthly Energy Consumption vs. Total Electricity Costs

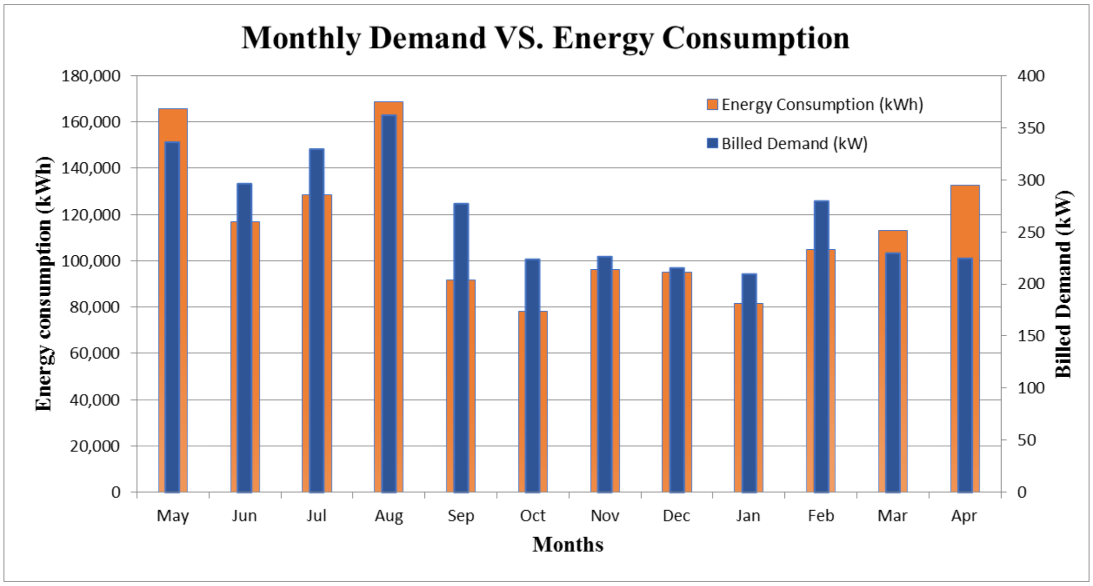

Figure 22: Monthly Demand vs. Monthly Energy Consumption

From Figures 20 to 22 one can observe the basic trends which can be found by breaking down and analyzing a year's worth of bills from a facility. These figures provide valuable insight into how the plant operates throughout the year and where improvements can be made as far as peak demands are concerned. Usually, total energy consumption cannot be mitigated, but peak demand charges can be brought down with revised operating procedures which can reduce total billing for the year considerably. A plant can most likely be considered running fairly efficiently when the two sets of bars in Figure 22 almost line up with each other each month meaning demand and consumption are fairly consistent with one another. Having higher demand charges compared to overall consumption for a month will lead to a lower load factor for that month meaning the plant is not utilizing their energy efficiently throughout that billing cycle.

These figures also show how the bills adjust seasonally, and since it can clearly be seen that in the hottest months of the year, May to August, the total sum of all costs listed on the bill are at their maximum. This relates to the high demand placed on the air conditioning units of the facility which have difficulty regulating the temperature in these hottest days of the year. There is also a corresponding dip in total costs in the fall and winter months as well with the month of October being the lowest overall since this is when outdoor temperatures most closely matches the desired interior temperature for the facility's buildings. These are just a few of the pieces of valuable information which can be perceived by viewing the simplified trends in electrical data that the IAC provides each assessed company. The facility in question can utilize the information in this section of the assessment report to begin adjusting their operating procedures to begin bringing down their costs.

Avoided Cost of Electrical Energy

The avoided cost of electrical energy is a simplified estimate of the rates at which a company pays for their electricity. The first calculation that is made is based on the total yearly consumption of the plant taken from the billing analysis and the costs directly associated with that consumption. To obtain the avoided cost of electricity associated with consumption one must divide the total yearly sum of consumption charges from a plant by the total yearly amount of kilowatt-hours consumed. This is demonstrated below using the data that was found in the billing analysis shown in Table 1.

$$\frac{\text{Yearly Sum of Consumption (\$)}}{\text{Yearly kWh}} = \frac{\$112{,}735}{1{,}513{,}920\ \text{kWh}} = \frac{\$0.0745}{\text{kWh}}$$

The next form of avoided cost is based on the yearly demand in kilowatts a company is charged for. To obtain this value one must divide the cost total yearly sum of the demand charges by the sum of all of the monthly demand amounts in kilowatts. This is again demonstrated below using the values shown in Table 1.

$$\frac{\text{Yearly Sum of Demand Charges (\$)}}{\text{Yearly Sum of Billed Demand (kW)}} = \frac{\$14{,}263}{3{,}565.68\ \text{kW}} = \frac{\$4.00}{\text{kW}}$$

This avoided cost of electrical demand ($/kW) can then be transformed into having the same units of the avoided cost of consumption ($/kWh) by dividing by the average load factor for the year and the number of hours in a monthly billing period of 30 days. This allows the IAC to display a total avoided cost of electricity by combining the two once this is calculated.

$$\frac{\text{Avoided Cost of Electrical Demand }(\frac{\$}{\text{kW}})}{\text{(Average Load Factor)(Average Hours in a Month)}} = \frac{\frac{\$4.00}{\text{kW}}}{(0.59)(720\text{hours})} = \frac{\$0.0094}{\text{kWh}}$$

Finally, the total avoided cost of electricity is obtained by combining these two values to find a single value which represents an approximate measure of how much money the plant spends for every kWh of consumption and kW of demand. This total avoided cost is used for savings and payback calculations for the different assessment recommendations in each report. Below is an example of a total avoided cost of electricity that was found using the same values that were calculated above.

$$\text{Avoided Cost of Electrical Energy } \left(\frac{\$}{\text{kWh}}\right) + \text{Avoided Cost of Electrical Demand} \left(\frac{\$}{\text{kWh}}\right)$$

$$= \frac{\$0.0745}{\text{kWh}} + \frac{\$0.0094}{\text{kWh}} = \frac{\$\mathbf{0.0839}}{\mathbf{kWh}}$$

This resulting value can be multiplied by the potential electrical savings in kWh for any given recommendation the IAC finds in order to provide an estimate into approximately how much money can be saved based on their electricity costs alone. It is not a perfect measure, but it provides a good approximation that allows the IAC to estimate the total savings achievable from a wide range of recommendations. However, some centers prefer to not use the combined total avoided cost and instead utilize the consumption and demand avoided costs separate and calculate individual savings in regards to each. But, by combining the two it has been found that a more conservative savings approximation is found since the demand rate can sometimes inflate the savings in demand costs, and when it comes to finding overall savings it is better to underestimate and be more true to life than using values which would cause the findings to be higher. The discrepancy in savings findings is due to the number of days in certain billing cycles fluctuating leading to slightly altered values in avoided cost of billed demand and load factor month to month. By using the yearly average value for load factor and only 30 days for the month to convert the demand avoided cost we ensure a lower overall value is obtained for the total avoided cost. The IAC specializes in making approximate estimations in savings for electricity and by presenting the savings findings as conservatively as possible the centers are able to provide results to the companies they assess which they will most likely be able to achieve in approximate amount of time they suggest with their payback time calculations. It is a common practice to conservatively estimate lower savings potentials if possible rather than inflate the savings and present unachievable real world results.

Load Factor Analysis

The electrical load factor (ELF) has been mentioned in previous sections because it is used to derive certain values such as the total avoided cost of electrical energy, but it plays an essential role in showing how a plant can become more efficient in its energy usage. It is essentially a quantifier for how effective a plant’s machinery is running and is calculated by taking the total energy (kWh) used during a specified billing period and dividing it by the product of the total energy used in that period during peak demand (kW) and the total number of hours for that period. This value will range month to month, but an average is used to determine the total avoided cost of electricity for a company. If the load factor of a facility is below 0.5 this indicates high demand with a low utilization rate. If load factor is at or above 0.75 a facility is deemed reasonably efficient overall; this means that the equipment is running consistently during their respective peak demands and consuming a proportionate amount of energy during these peaks throughout the month. Based on the findings from a load factor analysis, the approximate savings can be found if the assessed company is able to increase their load factor to different degrees. A demonstration of the calculation to find the ELF for one month is described below using the data from Table 1 for the month of May 2018:

$$\text{ELF} = \frac{\text{Monthly Energy Consumption (kWh)}}{\text{Monthly peak Demand (kW)} \times \text{Hours per Billing Period (hours)}}$$

$$\text{ELF} = \frac{161{,}280\ \text{kWh}}{440.88\ \text{kW} \times 720\ \text{hours}} = 0.51$$

This load factor is considered to be on the lower side and is the result of a high peak demand period for the month in comparison to lower overall energy consumption. The monthly load factors are all calculated and then averaged together to obtain the average load factor for the year which can be used for the avoided cost calculations mentioned earlier. Once the average yearly load factor is found then a load factor analysis can then be conducted which shows the potential savings that can be achieved with just a slight increase in overall energy efficiency and general utilization which matches the demand peaks for the company. To obtain the potential savings that can be obtained from decreasing load factor one must choose a new value the facility can easily obtain with a few adjustments, usually an increase of approximately 10%. Then the calculation is done in reverse to obtain the new demand peak that would match the new load factor value for each month. This new demand value is then multiplied by the avoided demand cost to find associated demand cost savings for each month which can be summed together to show savings for the year due to the new load factor. Finally, this new yearly demand charge is subtracted from the current yearly demand charge total to obtain the total amount of money that would be saved. This can then be compared to the total amount of money spent by the company on energy to obtain the respective percent savings that would be achieved as well.

Table 2: Load Factor Analysis for Potable Water Treatment Plant

Load Factor Analysis													
Load Factor Details													**Total/Avg**
New load factor	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
New Peak demand	334	214	268	299	191	163	194	180	170	226	228	250	**226**
New Demand charges	$1,336	$854	$1,071	$1,198	$764	$652	$776	$719	$678	$904	$912	$1,000	**$10,865**
Year Savings													**$1,980.12**
Percent savings													**1.94**
Peak Demand	336.38	296.45	329.47	362.11	277.63	223.49	226.18	215.81	209.66	279.94	229.63	224.64	**267.62**

Potential Savings when changing Load Factor (efficiency)			
New load factor	0.69	0.75	0.8
Year Savings	$1,980	$2,849	$3,474
Percent savings	1.814	2.797	3.410
Peak demand decrease	41	59	72

This table shows the load factor analysis based on the billing analysis shown in Table 1, the new load factor used for the first set of calculations was based on the original yearly averaged load factor of 0.59. For this load factor analysis the IAC staff chose to simulate an approximate 10% increase in load factor for the first set of calculations and the second and third were for 16% and 21% respectively, signifying increases in load factor efficiency up to 0.69, 0.75, and 0.8 respectively. These adjustments would be made by lowering the company's peak demands throughout the year which can be done in a variety of ways mentioned in this document.

These are but a few of the energy analyses normally performed by IAC centers throughout the country, but for water treatment plants these are the primary analyses and calculations that would be done since most water treatment facilities do not usually utilize natural gas for their operations, and they do not have any need for outside sources of water so water bills are usually nonexistent except for their sewage disposal in some cases. The electrical billing analysis allows the staff of a facility to readily observe the values that affect their electricity bills directly and quickly compare month to month totals. Figures which demonstrate these energy trends can be essential to simply display how the monthly bills are affected directly by both the consumption and demand, and how they relate clearly to each other. The total avoided cost of electricity is used extensively throughout the rest of the assessment report to determine the overall savings of recommendations that deal with energy consumption. The load factor does not come up in subsequent recommendations unless the IAC staff wish to pursue recommendations which deal with trimming peak demand, or installing demand controllers which will in turn increase the facility's overall load factor in turn.

CHAPTER III

EQUIPMENT, PRACTICES AND EMISSIONS REDUCTION

During the assessment process the IAC staff are required to try and document and list all of the major pieces of equipment used at a given facility to maintain normal operations in addition to listing some of the main practices that are performed by the staff at the facility. This is beneficial for several reasons when trying to develop recommendations, but it also demonstrates to IAC staff some of the measures the facility undergoes to maintain its output safely. Another aspect of most assessment reports is a section on reducing overall emissions through energy efficiency. This section is usually completed after the billing analysis is finished and the recommendations are completed and describes the amount of emissions that are created by power plants to currently power the facility. It also lists the amount of harmful emissions that will be prevented if the company were to implement the electricity saving recommendations that are described in the subsequent sections of the report.

Compiling Equipment

While gathering the information on the general energy consuming equipment of a facility, the staff must also ascertain and describe several pieces of information about the equipment such as the total horsepower, voltage, current, and any prominent components the equipment utilizes such as belts for motors and pumps as well as pump seals which are the primary focus for water treatment facilities. The list can include anything from 50 ton presses, large scale pumps, multi stage furnaces, mulching machines, mixers, compressors, air conditioning units, spooling units, blowers, furnaces, motor operated valves and many more. Some manufacturing machines consist of multiple mechanisms such as compressors, engines, and furnaces working in concert with one another to achieve the desired outcome such as with the aluminum tube extruder shown below. For these larger pieces of equipment which combine several different machines to create a product, the principle components can be listed in the equipment section separately.

Figure 23: Front End of Tube Extruding Machine

Approximately each horsepower listed on a machine operating at full load consumes power at approximately 1 kilowatt-hour each hour. When a plant is running every day of the year, such as in most water treatment facilities, then this information can be very valuable to have listed not only for the plant itself but also for developing assessment recommendations by IAC staff. The following table has been taken from an assessment report done for a water treatment plant that has had a thorough review of nearly all of the equipment and machinery present which utilize electricity.

Table 3: List of Major Energy Consuming Equipment for a Water Treatment Plant

Equipment Name	Quantity	Horsepower (Hp)	Voltage (Volts)	Current (Amps)
Raw Water Pump #1	1	100	460	52
Raw Water Pump #2	1	100	460	52
Raw Water Pump #3	1	20	460	28
Raw Water Pump #4	1	40	460	52
Air Compressor	2	25	460	6.9
Air Dryer Fan for Compressors	1	6.25	460	6.5
Air Blower	1	40	460	34.7
Motor Operated Valve	4	0.14	115	1.9
Transfer Pump	2	100	460	115
High Service Pump #1	1	200	460	231
High Service Pump #2	1	200	460	231
High Service Pump #3	1	150	460	231
High Service Pump #4	1	150	460	231
High Service Pump #5	1	250	460	280
Filter Back Wash Pump	3	75	460	87.7
Air Conditioning Unit	3	5	240	5
Chemical Injection Pump	2	2	230	6
Sludge Pump #1	1	5	460	6.5
Sludge Pump #2	1	10	460	11.6
Sludge Pump #3	1	10	460	6.1
Flocculator Motor	8	3	460	4.35
Rapid Mixer Motor	1	15	230	6

A table such as this can provide additional insight into when a facility should engage certain machines to control their demand peaks. Water treatment plants utilize several pumps of varying size throughout their facilities, but usually do not operate them all at once. Depending on the plant's daily customer demand for water they choose to operate different pumps at various stages to ensure proper availability. For instance, in the summer months, when demand for water is at its highest, the two largest raw water pumps may work together at the same time to send source water to the pre-chlorination stage. To send water to the customers they might employ the 250 horsepower and the 150 horsepower high service pumps to ensure consistent pressure when the largest amount of customers are utilizing their at home dispensers for various purposes. In the winter when water demand is lowest, the company may use the 100 and 20 horsepower raw water pumps to keep up with customer usage, and may even alternate switching off the smaller pump throughout the day. To send water to customers in the winter, the company might only enlist the use of the two 150 horsepower high service pumps since customer usage would be much lower. These are just examples of how a water treatment plant could potentially utilize their different equipment throughout the year to keep up with their customer demand, but real life usages are far more complex and can utilize monitoring systems to operate the equipment in the most optimum combinations.

Figure 24: 150 Horsepower Pump Used in a Water Treatment Facility

By scheduling a proper and consistent operation schedule of the various equipment throughout the year a plant can see serious electricity savings by decreasing their peak demand.

Operating numerous pieces of equipment within a single fifteen minute interval can lead to thousands of dollars lost to ratchet demand charges in a single year since a nationally funded utility keeps that single peak as the standard for the next eleven months. IAC staff are able to learn and observe some of the operating and maintenance procedures the various companies undergo to operate their facilities, and this offers invaluable knowledge to the students who are able to see firsthand how the machines and procedures work to provide valuable goods and services to their community.

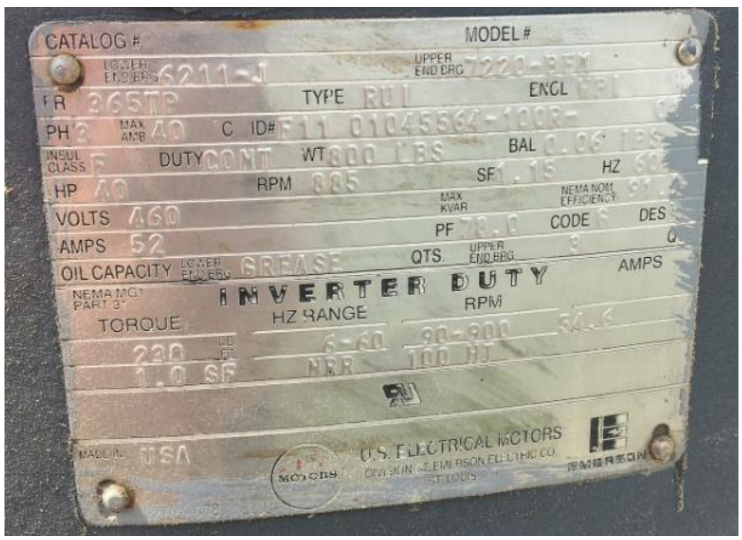

Figure 25: Pump Nameplate with Operating Data Visible

Practices

While IAC staff tour the various facilities they assess they must pay close attention to how the facilities operate and what practices they follow in order to maintain consistent, safe and sustainable output. However, they may also observe some things that the facility may be doing that are ultimately detrimental overtime to the company's bottom line. When the IAC staff complete an assessment report, there is a section they must include that lists these practices, both the ones that are exemplary and those that the IAC thinks the facility may want to adopt. These two sections are listed as best practices and recommended practices.

Figure 26: Common Personal Protective Equipment (PPE) Used in Manufacturing Facilities (Thinglink, 2020)

The best practices a facility may follow include various procedures and programs that the IAC staff find to be commendable in the company's respective industry. These could sometimes comprise of rigorous safety standards and procedures that the company adheres to such as training and Exit strategies that are described to the IAC staff in case of catastrophic failure of chemical containment such as seen in water treatment facilities. Chemical containment failure is an extremely rare occurrence, but most water treatment facilities take the possibility very seriously and train the staff to recognize the direction and speed of the wind and how best to leave the facility safely in such an emergency.

Figure 27: Windsock Used to Identify Wind Direction and Speed (Means, 2015)

Nearly all manufacturing facilities will request the IAC staff bring their own safety equipment such as hardhats and steel toed boots, but some companies provide additional safety equipment such as latex gloves for food companies or ear protection when viewing particularly noisy equipment in use. In order to maintain smooth operations consistently throughout the year which react to varying demand in industries such as water treatment a Supervisory Control and Data Acquisition (SCADA) system is sometimes employed which can easily regulate processes and outputs of different parts of a facility. Regular maintenance scheduling is another key practice that is usually mentioned during IAC assessments and these procedures truly are necessary if a company wants to ensure there is little to no downtime during production throughout the year. This is usually the reason why a company such as a water treatment facility may have several redundant pumps at each station of their operation; when one pump must be shut down to fix an issue, replace a component or simply apply some general maintenance the others can maintain the necessary output to continue consistent outflow year-round. Utilizing updated materials such as LED lights, occupancy sensors, cogged belts or mechanical seals are usually mentioned in this section, and if the company has already upgraded their facility a bit before an IAC assessment is done it is also mentioned. Finally, most companies will also mention that they turn off lights for rooms which are not in use to ensure energy usage is kept to a minimum as best they can.

The facilities the IAC tours are not perfect however, and some simple improvements can be easily made to a company's everyday procedures in order to reduce electrical load and consumption as well as overall waste production. Sometimes facilities are not so steadfast when it comes to shutting off their lights when not in use so the IAC can gently recommend in this section that they may need to ensure that their staff turns off any lighting equipment when it is not necessary for it to be on. It has been seen that sometimes exterior light fixtures are sometimes on during the day for instance. This is a quick fix that may not require an extensive recommendation be described in full for instance. Another suggested practice might be to adjust the preset air conditioning temperatures to a slightly higher temperature to reduce the demand required of the units themselves. The IAC staff might also recommend in this section that the company may want to install a smart electrical meter which would allow them to clearly observe their usage and demand throughout the month and year to better combat their demand peaks. The IAC also recommends that companies should look into creating a new role for their facility that would cover the job of essentially what could be referred to as an energy manager. This new employee would relay messages and engage with the staff of the company to try and implement ways for the facility to become more energy efficient. The energy manager would need to have technical background experience such as an engineering degree, professional engineer's (PE) license, or certification as an energy manager (CEM). He or she would have the skill and authority to develop and carry out all aspects of the company's energy management plan and should have a clear understanding of how indoor environmental quality (IEQ) issues relate to energy efficiency. A good energy manager would need good communication skills, the ability to make a business presentation to the organization's financial officers and would act as a strong advocate for the energy management plan of the facility.

Emissions Reductions

Based on the results obtained from the company's billing analysis, a total yearly consumption can be found for the facility, and this value in kWh can easily be converted utilizing online tools to show just how much energy is being consumed by the plant in various forms. The Greenhouse Gas Equivalencies Calculator uses the AVoided Emissions and geneRation Tool (AVERT) United States national weighted average CO_2 marginal 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 (EE) or renewable energy (RE) programs. Calculating the emission impacts of EE and RE on the electricity grid requires estimating the amount of fossil-fired generation and emissions being displaced by EE and RE programs. A marginal emissions factor is the best representation to estimate which fossil-fired units EE/RE programs are displacing across the fossil fuel burning fleet. EE and RE programs are not generally assumed to affect baseload power plants that run all the time, but rather marginal power plants that are brought online as necessary to meet demand. Therefore, AVERT provides national marginal emissions factors for the Equivalencies Calculator. These emission factors are as follows:

Table 4: Plant Fossil Fuel Emission Factors

Variable	Description	Value
E_{CO2}	CO_2 Emission Factor	$0.00159 \frac{\text{tons}}{\text{kWh}}$
E_{NOX}	NO_X Emission Factor	$0.000867 \frac{\text{lbs.}}{\text{kWh}}$

These factors can be used for the various energy saving recommendations the IAC creates to demonstrate in physical units the tons of carbon dioxide and pounds of nitrogen oxide the recommendations would be preventing from entering the atmosphere if implemented as demonstrated. For smaller recommendations such as installing window tint or replacing Exit sign incandescent bulbs with LEDs the reductions in emissions could be fewer than 10 tons of CO_2 a year, but for renewable energy recommendations it could be several thousand tons of harmful emissions that would be prevented from entering the Earth's atmosphere.

Figure 28: U.S. Power Plant Emitting Air Pollutants (Hislop, 2015)

There are other helpful demonstrations which can display in various terms how harmful and detrimental a plant's current energy consumption is to our society. The Environmental Protection Agency of the U.S. provides another type of online equivalencies calculator which lays out in several forms how the energy that is consumed by a facility and CO_2 subsequently produced can be translated to other every-day terms. This calculator can be found here: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. These include comparing the energy consumption to miles driven by passenger vehicles, gallons of diesel fuel consumed, railcars full of coal burned, and even smartphone charges. They also show how this energy consumption can be translated through avoided emissions as well including recycling bags of waste which would normally be landfilled, and how the carbon can be sequestered by acres of forests in the U.S. The emissions equivalencies for one water treatment facility are shown below using the total value of energy consumption shown in Table 1.

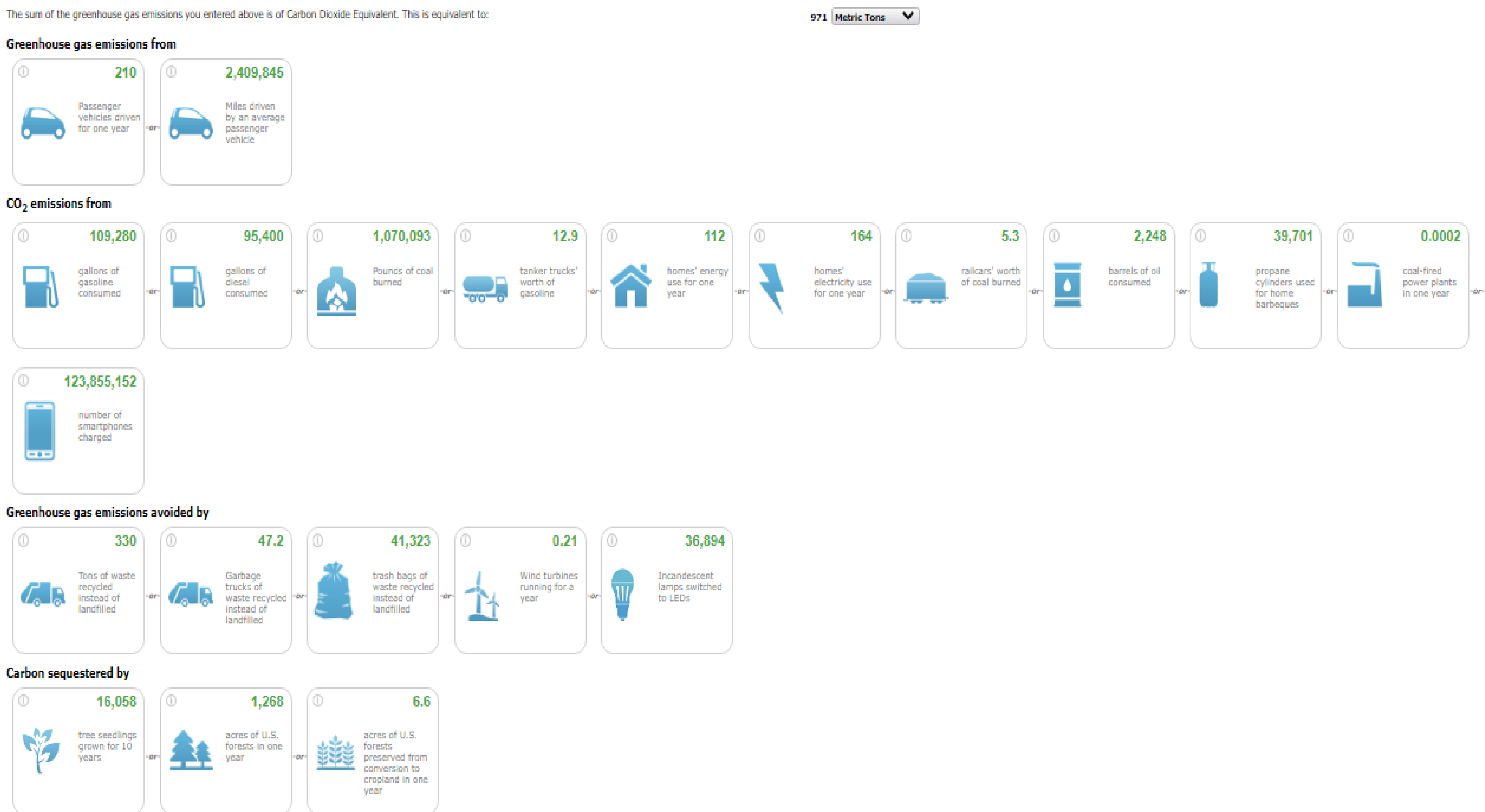

Figure 29: CO_2 Emissions Equivalencies for a Water Treatment Facility

Based on the various recommendations IAC staff are able to develop the estimated amount of emissions each implementation would achieve is then calculated and listed in this section of the assessment report. These are reductions are calculated using the two emissions factors mentioned in Table 4 above.

Table 5: Total Emission Reductions Possible for a Water Treatment Plant

AR #	Description	Annual CO_2 Reduction (tons)	Annual NO_X Reduction (lbs.)
1	Retrofit Outdoor Lights to LED's	44.61	24.32
2	Retrofit Indoor Lights to LED's	35.55	19.38
3	Utilize Energy Efficient Belts	27.38	14.93
4	Retrofit Incandescent Lights in Exit Signs to LED's	8.02	4.37
5	Maintain Machines to Reduce Leaks	N/A	N/A
6	Install Shade Balls for Reservoir/ Clarifiers	N/A	N/A
7	Install Window Tinting to Reduce Heat Gain	27.02	14.73
8	Install Solar PV Array	1,987.33	1,083.66
	Total	**2,129.91**	**1,161.39**

As seen in Table 5 above, the various recommendations the IAC develop for each plant combine to produce substantial reductions in toxic emissions to the environment which would ultimately contribute to global warming and climate change. If a facility were to implement these recommendations then they could claim they are indeed making a difference in their local region by not only providing essential products to the area, but also doing their part to work on improving the environment and their constituents' health. Climate change will continue to be a serious issue that needs to be dealt with and slowed down in the coming decades before irreparable damage is done to the Earth's ecosystems. By implementing these energy saving recommendations not only will companies save money on their bottom line, they are also providing a service to the world by reducing their carbon footprint and overall emissions.

In the subsequent chapters the numerous recommendations that are achievable in the various water treatment facilities the UTRGV branch of the IAC has assessed are described a length. Many of these recommendations are not only applicable to water treatment facilities but for many other manufacturing facilities around the country.

CHAPTER IV

UPDATING LIGHTING SYSTEMS

Updating a company's lighting systems can be one of the simplest and most cost effective ways to increase energy efficiency. There are numerous ways to achieve this, but the first step is usually to have the IAC staff observe what lighting equipment is currently being utilized by the company. This is usually done during the assessment as the IAC team walks through the plant during their tour of the facility. All lighting systems and styles are recorded or estimated and pictures are taken to verify their number and location in order to get accurate results for subsequent recommendations. These systems include any outdoor, indoor, Exit signs and occupancy sensors currently in operation. Some companies wish to remove certain fixtures or install skylights to reduce overall usage, but it is ultimately up to the assessment team what recommendations to provide to the company in the final assessment report.

To begin with, the main focus of most lighting recommendations is to upgrade the current lighting systems into either being retrofitted or have the entire fixture replaced with LED equivalents. LEDs, or light emitting diodes, are a wide-ranging form of lighting currently experiencing a rapid expansion in development and implementation globally as incandescent and fluorescent bulbs are being phased out. However, there have also been vast improvements in LED technology for every other imaginable lighting situation both outdoor and indoor. This includes high pressure sodium (HPS) bulbs, metal halide bulbs, flood lights, parking lot box lights, wall packs, security lights, high bay bulbs, Exit sign bulbs fluorescent bulbs and incandescent bulbs of course. Each of these has an LED equivalent counterpart which can either be easily retrofitted into the existing fixture, or will replace the fixture entirely. Lighting fixtures, referred to as ballasts in some cases, can actually be a large draw of electrical energy, and an upgrade of the ballast itself can also be very beneficial to a facility in the long run.

Occupancy sensors are another update to a company's lighting system that may go overlooked at first, but when implemented correctly large amounts of savings can be created as well. A lot of companies are unaware of the amount of time certain lights are on in their facility throughout the day unnecessarily, this can add up over the years to tremendous amounts of wasted energy. Occupancy sensors allow companies to have an automatic light cutoff happen after a certain amount of time has passed in a given area with no movement. This can reduce energy consumption drastically when some room lights remain on 24/7 unnecessarily before the installation.

By installing skylights and allowing more natural light to fill the facility during the day, the company could either reduce their total lighting equipment inside their buildings, or at least utilize existing fixtures far less often during the day. This recommendation can involve a bit of construction, so it is best done in facilities with thinner roofs or those that are not cooled using air conditioning. This is because these buildings could potentially be heated by the sunlight during the day which would then be needed to be removed by the air conditioning system

When dealing with lighting, one will find the terms scotopic and photopic lumens, which describe the amount of light produced by a piece of lighting equipment. The human eye consists of microscopic structures named cones and rods which allow us to see better during the day and at night respectively. This relates directly with photopic seeing being used in the daytime and scotopic seeing used at night. Since our eyes use this combination of seeing for different conditions, artificial light cannot be measured using one scale or the other, but by a combination of the two forms (Premier Lighting, 2015). The scotopic/photopic ratio, or S/P ratio, is a multiplier that is applied to the advertised photopic lumens of a lamp, bulb or lighting fixture to find the true amount of scotopic lumens one would expect to observe in a low-light situation (Berman, 1992). For each main type of bulb, HPS, metal halide, fluorescent, incandescent and LED, there exists a specific S/P ratio that shows how truly bright certain lighting systems are according to our vision.

Table 6: S/P Ratios for Common Current Lighting Sources and LEDs (Ylinen, 2011)

Light Source	**S/P Ratio**
Low Pressure Sodium	0.25
High Pressure Sodium	0.50
Metal Halide	1.20
Incandescent	1.36
Fluorescent (3500 K)	1.36
Fluorescent (5000 K)	1.97
LED (3500 K)	1.39
LED (6000 K)	2.18

This ratio allows for various light sources to be properly compared for their actual light output based on how the lumens are observed based on both our day and nighttime vision. Even though HPS, metal halide, fluorescent and incandescent bulbs usually have higher advertised lumens than LEDs, the S/P ratio puts into perspective just how effective LEDs truly are at providing crucial lighting for much less power. As seen in the table above, HPS lighting usually have an average S/P ratio of 0.5, metal halide bulbs have an average of 1.20, commonly used fluorescent lights have an average S/P ratio of 1.36, incandescent lights have an average of 1.36, and LED lighting systems usually have an average S/P ratio of approximately 2 based on the number of rated Kelvins (Ylinen, 2011). One will note that LEDs clearly have the highest S/P ratio which allows them to have equivalent replacements for the other categories that have lower advertised lumens. Since the S/P multiplier for LEDs is so high, what is usually seen is that the true lumens achievable by LED replacements will actually surpass what is expected or seen by their forerunners.

Another reason why LED lighting is so efficient at illuminating its target area is because they produce directional lighting instead of omnidirectional lighting, which the traditional styles normally emit. What this means is that LEDs are usually oriented inside of their housing so that they are focused in a specific direction instead of emitting light in every direction originating from a filament of various orientation. Older style lighting also has the tendency to almost immediately produce lower lumens after only months from the initial installation. The lumen degradation seen in these styles is significantly reduced for LED lighting, with the lumens depreciating past usable levels after far longer than in their predecessors as shown in the figure below.

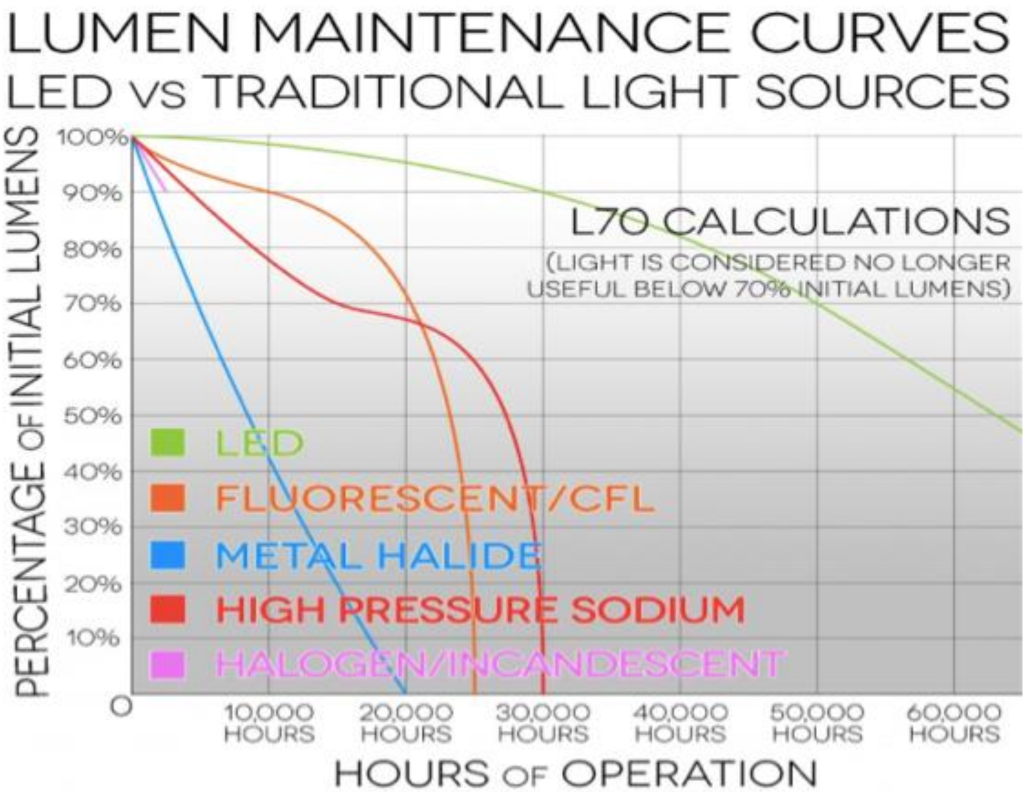

Figure 30: Lighting Degradation Chart (Roger, 2014)

Not only do LEDs have optimal lighting performance, they are able to produce this increased, more precise brightness with around half the power of their predecessors, approximately 55% on average (USDOE, 2020). This allows companies to nearly halve their electricity usage associated with lighting immediately after installing LEDs in their facilities. Not only that, but there are also unseen benefits as well. When older style bulbs are used they produce large amounts of waste heat while inside of their ballast, which in turn increases the energy being used by the ballast as it tries to compensate for the excess heat. This heat is then ultimately dealt with by using the air conditioning system to cool the ambient temperature around the fixtures. So by switching to LEDs a company will have an easier time maintaining their preferred indoor temperature while also saving energy that the ballast would normally use in excess. Yet another benefit that is often overlooked is the increased lifespan of LEDs. Most old style bulbs can last for a couple years at maximum, with fluorescent lighting in particular having to be replaced multiple times a year in most cases. Various forms of LED lighting have lifespans, or rated life, of up to 50,000 hours usually, which can be up to 10-20 times longer than their predecessors. This means if an LED bulb is only used for 12 hours a day, they could easily last over 10 years. This not only decreases the amount of investment a company would need for the lighting themselves, but the company would also need to replace the lighting far less often. So instead of maintenance workers having to replace a bulb once every few weeks around the facility taking up time from their schedule, they could focus on other tasks, meaning there are lower overall labor costs associated with installing LEDs overall.

Outdoor Lighting

Most outdoor lighting consists of a few main forms of lighting equipment such as parking lot box lights to illuminate large areas, wall pack fixtures to light up the sides of buildings, flood lights to provide general illumination to the perimeter of a facility or body of water, security lights to provide lighting to outdoor equipment, and even general incandescent bulbs used around doorways. All of these types, besides incandescent bulbs, will generally utilize HPS bulbs, but in some cases metal halides are preferred as well. Each of these lighting formats have LED equivalents which can be easily implemented by either retrofitting with LED bulbs, or by replacing the entire fixture itself for overall improved performance for the entire unit. Box lights, security lights and wall packs for instance usually require a fixture replacement in order to achieve optimum savings, but flood lights, and incandescent lights can easily be retrofitted with an LED equivalent bulb.

Figure 31: 1000W Flood Light Pole

For each form of replacement an equivalent fixture or bulb replacement must be found that matches the performance of the current systems presently utilized. This involves searching through online vendors to find an appropriate replacement that is able to produce the same output using less energy. There are many vendors and bulb companies that can be perused online so comparisons must be made to find the best option for the company. However, the IAC cannot recommend a product or company specifically, so by supplying an example of a possible solution and a link to a site where other similar options are available the center ensures that there are no specific endorsements occurring. As far as pricing goes, the IAC can choose whether to include bulk pricing or individual bulb prices since either can be chosen by a facility, but a company that has an assessment done will more than likely need to buy bulbs in bulk to ensure all of their necessary replacements are covered as well as a few spares for future use.

Figure 32: 400W Wall Pack Fixture on Side of Building

The lumens listed by the bulbs or fixtures are a significant point IAC staff pays close attention to since they want to ensure the level of lighting is maintained with the LED replacements. The S/P ratios mentioned above come in extremely useful at this point in the investigation so that the actual true lumens provided by the products can be compared accurately since the ones listed by the products are not totally correct in the needed lighting condtions. Below are a few examples of power and lumen comparisons that were created for outdoor lighting investigations at different water treatment facilities.

Figure 33: 400W Parking Lot Box Light Pole

Table 7: Flood Light Specifications Comparison

	Current HPS Flood Light Specifications	**Recommended LED Flood Light Specifications**
Power (Watts)	1000	450
Lumens (Lm)	110,000	65,000
True Lumens	5,500	130,000

Table 8: Wall Pack Specifications Comparison

	Current HPS Wall Pack Specifications	**Recommended LED Wall Pack Specifications**
Power (Watts)	400	75
Lumens (Lm)	38,000	9,375
True Lumens	19,000	18,750

Table 9: Parking Lot Box Light Specifications Comparison

	Current HPS Box Light Specifications	**Recommended LED Box Light Specifications**
Power (Watts)	400	200
Lumens (Lm)	50,000	26,000
True Lumens	25,000	52,000

Table 10: Security Light Specifications Comparison

	Current HPS Security Light Specifications	**Recommended LED Security Light Specifications**
Power (Watts)	100	50
Lumens (Lm)	8,500	7,150
True Lumens	4,250	14,300

Table 11: Incandescent Light Specifications Comparison

	Current Incandescent Bulb Specifications	Recommended LED Bulb Specifications
Power (Watts)	150	20
Lumens (Lm)	1,500	2,150
True Lumens	2,040	4,300

In order to find the power savings achievable by updating a facility's lighting equipment, one must make some assumptions as to how long the lights are currently being run for in a day. For the assessments of the water treatment facilities that were done an estimation of 12 hours of consistent usage was utilized to approximate the total current energy consumption of the current equipment, and the proposed energy usage of the LED replacements. This could be potentially be more or less, but it is a good approximation as the plants mentioned that outdoor lighting is usually on throughout the night from around 7 pm to 7 am. If they remained on longer than this, then the total energy savings would increase accordingly.

To find the current energy usage of the lighting equipment, one must multiply the wattage of each bulb or fixture throughout the facility by the observed number of those bulbs or fixtures, and then each of these products must be added together. This sum is then multiplied by the number of hours operated in one year, in this case 4,380 hours (12 hours a night for a full year), and then converted from watts to kilowatts to find the total number of kilowatt-hours consumed by the current outdoor lighting equipment. This same process is then conducted for the LED replacements with their new wattages supplemented into the equation to find the proposed energy usage for the recommendation. Then the total energy savings can then be found by subtracting these two values and the cost savings can be calculated by multiplying the energy savings by the total avoided cost of electrical energy for the plant which shows the total amount of money that will be saved in one year by switching the outdoor lighting to LED equivalents.

Figure 34: LED Parking Lot Box Light Fixture Replacement (1000bulbs, 2020)

To find the simple payback time for the recommendation capital cost must be found next, and this is done by multiplying the cost of the individual LED replacement bulbs or fixtures by their respective number of bulbs or fixtures the IAC staff observed. Next, the total implementation cost is found for the recommendation by combining the capital cost along with the cost of installing each of the bulbs or fixtures themselves. The installation cost is obtained by multiplying the estimated time to install the individual fixtures or bulbs along with the cost of maintenance labor and the finally total number of bulbs or fixtures to replace. With this being completed, the simple payback can then be found by dividing the recently obtained implementation cost by total yearly energy cost savings. Additionally, the emissions reductions can then be calculated by taking the total energy saved by the LED replacements and multiplying by each of the emissions factors (shown in the previous chapter) separately to find the total CO_2 and NO_x emissions that this recommendation is preventing from being expelled to the atmosphere in tons and pounds respectively.

Below is a table which describes the savings that could be achieved by the three water treatment facilities that are the focus of this thesis for their outdoor lighting alone.

Table 12: Total Outdoor Lighting Savings for all Water Treatment Plants

Facility	**Energy Savings (kWh/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #1	22,645	1,893	2,389	1.26
Plant #2	28,054	2,354	4,519	1.92
Plant #3	150,058	12,965	24,824	1.91

It can plainly be seen that by replacing outdated outdoor lighting equipment with LEDs a facility can save thousands of dollars a year potentially. This is one of the most straight-forward recommendations IAC staff can describe, but it is indeed a powerful demonstration of a simple replacement procedure that can be extremely beneficial to the facility in question.

Indoor Lighting

An indoor lighting recommendation performed by the IAC is very similar in many aspects to an outdoor lighting recommendation, but usually it is slightly simpler since most companies utilize only a few kinds of lighting indoors for their facilities when compared to the several varieties found outdoors. Fluorescent lighting has been the standard used by thousands of companies for the past several decades since it is fairly reliable and easy to install and maintain with replacement bulbs. This leads to many facilities using one of several variations of fluorescent light fixtures that can range in length and number of bulbs they accommodate. The bulbs themselves can range in wattage depending on their diameter and length and it is up to IAC staff to determine the current style a facility they assess uses. They also must try and count the total number of fixtures and bulbs in each fixture so an accurate count of the total indoor lighting equipment can be found so a proper recommendation can then be created. Most fluorescent lighting ballasts are able to support direct “plug and play” retrofit LED replacements so installation can be as simple as replacing the bulbs which the maintenance crew of a facility is most likely well versed in. In some facilities high powered HPS high bay fixtures are used to illuminate the interiors of buildings with high ceilings such as in warehouses, garages, or maintenance areas. These fixtures can also easily have retrofitted bulbs installed without much effort involved besides reaching the fixture themselves.

Figure 35: 32W T8 Fluorescent Light Fixtures

Again, the IAC does not recommend or endorse any specific products or bulb replacements but merely creates an assessment recommendation that utilizes one of the many online sources for lighting equipment and information to obtain wattage, lumens and pricing data. This data is crucial for the overall recommendation since the IAC staff want to ensure proper illumination is maintained with the LED equivalent replacements. This is found by using the S/P ratio for both fluorescent lighting and HPS bulbs to find the true brightness the facility would expect to see in their low-light conditions. Below are a few of the specification comparisons that were created for some of the indoor lighting equipment for the three water treatment facilities focused on in this thesis.

Figure 36: 1000W High Bay Fixtures

Table 13: T5 Specifications Comparison

	Current T5 Fluorescent Specifications	**Recommended T5 LED Specifications**
Power (Watts)	54	25
Lumens (Lm)	4,850	3,500
True Lumens	6,596	7,000

Table 14: T8 Specifications Comparison

	Current T8 Fluorescent Specifications	**Recommended T8 LED Specifications**
Power (Watts)	32	15
Lumens (Lm)	2,635	2,000
True Lumens	3,584	4,000

Table 15: High Bay Light Specifications Comparison

	Current HPS High Bay Light Specifications	Recommended LED High Bay Light Specifications
Power (Watts)	1,000	270
Lumens (Lm)	110,000	37,500
True Lumens	55,000	75,000

Finding the savings achievable for the various plants the IAC visits for indoor lighting replacements is very similar to what is done for the outdoor lighting. The current energy usage is found by multiplying the wattage of each bulb type throughout the facility by the observed number of those bulbs, and then each of these products must be added together. This sum is then multiplied by the number of hours the indoor lights are operated for one year. For the three water treatment facilities assessed in this report the IAC staff chose to use 4,380 hours or 12 hours a day for a full year. This could range considerably for each set of lights for a facility, but the assumption allows for a conservative estimate since water treatment facilities run throughout the year and have many of the indoor lights on continuously. The product is then converted from watts to kilowatts to find the total number of kilowatt-hours consumed by the current indoor lighting equipment. This same process is then conducted for the LED replacements with their new wattages supplemented into the equation to find the proposed energy usage for the recommendation. Then the total energy savings can then be found by subtracting these two values yet again and the cost savings can be calculated by multiplying these energy savings by the total avoided cost of electrical energy for the plant which provides the total amount of money that will be saved in one year by switching the indoor lighting equipment to LED equivalents.

Figure 37: LED Fluorescent Light Bulb Replacement (1000bulbs, 2020)

To find the simple payback time for the recommendation capital cost must be found next, and this is done by multiplying the cost of the individual LED replacement bulbs by the respective number of bulbs the IAC staff observed. Next, the total implementation cost is found for the recommendation by combining the capital cost along with the cost of installing each of the bulbs themselves. The installation cost is found by multiplying the estimated time to install the individual fixtures or bulbs along with the cost of maintenance labor and the finally total number of bulbs or fixtures to replace. With this being completed, the simple payback can then be found by dividing the recently obtained implementation cost by the total yearly energy cost savings. Additionally, the emissions reductions can then be calculated by taking the total energy saved by the LED replacements and multiplying by each of the emissions factors separately to find the total CO_2 and NO_x emissions that this recommendation is preventing from being expelled to the atmosphere in tons and pounds respectively.

Below is a table which describes the savings that could be achieved by the three water treatment facilities that are the focus of this thesis for their indoor lighting alone.

Table 16: Total Indoor Lighting Savings for all Water Treatment Plants

Facility	Energy Savings (kWh/year)	Cost Savings ($/year)	Implementation Cost ($)	Payback Time (years)
Plant #1	24,642	2,060	1,959	0.95
Plant #2	22,356	1,876	1,778	0.95
Plant #3	117,585	10,090	11,905	1.17

Replacing indoor lighting, just like with outdoor lighting, provides vast yearly savings without even taking into account product and installation cost savings as well such as what is done for the Exit sign recommendations. By switching from fluorescent to LED bulbs a company would see considerable savings on multiple fronts that are just too good to pass up, and with payback periods of just over a year the switch would pay for itself faster than nearly all other recommendations.

Exit Signs

Finding the savings possible by replacing the incandescent light bulbs inside of Exit signs around facilities is a similar process compared to outdoor and indoor lighting. The exception is that since the total wattage that is saved is substantially less, the IAC staff must demonstrate that the savings will still be significant since the LEDs replacing the incandescent lights will last much longer and will need to be replaced far less often. Exit signs are special in that they are mandated by the federal government to remain on 24/7 in case of emergencies so that any building occupants can know where to leave immediately if necessary. The energy consumption of these signs can be considerable even though they only utilize two 25W incandescent bulbs, leading to substantial energy savings since their LED equivalents use only 1 watt of power to operate.

Figure 38: Exit Sign That Uses Incandescent Bulbs (QFRS, 2019)

The energy cost savings are found much the same way as with outdoor and indoor lighting. To find the total energy consumed by the signs the total number of signs at the facility are multiplied by two to cover the two incandescent bulbs inside of them, 25 watts for each bulb, the total number of hours in a year, 8,760, and then finally by a conversion factor to get a final value in kilowatt-hours per year. This is then done again, but a 1 replaces the 25 in the equation described above representing the LED equivalent giving the proposed energy usage for the recommendation. The two products are then subtracted from one another to find the energy savings, which is in turn multiplied by the total avoided cost of electricity to find the total energy cost savings.

Since the operational life of the Exit sign incandescent bulbs is only 1,500 hours, the company will have to purchase and install several replacement bulbs throughout the year to ensure the signs are constantly lit and they are meeting government standards. Since the lifetime is so short for these bulbs, by replacing them with LED equivalents which have lifespans upwards of 50,000 hours a company would save not only on product costs but also maintenance costs throughout the years to come. In order to find the maintenance cost savings the number of signs, the number of bulbs in each sign, the estimated time necessary to replace the bulbs, the total operational hours in a year, and the average maintenance labor rate are all multiplied and subsequently divided by the operational life of the incandescent bulbs. The bulb replacement cost savings are found similarly, the number of Exit signs is multiplied by the number of bulbs in each sign, the cost of each replacement bulb, and the total hours in a year, and then this product is divided by the average operational life of the Exit sign incandescent bulbs to find the total savings seen in one year.

Figure 39: Exit Sign LED Retrofit Kit (Atlanta Light Bulbs, 2020)

The electrical, maintenance and replacement cost savings are then all added together in order to obtain the total cost savings for the recommendation. Then the capital cost is calculated by multiplying the number of signs by the cost of a LED replacement package which contains two LED bulbs ready to replace the existing incandescent bulbs. This is then added to the product of the number of signs, the number of bulbs in each sign, the estimated time to install the bulbs and the average maintenance labor rate in order to find the total implementation cost. The simple payback time is then calculated by dividing this implementation cost by the total yearly savings which would be seen for the recommendation. The avoided emissions calculations are then made to complete the work for the recommendation.

Listed below are results of Exit sign recommendations done for two of the three water treatment facilities that had an abundance of buildings with Exit signs which were deemed a necessary amount to pursue a full recommendation. It can be seen when adding all of the different ways to save money from this recommendation a substantial amount of savings can be obtained for a facility once the LEDs have been installed.

Table 17: Exit Sign Savings for two Water Treatment Plants

Facility	**Energy Savings (kWh/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #2	5,046	959	225	0.23
Plant #3	6,728	1,296	270	0.21

Occupancy Sensors

This type of recommendation is not something every type of facility could benefit from too much, but when installed correctly at a proper facility such as one that operates constantly like at water treatment facilities, a company can see thousands of dollars of savings over the years to come. Occupancy sensors are devices which control the lighting in a certain room or area so that the lights only turn on when movement is detected in the vicinity of the sensor. If there are certain rooms of a facility that are not often utilized throughout the day and night then occupancy sensors can be installed to reduce the energy usage of these rooms by up to 90% in some cases. The devices are simple to install and program to whatever timing setting a company would prefer for each room, and customization of the interactions ensures they work appropriately and are not detrimental to workflow. They have been shown to be extremely effective at reducing unneeded energy usage in a wide variety of facilities and they can be a very effective tool when it comes to enhancing energy conservation. If certain rooms of a building experience intermittent occupancy, these sensors will ensure the lights will be consistently turned off when the rooms have been emptied.

Figure 40: Various Styles of Occupancy Sensors (Leviton, 2017)

Finding the savings achievable with this recommendation involves estimating the amount of occupancy that the target areas currently have; IAC staff usually base their estimates of this off of interactions with the staff during an assessment tour. Once the occupancy estimation is done, then the number of lighting fixtures and bulbs in the target areas needs to be determined. The current energy usage is found similarly to how the indoor lighting recommendation was done; the number of bulbs is multiplied by the wattage of said bulbs as well as the estimated number of hours the lights are on for a year, and then finally multiplied by a kilowatt conversion factor. This gives a current energy usage in terms of kilowatt-hours per year which is then multiplied by the occupancy percentage estimation for the target rooms to find the proposed energy savings the occupancy sensors would provide. Then the total energy savings are found by subtracting these two values, and the energy cost savings are determined by subsequently multiplying these energy savings by the total avoided cost of electricity. Capital cost is then found by multiplying the cost of a sensor (found from online sources of which the IAC staff does not specify any brand or style the assessed facility should use in particular) with the estimated number of sensors that would be able to cover the target rooms or areas completely to ensure there are no blind spots the sensors would be subject to. Next, the total implementation cost is determined by adding the capital cost to the installation cost which is simply the product of the estimated number of sensors, the estimated time to install each sensor and the average maintenance labor rate. The simple payback time is then calculated by dividing this implementation cost by the yearly savings which would be seen for the recommendation. The avoided emissions calculations are then made to complete the work for the recommendation.

This recommendation was only done for one of the three water treatment facilities that this thesis focuses on providing the following results. One will note that when implemented correctly in facilities that utilize fluorescent lighting there can be drastic energy savings that are achievable when installing occupancy sensors. If this recommendation is used in addition to applying LED lighting a company could potentially see even more energy savings after the additional cost is paid off.

Table 18: Occupancy Sensor Savings for one Water Treatment Plants

Facility	Energy Savings (kWh/year)	Cost Savings ($/year)	Implementation Cost ($)	Payback Time (years)
Plant #1	14,786	1,274	616	0.48

Other Lighting Recommendations

There are other lighting recommendations that can be done by IAC staff when they deem it necessary or when the staff of a facility requests particular investigations to be done. These can include adding skylights to certain buildings, adding timers to lights so they automatically shut off at certain times of day, adding photocell controllers which respond to ambient light to regulate outdoor lighting equipment, upgrading ballasts to more modern units, lowering light fixtures so certain areas receive more focused light, or removing redundant lighting sources inside or outside.

Figure 41: Industrial Skylight Fixtures (Kimball, 2016)

These are but a few of the possible lighting recommendations the IAC has conducted in the past, and all have shown to potentially save thousands of dollars when implemented correctly. Lighting in general is a very crucial aspect of all manufacturing facilities and finding the right recommendations to help a facility save on energy through lighting can be a very rewarding experience for IAC staff in addition to the assessed facility itself.

CHAPTER V

INSTALLING EFFICIENT EQUIPMENT

Many manufacturing facilities throughout the United States and the world often use outdated components in the machines and equipment throughout their operation. Thousands of manufacturing plants are unaware of the benefits that could be seen on their bottom line by making simple upgrades or updating their equipment with items that have been shown to have improved capabilities. By doing a simple tour of a facility, the IAC is able to locate these outdated pieces of equipment for future recommendation investigation.

Figure 42: Outdated Air Conditioning Unit Used at a Water Treatment Facility

These upgrades can range based on the equipment each facility utilizes but can include upgrading insulation on furnaces or pipes, utilizing improved lubricants that have enhanced viscous properties for certain operations, applying hydrophobic coatings in containers and mixers to reduce drying on surfaces, replacing out of date air conditioning units and in particular for water treatment facilities implementing mechanical seals on pumps and replacing v-belts with cogged v-belts. These are but a few of the equipment upgrades the IAC has created recommendations for in the past and can lead to facilities saving thousands of dollars over time if implemented correctly.

Figure 43: Outdated Steam Pipe Insulation at an Aloe Vera Processing Facility

Mechanical Seals

In water treatment facilities a multitude of pumps of varying size are used to move water throughout the different stations of the facility. These pumps can come in several different forms, but a constant among them is the layout of the pump mechanism itself. A pump will almost always consist of a motor attached to a shaft by either a belt or a direct drive system which is then connected to an impeller inside the pump housing. This impeller is then rotated at high speeds in order to move the water provided by the intake, and sending it to the outtake of the housing. This is not a perfect system since the housing must also encapsulate part of the shaft that moves the impeller, and there usually exists a gap between the shaft and housing where fluids can travel along the shaft and out of the housing altogether. This has been dealt with for decades by utilizing what is known as gland packing, where the pump operators insert a rope like material into this gap using specialized tools and different orientations in order to plug the gap up and reduce the fluid leakage. This is not ideal since it does not create a perfect seal and fluid is actually encouraged to soak into the gland packing itself and cause lubrication around the shaft so that the pump can operate as efficiently as possible. This type of seal causes leakage at an almost continuous rate, that increases more and more until the gland packing must be replaced. Gland packing is only used in facilities where there is no hazard from the loss of the working fluid, and it is actually detrimental to the pump itself since the seal depends on pressure between the shaft and housing which in turn slows the shaft down making it use more power to maintain proper output. Gland packing must also be wound around the working shaft several times, usually around 5 to 7 full rings which must be cut to size manually, to create a snug fit and reduce the leakage to a minimum. The cost of gland packing by the foot can be considerable when utilizing a higher end style and considering the time needed to remove and replace the packing itself the investment is undeniably substantial to maintain this style of seal. The fluid loss that occurs over time when several pumps are leaking fluid at constant rates can be extensive, and an alternative seal style is suggested to decrease this loss.

Figure 44: Water Pump with Gland Packing (Left) and a Mechanical Seal (Right) (Hanjra, 2020)

Mechanical seals are utilized in facilities where tolerance for leakage of working fluids must be kept to a minimum. There are several styles of mechanical seals used around the world, but most involve two finely polished plates, one attached to the spinning shaft and the other attached to the stationary pump housing, sliding past one another to form a fast moving almost perfect seal that allows only small amounts of vapor to escape instead of potentially thousands of drops a day. The large reduction of fluid loss a plant could see when switching from gland packing could be over 95% in some cases. The amount of power required to drive a pump that uses a mechanical seal is far less compared to pumps which use gland packing since the polished plate surfaces produce almost no friction as they spin facing with one another. This not only increases the efficiency of the pump itself, but the entire plant's operation in general when taking all of the increases in shaft efficiency across all of the pumps at a facility running throughout the year into account. Another benefit of switching to mechanical seals is that the maintenance costs and times are reduced drastically. The average expected operating lifetime of a gland packing seal is only around half a year before it needs to be replaced whereas a mechanical seal can last up to 3 to 5 years in some cases. The installation of mechanical seals has improved drastically over the years, and depending on the model it may take approximately the same amount of time to install as the original gland packing seals. There are many clear benefits to using mechanical seals, and implementing them throughout a facility should be a clear way to reduce waste overall.

Figure 45: High Service Pump with Gland Packing Leaking Water

In order to find the savings that can be obtained by implementing mechanical seals at water treatment facilities the IAC team must observe how many pumps are currently using gland packing and estimate a rate at which they are losing water. Once these values are obtained IAC staff can determine approximately how many gallons of water are wasted each year by multiplying the leakage rate in drops per minute, the total number of minutes in a year, and the total number of leaky pumps, and then dividing this product by the number of drops in one gallon (approximately 15,140). Next, IAC staff can approximate the potential profit that could be made from this water loss by obtaining the customer rates the water facility charges their customers. A good approximation that can be used when trying to find the profit is multiplying the total loss in gallons per year by the lowest customer rate and then by .99, signifying that approximately 99% of the water saved would be sold to customers at the lowest rate. Then, the highest customer rate can be multiplied by the total gallons saved in a year and then by .01 which provides a potential profit for just 1% of the water company's customers who would buy the water at the highest rate that would normally be lost from the gland seals. These two percentages and customer rates provide a conservative estimation for the profit that could be seen for the water that could be saved and sold. There could potentially be a higher percentage using the higher rate, and there are certainly different percentages using the rates that fall between the range of pricing, but this simplified model provides a good approximation for what could be sold by the company. These two potential profits are then added together and then multiplied by 0.95 signifying the company saving and selling 95% of the water if they switched from gland packing to mechanical seals.

Next, the annual cost of using gland packing is estimated by multiplying the number of leaky pumps by 5, which is the minimum number of rings of gland packing most facilities would use to seal a pump (it can be much higher), then by the circumference of the working shaft, the cost of gland packing per inch, and the number of hours the pump would be operating for the year. This product is then divided by the average operating life of gland packing, 4,380 hours, providing the total cost of the gland packing for the pumps for 1 year of service. Then, the operating cost of mechanical seals can be found by multiplying the number of pumps who would be receiving the seals, the cost of a mechanical seal (any variety will do, but there are numerous styles to choose from with varying efficiencies), and the operating hours for one year. This product is then divided by the average operating life of a mechanical seal, 3 years, in order to find the average cost of using the mechanical seals for one year. These two operating costs are subtracted from one another in order to provide an estimate for the total operating cost savings when using mechanical seals for one year.

The potential profit from the water leakage prevented by the mechanical seals and the operating cost savings are then added together to provide a total for the yearly savings the company could potentially obtain when switching to mechanical seals. Next, the capital cost is calculated by simply multiplying the cost of the example mechanical seal by the number of pumps they would be applied to. This capital cost is then added to the installation cost found by multiplying the number of pumps needing the installation by the average maintenance employee pay and the estimated time to install the mechanical seals. This provides a total implementation cost which can then be divided by the total yearly savings to provide a simple payback time.

The following table displays the results obtained by creating a recommendation for two of the three water treatment facilities that are the focus of this thesis. The manager of these facilities understood the significant improvements that would be seen by implementing these seals since the third plant had them installed when the plant was first created. The savings created using these improved seals speak for themselves, and they provide a prime example of how improved technologies can be implemented into the processes of different plants successfully and without much disruption to day to day processes.

Table 19: Mechanical Seal Savings for two Water Treatment Plants

Facility	**Water Savings (gallons/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #1	10,415	1,094	844	0.77
Plant #2	16,664	1,751	1,351	0.77

Cogged V-Belts

Most manufacturing facilities around the world utilize belts to transfer mechanical power from motors to other machinery such as pumps, presses, mixers and other equipment depending on the facility itself. These belts usually consist of the industry standard v-belts, which transfer approximately 95% of the mechanical energy provided by the motor to the respective piece of equipment it powers. This is because of slippage that occurs as the belt does not make perfect contact and grip of the working shaft. The technology for these belts has advanced substantially to produce belts that are more akin to chains or gears which are able to transfer the energy more successfully and efficiently with less slippage occurring. The notches in these belts reduce the amount of material that must be compressed or stretched around the spindle or shaft of a machine. Flat belts are stretched on the outer radius and compressed on the inner radius, which diverts energy away from the desired end point. The Department of Energy estimates that a 1-3% efficiency improvement is seen when retrofitting smooth belts with notched belts. Additionally, the lifetime of notched belts is approximately double that of standard smooth belts, with only a 20-30% increase in cost. The visual difference between these two types of belts is shown below.

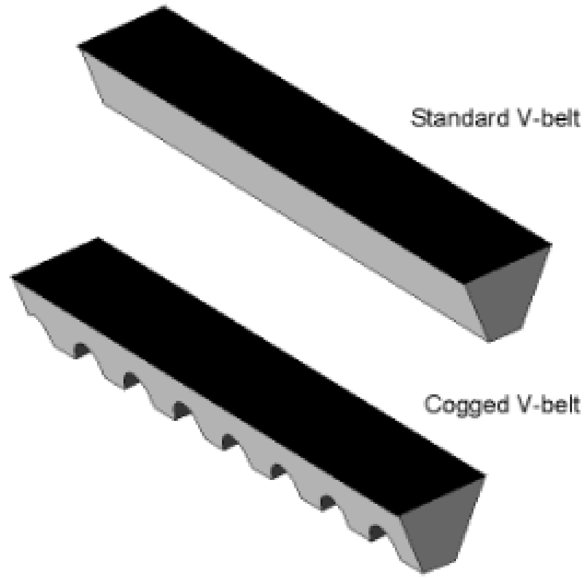

Figure 46: Visual Difference between Standard V-Belts and Cogged V-Belts (Tribe, 2020)

The increase in efficiency when switching to cogged v-belts is only a few mere percentage points, but when applied to all of the equipment that utilize belts, a plant can see substantial energy and cost savings throughout the year by making the switch. Since the cogged belts are of similar price and have operational lives substantially longer than normal v-belts the implementation cost is negligible and the payback can be considered immediate as the machines will instantly increase their efficiency and will have to be replaced far less often.

Figure 47: Cogged Belts Used on Industrial Metal Press

In order to find the current belt energy usage one must first calculate the energy used by all of the pieces of equipment that are powered by the belts. This is done by multiplying the horsepower of the machines in question by the number of machines present, then by the load factor (the ratio of electrical load the motor draws and the total load it can draw), duty factor (the ratio of the duration of working under load and the duration of one complete cycle), the total operating hours for the machines in one year, and finally a conversion factor from horsepower to kilowatts (Dooley & Heffington, 1998). This product is then divided by the motor's efficiency in order to get the current energy used in kilowatt-hours per year by the equipment. To find the energy which is consumed by the current v-belts, one takes the combined energy used by all of the equipment and multiplies it by 0.05. Since the efficiency of v-belts is approximately 95%, the remaining 5% of the energy is technically consumed by the belt. To find the proposed cogged belt energy usage one takes the total combined energy used by all of the equipment once again and multiply it by 0.03, which represents a two percent increase in efficiency compared to the normal v-belts (EERE, 2012). This proposed cogged belt energy consumption is then subtracted from the current belt energy consumption to obtain the final energy savings of the cogged belts, which can then be multiplied by the total avoided cost of electricity to find the total energy cost savings for each year of operation. The capital cost, as was mentioned earlier is only slightly higher than the average v-belt and the operating lifespan is doubled leading to the total implementation cost being zero dollars essentially. This means the simple payback would be immediate since the difference in cost is negligible and the performance and longevity of the cogged belts ensures instantaneous savings. Below is a table that shows the cost savings the three water treatment plants that were assessed would see when integrating cogged belts into their machinery.

Table 20: Cogged Belt Savings for all Water Treatment Plants

Facility	**Energy Savings (kWh/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #1	16,606	1,388	0	Immediate
Plant #2	17,222	1,445	0	Immediate
Plant #3	7,305	631	0	Immediate

Other Efficient Equipment

These are but a few of the enhancements in equipment manufacturing facilities can employ in their processes in order to see immense improvements in efficiency but savings as well. As time progresses and knowledge on ways to further improve machinery increases there will be other improvements which can be further utilized in the machines of the future such as improved motor designs as a prime example, and it will be up to the IAC to identify, describe and explain how these new technologies will fit in the manufacturing processes of the future. Eventually there will be a slew of ways to further improve processes, machinery and the various components that comprise them.

CHAPTER VI

UPDATING FENESTRATION AND INSULATION

The fenestration of buildings, otherwise known as the windows and doors on the exterior, is another avenue with which IAC personnel can develop energy saving recommendations for manufacturing facilities. Oftentimes the facilities the IAC assesses have outdated or deteriorated fenestration which can be upgraded through various means in order to reap numerous sources of energy savings. Windows in particular allow sunlight to enter buildings which can be beneficial since this decreases the demand for artificial light during the day, but they also allow large amounts of heat energy into the building. This heat energy could potentially be beneficial on a cold day for instance when the heaters are working inside of the building, but if a facility is trying to cool the interior of the building this can quickly become difficult to compensate for. There are several different varieties of windows and tinting varieties available to consumers and each of these styles offers different levels of light and heat transmission. For example, a single paned glass window allows almost no protection from ultraviolet rays entering into a building and heating it up, while a double paned glazed window allows only a fraction of this heat energy to be transmitted indoors. When installed correctly, window tinting can have a drastic impact on the amount of heat energy that is allowed to enter a building. Reducing this total amount of heat energy exchange to the inside of the building can translate to thousands of dollars of savings in air conditioning energy consumption.

There are other ways facilities can alter their building to update their fenestration such as installing new weather stripping around their doors and any other gaps in the buildings envelope that allow access to the outdoors such as loading bays. This will limit the exfiltration of cooled or heated air produced by the building’s air conditioning units as well as the infiltration of outside air that would otherwise cause more work for the air conditioning unit to maintain its preset temperature. By limiting or entirely eliminating these gaps to the outside environment different facilities could potentially observe thousands of dollars of savings to their energy bill since the air conditioning units would have to expend far less energy overall. Some plants can also install plastic industrial curtains, or strip curtains, to separate different parts of their facility in addition to making a semi impermeable layer so cooled air in the facility does not escape as much during loading and unloading of materials. These curtains can drastically reduce the loss of treated air from inside facilities and also help reduce the demand placed on air conditioning units in general.

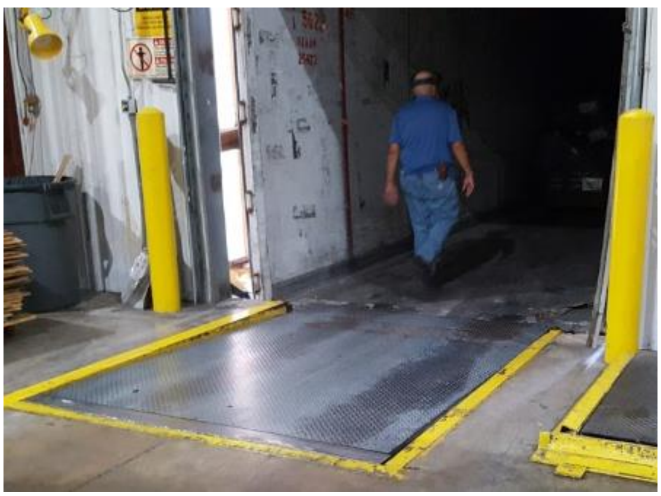

Figure 48: Loading Bay Door with Several Visible Gaps to the Outside

Not only does the fenestration of a building play a crucial role in the transfer of heat, but so too does the insulation that was used to construct the building itself. In older buildings some insulation that was first used can not only be out of date and ineffective, but also potentially harmful to employees. By upgrading or installing ceiling, wall and roof insulation a facility could potentially save thousands of dollars a year by reducing heat gains and losses through the building itself. The fundamentals of heat transfer demonstrate that every material allows heat to move through it from high to low concentrations, and metal is an especially good conductor of heat. Since most industrial buildings are constructed of metal this can be a serious issue that must be mitigated to conserve cooling energy costs and prevent extensive heat transfer from occurring. Insulating materials have seen vast improvements over the past twenty years and installing newer forms of it throughout the sides and ceiling of a building can conserve cooler temperatures indoors while drastically decreasing the demand on the air conditioning system. This can also be achieved by painting the roof with a reflective insulating paint that reflects the majority of the light and heat energy directed at it.

Figure 49: Outdated Ceiling Insulation in an Industrial Building (Metalguard, 2020)

These are all just a few ways of upgrading a facility's building to become more energy efficient, but there are still many other options that can be pursued to achieve savings. However, window tinting in particular is one of the cheapest and most cost effective options available to different plants, and not many facilities utilize this simple energy saving measure. All three of the water treatment plants covered in this thesis had window tinting investigations done on buildings located at their facilities with extremely positive results.

Window Tinting

For water treatment facilities, installing window tinting may not be the first recommendation one would think to pursue, but when the existing windows of a facility are single paned and do not offer any protection then the benefits can be plainly seen through various avenues. Some of the equipment IAC teams take to assessment tours includes industrial infrared thermometers and thermal imaging cameras, and with these devices one can easily see the impact that windows can have on the ambient temperature of a building's interior. During the day the windows heat up substantially and by utilizing thermal measuring and imaging equipment the IAC staff can observe how the windows transfer the heat quickly to their surroundings. This transfer of heat not only is detrimental to the buildings cooling ability, but it can also affect the instruments and equipment inside the facility as well. Certain instruments must maintain a proper ambient environment to ensure their operation is sustained, and if there are fluctuations in indoor ambient temperature occurring throughout the day this can lead to improper readings and faulty signaling. These are but a few of the issues that can be managed by installing window tinting throughout a manufacturing facility, and why it is important to understand how much ambient heating can affect workflow and energy management and efficiency.

Figure 50: Normal and Thermal Images of Single Paned Windows and Surrounding Equipment

To begin a window tinting recommendation, the IAC staff first need to identify the type of windows a facility has installed including their size and location in the target building, and the temperature the facility sets their air conditioning units to maintain. The windows on any exterior doors can also be taken into account since they can cause significant heating depending on their orientation in relation to the sun’s day-to-day trajectory. The temperature the company wishes to maintain in its interior is the ultimate determining factor when trying to calculate how much energy is being expended through cooling. The outdoor temperature fluctuates not only throughout the year, but also throughout the day and depending on what the temperature is set to can determine the overall electrical demand placed on the air conditioning system. This is why local weather data must also be obtained in order to develop a window tinting recommendation, so that the differences between outdoor and indoor temperature can be estimated and used to find the overall exchange of heating energy. For these recommendations, Btu's, or British thermal units, are used as the heating unit that a building absorbs. Each type of window design can be described by its respective U value, or the amount of heat transmittance that it is able to pass through it (Madico, 2016). For well-insulated windows such as double paned or triple paned windows, this U value is usually fairly low, but for single paned glass windows such as the ones utilized by the three water treatment facilities surveyed in this paper, the U value is much higher. For these tinting investigations, the U value for the windows currently in use was determined to be $0.7\frac{\mathrm{Btu}}{\mathrm{hrft^2{}^\circ F}}$ which allows the IAC staff to produce a conservative estimate for the amount of heat the windows are currently allowing to enter before any tinting is applied (Schiff, 2014). Window tint would insulate the windows and reflect a large portion of sunlight off the surface of the glass, preventing that heat from transferring into the building. Just installing a single layer of window tinting to single paned glass windows has been shown to reflect over 50% of the heat energy that would normally be allowed into the building in most cases.

A total value for heat gain allowed by all windows of the target building must be found by multiplying the settled upon U value by the various areas of the windows used throughout the building and their respective total numbers present. The products for each respective window type are then all added together to create a total heat gain value for all of the windows in the target building. This value is only an estimate however, and more precise models for finding this value exist that take into account various other factors such as the directional orientation of each window since the sun will affect windows on the East and West sides of a building more than those on the North and South. For this analysis a simplified approach is used, and an underestimation of the window tinting efficiency is also used to accommodate for these discrepancies and provide a more conservative estimate for the total energy savings.

In order to find the total amount of heat energy currently allowed to enter a facility, local weather data must be analyzed and modeled to predict the average temperature the facility would experience each day throughout the various months of the year. The table below demonstrates the results of a temperature analysis that was done for a window tint recommendation for one of the water treatment facilities focused on in this report.

Table 21: Average Daily Temperatures throughout the Year (ºF)

	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm
Jan	56.0	57.6	59.3	60.9	62.6	64.3	66.0	67.6	69.3	71.0	69.3	67.6	66.0
Feb	59.3	61.1	62.8	64.6	66.3	68.1	69.8	71.5	73.3	75.0	73.3	71.5	69.8
Mar	65.4	67.2	69.0	70.8	72.7	74.5	76.4	78.3	80.1	82.0	80.1	78.3	76.4
Apr	71.3	73.1	74.8	76.6	78.3	80.1	81.8	83.5	85.3	87.0	85.3	83.5	81.8
May	77.0	78.6	80.3	81.9	83.6	85.3	87.0	88.6	90.3	92.0	90.3	88.6	87.0
Jul	81.0	82.7	84.3	86.0	87.7	89.3	91.0	92.7	94.3	96.0	94.3	92.7	91.0
Jun	81.4	83.2	85.0	86.8	88.5	90.2	91.9	93.6	95.3	97.0	95.3	93.6	91.9
Aug	82.2	83.9	85.7	87.4	89.2	90.9	92.7	94.5	96.2	98.0	96.2	94.5	92.7
Sept	78.1	79.8	81.5	83.2	84.8	86.5	88.1	89.7	91.4	93.0	91.4	89.7	88.1
Oct	72.1	73.8	75.5	77.2	79.0	80.8	82.6	84.4	86.2	88.0	86.2	84.4	82.6
Nov	64.2	65.9	67.7	69.4	71.2	72.9	74.7	76.5	78.2	80.0	78.2	76.5	74.7
Dec	57.0	58.7	60.3	62.0	63.7	65.3	67.0	68.7	70.3	72.0	70.3	68.7	67.0

These temperature predictions are then used to create subsequent tables that show the temperature difference between the outdoor and indoor building temperatures the air conditioning system is set to. If the outdoor temperature is lower than the air conditioning system's preset value, then the difference is described as zero. Below is the table that was created using the data in Table 21 as well as the air conditioning temperature for the facility of 70ºF.

Table 22: Temperature Difference in Filter Building (ºF)

	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.3	5.0	3.3	1.5	0.0
Mar	0.0	0.0	0.0	0.8	2.7	4.5	6.4	8.3	10.1	12.0	10.1	8.3	6.4
Apr	1.3	3.1	4.8	6.6	8.3	10.1	11.8	13.5	15.3	17.0	15.3	13.5	11.8
May	7.0	8.6	10.3	11.9	13.6	15.3	17.0	18.6	20.3	22.0	20.3	18.6	17.0
Jul	11.0	12.7	14.3	16.0	17.7	19.3	21.0	22.7	24.3	26.0	24.3	22.7	21.0
Jun	11.4	13.2	15.0	16.8	18.5	20.2	21.9	23.6	25.3	27.0	25.3	23.6	21.9
Aug	12.2	13.9	15.7	17.4	19.2	20.9	22.7	24.5	26.2	28.0	26.2	24.5	22.7
Sept	8.1	9.8	11.5	13.2	14.8	16.5	18.1	19.7	21.4	23.0	21.4	19.7	18.1
Oct	2.1	3.8	5.5	7.2	9.0	10.8	12.6	14.4	16.2	18.0	16.2	14.4	12.6
Nov	0.0	0.0	0.0	0.0	1.2	2.9	4.7	6.5	8.2	10.0	8.2	6.5	4.7
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	0.3	0.0	0.0

Next, these temperature differences are then multiplied by the total heat gain allowed by all of the windows of the target building to obtain the heating that is done to the building every hour in Btu's per hour, which is a typical air conditioning unit used in the U.S. The following table was created by taking the values observed in Table 22 and multiplying by the total window heat gain of a building at one of the three water treatment facilities assessed by the UTRGV IAC.

Table 23: Heating per Hour during the year (Btu/hr)/hr

	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm
Jan	0	0	0	0	0	0	0	0	0	185	0	0	0
Feb	0	0	0	0	0	0	0	283	604	924	604	283	0
Mar	0	0	0	148	493	838	1,183	1,528	1,873	2,218	1,873	1,528	1,183
Apr	240	567	893	1,220	1,540	1,860	2,181	2,501	2,821	3,142	2,821	2,501	2,181
May	1,284	1,589	1,894	2,199	2,510	2,821	3,132	3,443	3,755	4,066	3,755	3,443	3,132
Jul	2,033	2,341	2,649	2,957	3,265	3,573	3,881	4,189	4,497	4,805	4,497	4,189	3,881
Jun	2,107	2,439	2,772	3,105	3,419	3,733	4,047	4,361	4,675	4,990	4,675	4,361	4,047
Aug	2,255	2,575	2,895	3,216	3,542	3,868	4,195	4,521	4,848	5,174	4,848	4,521	4,195
Sept	1,497	1,811	2,125	2,439	2,741	3,043	3,345	3,647	3,949	4,250	3,949	3,647	3,345
Oct	388	702	1,016	1,331	1,663	1,996	2,328	2,661	2,994	3,326	2,994	2,661	2,328
Nov	0	0	0	0	216	542	869	1,195	1,522	1,848	1,522	1,195	869
Dec	0	0	0	0	0	0	0	0	62	370	62	0	0

The resulting values are then summed for each month to obtain the Btu's per hour for each day of the month, and then these sums are multiplied by the respective days in each of the months in order to obtain the Btu's per hour one would approximately expect to see for each of the months of the year. These values are then multiplied by the number of actual heating hours that are experienced by the building on average each month. Finally, the value of total Btu's that are allowed to enter the building each month is found which can be used to complete the rest of the energy savings analysis. The following table displays the results of these calculations using the data seen in Table 23.

Table 24: Heating Allowed Each Month

Month	(Btu/hr)/day	Days per Month	(Btu/hr)/Month	Heating Hours	Btu/Month
Jan	185	31	5,729	1	5,729
Feb	2,698	29	78,244	5	391,222
Mar	12,862	31	398,724	10	3,987,245
Apr	24,468	30	734,026	13	9,542,333
May	37,025	31	1,147,765	13	14,920,946
Jul	46,754	30	1,402,632	13	18,234,216
Jun	48,732	31	1,510,685	13	19,638,899
Aug	50,654	31	1,570,264	13	20,413,433
Sept	39,787	30	1,193,623	13	15,517,102
Oct	26,389	31	818,073	13	10,634,944
Nov	9,776	30	293,278	9	2,639,498
Dec	493	31	15,277	3	45,830
Total					**115,971,397**

To find the total amount of energy savings that can be achieved by installing window tinting to single paned glass windows, one simply take the total simulated Btu's for the year that would be expected to enter the facility and multiply by 0.5, which represents the 50% efficiency of a single layer of window tinting. Then, this value is simply converted from Btu's to kilowatt-hours using a conversion factor to obtain the final energy savings of window tinting. This energy would be normally enter the facility and need to be mitigated by the air conditioning system of the building to regulate the temperature based on the outdoor temperatures. To find the total cost savings the plant would see by installing the window tinting, one must take these energy savings and multiply by the total avoided cost of electricity. Next, to estimate the implementation cost, one must multiply the area of the target windows by their respective number present, then by the average cost of installing window tinting found from online installers. These costs for each window are then added together to obtain a final tinting implementation cost. The simple payback is then found using the same formula as all other recommendations; the total implementation cost is divided by the yearly cost savings. Finally, the emissions reductions are calculated similarly to other energy consumption recommendations by multiplying the energy savings achievable by the recommendation by the two separate emissions factors.

This evaluation for window tinting is not perfect, but it provides a conservative estimation for total savings which could be achieved by updating windows using simple tinting. If a company wishes to achieve even better energy conservation results they could completely replace the existing windows with more energy efficient models, but the implementation costs would go up drastically due to the window cost itself plus the installation labor costs. But this type of drastic remodeling is not completely necessary as window tinting has been shown to be extremely effective at reducing the total heat energy allowed to enter manufacturing buildings.

The following table illustrates the potential savings that were calculated for the three water treatment facilities covered by this document. Since the target buildings of the investigation range in the number of windows present as well as indoor temperatures, the savings vary considerably, but all of the final results showed the potential for thousands of dollars of savings over the years to come. This simple recommendation promotes tremendous savings when considering the small initial investment that can be made to update the windows and increase their heat reflection efficiency.

Table 25: Total Window Tinting Savings for all Water Treatment Plants

Facility	Energy Savings (kWh/year)	Cost Savings ($/year)	Implementation Cost ($)	Payback Time (years)
Plant #1	6,217	520	483	0.93
Plant #2	16,994	1,426	1,320	0.93
Plant #3	26,895	2,324	2,142	0.92

Other Fenestration and Building Insulation Upgrades

As was mentioned earlier, there are numerous ways to improve the energy efficiency of a manufacturing facility itself by paying closer attention to the buildings they operate in. Simple fixes such as replacing or installing weather stripping around doors or openings can drastically reduce the load on the air conditioning system of a plant. The type and amount of insulation present inside of a manufacturing facility (or in some cases the lack thereof), is an extremely important factor to consider when trying to make a plant more energy efficient. Insulation in general slows down unwanted heat transfer into and out of a building, and by upgrading or installing more in the ceilings and walls a facility could see vast improvements to their energy bottom line. Even simply painting the roof of a building a more reflective color can have drastic impacts on the resulting heat transfer allowed by a building. These are but a few of the ways the heat energy of a building's surroundings can be prevented from entering and making it more difficult to maintain comfortable working conditions. The prevention of this transmittance should be extremely important to consider when trying to make a facility more energy efficient and sustainable, and these recommendations provide straightforward approaches to improving a facility quickly and without much investment cost involved.

CHAPTER VII

UTILIZING SHADE BALLS AND CONTAINER COVERS

Covering containers to prevent evaporation from occurring is a simple concept that numerous recommendations for hundreds of facilities have explored the potential for energy and material savings. The concept is simple, by preventing heat from entering an open container and in turn heating a working fluid up to the point where evaporation begins to occur, a facility can save money preventing material loss both for use in the processing itself or as the product for sale. The use of covers on larger scales to prevent evaporation of water in reservoirs has seen increased interest in recent years since the amount of water that is lost due to evaporation at this scale is extremely significant over a year’s time.

Shade balls are somewhat novel inventions which were first intended to be used in order to deter birds from landing in chemical/water runoff ponds as well as small bodies of water near airports. Recently, the city of Los Angeles used these balls in order to prevent the formation of Bromate, a chemical which was seeping into their reservoirs from the ground water and activated by sunlight (Concio, 2019). The city was considering using billions of dollars in order to create a cover for their reservoirs, but the most cost-effective solution turned out to be shade balls.

Thanks to their implementation, bromate formation and in turn the overall evaporation of their water was reduced drastically. The water that was saved from evaporation was then treated in order to sell to the local population, which created profit which would normally have been a sunk cost of operating and maintaining the reservoir.

Figure 51: Shade Balls Installed in LA Reservoir (Grennell, 2018)

Not only do the shade balls significantly reduce evaporation, once installed they also deter algae growth since photosynthesis is prevented once the sun cannot penetrate the water's surface. This in turn lowers the amount of chemicals needed to treat and clean the water, mainly the chlorine which is used to fight and kill any algae present in the raw water as it enters the plant. These factors combine to potentially save a water treatment facility millions of dollars over the coming years once the balls are implemented.

Shade Balls

Shade balls are simple devices that are usually constructed of food safe high density polyethylene which is treated/colored with carbon black to produce a heat and corrosion resistant three dimensional structure. There have been numerous styles created in recent years that are able to gather in tighter formations, but the simplest form is spherical in design which has been shown to prevent up to 90% of evaporation due to reduced heat transfer (Youssef & Khodzinskaya, 2019). Other newer designs have focused on geometries, such as hexagonal and rhombohedral shapes, are able to group together even closer than spheres are allowed. Some even contain insulating foam inside which coupled with these new shapes in turn increases the efficiency of the evaporation prevention by up to 96% in total. Their ability to prevent sunlight transmittance into water allows for algae growth to be mitigated by up to 90% based on anecdotal accounts from facilities which have successfully implemented them into their water treatment process as well. Another benefit of their increased insulation properties is when they are utilized in colder areas to prevent reservoirs from freezing over in the winter. They insulate the reservoirs and allow for more water to be treated that would normally have to either be heated or left until temperatures increased.

Figure 52: Shade Balls in Spherical Configuration (XavierC, 2020)

In order to calculate the savings that are achievable by implementing shade balls for an assessment recommendation meant for a water treatment facility, the total amount of evaporation that would occur in both the reservoir and clarifier tanks of the facility must be calculated. After some research time was invested, a hydrology research manuscript was found which provided an equation to obtain the daily evaporation rate for a specific area based on its elevation from sea level, its latitude, the ambient outdoor temperature as well as the dew point (Linacre, 1977). The equation to find the evaporation rate (E_0) in millimeters per day is as follows:

$$E_0 = \frac{\frac{700 * T_m}{(100 - A) + 15(T - T_d)}}{80 - T} \left(\frac{mm}{day}\right)$$

Where T_m is based on the elevation of the plant location, A is the latitude of the location in degrees, T is temperature, and T_d is the dew point all in S.I. units. This is an older equation, and there are countless hydrology studies that assess evaporation in various ways, but this particular equation allowed for simplified inputs using data that was readily available to provide a solid approximation as to the daily rate of water loss that a certain geographic location may experience. There most likely exists improved ways to estimate water loss, but for this investigation this provided an appropriate avenue to estimate losses day to day for reservoirs and clarifiers of consistent depth.

The weather data then had to be located for the general area of the water treatment facilities and Y3 data was chosen since it provided the appropriate daily weather data for the various locations. Using this daily weather data IAC staff were then able to calculate the total loss of water for the year based on these simple variables in millimeters per year by summing the losses of each day. The average daily loss of water due to evaporation for the year was found to be approximately 5.5 millimeters or 0.2 inches per day. The team then converted this water loss to feet per year which is then multiplied by the combined exposed area of the reservoir and clarifier tanks to get the total estimate for the volume lost each year. This can then be translated to total gallons to foot-acres in order to find the potential loss in the water originally accessed by the local canals as well as the potential loss of profit once this water has been treated and is sold to various customers.

Figure 53: Hexagonal Shaped Shade Balls for Increase Coverage (AWTT, 2020)

In order to calculate the total preventable water loss a water treatment facility could see one has to multiply the estimated depth of water lost throughout a year by the total exposed acreage of the facility's reservoir in addition to its clarifier tanks. This product is then multiplied by 0.9 which represents a conservative 90% evaporation prevention efficiency for the shade balls, and then this is multiplied by various conversion factors in order to obtain a final value in gallons per year. Based on the large areas that would be covered by the balls, this translates to millions of gallons saved each year that would have usually been lost before and during the treatment process. To find the loss of water bought by the treatment facility, one must convert the preventable water loss for the reservoir and clarifiers to foot-acres since this is the unit the particular suppliers for the three treatment facilities covered in this thesis utilize for their access rates. These converted product values are then multiplied by the access rate and various conversion factors to obtain a value for the savings that would be gained by preventing the loss of the water from happening after its initial purchase.

Next, the potential profit that could be achieved by selling the once lost water is found in a similar fashion to what was used for the mechanical seals recommendation. IAC staff approximate the potential profit that could be made from this water loss by obtaining the customer rates the water facility charges their customers. A good estimation that can be used when trying to find the profit is multiplying the total loss in gallons per year by the lowest customer rate and then by .99, signifying that approximately 99% of the water saved would be sold to customers at the lowest rate. Then, the highest customer rate can be multiplied by the total gallons saved in a year and then by .01 which provides a potential profit for just 1% of the water company's customers who would buy the water at the highest rate that would normally be lost from evaporation. These two percentages and customer rates provide a conservative estimation for the profit that could be seen for the water that is saved and sold. There could potentially be a higher percentage of customers who are charged with the higher rate, and there are certainly different percentages using the rates that fall between the range of pricing, but this simplified model provides a good approximation for what profits could be seen by the company.

Since the algae growth in the reservoir would be drastically reduced by the use of the shade balls, the potential savings in chlorine usage are then found. An approximate price for chlorine usage each day was provided by the facility, which was then multiplied by the total number of days in a year and by 0.8, which signifies a conservative estimate of 80% algal growth reduction caused by the use of the shade balls; this is significantly less than estimates provided by shade ball companies and by customer testimony. The IAC staff feels that this is a good approximation that provides a realistic expectation of algae prevention the plant could expect.

All of these savings are combined in order to find the total potential yearly savings the shade balls provide which can then be used to obtain the payback time after the implementation costs are found. The implementation costs are calculated by taking the total square footage of both the reservoirs and clarifiers and multiplying first by the average maintenance labor rate and estimated installation time per square foot covered by the balls to find the total installation cost. Then the total square footage is multiplied by the rate at which the shade balls are sold which ranges. The style that was chosen for the simulations was sold by the square foot, which provides the total cost of the shade balls themselves based on total expected coverage. These two costs are combined to obtain the final implementation cost for the recommendation which is subsequently divided by the total yearly savings in order to obtain a simple payback.

This recommendation was found to have the highest yearly potential for savings out of all the recommendations provided to the three main water treatment facilities the UTRGV IAC assessed. Even though the implementation costs ranged around one million dollars for each plant, the payback time was only slightly longer than two years since each facility would be saving nearly half a million each year from the various savings provided by the shade balls. The following table provides the results for the shade ball recommendations for the three water treatment plants primarily covered by this thesis, and one can plainly see the massive potential in savings these simple structures can provide. A limitation of this recommendation is that the cost of treating the saved water is not taken into account. This would most likely lower the overall potential savings, but due to the fact that the IAC staff do not know the total cost to treat the water per gallon this estimation still provides a good approximation in savings based on the conservative variables used in the calculations.

Table 26: Total Shade Ball Savings for all Water Treatment Plants

Facility	**Water Savings (gallons/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #1	25,255,434	483,876	1,077,131	2.23
Plant #2	27,353,372	466,053	1,043,438	2.24
Plant #3	19,603,109	382,131	836,063	2.19

This recommendation could easily be implemented around the world to prevent evaporation from precious drinking water sources and increasing the longevity and viability of their respective reservoirs. With global warming and climate change continuing to be ever-growing problems, trying to contain and conserve fresh water supplies will in turn become essential. Utilizing shade balls is just one simple yet effective approach that can be used to curtail these issues until we manage to control the expulsion of green-house gases and harmful emissions and thus prevent the Earth from warming to unrecoverable extremes. Hopefully there is still time to reverse the damage and heating that have been caused up to this point, but until then resources such as shade balls appear to be the next phase needed to ensure fresh water availability for the foreseeable future.

Container Covers

The shade ball recommendations show the savings potential for covering large containers to prevent evaporation, but many facilities can apply this concept on a much smaller scale for a variety of working fluids. Some facilities for instance utilize water based inks or paints that could benefit from the principles of evaporation prevention. The difficulty in modeling recommendations such as these is modeling the evaporation behavior of course since evaporation rates are entirely dependent on ambient conditions, lighting, viscosity of the working fluid, color of the working fluid, and several other variables that can make evaporation recommendations slightly more cumbersome to calculate. After performing some research into the working fluids in question some previous investigations will most likely be found that deal with the same or slightly different fluids which can be used as close approximations in order to get some relatively accurate results. Small scale testing and experimentation can also be done in order to determine the overall evaporation rate of certain fluids which can then be scaled up for larger estimations as well. The potential for savings in recommendations such as these can be substantial, especially when high end working fluids are involved, or large amounts of water, so any manufacturing facilities that have any open containers should seek to install covers immediately to prevent losses in materials from occurring and in turn increasing their overall profit.

CHAPTER VIII

UTILIZING RENEWABLE ENERGY SOURCES

Over the past millennia, humans have utilized various sources of renewable energy such as seen in water wheels and windmills around the world. These are the crude predecessors to modern renewable energy equipment which can create tremendous amounts of energy using untapped resources that generate no harmful emissions to the environment around them. In particular, solar photovoltaic arrays, wind and hydroelectric turbines have seen massive adoption and exponential growth is usage over the past 20 years. These can be set up in a wide variety of locations and situations, and if installed on the premises of a manufacturing facility there could be a significant increase that facility's overall energy sustainability and decrease in their total carbon footprint. The installation of these renewable energy sources can be a boon for savings, providing millions of dollars of returns after the initial investment is paid off. Thankfully the U.S. government currently provides various tax incentives which have lowered the cost of implementing renewable energy sources considerably, making them the cheapest energy investment option compared to traditional power plant options. There are also a slew of useful tools which have been created and can be utilized in order to estimate the cost and output for renewable energy equipment to provide more accurate and robust recommendation potentials for

IAC centers. There also exists other forms of energy generating equipment which utilize the waste of various machines located in many manufacturing facilities. These may not be completely free of emissions, but can use the various forms of waste from other machines in order to reduce the total emissions of the facility while simultaneously producing energy for the company.

Solar Photovoltaic Arrays

Solar photovoltaic (PV) arrays are a renewable energy source that can provide a company with spare real estate either around their facility or on top of its buildings with a viable option to save vast amounts of energy and money on their monthly electric bills, in some cases almost bringing them down to zero. The costs of these systems have been going down over the years as more companies have begun manufacturing different varieties around the world, and the efficiency of the energy production has slowly but steadily been increasing over the years. The U.S. government also provides additional tax incentives for companies to install these renewable energy sources which bring down the initial investment costs substantially so a manufacturing facility could see their system providing profits almost immediately when everything is prepared correctly.

Figure 54: Solar PV Array in a Field (Graves and Wright, 2018)

Depending on the size of the facility in question, the size of the solar array is appropriately chosen to cover nearly all of the facility's electricity consumption. To begin a simple recommendation process, IAC staff chose to employ an online solar tool called the PVWatts calculator. This calculator can be accessed using this website provided by the National Renewable Energy Laboratory (NREL): https://pvwatts.nrel.gov/. The calculator utilizes relevant weather data gathered from multiple sources including TMY3 data and NREL International records based on the zip code the user provides. The image below shows the area one of the weather searches covered along with the location of the water plant the recommendation was developed for circled in red.

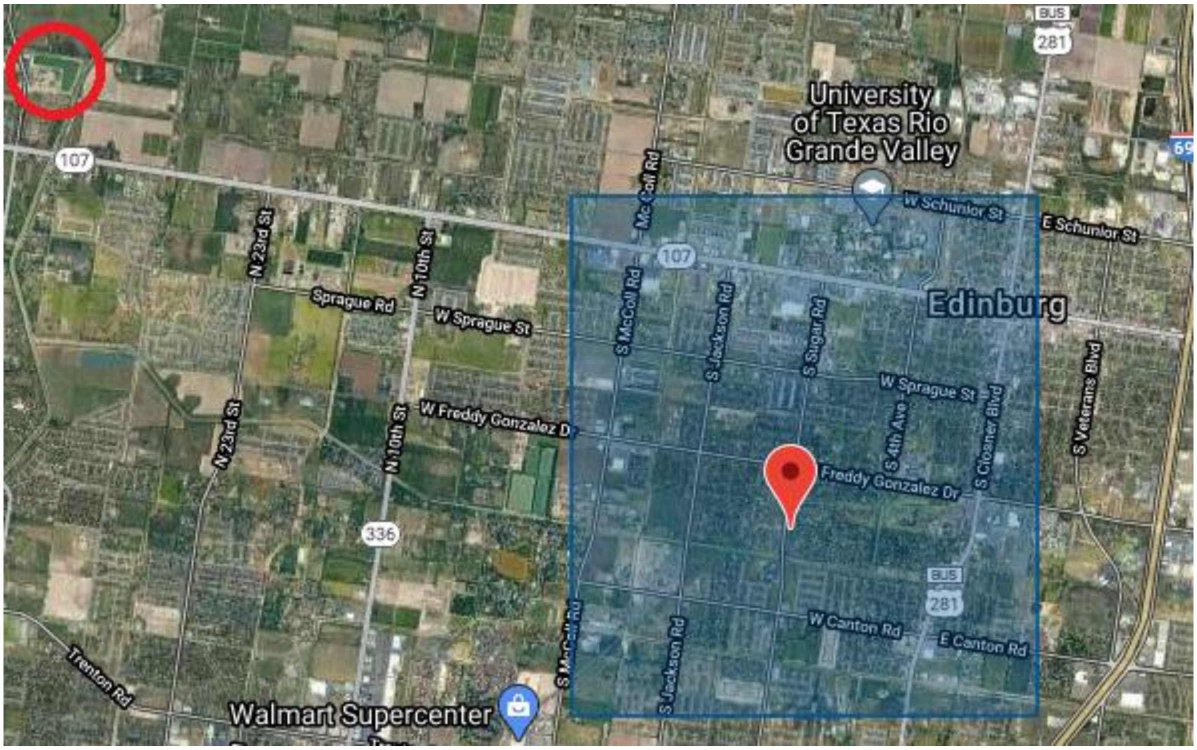

Figure 55: Area Covered by Weather Search with Water Plant Circled in Red

The next step in the recommendation process is inputting the relevant information about the specific site of the installation including the predicted size of the array, the module and array type, the approximate system losses (an average estimate is provided by the calculator), the tilt of the panels (the latitude of the facility), the azimuth (the degrees the array would be rotated clockwise from true north), the overall electricity rate for the facility (for our simulations the total avoided cost of electricity was used) and several other values which can either be left with their preset inputs or altered. These options allow the calculator to provide a robust approximation for the predicted output the facility which can then be used to determine system costs and payback times.

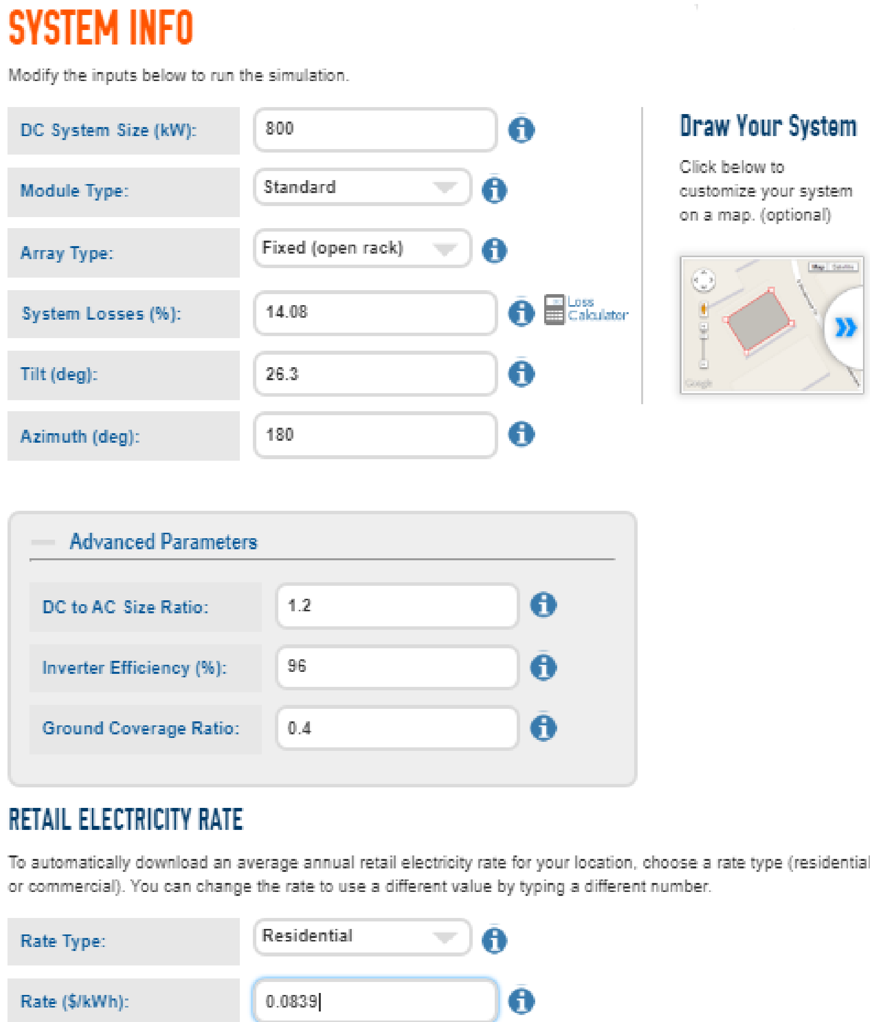

Figure 56: System Inputs for PVWatts Calculator

This screen also allows one to draw the specific area they wish the array to occupy in case they do not know what size of system would be possible for the location in question. This can then be tailored to better fit the consumption of the facility after the results are presented in the next screen. If a facility is not interested in purchasing a battery storage system to hold any excess energy then estimating to meet 80-90% of the yearly consumption is suggested.

Figure 57: Area Specified for Solar Array

Based on the manual inputs the calculator provides an estimate for the approximate savings that could be achieved with an array that fits in the specified area the user provided. It also provides monthly outputs one would expect to see throughout the year depending on average solar energy availability for the area in question. For the rest of the recommendation the IAC staff use the total system output for the year that was given by the calculator to determine the cost and payback estimates.

RESULTS

1,249,894 kWh/Year*

System output may range from 1,146,153 to 1,300,640 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	4.83	91,881	7,709
February	5.35	91,653	7,690
March	5.75	106,036	8,896
April	6.13	108,461	9,100
May	6.27	113,528	9,525
June	6.42	109,795	9,212
July	6.40	113,689	9,539
August	6.56	116,036	9,735
September	6.09	105,522	8,853
October	6.22	113,262	9,503
November	5.08	91,247	7,656
December	4.65	88,784	7,449
Annual	5.81	1,249,894	$ 104,867

Figure 58: Calculated Results for Proposed Solar Array

This total yearly energy potential is utilized to obtain the total energy cost savings the solar array would provide but multiplying by the total avoided cost of electrical energy for the plant in question. In order to provide a robust solar array for the facility, it is highly suggested that each panel installed has their own dedicated microinverter so the entire system is not reliant on a small number of inverters which could reduce production greatly when an issue occurs with one of them. Microinverters are electric equipment that convert the direct current energy provided by a solar panel to alternating current which can be utilized by the facility. In order to find how many solar panels are needed for the installation, IAC staff must choose a panel variety based on wattage and cost so that the total potential wattage of the solar array provided to PVWatts can be divided into a whole number of panels with no remainder. The total wattage potential for the array is then divided by the chosen panel wattage in order to find both the total number of panels needed as well as the microinverters. A proper microinverter price must be determined in order to find the total cost of the materials needed for the array. The number of panels and microinverters is multiplied by their respective costs and then these products are added to find the total cost of materials subject to sales tax for the installation. The sales tax is then found by multiplying this new sum by the tax rate of whichever state the project is to be installed in. The three water treatment facilities surveyed in this report are based in the Rio Grande Valley of Texas and the respective tax rate in 8.25%. The cost of installation is also found by taking the taxable sum and multiplying it by 0.1 signifying the installation rate being approximately 10% of the total cost of the materials which is a conservative estimate since labor rates can vary considerably based on the chosen installer. The total cost of the solar array project is found by adding all of these values together which then can be used to calculate the savings from the various tax incentives available to manufacturing facilities interested in investing in renewable energy sources.

There are multiple tax incentives which can be applied for separately and can help absorb a large portion of the initial investment for any large scale renewable energy investments. The solar and wind device tax credit provides for 10% of the total cost of the solar installation, and the investment tax credit in 26% of the total cost. Both of these savings can be found by multiplying the total solar array installation cost by .1 and .26 respectively and can eventually be combined into the savings that can be achieved in the first year of installation. Next, the investment itself can be broken down to provide a timeline for the facility to see what loan payments and repayment times they could expect to see until the project is paid off. First, the capital recovery factor is found by using an interest rate of 2% and a loan period of 15 years. These are loan options usually provided to companies that are pursuing renewable energy investments since they are usually a solid investment that will pay for itself multiple times over during its lifetime. Once the recovery factor is found, it is multiplied by the total cost of the project in order to find the annual loan payment the company would need to pay for the next 15 years. Next, the depreciation of the installation can be found using a simple 5 year straight line depreciation method. This is found by first multiplying the total cost of the system by 0.2, signifying 20% of the project depreciating in value the first year. Next, this annual depreciation value is then multiplied by 0.2 again which provides the depreciation savings that the facility could apply to their taxes for the first five years of the system's existence.

Next, the operations and maintenance costs are found by multiplying the number of panels/microinverters by an estimated maintenance rate. This can vary depending on the local solar maintenance services available, but is usually less than five dollars per panel. To provide the company with an estimate as to how much money will be saved by combining all of savings from the avoided consumption, various tax credits, and depreciation as well as subtracting the annual maintenance cost and the annual loan payment. This gives some financial incentive to pursue the installation since the company will almost immediately see hundreds of thousands in savings. A simple payback time can then be calculated by adding the annual loan payment with the yearly maintenance cost and dividing this sum by the yearly consumption savings. This is not a completely accurate way to depict the payback time, but for a recommendation such as this it can provide a decent approximation.

Due to the nature of the incentives mentioned above, the best way to predict a fully accurate payback time is to use graphic models and predictive variables. If the project delivered savings for 25 years and has these approximate costs, maintenance requirements, plus loan and incentive rates applied, the annual and cumulative cash flows can be seen in the following diagrams. The initial results are found using the current rate charged for electricity by the company's utility, but the other results shown in these figures show the results based on energy inflation predictions. These models utilize several assumptions such as a yearly energy inflation rate of 3.03% (the average weighted rate over the last 10 years according to the U.S. Department of Energy Annual Energy Review 2011) in order to find the inflated values observed. The inflated values used for the graphs also include an average degradation rate of 0.3% of potential power a year due to losses in efficiency inherent in solar technologies currently.

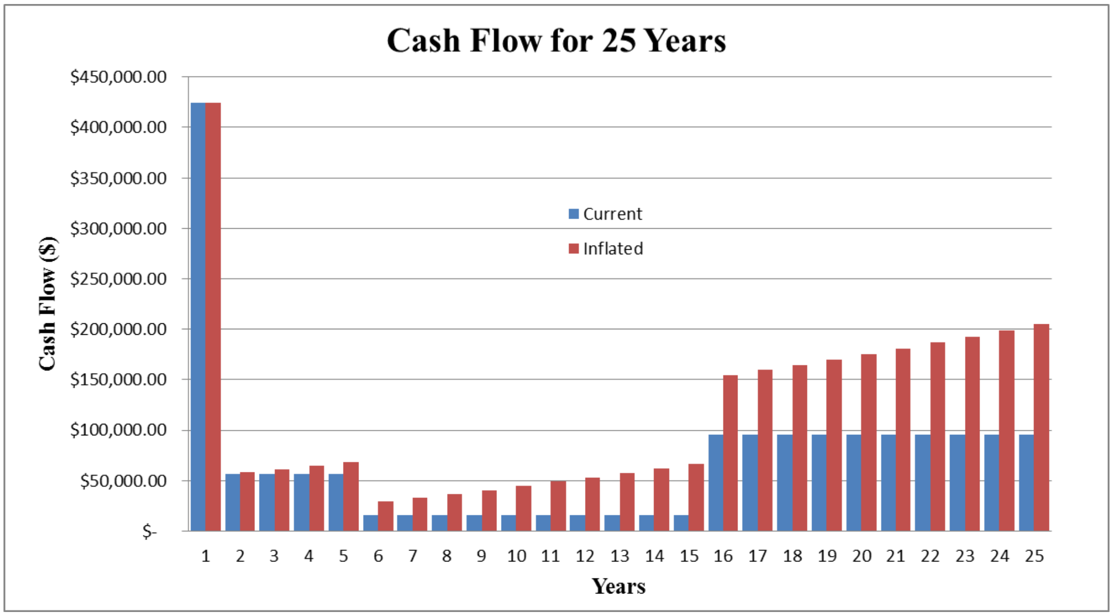

Figure 59: Annual Cash Flow for Solar Array over 25 years

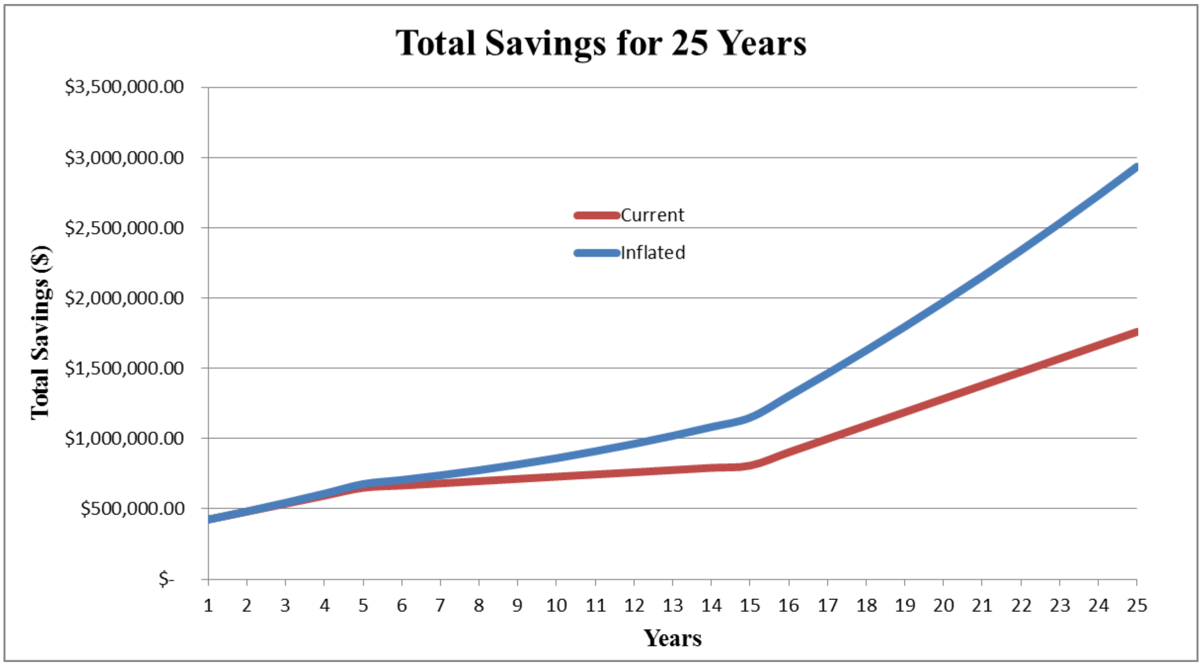

Figure 60: Total Savings for Solar Array over 25 years

Based on these diagrams, the payback time based on current and inflated energy cost predictions is almost immediate once the tax incentives are applied with a total possible revenue upwards of nearly $3 million. Once the loan has been paid in full, the company would see large returns if the array was operated consistently over time. This investigation only covered the first 25 years of the installation's lifetime which is usually the amount of time covered by the manufacturer's warranty, but predictions for current models have panel life expectancies of over 50 years with degradation of the panels remaining stable after a certain amount of time. This shows that a project like this will most likely be profitable for multiple decades if properly maintained.

The following table shows the results of solar array installation recommendations done for two of the three water plants reviewed in this paper, it can be observed that the potential for energy savings is immense, and installing a solar array is a sure bet for making a facility nearly completely energy sustainable.

Table 27: Solar PV Array Savings for two Water Treatment Plants

Facility	Energy Savings (kWh/year)	Cost Savings ($/year)	Implementation Cost ($)	Payback Time (years)
Plant #2	1,294,894	104,866	1,021,680	0.85
Plant #3	1,708,791	134,851	1,880,175	1.22

Wind Turbines

Wind Turbines are another piece of renewable energy technology that has seen immense improvements in quality, production and design over the past 20 years. Newer models can deliver immense amounts of electricity continuously throughout the year. Many models are self-regulating and have automatic shut off switches for when wind speeds get too high. Depending on the location of the facility, the total allowable height for the turbine can vary, but if the location is far enough away from any nearby airports then the company in question could potentially install a wind turbine with a maximum total height of 100 meters (approximately 328 feet). There are several factors which affect potential power output, central hub height being one of the more crucial aspects. The higher the central hub is from the ground, the laminar flow wind streams become less obstructed and can be harvested more consistently providing large amounts of steady power to the facility. The length of the turbine blades also play a key factor in the overall generation that is attainable; a simple rule of thumb is that the longer the turbine blades are, the more wind power they can harvest. Since most turbine blades are being made with ultra-light composite materials they in turn are being manufactured with increased lengths and the more area the blades cover, the higher the potential for power generation becomes, even in soft breezy weather.

Figure 61: Utility Scale Wind Turbine (Plaehn, 2018)

Calculating the potential savings a company could receive from a wind turbine is done slightly different than solar PV arrays in terms of modeling the power generation, but calculating the various installation and payback information is done in a similar fashion. First, the electrical energy generated by various wind turbines was calculated first by using the power curves available on www.en.wind-turbine-models.com/powercurves as an initial guide. These curves were then translated onto an excel spreadsheet to create equations used to estimate their power output based on wind speed data inputs. Below is one of the power curve models that were developed in order to better predict output with variable daily wind speeds.

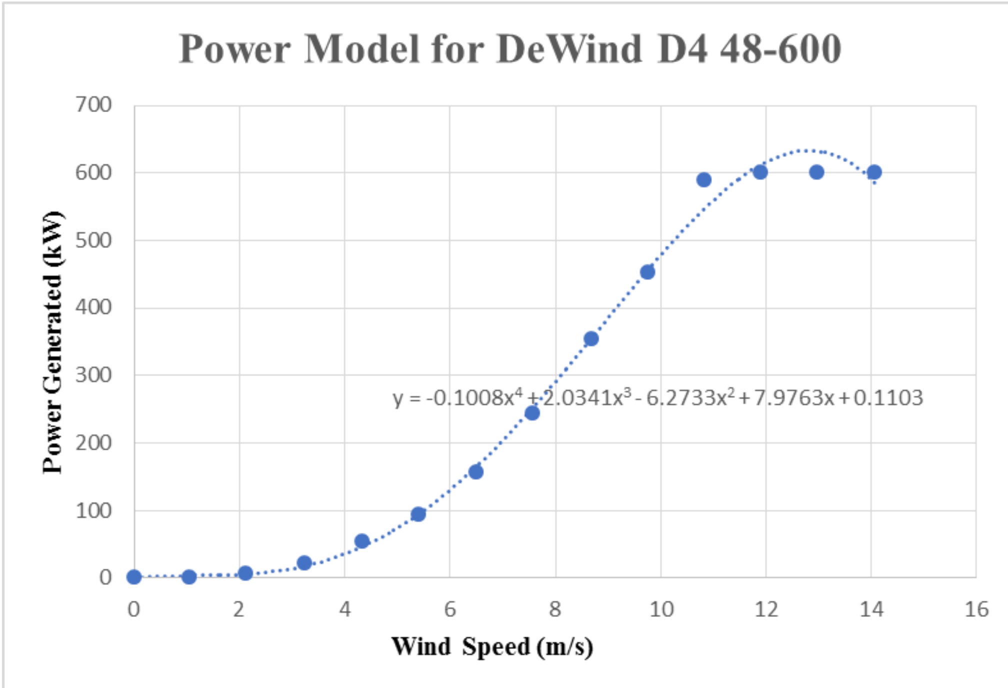

Figure 62: Predictive Power Model for a DeWind 600 kW Wind Turbine

The wind speed data was gathered from the Texas Commission on Environmental Quality online database at https://www.tceq.texas.gov/cgi-bin/compliance/monops/yearly_summary.pl , which includes data from across the state of Texas. Wind speeds were scaled up based on the target location and estimated at various hub heights for several turbines in order to create accurate predictive models. Using the cut-in, rated, and cut-off speeds of each turbine along with wind speed and frequency data, IAC staff were able to estimate the potential output for one year of turbine use for the various models so the best option could be chosen for implementation that would be closest to the total energy consumption of the target plant. Below are the simulation results for some of the turbines.

Table 28: Simulation Results for Three Turbine Models

Machine Make & Model	Hub Height (m)	Rotor Diameter (m)	Total Height (m)	Rated Potential Output (kW)	Annual Generation (MWh)	Generation/ Consumption (%)	Approximate Turbine Cost ($)
DeWind D4 48-600	70	48	94	600	1,603	102	780,000
Windflow 45-500	47	45	69.5	500	972	62	650,000
Suzlon S.33-350	70	33.4	86.7	350	1,119	72	455,000

To calculate the savings for this recommendation, IAC staff chose to use the simulation results for the first turbine shown in Table 28, and since it showed it could potentially provide approximately 100% of the energy consumption for the water treatment plant in question. Based on this, the IAC staff chose to use the total billed consumption as the basis for the rest of the calculations for energy savings instead of potential energy generated. The total consumption was first multiplied by the total avoided cost of electrical demand in order to obtain the total cost savings. Then the cost of the turbine itself was estimated using a conversion which indicated wind turbine installations usually cost approximately $1.3 per watt (Kellner, 2019), so the total wattage of the chosen turbine was multiplied by this rate to provide a rough starting estimate for the cost of the total installation. IAC staff estimated that at least 80% of this cost would be put towards the materials necessary for the base and structure of the turbine, while the remaining 20% of the initial estimate would go towards the installation itself since there needs to be a stable concrete pad installed in the ground to ensure the turbine remains steady in varying conditions. The 80% materials estimate was further fleshed out by multiplying it by the state of Texas sales tax rate, which was then added to the initial price estimate to provide a slightly more accurate total cost. The incentives chosen to be used for this renewable energy device slightly differed from the solar installation due to the cost and energy generation potential of the turbines themselves. Instead of the investment tax credit, the production tax credit was used instead which takes the total energy the installation can produce in a year and multiplies it by a specified rate to provide a set of savings which can be claimed by the company on their taxes for the first 10 years of the installation's lifetime. Then the solar and wind device tax deduction is applied which covers 10% of the initial installation investment. Once again the total investment can be broken down to provide a timeline for the facility to see what loan payments and repayment times they could expect to see until the project is paid off. First, the capital recovery factor is found yet again by using an interest rate of 2% and a loan period of 15 years since these are the terms that most renewable energy devices or projects can be negotiated to. Once the recovery factor is found it is multiplied by the total cost of the project in order to find the annual loan payment the company would need to pay for the next 15 years. Next, the depreciation of the installation can be found using the same 5 year straight line depreciation method used for the solar arrays. This is done by multiplying the total cost of the system by 0.2, which signifies 20% of the project depreciating in value the first year. Next, this annual depreciation value is then multiplied by 0.2 again which provides the depreciation savings of 20% that the facility could apply to their taxes for the first five years of the system's existence.

Next, the operations and maintenance costs are estimated and subtracted along with annual loan payment from the year one net savings which include the total avoided consumption savings, various tax credits, and depreciation savings. This total can provide some financial incentive for the company to pursue the installation since almost immediately they will see hundreds of thousands in savings once the turbine begins working. A simple payback time can then be calculated by adding the annual loan payment with the yearly maintenance cost and dividing this sum by the yearly consumption savings. This is not a completely accurate way to depict the payback time since there are other factors at play, but for a recommendation such as this it can provide a decent approximation.

Due to the nature of the incentives mentioned, the best way to predict a realistic payback time is to use graphical models that can track the total savings and yearly cash flow. If the project delivered savings for 20 years and has these approximate costs, maintenance requirements, in addition to loan and incentive rates applied, the annual and cumulative cash flows can be seen in the following diagrams. The blue data indicates the results using the current energy rate that one of the water treatment facilities was charged for electricity while the orange shows the results based on energy cost inflation predictions. This assumes an energy inflation rate of 3.3% (the average weighted rate over the last 10 years according to the U.S. Department of Energy Annual Energy Review 2011) per year in order to find the inflated values observed.

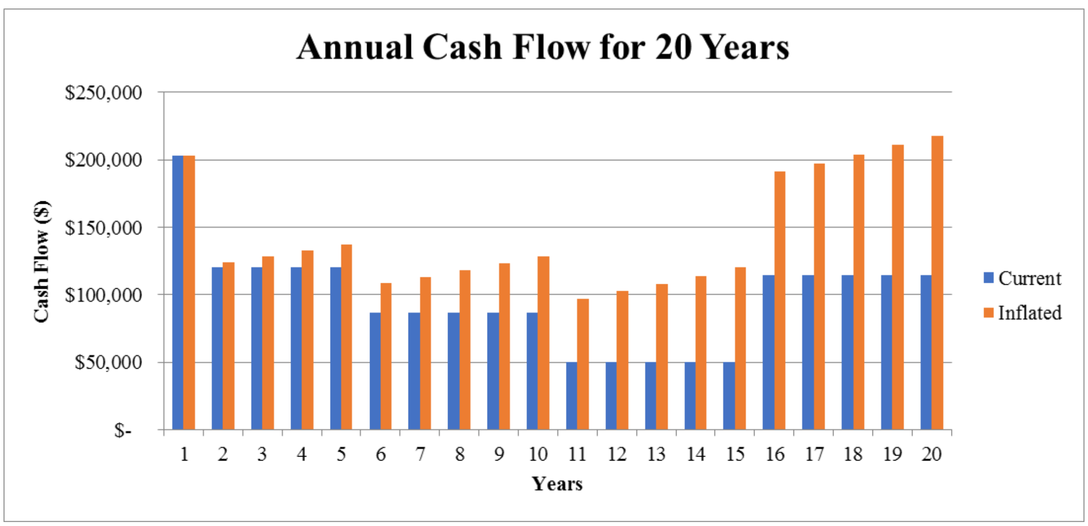

Figure 63: Annual Cash Flow for Wind Turbine over 20 years

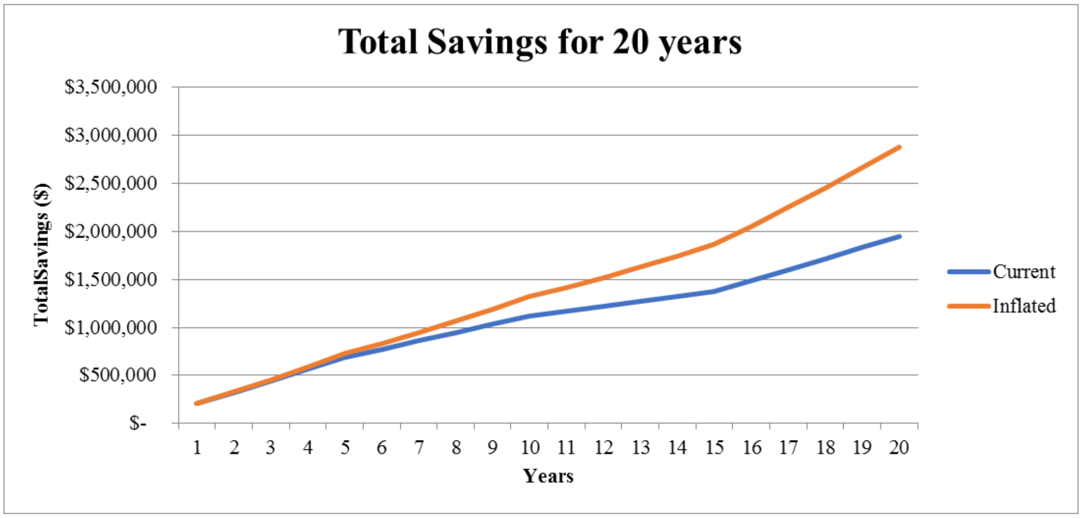

Figure 64: Total Savings for Wind Turbine over 20 years

Based on these diagrams it can be seen that the company would see continuous savings from the wind turbine installation over the next 20 years with a total possible savings upwards of $3 million. Once the loan has been paid, the facility would see much larger returns if the turbine was operated consistently over time. The following table shows the full results obtained for the wind turbine recommendation for one of the three water treatment facilities surveyed in this thesis.

Table 29: Wind Turbine Savings for a Water Treatment Plant

Facility	**Energy Savings (kWh/year)**	**Cost Savings ($/year)**	**Implementation Cost ($)**	**Payback Time (years)**
Plant #3	1,602,881	134,851	831,480	0.63

Hydroelectric Turbines

For the three water treatment facilities which serve as the focus for this thesis, there were no options available to develop fully fledged recommendations which could utilize hydroelectric turbines, but there are options out there that are strong possibilities for implementation if the facility is situated or set up in the right way. If a water treatment facility uses equipment known as pressure reduction valves for instance, there is serious potential for them to be replaced with a specialized water turbine that would fulfill the same operation. It was discovered through research that there are several water treatment facilities around the world which have replaced their pressure reduction valves (PRVs: common pieces of equipment used in many water treatment facilities) with energy recovering water turbines (Mcnabola, 2013). These turbines, which operate opposite of how normal pumps do, produce energy as they reduce a system's pressure, effectively replacing PRVs while providing their facility with extra power and reducing overall electrical demand.

Figure 65: In-Line Hydroelectric Turbine Replacing PRV (Soar Hydropower, 2020)

The savings IAC staff can predict from this particular recommendation cannot be quantified due to several pieces of information not being known at the current time. These values include the pressures before and after the various PRVs, size and output of turbine system needed, and total amount of flow seen at the PRVs throughout the year. Once these values are known an approximate savings amount could be calculated, but based on studies done on these devices, the savings should be considerable for this replacement (Samora, 2016). The implementation cost of this recommendation is also not quantifiable as of right now due to not knowing the proper size and cost of the system as well as the labor costs and time needed to replace the PRV itself. Once a system has been picked, a professional installer would need to connect the turbine to the appropriate equipment. Once these systems are in place at each of the available junctions then a facility could expect to see a significant amount of energy produced since water treatment plants run continuously throughout the year. These energy savings would be more than enough to repay these turbine substitutions in a matter of a few years at most based on anecdotal evidence gathered from various sources.

There are other forms of water turbines that could see usage in other manufacturing facilities depending on the layout of the plant itself. For instance, in waste water treatment facilities, there usually exists an outflow pipe that sends the freshly cleaned water back into the surrounding environment, whether it be a lake, river, stream or loch. This outflow pipe can be easily fitted with a hydroelectric turbine at its exit point which could utilize the full height and speed acquired from the water's potential energy to power the turbine and produce energy. Depending on the outflow's volumetric flowrate and the desired output, a hydroelectric turbine could provide thousands of dollars in savings to a facility if sized, implemented and installed correctly.

Other Renewable Energy Sources

There are potentially many more sources of renewable energy manufacturing facilities could utilize if they were to pursue them. For instance, waste heat generated by various pieces of equipment could be utilized to power a small steam turbine generator in some facilities. Other facilities that utilize diesel engines for their operations could also install a cogeneration turbine that uses the exhaust from an internal combustion engine to power a small turbine and create energy to reduce the facility's overall energy consumption. Some water treatment and waste water facilities use bacteria to break down their waste sludge, which can in turn create significant amounts of methane gas in their air-tight containers in certain cases. If carefully siphoned off, this methane gas could also be used to power a small combined heat and power (CHP) turbine generator to gain extra energy while preventing the escape of the methane to the atmosphere. These are just a few of the various other renewable energy sources that have been successfully integrated into different manufacturing facility's production lines to reduce their energy dependence from outside sources of energy and their overall carbon footprint while increasing their sustainability for the future to come.

Figure 66: Combined Heat and Power Methane Fueled Turbine Generator (TEDOM, 2020)

CHAPTER IX

OTHER ENERGY EFFICIENCY MEASURES

At the end of nearly every IAC assessment report there is a section titled Other Energy Efficiency Measures (OEEMs), which detail some of the research IAC staff members conducted into finding alternate sources of energy or waste management savings that could not fully come to fruition. This is usually due to lack of information, time, or the resources to take and record proper measurements, but the team members still want to inform the facility of their research results and findings which they deem could be potentially beneficial. These OEEMs provide further insight into potential recommendations that could become a reality if the IAC staff could work on the issue for several months straight to find the proper equipment, operating values, potential installers, deals, contracts, pricing and other information that only the staff of the facility being assessed may be privy to. For the three water treatment facilities that were assessed as the main bulk of this thesis, there were several OEEMs that were researched and developed which provide valuable insight into various avenues for potential savings that most water treatment facilities may not know about. They include using newer or underutilized technologies or products that need updated infrastructure or further research by the assessed facility to make the savings measures become a reality. The following sections describe the potential OEEMs that many water treatment facilities around the world could employ to drastically improve their overall performance, efficiency and waste management practices.

Replace Chlorination Stages with Ozone and Ultraviolet Light Stages

This recommendation is based off of research that was conducted in order to find a way to decrease overall chlorine usage at potable water treatment facilities. It was discussed during the IAC's assessments, in subsequent conversations with staff, and found in literature that chlorine is currently used extensively in many facilities throughout several of the main steps of the most often used water treatment processes. This is due to the purification and neutralization properties that chlorine possesses, but it does come with a steep price over time. Chlorine has been historically proven to destroy algal growth and harmful pathogens and it also reduces unwanted odors in the final water products; this is why it is still widely used today.

After some investigation and research it was uncovered that there have been significant improvements made to the clarification and treatment processes that have been used in the majority of facilities around the world. Many facilities in various countries have chosen to switch from using a chlorine based cleansing system to one that combines the use of ozone and ultra-violet light to obtain the same cleansing results for far less overall cost (Ried & Mielcke, 2006). Some facilities even produce their own ozone to further reduce overall chemical costs. A few of the benefits of using ozone in potable water treatment include increased disinfection rates, reduction of chlorine disinfectant by-products, and improved microcoagulation of debris. Some other additional benefits are enhanced biological filter performance and higher levels of oxidation of several harmful chemicals such as manganese, sulfide, taste and odor-causing compounds, pharmaceuticals, personal care products and other debilitating agents. Replacing chlorine with ozone in water treatment can be costly but after switching to new ozonation techniques there can be significant improvements to plant efficiency (Kasprzyk-Hordern et. al). Ozonation techniques have been shown to be faster than using chlorine which allows for an increase in overall plant efficiency which would potentially replace current chlorination and flocculation stages. Using ozone in both the pre and post-chlorination stages along with a final UV light stage ensures an extremely clean final product without any of the deleterious effects that chlorine can sometimes cause to both customers and plant workers (Camel & Bermond, 1998). By implementing this form of water clarification, a facility could see considerable cost savings over time and achieve even higher sustainability.

IAC staff recommend that water treatment facilities investigate and adapt their current clarification process to accommodate the use of ozone and ultraviolet (UV) light stages. Further research must be done in order to clarify the true potential of this recommendation however as the different components deal with many current unknowns. This new way of processing can be done with some alterations to most existing processes, but the steps that are currently undergone will generally remain the same. An ultraviolet light stage may also be implemented to finalize the water treatment process and completely remove the need for post chlorination. By substituting ozone and a UV process a plant's overall efficiency will increase drastically and overall costs will reduce over time. Most facilities could also implement their own ozone production area which could further decrease chemical shipping costs and increase a plant's sustainability.

Figure 67: Ultraviolet High Output Water Filtration System (TrojanUV, 2020)

Most facilities currently use large amounts of chlorine daily in order to disinfect and clarify the raw water they take from their respective reservoirs or other sources. It is also used in the final chlorination stage to ensure the final product is sufficiently cleansed of deleterious agents before it is sent to customers. This final chlorination stage usually lasts for an extended amount of time in order for the chlorine to diffuse sufficiently as well as lower the amount of detectable aroma and taste. Due to the amount of chlorine currently being used, most facilities ship in large canisters of the chemical, which, if not handled properly, could result in serious harm or death to employees. Precautions are taken to reduce the risk of this happening, but sometimes a chlorine leak can happen unbeknownst to plant operators.

Once chlorine has been replaced with ozone a facility will see vast improvements to overall plant efficiency and overall product quality. Based on current chlorine usage most facilities have the potential to use less ozone to achieve the same level of clarification and reduce the overall chemical cost. If the majority of water treatment facilities were to implement their own ozone generation infrastructure then the savings could be even more drastic once the chemical supply middle-man is removed.

If plants were to implement a UV stage at the end of the treatment process this would further reduce the chemical usage while sacrificing slightly more energy use. This would also increase the plant's efficiency and lower overall production time since the final chlorination stage can last for extended amounts of time. Using UV light to finalize potable water treatment has seen a huge adoption over the past 15 years, and a multitude of both water and waste-water facilities are implementing them throughout their facilities. There has even been advances in using LED technology to produce this UV stage for even less energy than most current systems utilize to achieve the same final purification results (Envirotec, 2019). Due to the nature of the existing stages, there is not a clear way of quantifying the total savings without access to in-depth analyses of existing systems as well as ozone replacement and usage data. It has been shown in previous plants to be extremely affective however, but the total cost savings can range drastically based on which options a plant goes with in the end.

The implementation costs of this alteration of a plant's operations cannot easily be quantified unfortunately due to the nature of the adjustments. The costs would include adapting the current chlorination areas to accommodate the ozone replacements in addition to the installation of a UV stage at the end of the operation before the water is stored for delivery. The chemical adjustments would most likely not be major, but the UV light stage could be fairly costly both upfront and over time due to the overall energy usage of the plant going up. Based on data from multiple sources this alternative treatment process has the potential to significantly reduce the overall chemical usage and increase both the quality of the final water product and a plant's productivity and efficiency.

Using Magnetic Technology to Treat Water

This recommendation is based on research that was done in order to better understand the potential for the use of high-gradient magnetic separation (HGMS) technology in treating and purifying water and improving a potable water treatment facility's purification processes. Most water treatment facilities utilize sand and gravel filtration in order to further clarify the water after flocculation has occurred. This method of filtration has been used successfully for over 100 years, but it can sometimes have a slow volumetric flow rate when compared to overall demand and can take up a significant portion of a facilities available space. There is also the fact that this type of filtration process is not perfect, and further chemical treatment is still necessary in order to finalize the cleaning process. Therefore, improvements can be made to make this filtration step more efficient and effective overall.

After some investigation it was found that using powerful magnetic technology such as HGMS has been proven to be even more effective at finalizing water treatment processes, and can even replace several steps of a normal treatment process to make efficiency even higher. Even though this seems like a novel water treatment process, this type of technology has been in use for treating and defouling water since the late 19th century. Magnetic water treatment technology has been utilized in a myriad of industrial settings such as in various materials development (steel, paper, clay, etc.) as well for pollutant separation and the cleaning of water lines from scale build-up (Ge et. al, 2017). Extensive research has been done into magnetic water treatment technologies since their initial utilization, and over the past 30 years it has been employed more frequently in water purification plants with great success. When compared to sand filtration, plants utilizing HGMS have reported lowered operating costs, lower feed times, higher flow rates/output of purified water, and usually less overall space is required (Ambashta

& Sillanpää, 2010). The cost of implementation has been shown to be only marginally higher than the cost of installing a new sand filter. There are several ways water treatment plants can utilize this technology with varying degrees of success based on the type of magnet technology implemented. The three main versions are permanent magnet-based, electromagnet-based and superconducting magnet-based, and each will give off higher intensity magnetic fields leading to different treatment results. Essentially the magnets are connected to a steel wool filter, which can have various configurations, that is able to separate out inorganic ions, organic contaminants, bacteria, viruses as well as radionucleides. The cleaning process for this type of filter is also faster than sand filter backwashing which decreases overall filter downtime. Another key improvement that would be seen in many facilities is the reduction of chemicals needed to purify the water to proper current standards since this filtration type is extremely effective at removing so many different contaminants in one step.

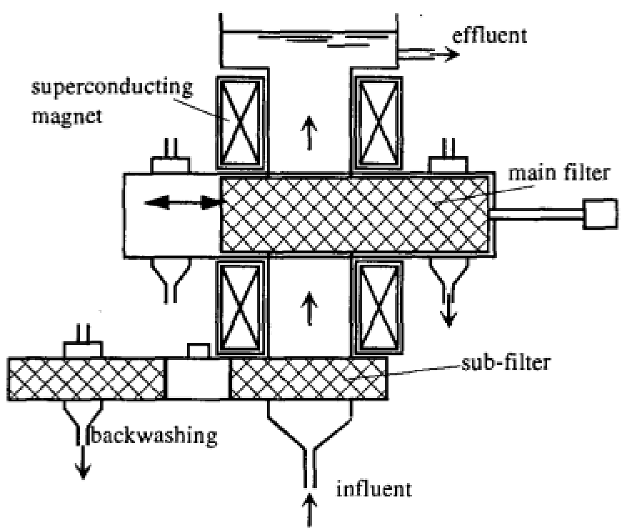

Figure 68: Simple Schematic of a HGMS Water Purification System (Saho et. al, 1999)

IAC staff recommends that water treatment facilities conduct further research into the usage of magnetic filter technology for water treatment processes to find which method would work best for each operation. A facility could try to implement a HGMS method on a small scale to test the viability of the overall efficiency when compared to sand filters. Once it is confirmed as a possibility for full implementation then a facility could install a HGMS device in order to enhance overall efficiency and reduce chemical usage. After running this magnetic filtration operation for a set amount of time it would then be suggested to implement the same equipment and procedures at other facilities as well.

Nearly all water treatment facilities utilize sand and gravel filters in order to clarify their water further after the flocculation process is complete. This involves large storage tanks and a variety of pumps to regulate the flow into and out of the filters including the necessary backwashing needed to remove the buildup of debris over time. The water must be chemically treated further after this filtration is complete as some inorganic and organic debris in addition to various microorganisms may still be present. After a certain amount of use has been achieved, the sand and gravel filters must be backwashed to cleanse them of debris, and this now-soiled water is then sent back to the reservoir for recycling. This can take varying amounts of time based on daily usage and demand, and flow rates must be precise in order to ensure proper cleansing has been achieved.

If a facility were to implement one of the magnetic filtration methods described above they could potentially see vast improvements in efficiency and output, chemical usage reduction, and faster filter cleaning times (Saho et. al, 1999). Based on results provided from other plants, the filtering flow rate could improve by over 7 times causing the average feed times to drop by as much as 20 times. Not only would most plants be running more efficient, utilizing magnetic filtration methods like HGMS have been shown to be more cost effective compared to sand filters reducing costs by up to 30%. The time spent cleaning the filters has also been shown to be much faster, leading to a reduction in down time by as much as 30%. By utilizing a magnetic filtration system in place of sand filters most companies will be able to reduce chemical usage as well since the magnetic filters are far more effective at removing a myriad of contaminants that are shown to still be present after sand filtration. Combining these various improvements leads to a large return on investment for magnetic filtration, with savings coming from various areas such as higher efficiencies and outputs, shorter downtimes, and lower operating costs and chemical usage that show this is the great way to improve a water treatment facility's processes and save large amounts of money for years to come.

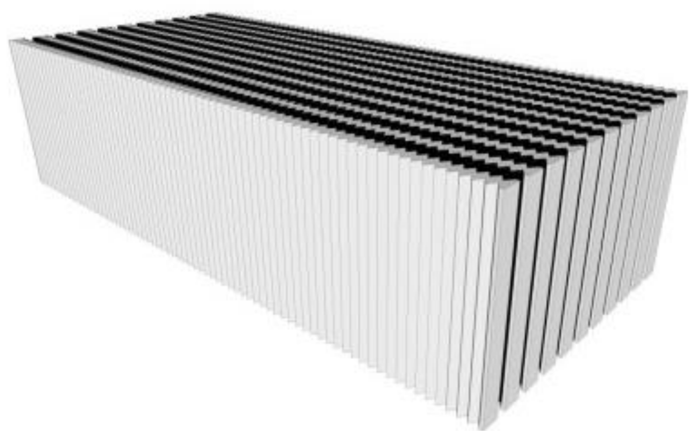

Figure 69: Grooved Plate Magnetic Filter Matrix Used in Some HGMS Systems (Ge et. al, 2017)

The implementation costs cannot necessarily be quantified currently due to the fact that there are several magnetic filtration options available that each involve specialized equipment that operate at different efficiencies. The costs to implement these processes would include the filters themselves, upgrading a facility to house the magnetic filters, the necessary connecting infrastructure and the installation itself. Installing magnetic filters has been shown to be slightly more expensive than installing a new sand filter (~10% increase), but the installation would pay for itself in a short amount of time based on the various cost-saving factors mentioned above. The majority of facilities would most likely want to include the tests necessary to confirm filtration efficiency, but these tests are most likely part of their current treatment regime already. However, based on data obtained from multiple sources, the usage of magnetic filtration methods such as HGMS are extremely beneficial processes that could prove advantageous to any facilities that chose to implement them for years to come.

Recovery of Metals from Water (Membrane Separation, Ion Exchange, Donnan Dialysis, Electrodialysis)

This recommendation is based on research that was done in order to better understand the flocculation process used in the majority of water treatment facilities and to find out if there are any possibilities of improving this treatment process. It was mentioned during our assessments that the treatment process uses a chemical known as Alum during the rapid mix portion of the procedure to begin the coagulation of small particulates that are present after the pre-chlorination stage. Alum is a form of hydrated double salt which has many uses including as a flocculent in water purification. It is able to do this since it creates a positively charged crystal ion after entering water which allows it to attract negatively charged colloids and suspended solids. Once flocculation is complete, then the sedimentation and sludge collection portion are conducted where the used alum is removed along with the unwanted particulates that were attracted to the coagulant.

After some investigation it was found that the use of metal based flocculants, such as alum, is responsible for a large portion of most water treatment plants' total costs of operation, approximately 25-30% in some facilities (Keeley et. al, 2014). Extensive research has been done into recovering the metal based salts used as flocculants in various forms of water treatment that show extremely high recovery rates and purities of recovered coagulant for the various methods used thus far. There are several methods which have been proven to be effective in recovering the various coagulants used in water treatment facilities and these include pressure-driven membrane separation, different forms of ion exchange, Donnan dialysis and electrodialysis to name a few. Each of these methods has different methods and efficiencies for achieving their respective coagulant recovery rates and overall purity, but all have been successfully implemented in water treatment facilities around the world (Keeley et. al, 2014). These recovery rates can be up to 75% with purities that can reach upwards of over 90%. If most facilities are able to implement a coagulant recovery method like the ones mentioned above then they would see savings not only in overall alum use, but also in sludge disposal as well as the actual transport of the chemical itself over time.

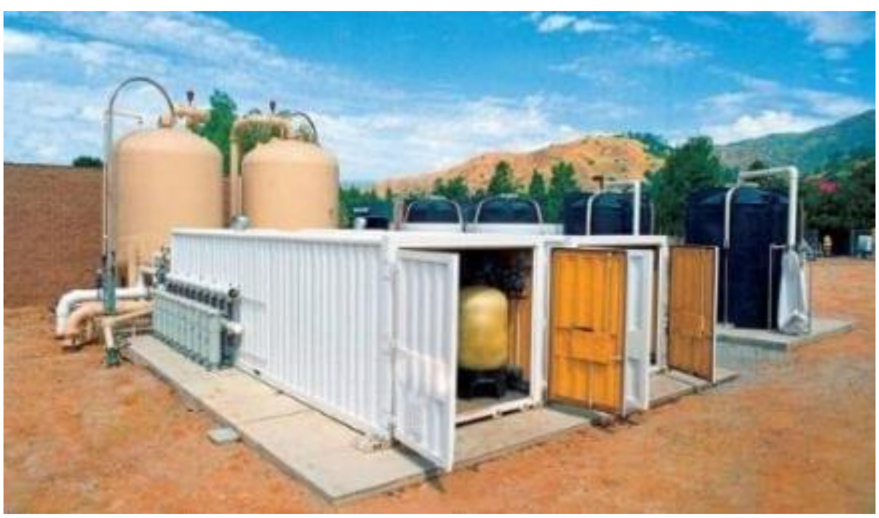

Figure 70: Ion Exchange Equipment Used at a Water Treatment Facility (Envirogen, 2020)

IAC staff recommend that water treatment facilities conduct research into these recovery methods to find which method would work best for their operation, and then try to implement a recovery method on a small scale to test the viability of the overall recovery. Once it is confirmed as a possibility for full implementation then it is suggested that the facility installs a coagulant recovery area in order to recycle the alum used during production. There would need to be tests added to the facility's operation to examine coagulant purity periodically to ensure the recycled alum is still able to meet the demand and quality expectations (Keeley et. al, 2016). After running this recovery operation for a set amount of time it would then be suggested to implement the same facilities and procedures at any other facilities.

Most water treatment facilities utilize large amounts of alum in order to properly remove any particulates left in the water after pre-chlorination is complete. The chemical itself is shipped in large containers to facilities which are then used to supply the rapid mix area for each operation. This flocculent is used to coagulate any remaining solids in the water and the soiled product is eventually removed afterwards as sludge. This sludge is then dried in ponds and removed via dump trucks to a landfill which costs most facilities significant amounts of money in collection and transportation fees.

If a facility were to implement one of the recovery methods mentioned above they could potentially see immense savings in the years to come. Not only would they be able to reuse the alum which is normally removed and added to the overall sludge volume, they would need to purchase the chemical and remove the resulting sludge less often (Prakash et. al, 2004). This will reduce their overall operation costs greatly meaning the implementation of a recovery system would most likely pay for itself in only a few years at maximum. Unfortunately there is no way to completely quantify these savings and the payback period without further testing and research, but based on the gathered evidence this is a viable method of reducing overall costs and increasing a plant's sustainability.

The implementation costs cannot necessarily be quantified currently due to the fact that there are several recovery options available with each one involving specialized equipment to complete the recovery process. The costs to implement these processes would include building a facility to house the recovery equipment, the necessary connecting infrastructure, the chosen filtration system itself and its installation. Most facilities would most likely want to include the tests necessary to confirm recovery efficiency as well as alum purity. However, based on data obtained from multiple sources, the recovery of coagulant is an extremely beneficial process that could prove very useful to many facilities for years to come.

Use Alternative Flocculent/Filtration Methods to Minimize Sludge Volume

This recommendation is based on research that was conducted in order to try and reduce the resulting sludge produced by most water treatment facility's current water treatment processes. Currently, most facilities utilize Alum in order to coagulate and collect any contaminants that remain in the water before and after the chlorination stages. This chemical has to be used in correct proportions in order to reduce overall sludge production and usage of product. In some instances the pH of the water itself must be adjusted in order to accommodate the use of alum and ensure proper efficiencies are met. The aluminum based salt has been used for centuries and will continue to be utilized by water treatment facilities for years to come based on its proven track record.

After some investigation and research, it was discovered that there has been several studies that have been done into alternative flocculants and filtration processes which mitigate chemical usage considerably. These alternatives have been shown to remove much more organic material from the water such as dissolved organic carbon (DOC), and produce far less deleterious waste products that are generated using a plant's current processes (Plourde-

Lescelleur et. al, 2014). Some of these alternative methods include using intermediate ozonation, powdered-activated carbon, and ion exchange resins which would act in conjunction with current alum processes to further cleanse a facility's water while using less overall alum in the procedure. A complete alum replacement could be poly aluminum chloride which has been shown to be as effective as alum at coagulating organic material in water treatment processes while using far less chemical volume (Pernitsky & Edzwald, 2006).

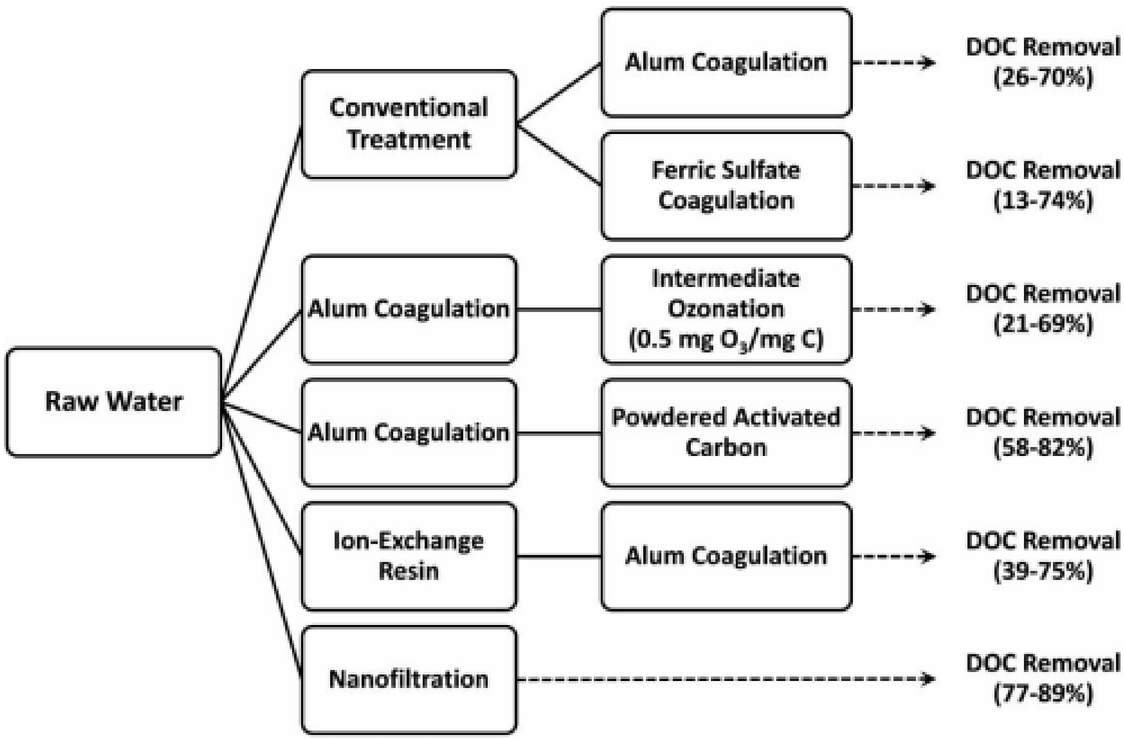

Figure 71: Diagram of Alternative Water Treatment Processes (Plourde-Lescelleur et. al, 2014)

Spiral-wound nanofiltration has also been shown to be able to completely replace flocculation processes in water treatment facilities while simultaneously removing far more dissolved organic compounds than any other method mentioned previously. By replacing the flocculation process with a nanofiltration stage a company could remove nearly all natural organic matter present in the raw water in one step with far less time and chemical usage involved. All of these alternatives have been shown to be cost effective in reducing or replacing alum or completely removing the flocculation stage entirely, and can lead to far less overall sludge production as well as changing the composition of the sludge produced to being much less toxic than what is being currently produced. If most companies were to replace the alum flocculation process with any of these alternatives not only would they be saving money on total chemical usage and cost, there will be a chance of producing much less sludge or even non-toxic sludge which can then be donated to local organic composting facilities. After implementing one of these alternative treatments a facility could see immense improvements in overall chemical usage and reductions in waste disposal costs that would be able to easily pay for the initial implementation costs in a short period of time.

IAC staff recommend water treatment companies research these alternative treatments further to find which solution would be best to integrate into their current operations. The alternative flocculent poly aluminum chloride could completely replace the alum most facilities currently use while costing far less overall for instance, but there are other promising alternative flocculants (Malhotra, 1994). By adding stages to a facility's process such as intermediate ozonation, powdered-activated carbon, and ion exchange resins a company could reduce their overall alum usage by a large margin. If a company were to invest in installing a spiral-wound nanofiltration stage they could completely negate the use of a flocculation stage entirely. Each of these alternatives could reduce the overall flocculent usage greatly, saving vast amounts of money over the years since alum is a very costly chemical.

Figure 72: Nanofiltration System Employed at a Water Treatment Facility (H2OInnovation, 2020)

Once one of these methods is implemented a water treatment company could potentially produce far less waste sludge overall leading to lower disposal costs. If they were to implement a nanofiltration stage for instance there is an opportunity to produce much less toxic sludge waste which could potentially be used to benefit the environment such as using or donating the waste in cooperation with local composting or fertilizing projects. All of these methods would benefit nearly all water treatment facilities in general for years to come and could easily be implemented in other plants increasing their profit and reducing their overall costs across the board (IWA Publications, 2014).

Most water treatment facilities currently utilize large amounts of alum, an aluminum based salt coagulant, to aggregate any organic materials left in the water after initial chlorination is implemented. This alum addition is done through a rapid mix procedure which is necessary to allow proper diffusion of the coagulant and promote the formation of flocs during the flocculation stage. This stage entails the further mixing of the treated water in large million gallon tanks so the flocs can group together and sink to the bottom of the tank and collect as sludge which will be eventually be removed leaving the clean water above to be further cleansed. After the sludge collects in the tanks it is then sent to drying ponds where the sun and ambient outside temperature is used to dry out the water remaining in the sludge which can take several days and involve a number of ponds to accommodate the large sludge output produced by this coagulation procedure. Since the dried alum sludge is toxic it must be removed and shipped to landfills which involve a third-party shipping company.

After implementing one of these methods or flocculent alternatives a facility would immediately see a reduction in overall chemical usage and waste production. This would translate to major savings in just a single year's time by causing the company to buy less flocculent since it will not be used as much which would cause reductions to their sludge disposal costs. Due to the nature of this recommendation and the number of alternative treatments available it is difficult to quantify the total expected savings these methods would produce, but based on proven research it is indeed a viable alternative which will save any water treatment company money in the years to come.

The implementation costs cannot be fully quantified since there are several variables which affect the outcome that cannot be estimated currently. These include whether or not a facility could implement an additional stage mentioned above to their current flocculation process, replacing alum with a flocculent alternative such as poly aluminum chloride, or completely circumventing the flocculation stage by implementing a nanofiltration stage. Each of these changes would produce different results but all would be able to save the facility vast amounts of money overall thanks to lowering flocculent usage in general and reducing the amount of waste produced. These methods all need further investigation and cost estimates to fully realize the scope of their implementation, but research and data from multiple sources show that they are each viable methods which would benefit any potable water treatment facility and have the potential to save millions of dollars for decades to come.

Use Drying Oven to Reduce Sludge Volume & Sell Waste

This recommendation is based off of research that was done to try and decrease the overall waste removal payments for a water treatment facility. It was mentioned during our assessment tours that when the waste sludge most treatment processes produce is pumped to the drying ponds, it is allowed to air dry for several days in order to reduce its moisture content. Eventually most companies will have excavators come and remove the semi-dried sludge and put it into large shipping containers to be dumped at a nearby landfill, which adds up considerably in shipping fees throughout the year. This is done because of the chemicals still remaining in the sludge make it unsuitable for any alternative uses once dried in the ponds.

After some investigation and research, it was discovered that in several countries around the world water treatment facilities have been implementing drying ovens in order to remove moisture more effectively than in drying ponds (Ahmad et. al, 2016). This reduces the volume of the sludge considerably which reduces disposal costs over time. Some facilities have taken it a step further however, and have made deals with local brick manufacturers to sell their oven dried sludge which will then be used in a brick making process in partial substitution of clay. This material substitution created bricks which were substantially stronger than the only-clay made versions; this creates an incentive for the brick manufacturers to pay a significant amount for the sludge since it produces higher quality bricks (Ramadan et. al, 2008). This type of deal could potentially help pay for the initial drying oven installation and implementation and possibly create an eventual extra revenue source over time.

IAC staff recommend that water treatment companies purchase industrial drying ovens and install the necessary facilities which would be able to accommodate their sludge disposal rates appropriately. This will allow for reduced disposal fees since the overall shipping volume would be smaller and therefore would require fewer pickups throughout the year. This reduction in disposal fees would be able to pay off the drying oven and its facilities fairly quickly since the price of disposal for one year can be extremely expensive.

Figure 73: Industrial Sludge Dryer (Komline-Sanderson, 2020)

Once an oven is implemented the facility’s management could reach out to local brick manufacturing facilities, of which there are many throughout the U.S., and offer this alternative material to them for a certain rate. This type of negotiation could also potentially help pay for the initial oven investment as well as provide an extra substantial revenue stream for a facility for years to come. This has been done successfully in other water treatment facilities and can easily be attained in various other locales.

Most facilities have multiple large sludge drying beds which take up a significant percentage of a plant's available land. These are cycled throughout the day so certain ponds can dry in the sun while others fill up. Once a few ponds are relatively dry, an excavator scoops out the mostly-dried sludge and dumps it into a large truck trailer. These trucks then travel to the nearest landfill for disposal. Due to the nature of the chemical cleaning process used in most facilities, the sludge waste product is not suitable for use as a fertilizer or in composting operations and must be disposed of safely in landfills.

Once a proper oven/dryer and corresponding facility are set up to accept the sludge input, a company will immediately see less waste volume overall leading to reduced amounts of disposals throughout the year. This should reduce the total disposal costs considerably, but as of right now there is no way to quantify the total potential amount a company would be saving due to several variables such as the cost of the oven and its facilities themselves which could be set up in several different variations and combinations.

Another major variable is the potential deal which could be made with local brick manufacturers to sell the oven-dried sludge for a considerable potential profit. This could be fairly lucrative as the sludge made bricks have been proven to be strong and effective alternative composite materials (Benlalla et. al, 2015). The disposal fees could be potentially completely removed and the water treatment facility could be receiving funds for their new 'product' at the same time.

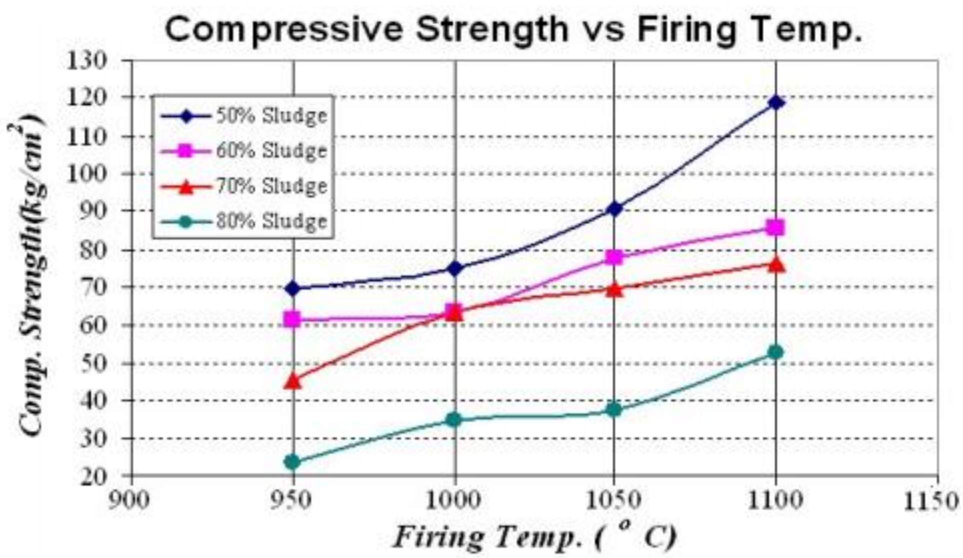

Figure 74: Sludge Brick Compressive Strength Testing Data (Ramadan et. al, 2008)

The implementation costs cannot necessarily be quantified since there are several variables which affect the outcome which cannot be estimated currently. These include oven size, the cost to build the facilities to house the oven or dryer, connecting infrastructure, and the actual cost to install the oven itself. All of these questions would need to be answered in order to give a proper estimate as to the total cost to implement this recommendation. However, based on data from multiple sources, this alternative drying method has huge benefits and has the potential to save any water treatment facility millions of dollars throughout the years.

Other OEEMs

There are countless other energy efficiency improvements which can be applied to not only water treatment processes but to all manner of manufacturing facilities. Most will be specific to the assessed plant in question, but there are plenty of wider ranging suggestions that can be recommended, the IAC assessment team just has to have the inspiration to look into them more. Some reports do not include any OEEMs at all, but if the team digs deep enough there is always at least one recommendation that could be pursued that is just out of the scope of a normal assessment recommendation.

CHAPTER X

CONCLUSION

This thesis covered the overall IAC assessment reporting process, a simple breakdown of the water treatment process and the main recommendations that were developed for three water treatment facilities based in the Rio Grande Valley of Texas. This is, what some would say, just the tip of the iceberg in regards to the wide variety of manufacturing facilities that IAC teams have visited and successfully assessed over the past decades. However, these water treatment plants and the recommendations that were provided to them were thoroughly worked on and researched to ensure that the findings and data were clear and concise. For some of the recommendations such as the OEEMs there was no way of fully realizing how the companies would go about achieving a full implementation, but by providing a thorough review of the current understanding of the subject there is hope for future improvements to be made. There are still a few minor, but necessary points to discuss that the IAC always suggests companies pursue.

Further Energy Management

Using energy efficiently helps organizations and companies save money and help to conserve resources and tackle climate change. Energy management can be considered a comprehensive and systematic approach for energy conservation efforts in an organization or a facility. An energy management system (EnMS) is built to continuously reduce an organization's energy costs by forming a set of well-planned procedures. An EnMS is a system of computer-aided tools which defines the goals, policies, procedures and processes of a facility and allows the user to monitor, control and optimize the performance of the operation. This is similar to a SCADA system mentioned earlier in this document, another system monitor/controller that allows users to easily identify issues and organize workflow and the processes of a facility based on the product demand for the day.

Figure 75: Example of a Demand Controller (Sigma IC, 2020)

Demand controllers are also another useful tool to help companies maintain a more level demand usage throughout the year. These can save a company thousands of dollars over the years in demand costs and are an extremely valuable piece of equipment to possess if the electricity utility a company uses employs ratchet demand charges. ISO 50001 is a company level certification based on a standard published by the International Organization of Standardization (ISO) and is designed to create and expand energy efficiency culture in an organization. ISO 50001 is based on the management system model of continual improvement also used for other well-known standards such as ISO 9001 or ISO 14001.

Cybersecurity

As systems to control energy-using manufacturing equipment become more connected to the internet, it is important for plant operation staff as well as office staff to have a well-rounded understanding of cybersecurity risks. It is essential to coordinate risk management activities within a facility and organization overall. Small businesses may not consider themselves targets for cyber-attacks, however they have valuable information cyber criminals seek, such as employee and customer records, bank account information, and access to larger unsecured networks. Small and medium sized companies and manufacturing facilities can be at a particularly high risk for cybersecurity attacks because they usually have fewer resources dedicated to cybersecurity in general. By addressing various risk areas, a facility can protect their business from damage to their information or systems, intellectual property theft, regulatory fines/penalties, decreased productivity, or a loss of trust with their customers and investors.

Figure 76: Online Cybersecurity Hacker (Blackwood, 2018)

IAC clients may elect to receive cybersecurity risk assessments to identify security and privacy deficiencies in their business infrastructure, with a focus on vulnerabilities associated with industrial controls systems. The IAC Industrial Control Systems Cybersecurity Assessment Tool includes 20 simple questions to characterize industrial control systems and plant operations, and the tool also provides a risk assessment level (high, medium, or low). The Companion User Guide provides additional context for the questions included in the tool, to help clients understand how certain business practices lead to an increase in cybersecurity risks. Upon conclusion of the assessment, the tool generates a customized list of action items associated with the risks identified. For additional guidance, IAC associates refer clients to additional technical resource materials available through the NIST Manufacturing Extension Partnership (MEP) and other organizations. Both the tool and the user guide can be found at https://iac.university/cybersecurity.

Follow-Ups and Final Suggestions

As discussed during IAC visits to various manufacturing facilities, the IAC director of the local branch will contact key facility personnel within six to twelve months to collect information to see if any of the recommendations in the assessment report have been (or will be) implemented; this involves only a short telephone conversation.

Additionally, these resources are also available and may prove useful to many facilities:

- *Energy Savings Assessments:* “Better Plants” is part of a national campaign to highlight easy ways for Americans to save energy now, when energy prices are expected to remain high. This initiative provides U.S. industries with technical assistance and information to save energy and money and increase productivity immediately. U.S. industrial manufacturers are encouraged to sign up for the E-Bulletin e-mail newsletter to receive

energy-saving information and updates from *Save Energy Now*.
http://www1.eere.energy.gov/manufacturing/tech_deployment/betterplants/

- *BestPractices:* This covers the BestPractices software tools, information about resources, technical assistance, and partnership opportunities from the Department of Energy.
https://ecenter.ee.doe.gov/Pages/default.aspx

Final Thoughts

During my tenure with the IAC I have had the privilege of working with some extremely intelligent and hard-working individuals, and have successfully completed work for numerous reports with recommendations I have personally finalized totaling yearly savings of well over $1.5 million. However, I would not have been able to accomplish this without the support of my mentors and team members that contributed their time and effort during the assessments and report creation process. Learning and understanding the ins and outs of the IAC, developing energy saving recommendations, and conducting in-depth research into water treatment processes has been eye-opening, challenging, and thoroughly enjoyable. I will fondly look back on my time working as a graduate assistant with the IAC at UTRGV.

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APPENDIX A

APPENDIX A

Table 30: State-of-the-Art Equipment Used in Research

Equipment	Purpose	Results Obtained
FLIR C2 Compact Professional Thermal Imaging Camera	Measure heat transfer and overall temperature	Window and cooling system temperatures

Table 31: State-of-the-Art Software Used in Research

Equipment	Purpose	Results Obtained
Microsoft Excel	Entering raw data into worksheets and manipulating it with formulas to obtain results	Data for various recommendations used in final analysis

Table 32: Variables Used For Recommendation Analyses

Variable	Description	Units
D_E	Total Avoided Cost of Electricity	$\frac{\$}{kWh}$
O_D	Days in Operation	$\frac{days}{year}$
O_H	Operating Hours	$\frac{hours}{year}$

C_L	Cost of Labor	$\frac{\$}{hour}$
K_{W2kW}	Watt to Kilowatt Conversion Factor	$\frac{kW}{W}$
E_{CO2}	CO_2 Emission Factor	$\frac{tons}{kWh}$
E_{NOX}	NOX Emission Factor	$\frac{lbs.}{kWh}$
E_C	Current Energy Usage	$\frac{kWh}{year}$
E_P	Proposed Energy Usage	$\frac{kWh}{year}$
E_S	Energy Savings	$\frac{kWh}{year}$
E_{CS}	Total Energy Cost Savings	$\frac{kWh}{year}$
C_T	Total Cost Savings	$\frac{\$}{year}$
C_C	Capital Cost	$
C_I	Implementation Cost	$
T_P	Simple Payback Time	years
G_{CO2}	Equivalent CO_2 Emissions Reductions	$\frac{tons}{year}$
G_{NOX}	Equivalent NOX Emissions Reductions	$\frac{lbs.}{year}$
P_{Flood}	HPS Flood Light Power	$\frac{W}{lamp}$
P_{Box}	HPS Box Light Power	$\frac{W}{fixture}$

P_{Wall}	HPS Wall Pack Power	$\frac{W}{fixture}$
P_{Sec}	HPS Security Light Power	$\frac{W}{fixture}$
P_{Bulb}	Incandescent Bulb Power	$\frac{W}{bulb}$
N_{Flood}	Number of HPS Flood Lights	lamps
N_{Box}	Number of HPS Box Lights	fixtures
N_{Wall}	Number of HPS Wall Packs	fixtures
N_{Sec}	Number of HPS Security Lights	fixtures
N_{Bulb}	Number of Incandescent Bulbs	bulbs
P_{FLED}	LED Flood Light Power	$\frac{W}{lamp}$
P_{BLED}	LED Box Light Power	$\frac{W}{fixture}$
P_{WLED}	LED Wall Pack Power	$\frac{W}{fixture}$
P_{SLED}	LED Security Light Power	$\frac{W}{fixture}$
P_{BULED}	LED Bulb Power	$\frac{W}{bulb}$
C_{FLED}	Cost per LED Flood Light	$\frac{\$}{lamp}$
C_{BLED}	Cost per Box Light LED Fixture	$\frac{\$}{fixture}$
C_{WLED}	Cost per Wall Pack LED Fixture	$\frac{\$}{fixture}$

C_{SLED}	Cost per Security Light Fixture	$\frac{\$}{\text{fixture}}$
C_{BULED}	Cost per LED Bulb	$\frac{\$}{\text{bulb}}$
T_{I1}	Installation Time for Lamps/Fixtures	$\frac{\text{hours}}{\text{lamp/fixture}}$
T_{I2}	Installation Time for Bulbs	$\frac{\text{hours}}{\text{bulb}}$
P_{T5}	Fluorescent T5 Light Power	$\frac{\text{W}}{\text{lamp}}$
P_{T8}	Fluorescent T8 Light Power	$\frac{\text{W}}{\text{lamp}}$
P_{HB}	HPS High Bay Light Power	$\frac{\text{W}}{\text{lamp}}$
N_{T8}	Number of T8 Fluorescent Lights per Fixture	$\frac{\text{lamps}}{\text{fixture}}$
N_{T5}	Number of T5 Fluorescent Lights per Fixture	$\frac{\text{lamps}}{\text{fixture}}$
N_{HB}	Number of HPS High Bay Lights	lamps
X_{T8}	Number of T8 Fixtures	fixtures
X_{T5}	Number of T5 Fixtures	fixtures
P_{L}	LED T8 Light Power	$\frac{\text{W}}{\text{lamp}}$
P_{L2}	LED T5 Light Power	$\frac{\text{W}}{\text{lamp}}$
P_{LHB}	LED High Bay Light Power	$\frac{\text{W}}{\text{lamp}}$

C_{T8}	Cost per T8 LED	$\frac{\$}{lamp}$
C_{T5}	Cost per T5 LED	$\frac{\$}{lamp}$
C_{HB}	Cost per High Bay LED	$\frac{\$}{lamp}$
P_{IL}	Power of Incandescent Exit Lamp	$\frac{W}{lamp}$
T_{IL}	Incandescent Exit Lamp Lifetime	hours
C_{IL}	Purchase Price of Incandescent Exit Lamp	$\frac{\$}{lamp}$
N_{LE}	Number of Lamps in Exit Signs	signs
T_{INC}	Time to Replace Exit Bulbs	$\frac{hours}{lamp}$
X_{LE}	Number of Lamps per Exit Sign	$\frac{lamps}{sign}$
P_{ELED}	Wattage of LED Lamp	$\frac{W}{lamp}$
T_{ELED}	LED Exit Lamp lifetime	hours
C_{ELED}	Purchase Price of LED Retrofit Kit (2 lamps/kit)	$\frac{\$}{sign}$
T_I	Installation Time for LED Exit Lamp	$\frac{hours}{lamp}$
X_{TR}	Number of Lamps in Target Room	lamps
T_{TR}	Current Occupancy Percentage of Target Room	%
X_{OS}	Number of Occupancy Sensors Needed	sensors

T_{IOS}	Installation Time per Sensor	$\frac{hour}{sensor}$
C_{OS}	Occupancy Sensor Cost	$\frac{\$}{sensor}$
W_{Loss}	Pump Water Loss Rate	$\frac{drops}{minute}$
D_{Gal}	Number of Drops in a Gallon	$\frac{drops}{gallon}$
N_{Pumps}	Number of Leaky Pumps	pumps
R_{Low}	Lowest Customer Rate	$\frac{\$}{gallon}$
R_{High}	Highest Customer Rate	$\frac{\$}{gallon}$
C_{Pump}	Pump Shaft Circumference	$\frac{inches}{ring}$
C_{Gland}	Price of Gland Packing	$\frac{\$}{inch}$
N_{Rings}	Number of Packing Rings per Pump	$\frac{rings}{pump}$
P_{Life}	Operating Lifetime of Gland Packing	hours
C_{Seal}	Cost of Mechanical Seal	$\frac{\$}{pump}$
M_{Life}	Operating Lifetime of Mechanical Seal	hours
M_{Eff}	Mechanical Seal Efficiency	%
T_{MS}	Time to Install Mechanical Seal	$\frac{hours}{pump}$
L_P	Total Water Loss	$\frac{gallons}{year}$

P_{Low}	Potential Profit at Lowest Rate	$\frac{\$}{year}$
P_{High}	Potential Profit at Highest Rate	$\frac{\$}{year}$
P_Y	Potential Yearly Profit Lost	$\frac{\$}{year}$
G_{Ann}	Gland Packing Annual Cost	$\frac{\$}{year}$
M_{Ann}	Mechanical Seal Annual Cost	$\frac{\$}{year}$
S_{Ann}	Annual Operating Cost Savings	$\frac{\$}{year}$
P_M	Motor Power	HP
η_M	Motor Efficiency	%
X_M	Number of Motors	motors
L	Load Factor	%
D	Duty Factor	%
η_C	Current Belt Efficiency	%
η_P	Proposed Belt Efficiency	%
E_M	Current Motor Energy Usage	$\frac{kWh}{year}$
E_C	Current Belt Energy Usage	$\frac{kWh}{year}$
E_P	Proposed Belt Energy Usage	$\frac{kWh}{year}$
$A_{\#}$	Area of Windows	ft^2

$N_{\#}$	Number of Windows	windows
$T_{Building}$	Operating Temperature of Building	°F
C_{Tint}	Cost of Window Tint	$\frac{\$}{ft^2}$
U_{Value}	U Value For Un-Tinted Single-Paned Windows	$\frac{Btu}{hrft^2°F}$
T_{Eff}	Efficiency of Window Tint	%
$Q_{\#}$	Heat Gain Per Degree Temperature for Windows	$\frac{Btu}{hr°F}$
E_{Total}	Total Energy Loss Prevented by Applying Window Tint	$\frac{kWh}{year}$
W_{Acc}	Water Access Rate	$\frac{\$}{acre * foot}$
A_{Res}	Area of Reservoir	acres
A_{Clar}	Area of Clarifiers	ft^2
E_{Loss}	Evaporation Loss Rate	$\frac{feet}{year}$
C_{Cost}	Chlorine Cost	$\frac{\$}{day}$
C_{Ball}	Cost of Hex Protect Shade Balls	$\frac{\$}{ft^2}$
T_{Ball}	Time to Install Shade Balls	$\frac{\$}{ft^2}$
L_{Res}	Preventable Reservoir Water Loss	$\frac{gallons}{year}$
L_{Clar}	Preventable Clarifier Water Loss	$\frac{gallons}{year}$

L_{Year}	Total Yearly Preventable Water Loss	$\frac{\text{gallons}}{\text{year}}$
L_{Acc}	Loss of Bought Water	$\frac{\$}{\text{year}}$
C_{Save}	Potential Chlorine Savings	$\frac{\$}{\text{year}}$
T_{Pot}	Total Yearly Potential	$\frac{\text{kWh}}{\text{year}}$
W_{Pan}	Wattage for Each Panel	W
C_{Pan}	Cost of Each Panel63F	$
C_{Mic}	Cost of Each Microinverter	$
T_{Sal}	Material Sales Tax	%
I_{Rate}	Installation Rate	%
I_{TC}	Investment Tax Credit Rate	%
S_{Tax}	Solar Device Tax Deduction	%
L_{Rate}	Loan Interest Rate	$\frac{\%}{\text{year}}$
L_{Per}	Loan Period	years
D_{Rate}	Annual Depreciation Rate	%
F_{Rate}	Federal Tax Rate	%
M_{Cost}	Cost to Maintain Each Panel/Microinverter	$\frac{\$}{\text{year}}$
N_{Pan}	Number of Panels/Microinverters Needed	#
T_{Pan}	Total Cost for Panels	$
T_{Mic}	Total Cost for Microinverters	$

M_{Tax}	Total Materials Subject to Sales Tax	\$
C_{Ins}	Cost of Installation	\$
S_{Tax}	Sales Tax on Materials	\$
C_{Tot}	Total Cost with Tax	\$
D_{Tax}	Savings from Solar Device Tax Deduction	\$
I_{Save}	Investment Tax Credit Savings	\$
C_{RF}	Capital Recovery Factor	\$
A_{LP}	Annual Loan Payment	\$
D_{Ann}	Annual Depreciation	\$
D_{Save}	Annual Depreciation Savings	\$
O_{Cost}	Operations and Maintenance Cost	\$
S_{One}	Year One Net Savings Including Loan Payment	\$
P_{Pot}	Approximate Potential Power of Wind Turbine	W
C_{Watt}	Cost per Watt for Turbine	$\frac{\$}{W}$
P_{TC}	Production Tax Credit Rate	$\frac{\$}{kWh}$
P_{Save}	Production Tax Credit Savings	\$

Equations Used For Recommendations

Outdoor Lighting Current Energy Usage

$$E_C = [(P_{Flood} * N_{Flood} * X_{Flood}) + (P_{Wall} * N_{Wall}) + (P_{Box} * N_{Box}) + (P_{Sec} * N_{Sec})] * (To * K_{W2kW})$$

Outdoor Lighting Proposed Energy Usage

$$E_C = [(P_{FLED} * N_{Flood} * X_{Flood}) + (P_{WLED} * N_{Wall}) + (P_{BLED} * N_{Box}) + (P_{SLED} * N_{Sec})] * (To * K_{W2kW})$$

Total Energy Savings

$$E_S = E_C - E_P$$

Total Energy Cost Savings

$$E_{CS} = (E_S)(D_E)$$

Outdoor Lighting Capital Cost

$$C_C = (C_{FLED} * N_{Flood} * X_{Flood}) + (C_{WLED} * N_{Wall}) + (C_{BLED} * N_{Box}) + (C_{SLED} * N_{Sec})$$

Outdoor Lighting Implementation Cost

$$C_I = C_C + [(N_{Flood} * X_{Flood}) + N_{Wall} + N_{Box} + N_{Sec}] * (T_I * C_L)$$

Simple Payback

$$T_P = \frac{C_I}{C_T}$$

Equivalent CO_2 Emissions Reductions

$$G_{CO2} = (E_S)(E_{CO2})$$

Equivalent NOx Emissions Reductions

$$G_{NOX} = (E_S)(E_{NOX})$$

Indoor Lighting Current Energy Usage

$$E_C = (P_{T5} * X_{T5}) * (To * K_{W2kW})$$

Indoor Lighting Proposed Energy Usage

$$E_C = (P_L * X_{T5}) * (To * K_{W2kW})$$

Indoor Lighting Capital Cost

$$C_C = C_{T5} * X_{T5}$$

Indoor Lighting Implementation Cost

$$C_I = C_C + (X_{T5} * T_I * C_L)$$

Exit Sign Current Energy Usage

$$E_C = (P_{IL})(X_{IL})(N)(K_{W2KW})(O_H)$$

Exit Sign Proposed Energy Usage

$$E_P = (P_{LED})(X_{IL})(N)(K_{W2KW})(O_H)$$

Exit Sign Maintenance Cost Savings

$$M_{CS} = \frac{(N)(X_{IL})(T_{INC})(O_H)(D_L)}{T_{IL}}$$

Exit Sign Re-Lamping Cost Savings

$$R_{CS} = \frac{(N)(X_{IL})(C_{IL})(O_H)}{T_{IL}}$$

Exit Sign Total Cost Savings

$$C_T = E_{CS} + M_{CS} + R_{CS}$$

Exit Sign Capital Cost

$$C_c = (N)(C_{LED})$$

Exit Sign Implementation Cost

$$C_I = C_C + (N)(X_{LED})(T_I)(D_L)$$

Current Energy Usage without Occupancy Sensors

$$E_C = (X_{TR})(P_{T5})(T_O)(K_{W2KW})$$

Occupancy Sensor Proposed Energy Usage

$$E_P = (E_C)(T_{BR})$$

Occupancy Sensor Capital Cost

$$C_c = (D_{OS})(X_{OS})$$

Occupancy Sensor Total Implementation Cost

$$C_I = C_C + (X_{OS})(T_I)(D_L)$$

Current Pump Seal Water Loss

$$L_P = \frac{W_{Loss} * O_D * N_{Pumps}}{D_{Gal}}$$

Potential Profit of Saved Water Sold at Lowest Rate

$$P_{Low} = R_{Low} * L_P * 0.99$$

Potential Profit of Saved Water Sold at Highest Rate

$$P_{High} = R_{High} * L_P * 0.01$$

Potential Yearly Profit Using Mechanical Seals

$$P_Y = (P_{Low} + P_{High}) * M_{Eff}$$

Annual Cost of Using Gland Packing Seals

$$G_{Ann} = \frac{N_{Pumps} * N_{Rings} * C_{Pump} * C_{Gland} * O_H}{P_{Life}}$$

Annual Cost of Using Mechanical Seals

$$M_{Ann} = \frac{N_{Pumps} * C_{Seal} * O_H}{M_{Life}}$$

Annual Mechanical Seal Operating Cost Savings

$$S_{Ann} = G_{Ann} + M_{Ann}$$

Total Mechanical Seal Yearly Savings

$$T_Y = P_Y + S_{Ann}$$

Mechanical Seal Capital Cost

$$C_C = C_{Seal} * N_{Pumps}$$

Mechanical Seal Implementation Cost

$$C_I = C_C + \left(D_L * T_I * N_{Pumps}\right)$$

Current Motor Energy Usage

$$E_M = \frac{(P_M)(X_M)(K_{HP2KW})(L)(D)(T_O)}{(\eta_M)}$$

Current Belt Energy Usage

$$E_C = (E_M)(1 - \eta_C)$$

Proposed Cogged Belt Energy Usage

$$E_P = (E_M)(1 - \eta_P)$$

Heat Gain per Temperature Degree

$$Q_{\#} = U_{Value} * A_{\#} * N_{\#}$$

Total Window Tinting Energy Savings

$$E_{Demand} = S_{heating} * T_{Eff}$$

Window Tinting Implementation Cost

$$Q_{\#} = C_{Tint} * A_{\#} * N_{\#}$$

Preventable Reservoir Water Loss

$$L_{Res} = (A_{Res})(E_{Loss})$$

Preventable Clarifier Water Loss

$$L_{Clar} = (A_{Clar})(E_{Loss})$$

Total Yearly Preventable Water Loss

$$L_{Year} = (L_{Res}) + (L_{Clar})$$

Loss of Bought Water

$$L_{Acc} = (A_{Res})(W_{Acc}) + (A_{Clar})(W_{Acc})$$

Potential Chlorine Savings

$$C_{Save} = (C_{Cost})(O_D)(.8)$$

Potential Shade Ball Yearly Savings

$$P_Y = (P_{Low}) + \left(P_{High}\right) + (C_{Save}) + (L_{Acc})$$

Shade Ball Implementation Cost

$$C_I = \{[(A_{Res}) + (A_{Clar})](C_{Lab})(T_{Ball})\} + [(A_{Res}) + (A_{Clar})](C_{Ball})$$

Number of Solar Panels/Microinverters Needed

$$N_{Pan} = \frac{P_{Pot}}{W_{Pan}}$$

Total Cost of Solar Panels

$$T_{Pan} = N_{Pan} * C_{Pan}$$

Total Cost of Microinverters

$$T_{Mic} = N_{Pan} * C_{Mic}$$

Total Cost of Solar Array Materials Subject to Sales Tax

$$M_{Tax} = T_{Pan} + T_{Mic}$$

Total Cost of Solar Array Installation

$$C_{Ins} = M_{Tax} * I_{Rate}$$

Total Sales Tax on Materials for Solar Array

$$S_{Tax} = M_{Tax} * T_{Sal}$$

Total Cost of Solar Array with Sales Tax

$$C_{Tot} = M_{Tax} + C_{Ins} + S_{Tax}$$

Savings from Solar Device Tax Deduction

$$D_{Tax} = C_{Tot} * I_{TC}$$

Investment Tax Credit Savings

$$I_{Save} = C_{Tot} * W_{Tax}$$

Capital Recovery Factor

$$C_{RF} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Annual Loan Payment

$$A_{LP} = C_{Tot} * C_{RF}$$

Annual Depreciation

$$D_{Ann} = C_{Tot} * D_{Rate}$$

Annual Depreciation Savings

$$D_{Save} = D_{Ann} * F_{Rate}$$

Operations and Maintenance Cost

$$O_{Cost} = N_{Pan} * M_{Cost}$$

Year One Net Savings Including Loan Payment

$$S_{One} = T_{Year} + D_{Tax} + I_{Save} + D_{Save} - M_{Cost} - A_{LP}$$

Solar Array Simple Payback Time

$$T_P = \frac{A_{LP} + O_{Cost}}{T_{Year}}$$

Cost of Wind Turbine

$$C_{Tur} = P_{Pot} * C_{Watt}$$

Total Cost of Wind Turbine Materials Subject to Sales Tax

$$M_{Tax} = C_{Tur} * C_{Watt}$$

Total Cost of Wind Turbine with Sales Tax

$$C_{Tot} = C_{Tur} + S_{Tax}$$

Production Tax Credit Savings

$$P_{Save} = T_{Pot} * W_{Tax}$$

BIOGRAPHICAL SKETCH

Brent A. DeKock was born in El Centro, California, and raised in Mission, Texas. He attended high school in Marble Falls, Texas and graduated in 2011, and received his undergraduate degree in Mechanical Engineering at the University of Texas- Rio Grande Valley in 2018. He went on to graduate in 2020 with his master’s in mechanical engineering at UTRGV. His current mailing address is 1501 Prosperity Dr. Apt. D in Edinburg, Texas 78541. He has worked as a Customer Service Associate with Lowe’s, Accounts Payable Specialist with Vantage Bank of Texas and as a Graduate Assistant with the branch of the Industrial Assessment Center located at UTRGV.