Feasibility of Enhancing Balboa Chilled Water Distribution by Implementing Co-generation and Absorption Process

A Major Qualifying Project

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Abstract

The Panama Canal Authority (ACP) uses an electric vapor compression chilling water distribution method to cool their facilities in the Balboa area. In preparation of the possibility of a relocation of facilities, the ACP is looking for alternatives to replace this existing 60-year-old plant. A notable alternative was proposed in previous years that evaluated the desirability of a central system of chilled water in Balboa and later the alternative of producing cold water by co-generation with excess heat emitted from the Mira Flores power plant. Aforementioned, the Balboa facilities are now cooled by conventional high electricity-consuming systems. Such levels of consumption reduce the amount of energy sold in the national electricity market. For this reason, it is important to consider and evaluate alternative technologies that will reduce energy consumption, giving margin to a higher sale of electricity as well as a decrease in operating costs. We are tasked to analyze the feasibility of implementing a chilled water distribution system pipeline, created through the processes of co-generation and absorption, from the Mira Flores thermoelectric plant to the Balboa facilities.

Executive Summary

The Panama Canal Authority contributes more to the country of Panama than just provide administration for the Canal. The ACP supplies a great deal of the chilled water supply for air-conditioning units in the Balboa and Corozal areas. From clientele outside of the ACP to multiple buildings on the ACP campus, the chilled water distribution supplied is of great importance. As you can imagine, in such a warm climate, air-conditioning is extremely important. The main chilled water facility currently in use is in the Balboa area. This facility currently houses outdated machinery and equipment. The cooling towers outside the facility are over 50 years old and are constructed with currently outdated material. If the ACP wants to remain a beacon of sustainable energy, then an analysis of new alternatives needs to be conducted.

Co-generation is a process that takes advantage of waste-heat, and converts it into raw energy. The ACP has a thermoelectric power plant in Mira Flores that emits a great deal of waste heat into the atmosphere. In order for the waste heat to be advantageous, an absorption chiller must be put in place. Absorption chillers physically take the heat, usually steam, emitted from the power plant and convert the steam , using thermodynamic properties of water, to chill water for the air-conditioning units. In our case, chilled water generated through co-generation at Miraflores will traverse through a pipeline from Miraflores to Balboa, approximately 6 kilometers in length.

This project aimed to evaluate the feasibility of implementing such a pipeline from Miraflores to Balboa. In addition, this project analyzed another alternative scenario that calls for constructing a completely new electric chilling facility in the Balboa area that would serve the same purpose as

the pipeline. Not only is the current electric system in Balboa outdated, but our hypothesis predicts that annual electricity expenses can almost be eliminated with the processes of cogeneration and absorption. Instead of paying for electricity to power the chillers, co-generation allows for energy to be generated through waste energy, therefore saving money. In order to evaluate our theory, we needed to research current flows and operations. Site assessments and Supervisor interviews were conducted to obtain the information we needed. We generated a flow model to desirable ACP specifications, including pipe size; pump power, and storage tank volume. Once the most cost and energy efficient method was chosen, an economic analysis was performed.

Economic analysis model calculations take an investment value, annual expense values, and yearly income and compound the rate of return over the next twenty years. One model was created to compare the co-generation scenario to the current systems and the new facility scenario to the current systems. An ultimate question to be answered was: would it more efficient to implement the co-generation line, or to invest in all aspects of a new facility? In our research we found that the new facility scenario returned a 12% value. In the midst of project planning we set a minimum acceptable rate of return (MARR) of 14%. With that said, the new facility scenario would in fact lose the ACP money over the next twenty years. When compared with the co-generation scenario, we found a return rate of 22%. The amount of energy saved each year was more than enough to overcome any investment costs and would allow the ACP to profit from such an expansion, not to mention profit from sales to potential clients located in the path of the pipeline. The co-generation pipeline proved to be more energy efficient by using waste heat to power a new system, so that less electricity will be used in their operation and more can be sold to the national market. Therefore our recommendation to the ACP is to further investigate the co-generation scenario and make a plan of action to implement this alternative to their current chilled water distribution methods.

The work done for the ACP has been in fulfillment of WPI's Civil and Environmental Engineering Capstone design. The project scope included looking at economic feasibility, sustainability, the environment, and social implications. The economic portion of it came from analyzing all of the costs included in both alternative scenarios and assessing the feasibility of implementing these alternatives when compared to the current cost of operation. The sustainability and environment parts of the project were joined in one aspect of the project. This part was looking at the use of co-generation in conjunction with absorption chillers to use waste heat to provide the driving energy in the absorption process. This would be both environmentally conscious, and a good start to provide a sustainable base for the ACP's operations. Finally social implications were taken into account by looking at the impact of construction that would result from the project, and what the affects would be in the local area due to the construction. Based on these different criteria we provided results and recommendations that we found to be most appropriate for the given problem.

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Chapter 1: Introduction

The Panama Canal Authority (ACP) uses chilled water to provide air conditioning to several of its own facilities as well as other clients in the Balboa area of Panama. The water is cooled and then pumped through pipes that pass through the buildings, thus cooling the air in the buildings. The facility they use to provide this service is located in building number 9, which is a chilled water distribution plant in Balboa. This plant uses electric centrifugal chillers to create the chilled water. The plant is almost 60 years old, and is running with several inefficiencies due to outdated equipment. The harbor located next to the plant is doing well, financially, and is interested in buying the land that the current facility is located on. This is further motivating the ACP to look for alternatives for chilled water distribution in the Balboa area. The purpose of this project was to evaluate two potential scenarios or proposed solutions for replacing the existing chill water operations.

The first scenario assesses the reconstruction of the chilled water facility with new, updated, equipment with new technology. The new facility would be located in the Balboa area, and provide the same services as the previous facility. The newer facility would run more efficiently, thus saving energy usage and cost for the ACP. The task was to analyze this option in comparison with the current facilities operations.

The second alternative is to build a pipeline to distribute the chilled water from the Miraflores thermoelectric power plant to the current infrastructure in Balboa. This option would assess the process of cogeneration from waste heat given off by the power plant in combination with absorption chillers to provide chilled water to provide for the necessary demand. A pipeline analysis would also be assessed. In conjunction with the pipeline, the aide of a thermal storage tank will also be analyzed. Once each alternative has been compared against the status quo of the current facility, a proposal of beneficial future action will be presented to the ACP.

Chapter 2: Background

2.1 Panama Canal Authority (ACP)

On September 7, 1977, President Carter signed the Torrijos-Carter Treaty (Panama Canal Authority, 2012c). This treaty between the United States and the Republic of Panama, agreed to give complete control of the Canal to the Panamanian government on December 31, 1999. Panama and the United States also agreed upon the Treaty stating the Permanent Neutrality and Operation of the Panama Canal, which guarantees neutrality and safe passage to ships from all nations.

In 1997, the Panama Canal Authority (ACP) was created to take charge when the canal officially became in their control on December 31, 1999. The Authority was created to manage the operation, administration, maintenance and improvement of the Panama Canal and its watershed. The Authority is run by an administrator and deputy administrator at the head and backed by an eleven person board of directors. The ACP not only controls and operates the canal but also operates many other complexes that provide some essential services for panama. The ACP has 5 different departments, with 9,000 employees (Panama Canal Authority 2012d), that handle all of their responsibilities; Operations, Environment, water, and energy, Engineering and administer of programs, Administration and Finances, and lastly human resources. (Panama Canal Authority 2012e)

The two departments that provide direct services for the canal and the people of panama are operations, and environment, water, and energy. Operations are tasked with three major responsibilities: Monitor and support vessel traffic through the canal, and its ports in the Canal's operating waters, administer the rules and regulations related to shipping and transit through the canal, and its operating waters, and finally, manage tonnage rules as given by the regulations of the ACP. (Panama Canal Authority 2012f) Environment, water, and energy is responsible for; “meeting standards of environmental protection and conservation, supply chilled water for air conditioning, generate electricity, produce drinking water and treat wastewater”. (Panama Canal Authority 2012g) This department maintains and operates all of the ACP´s electrical generation through hydroelectric and thermoelectric plants. They also run all of the potable water facilities as well as several chilled water facilities. The drinking water for Colon and Panama City is entirely supplied by the ACP, and these two cities make up the majority of the population of Panama, which is why the work the ACP does is so valuable.

Another recent addition to the ACP’s already intense load of responsibilities was the planning, in 2000 by ACP, of a $5.9 billion expansion project to accommodate larger ships, and on October 22, 2006, 76.8% of the citizens of Panama voted to pass and approve a $5.25 billion expansion project (Timeline of the Panama Canal, n.d.; Bravo, n.d.). This expansion project is currently underway.

2.2 The Canal

The Panama Canal stretches from the Atlantic Ocean to the Pacific Ocean through the Isthmus of Panama and traverses through Lake Gatun. The canal uses three sets of locks to raise and lower ships 85 feet above sea level to reach the level of Lake Gatun and travel the 8 to 10 hours it takes to cross the 50 miles that separate the two oceans (Panama Canal Authority, 2012a). The three locks listed from the Atlantic to Pacific are; Gatun, Pedro Miguel, and Mira Flores locks. Each lock chamber is 110 feet wide by 1,000 feet long. The locks are filled with water from Lake Gatun and take about 8 minutes to fill.[1] The passage of each ship requires 52 million gallons of fresh water.

All of the fresh water comes from the Canal's large watershed that can be seen below in Figure 1. The Canal watershed is made up of three regions. The southern end of the figure shows the Mira Flores Lake sub-basin, which is the smallest portion of the watershed. The Alajuela Lake sub-basin is on the eastern side of the canal. The final and largest portion of the watershed is that of Lake Gatun, which takes up the central and western parts of the watershed. These three sub-basins that make up the canal watershed are all impacted by the activity and water usage of the canal (Panama Canal Authority, 2012b). As stated above, each ship passage uses 52 million gallons per trip and there are approximately 30-40 passages per day. There is a large concern about the amount of fresh water being used to fill the locks, because all of the water comes from Lake Gatun and the precipitation that flows through the watershed, which is shown in Figure 1. This freshwater is also used as a drinking water source for all the inhabitants of the Colon and Panama City areas, creating concerns about the longevity of their fresh water supply.

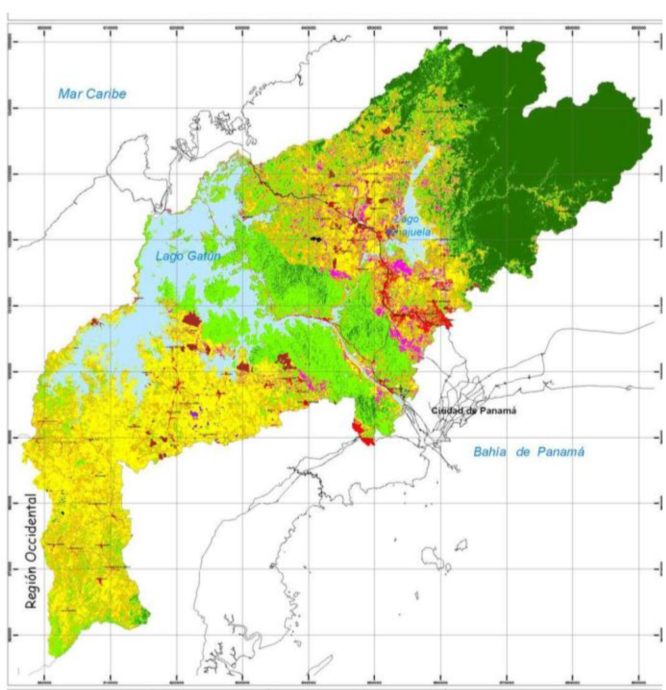

Figure 1: Panama Canal Watershed (Smithsonian Tropical Research Institute)

The Panama Canal currently has the capacity to hold ships known as "Panamax." "Panamax" is a term to describe the vessel limitations of the Panama Canal since it opened in 1914. The maximum dimensions for a Panamax ship are 950 feet (289.56 meters) in length, 106 feet (32.31 meters) in width, and 190 feet (57.91 meters) from the waterline to the highest point on the vessel (Panama Canal Authority, 2005). There are some exceptions to these rules. Ships larger than these dimensions, known as Post-Panamax ships, won't fit in the lock chambers and/or they will not fit under the Bridge of the Americas. These ships must travel around South America because they cannot traverse the canal.

As the number of ships that are classified as Post-Panamax continues to increase, an expansion of the canal was considered. The general idea of an expansion was to help manage the traffic within the canal and to allow for larger sized ships. The purpose of the expansion was proposed to the Executive Branch in April of 2006 with 4 goals in mind. According to the Panama Canal Authority, these goals were:

1) Achieve long-term sustainability and growth for the Canal's contributions to Panamanian society through the payments it makes to the National Treasury
2) Maintain the Canal's competitiveness as well as the value added by Panama's maritime route to the national economy
3) Increase the Canal's capacity to capture the growing tonnage demand with the appropriate levels of service for each market segment
4) Make the Canal more productive, safe and efficient (2006)

The Canal plays a major role in the economy of Panama so the ability to increase the profits made by the canal is a desirable goal. Figure 2 shows the components of the expansion project including location and type of work that is being completed.

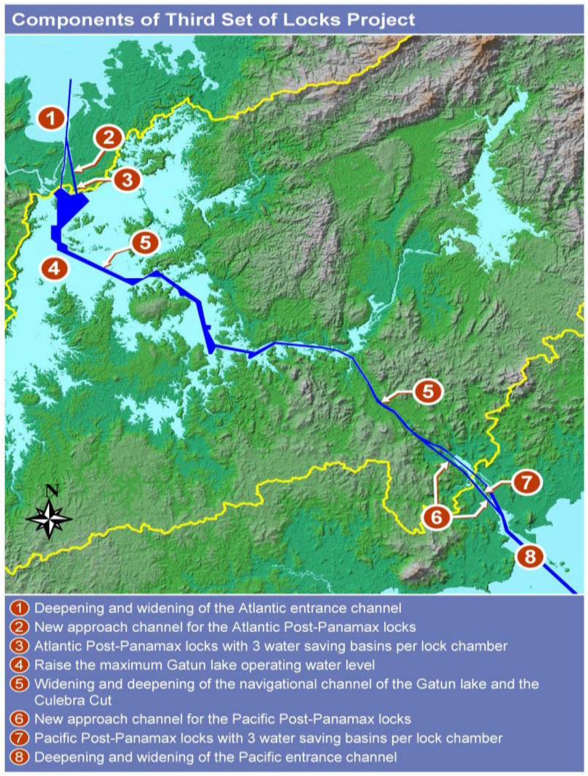

Figure 2: Panama Canal Expansion (Panama Canal Authority, 2006)

2.3 Expansion Efforts by the ACP

In the continuing spirit of preserving energy and increasing efficiency, the ACP has been implementing innovative efforts, beyond a canal expansion, throughout multiple areas of its organization to maintain production while reducing cost. This project group was asked to research and analyze the feasibility and efficiency of the (1) Cogeneration pipeline alternative and the (2) New facility alternative in comparison with the status quo of the current Balboa facility. Option one analyzes implementing a chilled water distribution system pipeline, using cogeneration to produce chilled water, which will supply the Balboa area facilities, versus the cost and efficiency of the current Balboa chilled water facility. Option two analyzes a new chilled water distribution plant in Balboa, with new chillers.

For option one, there would be absorption chillers purchased that would use cogeneration to create chilled water. This would be located at the Miraflores thermoelectric plant which is approximately 5 km away from Balboa. A pipeline would then run from the Miraflores plant to Balboa, and then connect into the existing infrastructure. In addition to this there would be a thermal storage tank, located near the Balboa facilities, which will provide storage to pull from when necessary for high chilled water demand. The tank will be filled during periods of low demand, especially at night, when the facilities are not in use. The costs of installing this pipeline, pumping energy required sending the water over the larger distance, the storage tank, and the absorption chillers will be compared with the current facilities costs and efficiency. A major factor to note is that the proposed pipeline would traverse a path abundant in potential clientele along the way, including Albrook Mall, numerous businesses, as well as additional ACP facilities.

The second option is the same pipeline analysis versus the costs and efficiencies of a new chilled water plant, which will have the same capacities and infrastructure as the old one, but with more up to date equipment. The factors that will go into analyzing the new plant will be; costs of new electric chillers, cost of land area for new facility, pumps, cooling towers, and installation costs. We will take into account the improved efficiencies achieved by having new equipment that will overall reduce costs once the plant is up and running. We will also analyze an electric vapor compression chilling system that will generate profit from sales to the company City of Knowledge.

2.4 Balboa Chilled Water Facility

The ACP uses an electric vapor compression chilling water distribution plant to cool their facilities in the Balboa area. In preparation for the possibility of a relocation, or elimination, of facilities, the ACP is exploring alternatives to replace the existing plant that is approximately fifty years old or more. Chilled water in Balboa is currently produced by three electric chillers and pumped through extremely outdated machinery. Figure 3, below, is a photo taken by Mario that shows a piece of history as the large machine to the right is made entirely of wood. The water is pumped and propelled by two large fans sitting atop the structure. The clear sustainability problem here comes from the wooden components. In this wet environment, the wood has the potential to rot. Imagine the many components that have had to be replaced in this machine over the past 50+ years. A notable alternative was proposed in previous years that evaluated the desirability of a central system of chilled water in Balboa and later the alternative of producing cold water by co-generation with excess heat emitted from the Mira Flores thermoelectric power plant. As mentioned before, the Balboa facilities are now cooled by conventional high electricity-consuming systems. Such levels of consumption reduce the amount of energy sold in the national electricity market. For this reason, it is important to consider and evaluate alternative technologies that will reduce energy consumption, giving margin to a higher sale of electricity as well as a decrease in operating costs. (Gonzal P., 2012)

Figure 3: Balboa Chilled Water Facility (Mario Reed, Keith Black, WPI '2013)

2.5 Mira Flores Thermoelectric Power Plant

Figure 4 is an image from MAN Power and Diesel who was the supplier of the equipment currently in the Miraflores thermoelectric power plant. The thermoelectric engine shown in the figure will be the heat source for the cogeneration process and with a capacity of 115 megawatts; the Mira Flores thermoelectric power plant constitutes the backbone of the ACP's power generation system. The plant's generation is vital because its power is not dependent on the weather conditions. The plant houses three gas turbines, two steam turbines and a newly installed Nordberg Diesel No. 6 engine. Between December 1926, and February 1927, the installation of the three large gas turbines (2.5 MW and 25 Hz each) made this plant the largest of its kind in the Western Hemisphere. Currently, the plant has been undergoing maintenance to replace any outdated engines or materials that may harm the systems progress in the near future. (Panamá Canal Authority, 2012f) The new engines in the plant are equipped with Turbo Compound

System (TCS). They will each develop 41.47 MW (m) at an efficiency rate of 49.2% (m) at 100% MCR at site ambient conditions. (Diesel and Turbo, 2012)

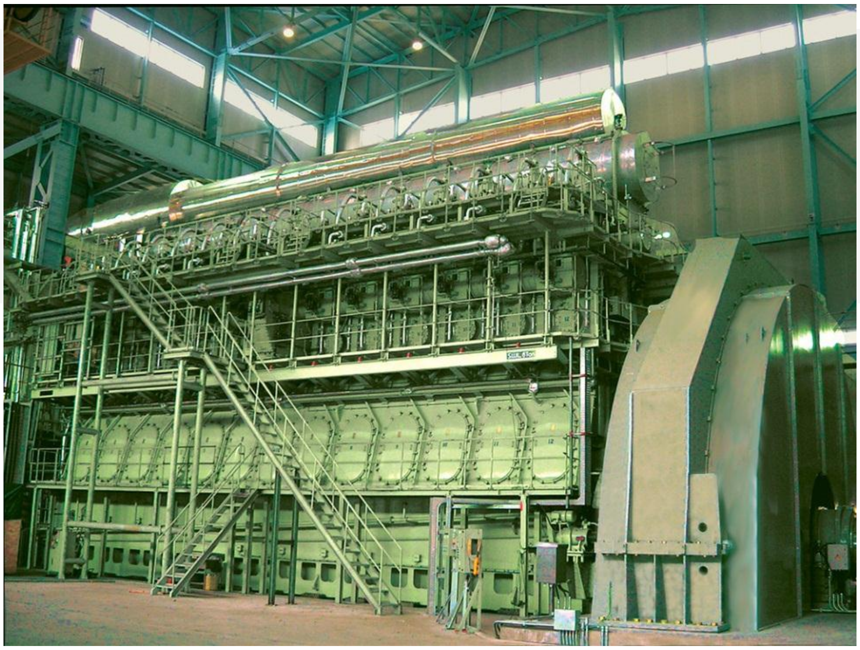

Figure 4: MAN B&W 12K80MC-S engines at Mira Flores Power Plant, (MAN 2012)

Thermoelectric modules are used to convert heat energy to electricity. Electricity is generated through a principle known as the "Seebeck Effect". The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. Although the power generated is not dependent on weather conditions, a consistent temperature differential is still required to provide electricity. Most modules are often combined with a natural gas of propane heat source for remote power generation of waste heat recovery. (Rouse, 2008) The ACP uses high grade bunker fuel to power its massive plant.

2.6 Co-generation

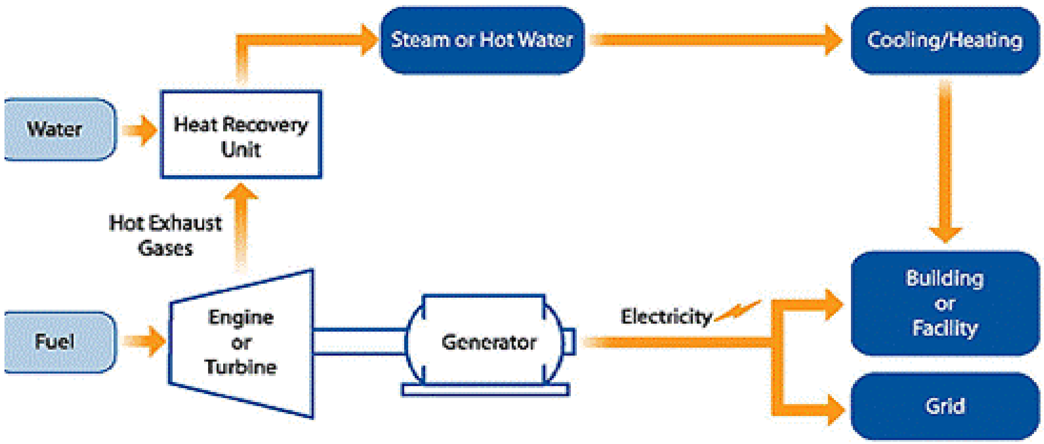

Figure 5: Process of Co-generation (Yale, USEPA)

Figure 5 breaks down the process of co-generation, also known as combined heat and power (CHP). Co-generation is the production of electricity and heat from a single fuel source. Considered highly efficient, co-generation captures heat lost during the production of electricity and converts it into useful thermal energy, usually in the form of steam or hot water. From Figure 5 we see that the steam or hot water is put into a cooling unit and then combined with electricity to supply the building or facility with cool air-conditioning. Typically, co-generation systems are 60-80 percent efficient which is significantly greater than the 45-50 percent efficiency currently being generated at the Mira Flores thermoelectric power plant. These efficiency gains also result in cost savings, reduced air pollution and greenhouse gas emissions, as well as increased power reliability and quality, reduced grid congestion, and avoided distribution losses. (Yale, USEPA) The process of co-generation fuels the process of absorption.

2.7 Absorption Chillers

Figure 6, below, details the most basic absorption process design. The chiller consists of five major parts; condenser, absorber, expansion valve, evaporator, and absorber. These parts work in a series to create chilled water or air. The process requires the use of a refrigerant and an absorbent that work well together. In most cases the refrigerant is water, and the absorbent is lithium bromide. Lithium bromide has a strong affinity for water, and a higher boiling temperature than water, both properties that benefit the process. The generator and condenser work in the same section of the overall system and operate at a higher pressure and temperature, typically 75 mmHg and 113 degrees Fahrenheit. While the evaporator and absorber operates at a lower temperature and pressure, typically 6.5mmHg and 40 degrees Fahrenheit. (CED Engineering) And the expansion valve acts as a barrier between the different operating conditions.

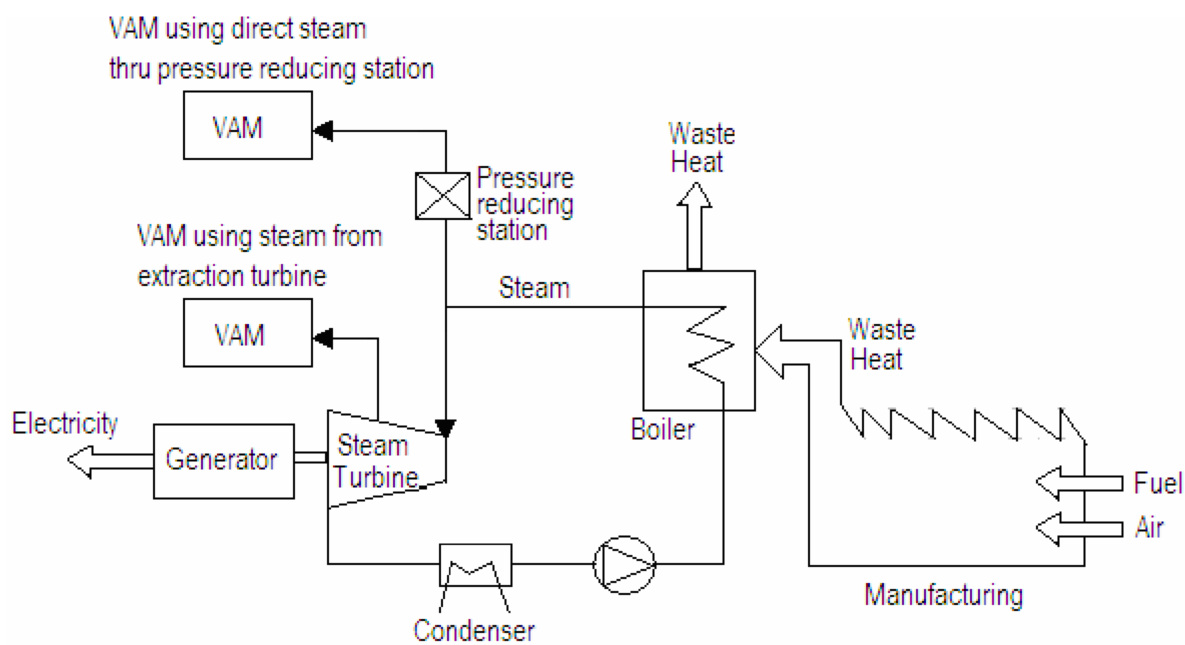

Figure 6: Waste Heat Recovery Process (CED)

Figure 7 is a schematic that shows the combined design for cogeneration process and absorption. The generator's purpose is to deliver refrigerant vapor to the rest of the system. It does this by flowing high temperature steam or hot water through tubes that are surrounded by an absorbent (lithium bromide) and refrigerant (water) solution. This separates the solution by vaporizing the water and leaving the lithium bromide in a more concentrated solution. The concentrated solution returns to the absorber to be used at the end of the system, and the refrigerant vapor travels to the condenser. The condenser is used to condense the, now vapor, refrigerant. (CED Engineering) The condenser is full of tubes flowing with cooling water, where the vapor from the generator condenses onto. The condensed refrigerant collects at the bottom of the condenser, where is then travels to the expansion valve.

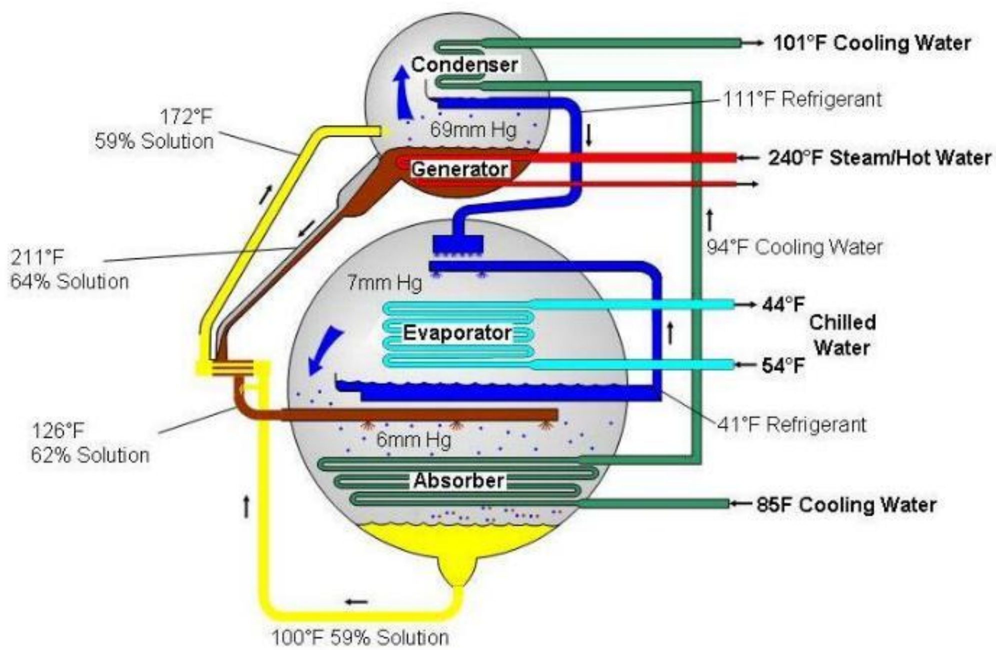

Figure 7: Cogeneration-Absorption Process Diagram (ESC, 2005)

The expansions valve is used to maintain the pressure difference between the high pressure condenser and the low pressure evaporator, by creating a liquid seal. The high pressure condensed refrigerant passed through the expansion valve causing a pressure drop that decreases the refrigerant pressure to that of the evaporator. The pressure drop causes some of the refrigerant to boil off, which cools the remaining liquid to the desired evaporator temperature. (CED Engineering) The mixture of vapor of water then travels to the evaporator.

The evaporator's purpose is to cool the circulating water. It contains a series of tubes that carry the water that is to be chilled. At the lower pressure, which is 6.5 mmHg decreased from the 75 mmHg it was at before, the boiling temperature of water is 40 degrees Fahrenheit. (CED Engineering) The new boiling point helps because the incoming water is warm enough, without having to be heated, to provide the energy needed to vaporize the incoming refrigerant. The refrigerant absorbs heat from the circulating water and evaporates, and therefore lowering the temperature of the circulating water. The newly formed vapor is removed to the absorber immediately, so there is no increase in pressure and therefore maintains the cooling process that just occurred. In the absorber the refrigerant vapor is absorbed by the diluted lithium bromide solution from the generator. As it is absorbed it condenses to a liquid and releases the heat it gained in the evaporator. The absorption process creates a lower pressure within the absorber, the lower pressure and lithium bromides affinity for water creates a constant flow of vapor from the evaporator. The released heat is removed by cooling water, which is circulated in tubes throughout the absorber. The more water the absorbent absorbs the less effective is becomes, so once it has acquired enough water it is pumped to the generator to start the series over again. (CED Engineering) Since absorption uses heated water, or water vapor to start the process it is an ideal candidate for the cogeneration process mentioned in chapter 2.6

2.8 Electric Chillers

A more conventional, yet effective, method of providing chilled water is through an electric vapor compression chilling system. New, up-to-date, electric chillers are currently being constructed in the Mira Flores plant that, upon completion, will allow the ACP to sell portions of their production to the City of Knowledge, Co., in Panama City. When it comes to feasibility, and ultimately profitability, we want to know if the most cost, time, and energy efficient method for supplying chilled water to Balboa is to replace the old Balboa plant with newer, up-to-date, electric chillers, or to implement a co-generation/absorption pipeline from the Mira Flores plant.. While an electric vapor compression chilling system is still highly effective, efficiency and lower operating costs are achieved through the co-generation/absorption cooling method. Absorption cooling substitutes a generator and absorber (thermal compressor) for an electric compressor to recover and supply heat to the generator. “Double-effect absorption cooling adds a second generator and condenser to increase the refrigerant flow, and therefore the cooling effect, for a fraction of the heat input of a single-effect system.” (ESC, 2005) The co-generation alternative warrants investigating the possibility of running a pipeline from the Mira Flores plant to Balboa to supply chilled water for the facilities there; thus replacing the outdated Balboa electric vapor compression facility, altogether. (Gonzal P., 2012)

2.9 Pipeline Analysis

The ACP needs to use a pipe for their potentially new chilled water pipeline. The pipe needs to be designed to transport chilled water with the minimal cost as possible. The pipe that the ACP has selected is Fiberglass reinforced pipe (FRP, or GRP). (Gonzal P., 2012) Fiberglass piping has many water applications; district heating and cooling, steam condensate return, heating water supply and return, chilled water supply and return, condenser and cooling tower piping, NSF listed for potable water, FM approved for underground fire mains, and thermal storage.(Fiber Glass Systems (b)) FRP suites the ACP's needs perfectly because it includes chilled water supply and return which is the initial application but thermal storage is also an important part of this system. The thermal storage application keeps the pipe insulated as much as possible so there is less thermal heat gain as the water travels through the pipe before it reaches the buildings it is designed to cool. And lastly the ACP uses potable water in their chilled water systems, and the FRP is used for applications with all three of these which make it well fitted for the ACP uses.

FRP is also the cheapest option for the ACP with lifecycle costs that are better than Schedule 40 steel and Schedule 80 PVC. As seen in the table below, comparing different size pipes for Schedule 40 steel, Schedule 80 PVC, Green Thread FRP, and Red Thread FRP. Green Thread is generally used for dilute acids, caustics, hot-water, and condensate return, and Red Thread is used for water, saltwater, and light chemical services. (Fiber Glass Systems (b)) Based on these uses Red Thread would be the best option for the chilled water network, as shown in Table 1.

Table 1: Pipe Size and Type vs. Life cycle cost (Fiber Glass Systems)

Cost Description	8" Sch 40 Steel	8" Sch 80 PVC	8" GT	8" RTII	10" Sch 40 Steel	10" Sch 80 PVC	10" GT	10" RTII
Year Zero Cost								
Pump, Motor & Combination Starter	$12,577	$11,777	$8,829	$8,829	$8,813	$8,226	$8,226	$8,226
Pipe Installed Cost	$42,095	$19,755	$40,730	$33,730	$54,135	$30,710	$55,285	$48,285
Year Zero Total	$54,672	$31,532	$49,559	$42,559	$62,948	$38,936	$63,511	$56,511
Year 1 - 20 Annual Electrical Cost	$12,536	$6,412	$4,993	$4,993	$4,073	$3,206	$2,838	$2,838
20 Year Discounted Life Cycle Cost	$674,238	$348,432	$296,328	$289,328	$264,248	$197,386	$203,773	$196,773

The costs do not seem to show a large gap in pricing but the table does not include several factors;

- Elimination of cathodic protraction needed with steel pipe
- Reduced usage of water treatment chemicals
- Lighter load rated pipe support systems
- Fewer pipe supports needed than with PVC Pipe
- Lower maintenance cost (Fiber Glass Systems (b))

Fiberglass piping is also lighter that steel and PVC as well as retaining strength, which reduces the number of supports needed, which can be additional cost savings. (Fiber Glass Systems (b))

Table 2: Pipe Weight per Linear Foot (lbs.) (Fiber Glass Systems (b))

Nominal Diameter	6"	8"	10"	12"
Sch. 40 Steel	18.9	28.5	40.8	53.5
Green Thread	2.4	3.9	5.9	7.7
Red Thread II	2.4	3.3	5.3	7.2
Sch. 80 PVC	5.5	8.3	12.2	16.9

These factors show in Table 1 and 2 can make a large difference when comparing prices, and FRP also has several qualities that make it superior other than pricing. FRP's absolute roughness is 0.00021 inches which is less than one eighth of non-corroded new steel which is 0.0018 inches. (Fiber Glass Systems (a)) The absolute roughness is equal to a manning "n" value of 0.009 and a Hazen-Williams coefficient of 150. (Fiber Glass Systems (b)) The values in Table 2 all reflect lower friction loss in FRP pipe, which is reflected in the dynamic head loss, shown in feet of water per 100 feet of pipe, is less than Schedule 40 steel, and schedule 80 PVC. (Fiber Glass Systems (b)) As shown in Figure 8 these values create better flows, reduced pump pressure, less horsepower, lower energy costs, and the ability to reduce pipe size. (Fiber Glass Systems (b)) For those reasons the ACP has decided that FRP can be implemented in their projects and reduce project costs.

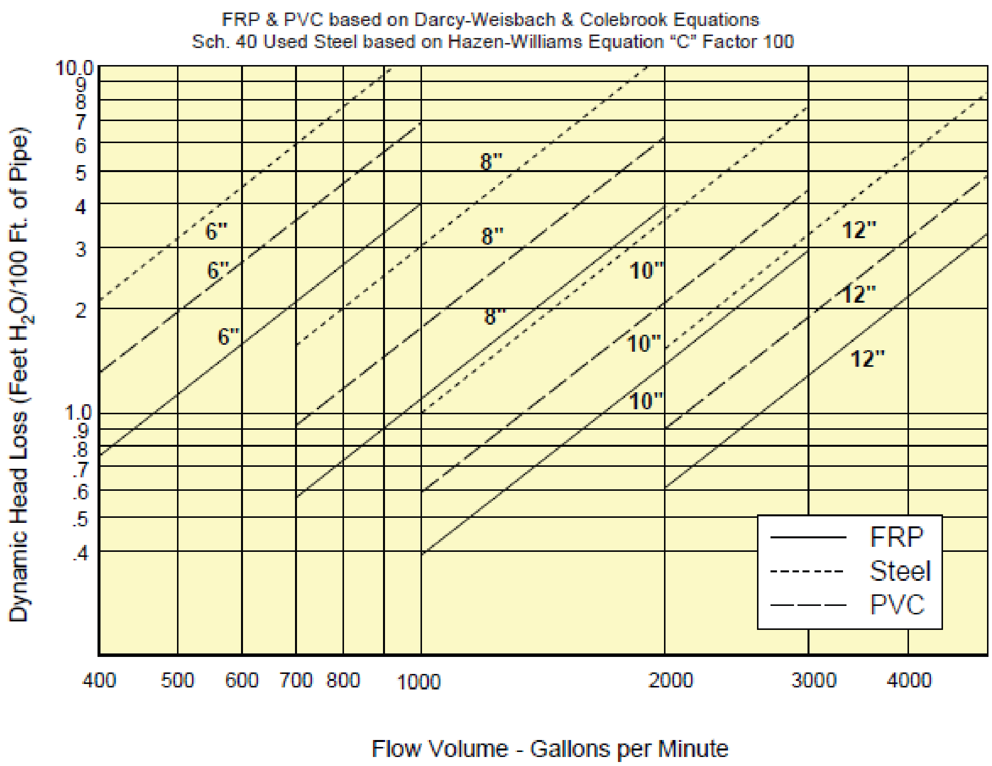

Figure 88: Pressure loss Curves for water (Fiber Glass Systems (b))

2.10 Thermal Storage Tank

The ACP is also considering a thermal storage tank to store chilled water to try and optimize the pipe size, flow rate and pumping power required in their pipeline system. With a thermal storage tank to help supply demand during periods of high demand, and be filled during times of low demand they can increase energy efficiency. Thermal energy storage (TES) works due to stratification, which works due to water‘s density change in relation to change in temperature. (ASHRAE, Orange Empire Chapter; CB&I co.) This density difference keeps cold and hot water separated from each other. That relationship is taken advantage of in TES by having cool water, used in the chilled water distribution, at the bottom and warmer water rising to the top. The load in these systems is proportional to flow and temperature change (ΔT), so an increase in ΔT decreases flow for the same load. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.) Stratification makes this system work and a viable option for chilled water systems.

The TES tanks have to be designed very specifically, so there is no disruption in stratification layers. Any turbulence can reduce stratification, thus ruining temperature layers and making the tank less efficient. For those reasons TES tanks try to minimize disruptions from recharging, and discharging by using diffusers. Two diffusers are used one place near the top of the tank and one placed at the bottom of the tank. The diffuser is used to tank water in and out of the tank without disturbing stratification, so any water intake or discharge is done at a very slow rate. The lower diffuser sends cool water in so it retains stratification, and the upper diffuser removes warm water to be returned and chilled. Figure 9 shows the typical setup for a TES tank.

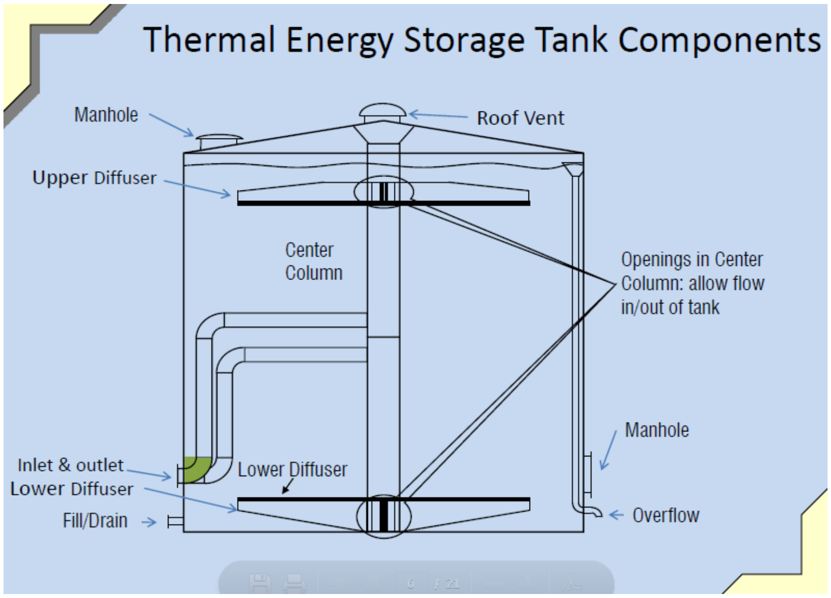

Figure 9: TES Tank Components (ASHRAE, Orange Empire Chapter; CB&I co.)

With this tank in place the over chilled water network has to operate different than a normal network in order to make the most use of the tank. Figure 10 shows, the different cycles for recharging, discharging and system shutdown.

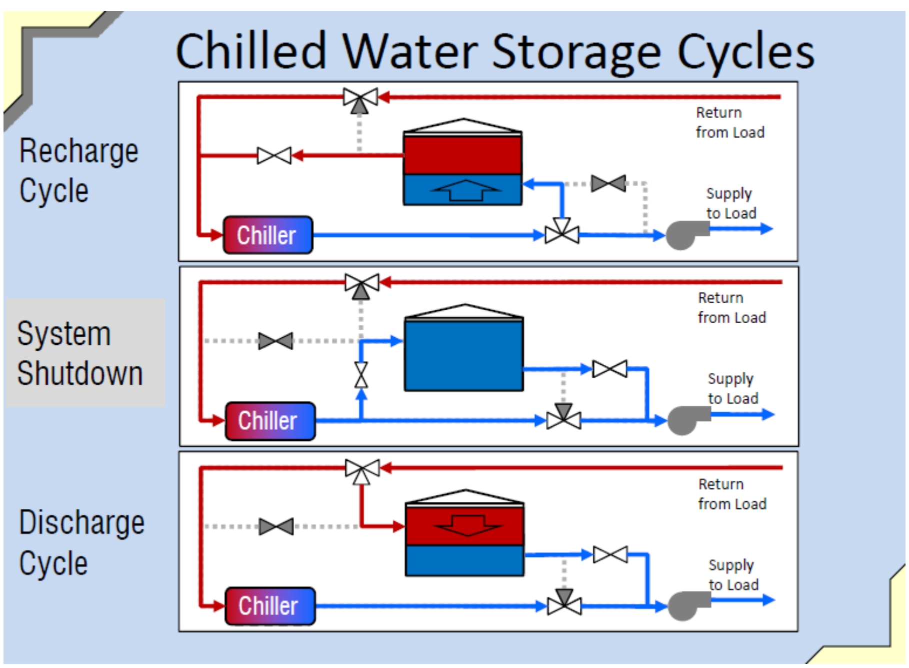

Figure 10: Chilled Water Distribution Network Storage Cycles (ASHRAE, Orange Empire Chapter; CB&I co.)

There are many benefits to having a TES tank in a chilled water system when properly applied. The best types of systems that can benefit are cyclical loads, where the peak is higher than the average. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.) The ACP fits that criterion since the facilities have high demand during the day, especially the afternoons, and very low demand at night since the majority of facilities are not in use. Since the facilities are not used at night it creates a very large difference between the average and the peak demand. The major benefits include;

- Improved plant efficiencies
- Increased operating flexibilities
- Lower energy use and costs
- Smaller needed equipment and electric service sizes
- Lower maintenance costs
- Back-up capacity
- Fire protection ability
- Less strain on utility production and distribution grid systems
- Lower capital cost when properly planned, designed, and constructed (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.)

The TES tank helps to reduce usage directly from the system by facilitating peak demand, and since the ACP has such a low nighttime demand in this grid they can use that time to fill the storage tank. And with proper operation there can be even more benefits. As mentioned above there is a proportional relationship between load and ΔT and flow. Twice the ΔT results in half the flow, which translates to one eighth the pumping power (in HP), required. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.) Therefor larger ΔT gives you; reductions in capital costs, smaller distribution piping, lower required pumping power, and smaller TES tank that results in the same capacity. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.)

The storage tanks can create extreme benefits but that is only when the system is run properly and is properly installed. Inefficient design and operation can reduce any economic benefits from the TES tank. As mentioned above ΔT has a big effect on system efficiency, so a low ΔT decreases the overall quality of the system. Improper tank flow designs reduce efficiency by not getting the full benefit of the storage available. Poor diffuser design creates turbulence in the system and inhibits proper stratification. And a varying chilled water supply temperature also has a large impact on stratification, which could ruin the balance of the system. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.) Taking these problems into account when construction and operating a TES tank is necessary to make sure the system is operating with the highest efficiency.

For the ACP, since they have a cyclic system and the ultimate goal for them is to optimize their chilled water distribution network the TES tank makes sense for their use. Monitoring of key data is important in order to assure proper operation; chilled water flows, temperature, TES tank storage capacity, thermocline thickness, diffuser pressure drop, and heat gain. (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.) The first operational consideration is to measure the flows and temperatures throughout their system, and to calculate that tank storage capacity to determine what the operation conditions should be to get the desired ΔT and flow. Thermocline thickness is the region of thermal diffusion between the chilled water and warm water, which is important to monitor to get an idea of where the temperatures are constant and where they are transferring heat.(ASHRAE, Orange Empire Chapter; CB&I co.)) Determining diffuser pressure drop shows what the pressure in the TES tank system is doing, under the different system conditions. Lastly it is necessary to measure the heat gain throughout the system to see what ΔT in the system is. The overall gain for using a thermal storage tank in a chilled water (CHW) distribution network is:

- Reduced Chiller Energy
- Lower Pump HP
- Smaller CHW pipes
- Un-insulated CHW return pipe potential
- Better Balancing & Control
- High Reliability
- Low Maintenance Cost
- Improved operating flexibility (ASHRAE, Orange Empire Chapter; Goss Eng., Inc.)

The ACP decided on a supplier for their TES tank, should that option seem to be the more cost effective. The supplier is CST industries aqua store tank. (Gonzal P., 2012) The tanks are designed to hold potable water, which is what the ACP uses in their chilled water network. Aqua store tanks use glass-fused-to-steel in their tanks. The glass-fused-to-steel is impermeable to liquids and gases and reduces undercutting caused by corrosion. A diagram of the tanks lining technology is shown in Figure 11, which dissects the different layers used to create the most efficient storage. (CST Industries)

Figure 11: Vitrium Technology For Aqua Store Tanks liner (CST Industries)

Aqua store tanks have a low maintenance cost, with greater lifespan than concrete or welded tanks. It is also cost effective by never having to be painted, and will not corrode or rust due to the vitrium glass-fused-to-steel technology. Another huge part of the cost reduction is the construction, which is done from the top down by using a jacking system that progressively elevates the structure during construction. (CST Industries) This takes out the need for high capacity equipment, like cranes, thus creating savings. This storage tank system will be the most cost effective tank for the ACP's needs.

Chapter 3: Methodology

The essential goal of this project is to analyze alternative methods of distributing chilled water to the Balboa area facilities. Alternative one distributes chilled water generated through the processes of co-generation and absorption using a new chilled water pipeline. The pipeline will be constructed along with a thermal storage tank and wok in conjunction with Balboa's current electric chilling systems. Alternative two analyzes the economic feasibility of distributing chilled water through an electric chilling facility that will be constructed and replace all current Balboa equipment.

To accomplish our goals, we completed the following tasks. First, we conducted site assessments to gather information on current conditions at the Balboa facilities, where machinery is outdated and energy efficiency is roughly 45-50% while a minimum desired value is 65-70% or better. (Gonzal P., 2012) Our next visit was conducted at the Miraflores thermoelectric power plant, where the co-generation/absorption processes will take place. Then, we analyzed pipeline efficiency and costs by creating models using Microsoft Excel. Factoring in storage tank costs for both scenarios (1) and (2), we then analyzed replacement and relocation costs of the Balboa facility. Lastly, we compared the results of future projections, for options (1) and (2), assessing the advantages and disadvantages of each, and proposed a suggested plan. This chapter provides the methods used to meet the project goals.

3.1 Site Assessment

We conducted a site assessment in the Balboa chilled water facility to gather background information about energy and efficiency issues related to the outdated equipment. We then visited the Miraflores thermoelectric power plant where we visually inspected the facility in which the cogeneration and absorption will occur. These site assessments included visual inspections and interviews with ACP contractors responsible for the areas studied.

3.1.1 Visual Inspections

Of the two site visits we conducted, Balboa's chilled water facility was the first. This site currently supplies chilled water to the ACP and other businesses in the Balboa region. On Wednesday, October 24, 2012, we inspected the outdated pumping equipment, as well as the conventional electric chillers. The oldest of the equipment was a cooling tower made entirely of wood. We were assured that what we were inspecting was a piece of history, as this 100-year old wooden tower is the last of its kind and will never be constructed again. Cooling towers of today's age are made of metal and do not possess the potential to rot in high water pressured environments like the wood does. (Gonzal P., 2012) After our visit to the Balboa chilled water facility, we ventured our way over to the Miraflores thermoelectric power plant. The plant was still under construction during our time, and access was limited, however, we were successful in gaining the necessary information in an interview of our supervisor. At each site, observations were made and photographs were taken.

3.1.2 Interviews with ACP Personnel

We were introduced to Eric Admade, the chill water plant supervisor of the Balboa chilled water facility, who gave us information on the plant's history as well as its future. The superintendent oversees all operations pertaining to the Balboa chilled water facility. In reference to the facility's future, we inquired as to the design of a current potable water pipeline that traverses from Miraflores to Balboa. Much of our construction and installation feasibility analysis will come from information already documented on the ACP portal about the potable water line. (Gonzal P., 2012) In order to obtain research on the Miraflores power plant, we conducted our own internet research and gathered information from a local contractor present during the initial construction of the plant. (Burmeister and Wein)

3.2 Determining Expenses and Income of Balboa Facility

In order to conduct a comparison analysis for the alternatives, we first needed to establish a baseline on how the current operations are working and what the expenses and incomes are in a given year. We needed to know what factors comprise the "expenses" total and what factors comprise the "income" total. The factors determined to be most necessary for our research were the human resource cost, energy consumption, and cost per kWh of electricity of the current electric chilling system purchased and sold by the ACP. (Admade, 2012) We retrieved the specific values for each of these factors in the interview conducted with Mr. Admade. Using the values presented, we used Microsoft Excel to calculate the annual expenses. By multiplying the cost of electricity per ton-hour by the number of ton hours of the system, we retrieved our annual amount spent on electricity. The additional contributing factor added to the annual expenses of the current facility was the cost of human resource. (Admade, 2012) The next task was to determine the annual income generated by the ACP.

The rates for the installed tonnage are shown in Table 3. The income for the plant is determined by the refrigeration ton-hrs sold and also by a tax on the installed tonnage per month. The installed tonnage is the amount that each building they service requires per month.

Table 3: Chilled water pricing and tax

Row	Description	Tariff
2040.0020	Demand charge, per ton installed, per month	B/. 29.59
2040.0030	Measured consumption charge, per ton-hours	B/. 0.1225

The first row of Table 3 is the demand charge per ton installed per month, and it is listed as 29.59 Balboa's, the Panamanian currency, which is equivalent to US dollars. The second line is the measured consumption charge per ton-hours, and is .1225 dollars per ton-hour. To calculate the income for the current facility we used information for a 6 month period that listed the ton-hour demand per day. We took the 6 month time periods total ton-hours and multiplied it by 2 to get a number for the entire year's consumption. Then that number was multiplied by $ .1225 to get the total income from ton-hours sold. The installed tonnage could not be calculated exactly with the information we had. The plant has a 2700 ton capacity and we assumed that all of it was being used to give a consistent figure to use throughout the analysis. This provided a number to work with, and multiplied that by $ 29.59 to get the monthly income from the installed tonnage, and then expanded that to cover the year's income.

3.3 Creating a Model

In order to process all of the information that was gathered, a model was created in Microsoft Excel. This model utilized the expense and income data and supplied us with a return over the next 20 years, allowing us to compare the cost efficiency of this current system versus the alternatives that we analyzed.

The comparisons were done using an economic analysis spreadsheet from the ACP, which requires the initial investments, costs, and income from the different scenarios. It compares two situations at a time, and gives an Internal rate of return (IRR) and an actual net value (ANV) for the project. (Appendix C) Figure 12 is an example of the spreadsheet:

	Alternativa A							Status Quo							Alt. A vs. Status Quo		Gráfica	
AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
2013	(2,000)			-	(2,000)	1.0000	(2,000.00)		-				1.0000	-	(2,000.00)	(2,000.00)	-	(2,000.00)
2014		(981)		-	(981)	0.8772	(860.88)		(1,402)	-	-	(1,402)	0.8772	(1,229.82)	420.60	368.95	420.60	-
2015		(981)		-	(981)	0.7695	(755.16)		(1,402)	-	-	(1,402)	0.7695	(1,078.79)	420.60	323.64	420.60	-
2016		(981)		-	(981)	0.6750	(662.42)		(1,402)	-	-	(1,402)	0.6750	(946.31)	420.60	283.89	420.60	-
2017		(981)		-	(981)	0.5921	(581.07)		(1,402)	-	-	(1,402)	0.5921	(830.10)	420.60	249.03	420.60	-
2018		(981)		-	(981)	0.5194	(509.71)		(1,402)	-	-	(1,402)	0.5194	(728.15)	420.60	218.45	420.60	-
2019		(981)		-	(981)	0.4556	(447.11)		(1,402)	-	-	(1,402)	0.4556	(638.73)	420.60	191.62	420.60	-
2020		(981)		-	(981)	0.3996	(392.20)		(1,402)	-	-	(1,402)	0.3996	(560.29)	420.60	168.09	420.60	-
2021		(981)		-	(981)	0.3506	(344.04)		(1,402)	-	-	(1,402)	0.3506	(491.48)	420.60	147.45	420.60	-
2022		(981)		-	(981)	0.3075	(301.79)		(1,402)	-	-	(1,402)	0.3075	(431.13)	420.60	129.34	420.60	-
2023		(981)		-	(981)	0.2697	(264.73)		(1,402)	-	-	(1,402)	0.2697	(378.18)	420.60	113.45	420.60	-
2024		(981)		-	(981)	0.2366	(232.22)		(1,402)	-	-	(1,402)	0.2366	(331.74)	420.60	99.52	420.60	-
2025		(981)		-	(981)	0.2076	(203.70)		(1,402)	-	-	(1,402)	0.2076	(291.00)	420.60	87.30	420.60	-
2026		(981)		-	(981)	0.1821	(178.68)		(1,402)	-	-	(1,402)	0.1821	(255.26)	420.60	76.58	420.60	-
2027		(981)		-	(981)	0.1597	(156.74)		(1,402)	-	-	(1,402)	0.1597	(223.91)	420.60	67.17	420.60	-
2028		(981)		-	(981)	0.1401	(137.49)		(1,402)	-	-	(1,402)	0.1401	(196.42)	420.60	58.92	420.60	-
2029		(981)		-	(981)	0.1229	(120.61)		(1,402)	-	-	(1,402)	0.1229	(172.29)	420.60	51.69	420.60	-
2030		(981)		-	(981)	0.1078	(105.79)		(1,402)	-	-	(1,402)	0.1078	(151.14)	420.60	45.34	420.60	-
2031		(981)		-	(981)	0.0946	(92.80)		(1,402)	-	-	(1,402)	0.0946	(132.57)	420.60	39.77	420.60	-
2032		(981)		-	(981)	0.0829	(81.41)		(1,402)	-	-	(1,402)	0.0829	(116.29)	420.60	34.89	420.60	-
2033		(981)		-	(981)	0.0728	(71.41)		(1,402)	-	-	(1,402)	0.0728	(102.01)	420.60	30.60	420.60	-
Totales	(2,000)	(19,628)	-	-	(21,628)		(8,500)	-	(28,040)	-	-	(28,040)		(9,286)	6,412	786	8,412	(2,000)
															21%	786		
															TIR	VAN		

Figure 12: Economic Analysis (Appendix C)

The model looks at a 20 year span, to determine the current value of the project. An IRR of 14% is needed for the project to be deemed profitable. All values are recorded in the thousands, so any value entered needs to be divided by 1000 before being used in the model. Values in columns with a (-) in the title need to be entered as negative numbers and columns with (+) need to be positive for the model to work appropriately. Then the left most part of the spread sheet is shown in Figure 13, which is the alternative option:

AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente
2013	(2,000)			-	(2,000)	1.0000	(2,000.00)
2014		(981)		-	(981)	0.8772	(860.88)
2015		(981)		-	(981)	0.7695	(755.16)
2016		(981)		-	(981)	0.6750	(662.42)
2017		(981)		-	(981)	0.5921	(581.07)
2018		(981)		-	(981)	0.5194	(509.71)
2019		(981)		-	(981)	0.4556	(447.11)
2020		(981)		-	(981)	0.3996	(392.20)
2021		(981)		-	(981)	0.3506	(344.04)
2022		(981)		-	(981)	0.3075	(301.79)
2023		(981)		-	(981)	0.2697	(264.73)
2024		(981)		-	(981)	0.2366	(232.22)
2025		(981)		-	(981)	0.2076	(203.70)
2026		(981)		-	(981)	0.1821	(178.68)
2027		(981)		-	(981)	0.1597	(156.74)
2028		(981)		-	(981)	0.1401	(137.49)
2029		(981)		-	(981)	0.1229	(120.61)
2030		(981)		-	(981)	0.1078	(105.79)
2031		(981)		-	(981)	0.0946	(92.80)
2032		(981)		-	(981)	0.0829	(81.41)
2033		(981)		-	(981)	0.0728	(71.41)
Totales	(2,000)	(19,628)	-	-	(21,628)		(8,500)

Figure 13: Example Alternative Economic Analysis (Appendix C)

In Figure 13, above, the column headings from left to right are; year, initial investment, expenses (annual), incomes (annual), losses (annual), total cash flow, present value factor (Appendix C), and present value. The total cash flow is the sum of the incomes, expenses, and losses, which is then multiplied by the present value decimal to provide the present value. In the case of an alternative scenario an initial investment is required, but in the Status quo the initial investment is not included because it is an ongoing operation. The first two sections of the model are exactly alike in term of information provided. The next important section is shown below:

Alt. A vs. Status Quo	
Flujo marginal	Valor Presente Marginal
(2,000.00)	(2,000.00)
420.60	368.95
420.60	323.64
420.60	283.89
420.60	249.03
420.60	218.45
420.60	191.62
420.60	168.09
420.60	147.45
420.60	129.34
420.60	113.45
420.60	99.52
420.60	87.30
420.60	76.58
420.60	67.17
420.60	58.92
420.60	51.69
420.60	45.34
420.60	39.77
420.60	34.89
420.60	30.60
6,412	786
21%	786
TIR	VAN

Figure 14: Example IRR and ANV (Appendix C)

The two columns here in Figure 14 are difference in cash flow, and difference in present value, which are taken from the previous sections. The cells located at the bottom of the columns are the IRR and ANV.

3.4 Co-Generation Pipeline and Storage Tank

3.4.1 Pipe Analysis

The ACP already decided to use fiberglass reinforced pipe (FRP), so the first objective was to obtain all the information about the FRP necessary to do calculations to obtain the optimal pipe size. The information needed to complete the pipe diameter design was the Manning's coefficient of .009, the Hazen Williams coefficient of 150, and an absolute roughness of .00021 inches of the FRP. (Fiber Glass Systems (a)) The ultimate goal for the pipe analysis is to calculate all factors that would affect the total cost of the pipe line. This would include materials, installation, insulation, and pumping power. The necessary information for costs was provided in a quote from the ACP, all that was needed was the length of the pipeline. The pumping costs required the following; pipe diameter, length, flow, area, velocity, Reynolds number, friction factor, friction loss, and pump energy in kilowatts (kW) and horse power (HP).

The pipeline for the chilled water distribution from Miraflores thermoelectric plant to Balboa would use a reasonable route following a potable water pipeline that currently runs from the Miraflores water treatment plant to Balboa. (Gonzal P., 2012) The potable water pipeline is mapped out on the ACP's geographic information system (GIS). Once the pipeline leaves the thermoelectric plant, it would follow the 30" potable water line, until it splits and ends up at a pump station where it would tie into the existing infrastructure. The length of the line was determined by tracing the 30" potable water line on one of the ACP's GIS maps. (Panamá Canal Authority (2012h)) The existing infrastructure has .4 meter (16 inch) diameter pipes but the ACP wants to minimize pipe costs so the other options are a .3 meter (12 inch) or a .35 meter (14 inch) line. These diameter values are used to determine different values in the calculations.

The flows used for the calculations are based off of the current plant's operating flow. Since this current operation is less efficient in both operating delta T and equipment the flow could be reduced at with the use of new chillers, and a higher delta T. For the purpose of the calculations flows from 1000 gpm to 4500 gpm, for every 500 gpm, were used to get an idea of different variables involved with varying flows.

The mass flow rate was determined by using the conversion factor of 15.8 gpm to 1 kilogram per second (kg/s). This mass flow rate was used to determine the kilowatts of refrigeration (kWr), with Equation 1:

Equation 1: Energy Storage in Water (engineering toolbox(c))

$$\Delta H = m \bullet C_p \bullet \Delta T$$

Delta H is in units of kilowatts of refrigeration (kWr), ṁ is mass flow rate in kilograms per second (kg/s); Cp is specific heat capacity in units of kilojoules per kilogram degree Celsius (kJ/kg°C). This delta H value is in kJ which is equivalent to kWr, which is the amount of heat energy provided. Once we found the kWr we converted that value into tons of refrigeration by using a conversion factor of 1 kWr for 3.517 tons of refrigeration. The current Balboa facility has an average of 25,000 ton hours (ton-h) per day supplied on the weekdays, and about 20,000 on weekends. (Appendix B)

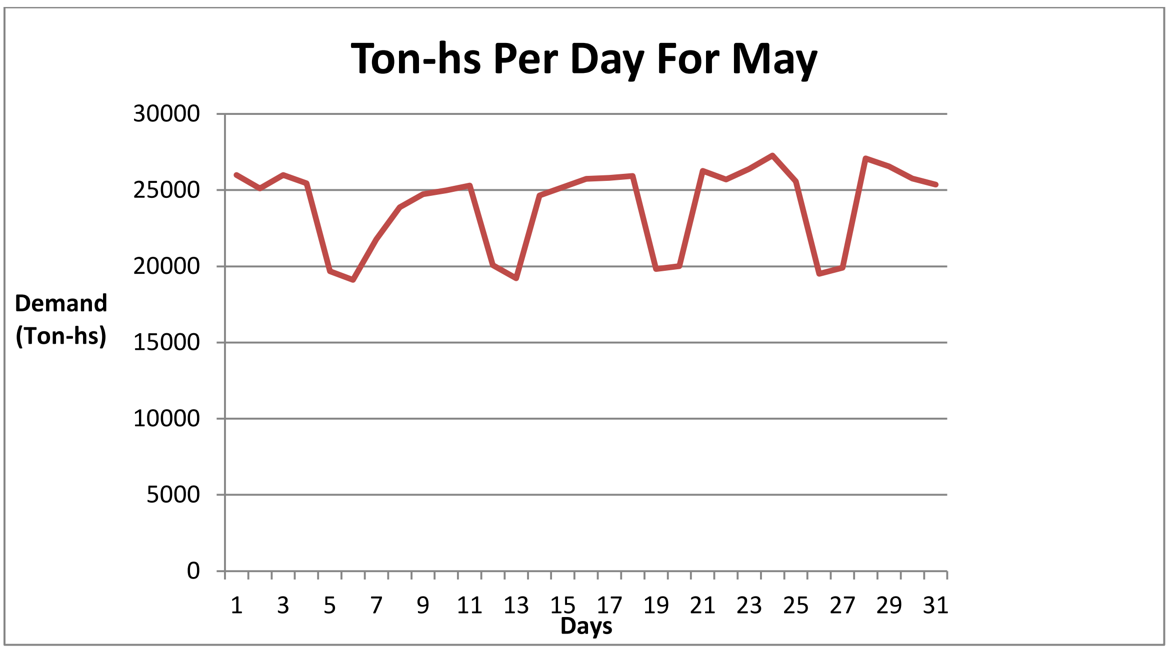

Figure 15: May ton-h demand per day (Appendix B)

In Figure 15 the ton-h per day for a one month span (May) is shown, with ton-h on the Y-axis and the days on the X-axis. The low points are the weekends and the higher values are the weekday demand. Figure 15 shows the weekday values consistently going above 25,000, which is because May is one of the hottest months of the year in Panama, causing more demand. This is a good baseline to work with because the designed system needs to be capable to handle the peak demand of the year. The highest values for ton-h in a day are approximately 27,000 ton-h. This means the system needs to provide 27,000 divided by 24 hours in a day, ton-h/hr. This value is 1125 ton-h per hour, which means that the system needs to be able to provide 1125 tons of refrigeration an hour for an entire day.

Since the potential diameters were already known, the area of the pipes was calculated using Equation 2:

Equation 2: Area of a circle

$$A = \pi \bullet r^2$$

Where A is the area, π is 3.14159 and r is the radius, which is half of the diameters given.

The area in m^2 and the flow in m^3 were used to calculate velocity with Equation 3:

Equation 3: Flow rate, rearranged for Velocity

$$v = Q / A$$

Where v is velocity, Q is flow rate, and A is area.

Reynolds number was calculated using Equation 4:

Equation 4: Reynolds Number (Fiber Glass Systems (a))

$$N_r = \frac{D \bullet V}{\upsilon}$$

Where Nr is the unit less Reynolds number, D is the diameter in meters, V is the velocity in meters per second, and ν is the kinematic viscosity in meters squared per second.

The Reynolds number is used in the equation to calculate the friction coefficient, so that over all friction loss can be determined. Equation 5 shows the Colebrook equation:

Equation 5: Colebrook Equation (Fiber Glass Systems (a))

$$\frac{1}{\sqrt{f}} = -2 \bullet \log(\frac{e}{3.7 \bullet D} + \frac{2.51}{N_r \bullet \sqrt{f}})$$

Where f is the unit less friction factor, e is the absolute roughness in millimeters, and the other variables are the same as listed for the Reynolds number equation.

This leads to the overall friction loss in the pipe, which is calculated with the Darcy-Weisbach equation:

Equation 6: Darcy-Weisbach equation (Fiber Glass Systems (a))

$$Hf = f \bullet \frac{L \bullet V^2}{D \bullet 2 \bullet g}$$

Hf is the pipe friction loss in meters, g is the acceleration due to gravity, and the rest of the terms are the same as defined above. This equation works well for this analysis because the minor losses and the static head (elevation difference) losses are negligible in this case because the friction losses will be so much larger and there is not a particularly large difference in elevations between the two locations.

Pressure loss was calculated next using the Darcy-Weisbach equation for pressure loss.

Equation 7: Darcy-Weisbach pressure loss (engineering toolbox (b))

$$\Delta P = f\left(\frac{l}{D} \bullet \frac{\rho V^2}{2}\right)$$

Where all terms are the same as above, P is pressure in Pascals and p is density in kilograms per meters cubed.

With all of these calculations completed the pumping energy required could be determined. The pumping energy required in kilowatts (kW) was calculated from equation 8:

Equation 8: Pumping Energy (engineering toolbox (d))

$$Energy = \frac{Q \bullet \rho \bullet Hl \bullet g}{3.6 \bullet 10^6}$$

Where Q is flow rate in meter cubed per hour (m^3/hr.), p is density in kilograms per meter cubed (kg/m^3), Hl is head loss in meters (m), g is gravity in meters squared per second (m^2/s), and $3.6*10^6$ is a conversion factor to get to kW. After the number of kilowatts was calculated we used a conversion factor of 1 kW to .7457 Horse power. (HP) With all of the variables calculated, they can be used to determine the total costs for the pipeline.

3.4.2 Pipe Costs

The cost for the materials for the pipeline was determined from a quote for the ACP. The only information we needed was the length of the pipeline in both directions. The quote for a different length of pipe and various diameters is shown in Table 4:

Table 4: Pipeline Quote (Appendix F)

ÍTEM	DESCRIPCIÓN	UND	CANTIDAD	VALOR UNITARIO (US$)	VALOR PARCIAL (US$)
1	Tuberia GRP DN800 PN10 SN2500	ml	2.000.00	$ 144.44	$ 288.880.00
2	Acople GRP DN800 PN10	un	178.00	$ 186.36	$ 33.172.00
3	Tuberia GRP DN400 PN6 SN5000	ml	5.000.00	$ 63.33	$ 316.650.00
4	Acople GRP DN400 PN6	un	453.00	$ 90.00	$ 40.770.00
5	Tuberia GRP DN350 PN6 SN5000	ml	5.000.00	$ 54.44	$ 272.200.00
6	Acople GRP DN350 PN6	un	445.00	$ 85.56	$ 38.074.00
	DN=Diámetro Nominal (mm), PN=Presión Nominal (bar), SN=Rigidez Nominal (N/m²), L=Longitud (m)			Subtotal	$ 989.746.00
				Transporte	$ 163.626.20
	La tubería se suministra para sistemas a flujo libre y a presión hasta 32 bar (470 psi), en diámetros entre 300 y 3700mm, cumpliendo con todas las normas de fabricación AWWA C-950 y las NTC 3826, NTC 3870 y NTC 3871.			Seguros	$ 11.533.72
				TOTAL	$ 1.164.905.93

The quote columns in Table 4, above, are item, description, unit, quantity, unitary cost, and price for quantity. The cost for the pipe includes two costs the material for the pipe, and couplings that are required approximately every 11 meters. (Appendix I) The 3 different pipe diameters shown are .8 meters (32"), .4 meters (16"), and .35 meters (14"). The .3 meter diameter costs had to be interpolated from the given information, while the other diameters of interest were already given. The unit prices need to be multiplied by the determined length of the pipeline to calculate the costs.

The next part of the pipe cost is the pumping costs. This was calculated by using the horse power (HP) value multiplied by $250 per HP. (Appendix A) The pump costs were varying based on the different flows so they were calculated for all the flows until an optimal flow and pipe size were selected to do a final analysis.

3.4.3 Tank

For the few first scenarios involving the tank we tried to calculate the volume based on mass flow rate coming from the tank. This scenario ended up providing tank volumes that were too small, so it was readjusted so that we started with a volume and then calculated the amount of refrigeration tons that could be provided based on that volume.

The volumes were estimated from 200,000 gallons up to 500,000 gallons. These numbers were based off rough estimates of the maximum volume the ACP wanted for purposes of costs and space and the minimum volume that would be beneficial to the chilled water system. From these volumes the potential tons of refrigeration were calculated using Equation 9:

Equation 9: Storage Tank Volume (U.S. Army Corps of Engineers)

$$V = \frac{Q}{C_p \bullet \Delta T \bullet FOM}$$

Where V is volume in ton-hours which was converted to gallons, Q is flow rate in ton-hour, Cp is specific heat capacity in British thermal units per pound mass degrees Fahrenheit (BTU/lb.*F), dT is change in temperate in Fahrenheit, and FOM is the figure of merit for the storage tank. (U.S. Army Corps of Engineers) The FOM value is recommended to be .9. (U.S. Army Corps of Engineers) The calculation ends up needing to convert ton-hour to BTU, and the conversion is 12,000 BTU per ton-hour, and also to convert lbm to gallons which is 8.36 lbm per gallon. (U.S. Army Corps of Engineers)

This equation was switched around to solve for Q, ton-hours of refrigeration. The tonnage that was calculated is the overall tonnage for the full tank. The number that we wanted to know was the amount it could give per hour, and ideally what it could provide during peak hours. Peak hours would be a maximum of about 8 hours per day, so a good estimate of the tanks value was to calculate the tonnage per hour for an 8 hour period.

The cost of the tank was found through several estimates $.50/gallon, $30-100 per ton of refrigeration, and a company's quote for a 158,000 gallons tank. The quote for the 158,000 gallon tank was priced at approximate $107,000. (Appendix G). We took a number based around these several different sources for pricing. 158,000 divided by 107,000 gives you a 1.45 volume to cost ratio which we found to be a good estimate for theses cost.

The ACP wanted to use a height preferably of no more than 10 meters, and with this in mind we were able to calculate the diameter need for the tank, using Equation 10:

Equation 10: Thermal Storage Tank Diameter (U.S. Army Corps of Engineers)

$$D = 2 \bullet (V / H)^{(1/2)}$$

Where D is the diameter in meters, V is the volume in meters cubed, and H is the height in meters. This also allowed us to calculate the height to diameter ratio, which is important because of stratification in the storage tank. The closer the height to diameter ratio is to one the more efficient stratification will be. A reasonable number for the ratio would be around .4. (U.S. Army Corps of Engineers) With a height max of 10 meters and a total volume no larger than 500,000 gallons, the height to diameter ratio was not a problem.

3.5 New Balboa Facility

We want to assess the feasibility of constructing a new facility of electric chillers to replace the current status quo. Technology has allowed for a much higher efficiency in today's electric chillers, which we predict will save us a great deal in electricity expenses per year. In order to make an accurate assessment, we had to research and calculate initial investment costs, along with annual energy savings and expenses data. What we want to analyze is if the return over the next 20 years will be worth the initial investment made. We inputted our calculations into a Microsoft Excel model to compare the scenario of a new facility versus that of the status quo. The following details the actions taken to retrieve our calculations.

3.5.1 Initial Investment Calculations

The initial investment factors pertaining to a new Balboa facility are the subtotal of the Electric Chillers, the Cooling Towers, Pumps, and the subtotal of the piping, insulation and installation. The sum of these values will then be added to a calculated construction quote to construct a new facility to house the equipment. Our research began by first determining the most cost and energy efficient centrifugal electric chillers.

Mechanical Solutions, Inc. supplied the best pricing for the most energy efficient water-cooled centrifugal chillers and cooling towers in Table 5. To decrease the margin of error in our rate of return calculations, we chose a higher cost value of $425/ton for water-cooled centrifugal chiller pricing and a higher cost value of $250/ton for cooling tower pricing. In choosing a higher-end value, we equate for any minor costs that we may have not been able to clearly define during our assessment.

Table 5: Actual Chiller and Cooling Tower Quote, MSI (appendix L)

Uninstalled Equipment Replacement Cost Guidelines (Cost Per Ton)

Service	Tonnage	Price Per Ton
Air-cooled Chiller (recip.)	40 - 60	**$575.00 - $650.00**
Air-cooled Chiller (recip.)	70 - 180	**$450.00 - $525.00**
Water-cooled Chiller (recip.)	40 - 60	**$525.00 - $575.00**
Water-cooled Chiller (recip.)	70 - 180	**$450.00 - $515.00**
Water-cooled Centrifuged Chiller	100 - 300	**$375.00 - $675.00**
Water-cooled Centrifuged Chiller	400 - 1600	**$300.00 - $365.00**
Cooling Towers, Induced Draft, assembled	10.0 - 40	**$225.00 - $265.00**
Cooling Towers, Induced Draft, assembled	50 - 150	**$175.00 - $215.00**
Cooling Towers, Counter-flow, Forced Draft	100 - 300	**$155.00 - $175.00**
RTU Gas Heat, DX	3.0 - 15	**$695.00 - $800.00**
RTU Gas Heat, DX	20 - 60	**$465.00 - $695.00**
RTU Multizone	3.0-15	**$1050.00 - $1195.00**
RTU Multizone	20 - 60	**$1125.00 - $1195.00**
Heat Pump: Water to Air	3.0 - 20	**$475.00 - $575.00**
Heat Pump: Air to Air Par.	3.0 - 7	**$675.00 - $735.00**
Heat Pump: Air to Air Split	2.0 -10	**$750.00 - $850.00**

*** NOTE**
Prices reflect cost-per-tonnage of uninstalled equipment.

We then calculated the approximate pump pricing based on interpolated values from a pump/pipe size capacity chart in Figure 16, below, supplied by TRANE to our supervisor Urho. (Gonzal, P., 2012)

TRANE

Water Piping Capacity (Tons)

		Chilled Water					
Pipe Size	GPM	20°ΔT	18°ΔT	16°ΔT	14°ΔT	12°ΔT	10°ΔT
	Price* Pump**	1.2 GPM/Ton	1.33 GPM/Ton	1.5 GPM/Ton	1.7 GPM/Ton	2 GPM/Ton	2.4 GPM/Ton
48	60,000 GPM	50,000	45,000	40,000	35,000	30,000	25,000
	$1200/ft 195 HP	40,000	36,000	32,000	28,000	24,000	20,000
42	40,000 GPM	33,300	30,000	26,600	23,300	20,000	16,600
	$1000/ft 115 HP	26,600	24,000	21,300	18,600	16,000	13,300
36	30,000 GPM	25,000	22,500	20,000	17,500	15,000	12,500
	$950/ft 110 HP	20,000	18,000	16,000	14,000	12,000	10,000
30	20,000 GPM	16,600	15,000	13,300	11,600	10,000	8,300
	$700/ft 80 HP	13,300	12,000	10,650	9,300	8,000	6,600
24	12,000 GPM	10,000	9,000	8,000	7,000	6,000	5,000
	$550/ft 45 HP	8,000	7,200	6,400	5,600	4,900	4,000
20	8,000 GPM	6,650	6,000	5,300	4,650	4,000	3,300
	$500/ft 32.2 HP	5,300	4,800	4,250	3,700	3,200	2,650
18	7,000 GPM	5,800	5,250	4,650	4,050	3,500	2,900
	$450/ft 37.6 HP	4,650	4,200	3,700	3,250	2,900	2,300
16	6,000 GPM	5,000	4,500	4,000	3,500	3,000	2,500
	$375/ft 43.5 HP	4,000	3,600	3,200	2,800	2,400	2,000
14	4,000 GPM	3,300	3,000	2,650	2,300	2,000	1,650
	$300/ft 26.1 HP	2,650	2,400	2,100	1,960	1,600	1,300
12	3,600 GPM	3,000	2,700	2,400	2,100	1,800	1,500
	$250/ft 29.4 HP	2,400	2,160	1,920	1,680	1,440	1,200
10	2,400 GPM	2,000	1,800	1,600	1,400	1,200	1,000
	$200/ft 22.8 HP	1,600	1,440	1,280	1,120	960	800
8	1,500 GPM	1,250	1,125	1,000	875	750	625
	$175/ft 18.3 HP	1,000	900	800	700	600	500
6	700 GPM	585	525	460	400	350	290
	$150/ft 7.9 HP	465	420	375	325	280	230
5	460 GPM	385	345	300	270	230	190
	$140/ft 5.9 HP	305	275	245	215	185	150
4	260 GPM	215	200	175	150	130	100
	$125/ft 3.5 HP	175	155	140	120	105	85
3	130 GPM	110	100	85	75	65	50
	$100/ft 1.9 HP	85	80	70	60	50	40
Pipe Size	Price* Pump**	20°ΔT	18°ΔT	16°ΔT	14°ΔT	12°ΔT	10°ΔT
	GPM	1.5 GPM/Ton	1.66 GPM/Ton	1.88 GPM/Ton	2.14 GPM/Ton	2.5 GPM/Ton	3 GPM/Ton

Figure 16: Pipe/Pump Sizing Chart, (Trane, Gonzal, P., 2012) (appendix A)

Horsepower gauges pump pricing, but we first need to determine the required horsepower to pump a flow rate of 4,500 gallons per minute. Once we enter each pump value, in relation to their respective flow rate, into our Excel file, we get in return the appropriate horsepower. Our interpolated quotes from TRANE for a flow rate of 4,500 gpm, yields a required HP of 34.6. Using the pump pricing of $300/HP we calculated the investment spent in pumps.

Current facility data supplied us with an approximate cost of piping between the facility itself, the piping to the receiving areas, and unions to join each pipe together. These costs were added to investment subtotal. A forty percent sub-charge for Installation and Insulation was calculated and added. Realistically the cost of installation and insulation would equate to about thirty percent of our total initial investment but to stay consistent with our "high-value" assumptions we used the additional ten percent for wiggle room.

The last factor in equating a total investment would be the cost for constructing a new facility to house the equipment. We researched the national average of construction costs for the United States and Panama. While the values were similar in range, the US construction quota provided us with more detail for a more accurate calculation. Having visited the current Balboa are facility, we determined that the most accurate building size would be a 10,000 sq. ft. facility, in which we followed US National construction cost guidelines to determine our estimate. Factors such as land development, and sales of current facility were negligible in this project but should be equated into any future and more detailed analysis.

In result, the total investment is the cost of chillers, cooling towers, pumps, isolated piping, piping unions, additional forty percent for installation and insulation, and cost of construction.

3.5.2 Energy Savings and Expenses Data

Energy savings data were calculated through our recovery of documents from the ACP portal, and quotes obtained from companies that have supplied equipment to the ACP before. We assumed a more accurate expense cost from companies with prior ACP experience. Equation 11 shows how to use the coefficient of performance to determine an energy value. In calculating the saving in energy efficiency, there were questions that we needed to address. (1) What is the electricity rate of the chillers? (2) What is the efficiency rate? (3) What are the correct COP values? (4) What should our IRR % be? (5) What should our VAN be? (6) What is the life expectancy of the new chillers? The stem of the calculations started with calculating the kW/ton of the current chillers and of the new chillers as well. Equation 11 below The COP is the key to our energy savings. The COP of the current Balboa systems is about 3.52, while the COP of a new system would be roughly 5.5; the higher the COP, the more efficient the system.

Equation 11: Kilowatt per ton of refrigeration (Appendix A)

$$kW / Ton = 3.516 / COP$$

A standardized calculation of energy efficiency in electric chillers uses an equation that calculates required energy through the amount of British Thermal Units per hour used. Given our invested tonnage of tons, we used the following equation to calculate the amounts of BTUs per hour that are required.

1 Ton (refrigeration) = 12,000 BTU/hr.

Once we equate the required BTUs, we can discover how much energy is required to power our system by Equation 12, below:

Equation 12: Required kW (Appendix A)

$$\text{Re}\,quired\,(kW) = \frac{BTU\,/\,hr}{3413 \bullet COP}$$

We then needed to calculate the number of full load hours that the system would need to run in order to supply 3000 tons of refrigeration. Table 6 displays chiller information, including the amount of full, and half load hours per day in addition to the number of days per year. To remain consistent with current calculations we divided to the given kilowatts per hour in the chart by the given kilowatts required to receive the number of hours per year the system would run.

The total number of full load time hours was calculated using the chiller energy consumption table supplied in the initial analysis.

Table 6: Chiller Energy Consumption, Initial Analysis (Appendix A)

Consumo de Energía para Chillers Eléctricos							
COP=	6		1 Ton =	12000	BTU/hr		
Días Laborales		260	días				
kW=BTU/hr / 3413* COP							
	Capacidad	Potencia Elec.	Horas de Uso		Consumo Elec.	Costo	Costo Anual
	Tons	*kW*	*Pico*	*Media Carga*	*kWh*	*$/ kWh*	*$*
Chillers	3000	1757.98	5	3	3656607.09	$ 0.1000	$ **365,660.71**

A B

<u>Full load time per year = B/A</u>

Multiplying the time in hours per year by peak power in kilowatts will result in the annual energy value required in kilowatt-hours per year.

In order to determine the total expense of electricity per year we multiplied our kilowatt-hours per year by the consistent electricity rate the ACP pays. The resulting value is the cost for the required amount electricity per year to chill 3000 tons per year. The key factor in our energy savings will be the chiller efficiency COP that is currently 3.52 due to outdated equipment but 5.5 with up-to-date equipment. Column B in Table 7, below, supplied to us in an initial analysis, is a column detailing costs of a new electric chilled water plant scenario. We extrapolated the ‘human resource” cost in the red box in the table and used it in our expense calculations. The Electricity cost plus the standard human resource cost, found in the chart analysis below will equate our total yearly expenses.

Table 7: Human Resources Cost (Appendix A)

	Alternativas							
	Status Quo	A	B	C	D	E	F
	Expansión directa enfriada por aire	Mini centrales de agua fría enfriadas por agua	Planta Central de Agua fría por chillers eléctricos	Planta Central de Agua fría por cogeneración	Red Urbana de frío con chillers eléctricos Red Tank/CDS	Red Urbana de frío con 50% cogeneración Red Tank /CDS	Red Urbana de frío con 100 % cogeneración Red Tank /CDS
Costos Capitales							
Inversión	**B/. 1,568,820.00**	**B/. 3,516,295.13**	**B/. 3,529,766.30**	**B/. 6,055,315.60**	**B/. 7,861,350.07**	**B/. 8,786,311.95**	**B/. 10,080,061.95**
Costos Operativos							
Electricidad	B/. 1,039,903.22	B/. 731,467.68	B/. 436,379.83	B/. 47,450.47	B/. 888,623.49	B/. 424,302.19	B/. 58,641.48
Mantenimiento	B/. 39,750.00	B/. 39,750.00					
Recurso Humano			B/. 167,447.45	B/. 167,447.45	B/. 167,447.45	B/. 167,447.45	B/. 167,447.45
Depreciación							
Total	**B/. 1,079,653.22**	**B/. 771,217.68**	**B/. 603,827.28**	**B/. 214,897.92**	**B/. 1,056,070.94**	**B/. 591,749.64**	**B/. 226,088.93**
Ingresos							
Por Demanda					B/. 569,160.00	B/. 569,160.00	B/. 569,160.00
Por Consumo					B/. 808,790.40	B/. 808,790.40	B/. 808,790.40
Total					**B/. 1,377,950.40**	**B/. 1,377,950.40**	**B/. 1,377,950.40**
Rentabilidad							
TIR		23%	39%	26%	27%	30%	30%
VAN (miles)		1,130	3,702	3,753	5,502	7,652	8,780
Toneladas	3000	3000	3000	3000	6000	6000	6000
Costo por Tonelada	B/. 522.94	B/. 1,172.10	B/. 1,176.59	B/. 2,018.44	B/. 1,310.23	B/. 1,464.39	B/. 1,680.01

Once each of the contributing factors above was calculated, we entered the information into an Excel model that compares the Internal Rate of Return and Actual Net Value over twenty years of our analyzed scenario versus the status quo of the current facility. The investment and expense columns of our model are entered as negative numbers, while the income column is a positive value. Choosing the projected years 2013-2033 our resulting IRR and VAN gives us a 20 year projection assuming the ACP takes action within the next year. The next following section will detail our results and discuss beneficial opportunities for the ACP in the future.

Chapter 4 Results

4.1 Energy and Cost Determination

4.1.1 Current Operations

As was stated before the yearly expenses and income were required for the status quo in order to perform the economic analysis. The first step was to determine the costs, which were determined from the monthly kWh added up and multiplied by the cost per kWh to get the overall cost for the year, as shown in Table 8 below:

Table 8: Monthly kWh and costs for current Balboa Facility (Appendix A)

Month	Energy (kWh)	Cost ($)
January	753,277	$105,458.78
February	766,399	$107,295.86
March	750,341	$105,047.74
April	818,500	$114,590.00
May	525,132	$73,518.48
June	758,409	$106,177.26
July	765,648	$107,190.72
August	737,600	$103,264.00
September	751,591	$105,222.74
October	818,377	$114,572.78
November	858,611	$120,205.54
December	674,432	$94,420.48

Table 8 shows the kilowatt-hours, the cost per month, and the total cost in the last column. The total cost per year for the facilities electricity usage is $1,256,964.38 per year. (Appendix H) This value was used as the yearly expenses in the economic analysis.

The next step was to determine the yearly income for the facility, and the calculations are shown here in Table 9:

Table 9: Income for Balboa facility per year (Appendix I)

Baseline at Balboa							
	Dec	Jan	Feb	Mar	Apr	May	Total
ton-hr sold	686874	683920	628689	713499	694496	743736	8302428
							$1,017,047.43
installed tons (assumed)	2700	2700	2700	2700	2700	2700	32400
							$958,716.00
						TOTAL INCOME	$1,975,763.43

Table 9 shows the information for a 6 month period, for ton-hrs sold and installed ton. Both of those figures were doubled in order to determine a rough yearly income. The total income for ton-hour sold is $1,017,047.43 per year, and the total for installed tons is $958,716.00 per year. The total income for the facility is approximately $1,975,763.43 per year. The final numbers to put into the economic analysis are $1,256,964.38 for expenses and $1,975,763.43 for income. These values will be constant for every year in the status quo scenario.

4.1.2 Alternatives Analysis I: New Facility vs. Status Quo of Current Facility

The total of annual expenses is the result of electricity costs to power the chillers, and cost for human resourcing. Our initial hypothesis stated that a great deal of money would be saved due to the enhanced energy efficiency of newer chillers. The higher coefficient of performance in the newer chillers allows for less electricity usage, and ultimately better efficiency. With a Cop of 3.52, the status quo or current kW/tonnage equals .99886 kW per ton. As before mentioned, the kilowatt-per-tonnage is the result of: the constant (3.516) divided by the coefficient of performance of the chiller. Considering the condition and age of the current equipment at the Balboa facility, a kW/ton value of roughly 1 is accurate. (Energy, US. 2012) New advances in technology have allowed for kW/ton efficiencies to reach values all the way down to .38. The COP of up-to-date electric chillers is roughly 6.10. When combined with cooling towers, and the required pumping equipment, we can accurately estimate that the net COP of the entire system will be roughly 5.5. When the constant (3.516) is divided by the new net COP of 5.5, we get a system kilowatts-per-ton of .64. The lower the kW/ton value, the better, and as you can see, our new value of .64 is much better than our previous value of 1. According to the U.S Department of Energy, a default and acceptable value for an energy efficient centrifugal chiller is 0.56 kW/ton. A 0.64 kW/ton value is the result of our new chillers with a NET COP of 5.5, so our value is acceptable enough for us to make our calculations and proposal assumptions. (Gonzal, P., 2012) As stated before, the COP value's relevance depends on the refrigeration tons required in BTU/hr.

The refrigeration capacity of the new facility is to be 3000 tons. We have found one ton of refrigeration to equal 12,000 British Thermal Units per hour, a common measurement in the international system. The total projected BTU's per hour of our projected system is 36 million. In order to calculate the energy savings we need to convert the capacity of refrigeration into capacity of energy. Retrieving the following formula from our methods section, we calculated the energy capacity to be 1917.80092 Kilowatts.

$$Capacity(kW) = \frac{BTU/hr}{3413*COP} = \frac{36,000,000}{3413*5.5} = \frac{36,000,000}{18,771.5} = 1917.80092kW$$

Referencing Figure 22 in the methodology chapter, the chiller energy consumption chart, we equated our full load time hours per year to be roughly 2,080 hours. The value of electricity per year in kilowatt-hours per year is equated below by multiplying the required energy by the amount of hours run per year. Table 10, below, displays the calculated totals of the energy and costs that make up the annual expenses. The amount of kilowatt-hours required annually for this system is 3,989,036.27. Given an electricity rate of $0.14 per kWh, the annual cost to power the 3000 ton facility would be $558,465.27. Electricity is not the only annual expense, however. Neglecting operation costs, we considered a "human resource cost" calculation of employees at the current Balboa facility of $167,447.26. (Admade, 2012) Our total annual expenses for the proposed new facility would be $725,912.53. The annual expense value was factored into our excel model each year to obtain our resulting IRR and VAN.

Table 10: Annual Expenses for Alternative One: Proposed New Facility (Appendix A)

Annual Expenses for New Facility	Amount	Rate	Subtotal
Electricity (kWh)	3,989,036.27	$0.14/	$558,465.27
Human Resources	---	---	$167,447.26
TOTAL			$725,912.53

The current facility's associated costs have been calculated and annual expense calculations for a new facility have been made. Now, the investment associated with alternative one (new facility) will be presented. The equipment cost of chillers, pumps, pipes, and towers were determined from direct quotes from companies we researched. Trane lists an accurate chilling price of $425/per ton of refrigeration. An investment of 1.275 million dollars is expected to be made just on the new chillers, assuming our new facility is to house 3000 tons of refrigeration. An updated quote from the manufacturer of the current facility listed cooling towers at $250/per ton of refrigeration, yielding a $750,000 investment in cooling towers. Trane supplied a quote of $300 per horsepower that allowed us to determine the total investment cost for the pumps required. Three 34.6 HP pumps yield a total cost of $31,140. Table 11, below, displays pipe cost information registered in the ACP database for the current Balboa facility including the total cost of piping for the isolated balboa area, piping to surrounding areas, and the unions to join each pipe (Admade, 2012)

Table 11: Total Piping cost for Balboa Area (Appendix A)

Pipes	
Balboa	$126,660.00
Isolation	$188,325.54
Unions	$15,517.24

Piping distributed to the surrounding Balboa area will cost $126,660. Piping for the isolated new facility will cost $188,325. The unions, joints, and fasteners will cost $15,517.24. Our total investment cost is the sum of the equipment cost, an insulation and installation cost of $954,657.112 (40% Insulation and Installation), and a new facility construction cost of $700,850. The construction cost of a new building comes from a quote given by Reed Construction for a 10,000 sq. ft. block masonry warehouse facility. (Means, 2008) The following results detail our calculations and findings of the New Facility scenario.

Table 12: Total Investment cost for New Facility (Appendix A)

Equipment for New Facility [Investment]	Unit Price	Quantity	Subtotal
1000 Ton Electric Chillers	$425,000	3	$1,275,000.00
1000 Ton Cooling Towers	$250,000	3	$750,000.00
34.6 HP Pump	$10,380	3	$31,140.00
Distributed Piping	$126,660		$126,660.00
Isolated Piping	$188,325		$188,325.00
Unions	$15,517		$15,517.24
40% Installation and Insulation	$954,657		$954,657.11
TOTAL			$3,341,299.89

Table 12, above, displays in detail our investment calculations. The equipment, price of equipment and quantity of equipment all make up the subtotal. The above investment calculation was placed into our Excel model and used to equate our internal rate of return and actual net value over the next twenty years.

4.1.3 Alternatives Analysis II: Pipeline with Thermal Storage Tank vs. Current Facility

4.1.3.1 Sizing and Flow Calculations

The total distance measured, using the ACP's GIS system, from the Miraflores power plant to the Balboa area was approximately 5973.83 meters. Since the chilled water distribution network requires a supply and return line this distance needs to be doubles for a total of approximately 12,000 meters of pipe. The calculations in the excel model were determined using a one direction distance because there will be pumps at both ends, so the friction losses were only necessary for one direction. The calculated numbers were doubled to account for the entire length of the pipeline when necessary.

The flows were converted from gpm to meters cubed (m^3)' , as shown in Table 13, using a conversion factor of 1 m^3 in 15852 gpm (Engineering Toolbox (a)).

Table 13: Flow, Length, Diameter (Appendix I)

Flow (gpm)	Length (m)	diameter 1 (m)	diameter 2 (m)	diameter 3 (m)	Flow (m^3/s)
1000	5973.81	0.3	0.35	0.4	0.063083523
1500	5973.81	0.3	0.35	0.4	0.094625284
2000	5973.81	0.3	0.35	0.4	0.126167045
2500	5973.81	0.3	0.35	0.4	0.157708806
3000	5973.81	0.3	0.35	0.4	0.189250568
3500	5973.81	0.3	0.35	0.4	0.220792329
4000	5973.81	0.3	0.35	0.4	0.25233409
4500	5973.81	0.3	0.35	0.4	0.283875852

The format for our excel model will be in this fashion for all other images showing values, and can be found in Appendix I. **Any column name with a 1 after it is referring to a .3 m (12") pipe, any column name with a 2 after it is a .35 m (14") pipe, and any column name with a 3 after it is referring to a .4 m (16") pipe.** The calculations were done out for the different pipe diameters to determine which one was the most cost effective.

These are the areas calculated from Equation 1:

Table 14: Area of Pipes (Appendix I)

Area 1 (m^2)	0.070685775
Area 2 (m^2)	0.096211194
Area 3 (m^2)	0.1256636

Table 15 shows the velocities calculated from Equation 3:

Table 15: Velocities in Pipes (Appendix I)

Velocity 1 (m/s)	Velocity 2 (m/s)	Velocity 3 (m/s)
0.892450038	0.655677579	0.502003146
1.338675057	0.983516368	0.75300472
1.784900076	1.311355158	1.004006293
2.231125095	1.639193947	1.255007866
2.677350114	1.967032737	1.506009439
3.123575133	2.294871526	1.757011012
3.569800152	2.622710316	2.008012585
4.016025171	2.950549105	2.259014159
2.361431725	1.734929431	1.328305345

The Reynolds numbers and the friction factors calculated from Equations 4 and 5 are shown in Table 16:

Table 16: Reynolds number and friction coefficient (Appendix I)

Flow (gpm)	Reynolds Number 1	Reynolds Number 2	Reynolds Number 3	Friction Factor 1	Friction Factor 2	Friction Factor 3
1000	186705.0289	160032.8819	140028.7717	0.015	0.0155	0.016
1500	280057.5433	240049.3228	210043.1575	0.014	0.0145	0.015
2000	373410.0577	320065.7638	280057.5433	0.0135	0.0135	0.014
2500	466762.5722	400082.2047	350071.9291	0.013	0.013	0.0135
3000	560115.0866	480098.6457	420086.315	0.0125	0.0125	0.013
3500	653467.601	560115.0866	490100.7008	0.012	0.0125	0.0125
4000	746820.1155	640131.5275	560115.0866	0.012	0.012	0.0125
4500	840172.6299	720147.9685	630129.4724	0.0115	0.012	0.012

The overall friction loss in the varying diameter pipes is in Table 17 calculated from Equation 6:

Table 17: Friction Loss in pipes, Darcy-Weisbach (Appendix I)

Flow (gpm)	Friction loss (DW) 1	Friction loss (DW) 2	Friction loss (DW) 3
1000	12.12523687	5.796912199	3.069200584
1500	25.46299743	12.20156519	6.474094981
2000	43.65085275	20.19569411	10.74220204
2500	65.6783664	30.38703975	16.18523745
3000	90.93927655	42.07436273	22.44352927
3500	118.8273214	57.26788261	29.37320871
4000	155.203032	71.8069124	38.3650073
4500	188.2443025	90.88062351	46.61348386

Table 18 shows the pressure loss in Pascals from Equation 7 and also the pressure converted to pounds per square inch (PSI):

Table 18: Darcy-Weisbach Pressure losses in Pascals and PSI (Appendix I)

Flow (gpm)	Pressure loss (DW) 1	Pressure loss (DW) 2	Pressure loss (DW) 3	Pressure loss (DW) 1 (PSI)	Pressure loss (DW) 2 (PSI)	Pressure loss (DW) 3 (PSI)
1000	133243.1891	86705.18893	59959.43509	19.32529075	12.57552448	8.696380837
1500	186540.4647	121666.9587	84317.95559	27.05540705	17.64630047	12.22928555
2000	239837.7404	151034.8452	104929.0114	34.78552335	21.90575231	15.21866646
2500	288693.5763	181801.2026	126476.9334	41.87146329	26.36803519	18.34392833
3000	333107.9727	209770.6184	146151.123	48.31322687	30.42465599	21.19742829
3500	373080.9294	244732.3881	163951.5803	54.1108141	35.49543199	23.77916635
4000	426378.2051	268506.3915	187373.2346	61.8409304	38.94355967	27.17619012
4500	459689.0023	302069.6905	202363.0934	66.67225308	43.81150462	29.35028532

The previous values all culminate in determining the Pump energy required, with the calculated numbers from Equation 8 are in Table 19:

Table 19: Pump energy in kW and HP (Appendix I)

Flow (gpm)	Pump power (kW) 1	Pump power (kW) 2	Pump power (kW) 3	Pump (HP) 1	Pump (HP) 2	Pump (HP) 3
1000	7.501443929	3.58633916	1.898802994	10.05960134	4.809359714	2.54633659
1500	23.62954838	11.32299823	6.00793135	31.68774423	15.18438974	8.056768117
2000	54.01039629	24.98868576	13.29162096	72.42912967	33.51037736	17.82435613
2500	101.5820532	46.99839625	25.03304729	136.2237682	63.02588335	33.56986715
3000	168.7824884	78.08964299	41.65499069	226.3410302	104.7199293	55.86025894
3500	257.2995268	124.0034609	63.60248312	345.0443261	166.2913691	85.29232914
4000	384.0739292	177.6973209	94.94014972	515.0515888	238.2960168	127.3168295
4500	524.0696265	253.0104433	129.7713172	702.7888988	339.2925708	174.0261913

Below in Table 20 are the unitary costs for the different pipe diameters determined from the pipe pricing quote. (Appendix E)

Table 20: Unitary Pipe Costs (Appendix I)

Material	Diameter (mm)	Diameter (in)	Pressure (Bar)	Normal Stiffness (N/m2)	Length (m)	# units	Unit Price/m	% of highests cost	Unit price/part
Tuberia GRP	DN800	32	PN10	SN2500	2.000.00		144.44	100	
Acople GRP	DN800	32	PN10			178			186.36
Tuberia GRP	DN400	16	PN6	SN5000	5.000.00		63.33	43.8	
Acople GRP	DN400	16	PN6			453			90
Tuberia GRP	DN350	14	PN6	SN5000	5.000.00		54.44	37.7	
Acople GRP	DN350	14	PN6			445			85.56
Tuberia GRP	DN300	12	PN6	SN5000	5000		47.71	33	
Acople GRP	DN300	12	PN6			445			79.29

The information provided by the quote gave two of the three pipe sizes of interest, except for the 12 inch pipe. The 12 inch rows were interpolated from the other data. The cost of the material for the different diameters was determined to be:

Table 21: Pipe Material Costs (appendix I)

Length (m)	Diameter (m)	Pipe Costs	Coupling Costs	Total Costs
11947.62	0.3	$570,020.95	$86,120.62	$656,141.57
11947.62	0.35	$650,428.43	$92,930.76	$743,359.19
11947.62	0.4	$756,642.77	$97,753.25	$854,396.03

The cost for the actual pump machinery is shown in table 22 which is calculated based on the required pumping energy and the price of $250 per HP.

Table 22: Pump Costs (Appendix I)

Flow (gpm)	Pump (HP) 1	Pump (HP) 2	Pump (HP) 3	Pump Cost 1	Pump Cost 2	Pump Cost 3
1000	10.05960134	4.809359714	2.54633659	$2,514.90	$1,202.34	$636.58
1500	31.68774423	15.18438974	8.056768117	$7,921.94	$3,796.10	$2,014.19
2000	72.42912967	33.51037736	17.82435613	$18,107.28	$8,377.59	$4,456.09
2500	136.2237682	63.02588335	33.56986715	$34,055.94	$15,756.47	$8,392.47
3000	226.3410302	104.7199293	55.86025894	$56,585.26	$26,179.98	$13,965.06
3500	345.0443261	166.2913691	85.29232914	$86,261.08	$41,572.84	$21,323.08
4000	515.0515888	238.2960168	127.3168295	$128,762.90	$59,574.00	$31,829.21
4500	702.7888988	339.2925708	174.0261913	$175,697.22	$84,823.14	$43,506.55

Table 23 shows the calculations for the thermal storage tank at different volumes:

Table 23: Thermal Storage Tank Calculations (appendix I)

Tank volume	Tank tons	tank cost	tons/hr for 8 hrs	Tank Diameter	Height to Diameter ratio
517616	2920.907088	$356,976.55	365.113386	27.99563382	0.357198557
500000	2821.5	$344,827.59	352.6875	27.51512311	0.363436498
475000	2680.425	$327,586.21	335.053125	26.81842464	0.37287798
450000	2539.35	$310,344.83	317.41875	26.10313774	0.383095707
425000	2398.275	$293,103.45	299.784375	25.36769008	0.39420223
400000	2257.2	$275,862.07	282.15	24.61027428	0.406334358
375000	2116.125	$258,620.69	264.515625	23.82879561	0.41966032
350000	1975.05	$241,379.31	246.88125	23.02080363	0.434389701
325000	1833.975	$224,137.93	229.246875	22.18340145	0.450787496
300000	1692.9	$206,896.55	211.6125	21.31312272	0.469194502
275000	1551.825	$189,655.17	193.978125	20.40576144	0.490057675
250000	1410.75	$172,413.79	176.34375	19.45613014	0.513976825
225000	1269.675	$155,172.41	158.709375	18.45770571	0.541779144
200000	1128.6	$137,931.03	141.075	17.40209183	0.57464356

The best option for tank size would be the 500,000 gallon tank, because it can provide a substantial tonnage to help provide relief for the chillers. The other tanks could provide some assistance but the smaller the tank gets the less beneficial it becomes to the overall system. For the purpose of further analysis a 517,616 gallon tank will be used, with a cost of $356,976.55. Using a more expensive tank also provides some sensitivity balance to the overall pricing; to help ensure that the investment costs were not under estimated.

4.1.3.2 Investment and Expenses

The current infrastructure in Balboa has 0.40 meters (16") pipes. (Balboa system map plan) The ACP wants to optimize the cost of the pipeline by trying to minimize pipe diameter, with a maximum diameter of 0.4 meters. The diameters that seemed to be feasible to minimize material costs and pumping costs are .3 meters (12"), .35 meters (14"), and the baseline of .4 meters, which would be the largest pipe that they would want to use. To get the most cost effective diameter we used the sheet model and calculations shown above to take into account the differentiating costs for the various pipe diameters. The Pipe size was optimized for the particular flows and can be seen in comparison scenarios in the Figure 17.

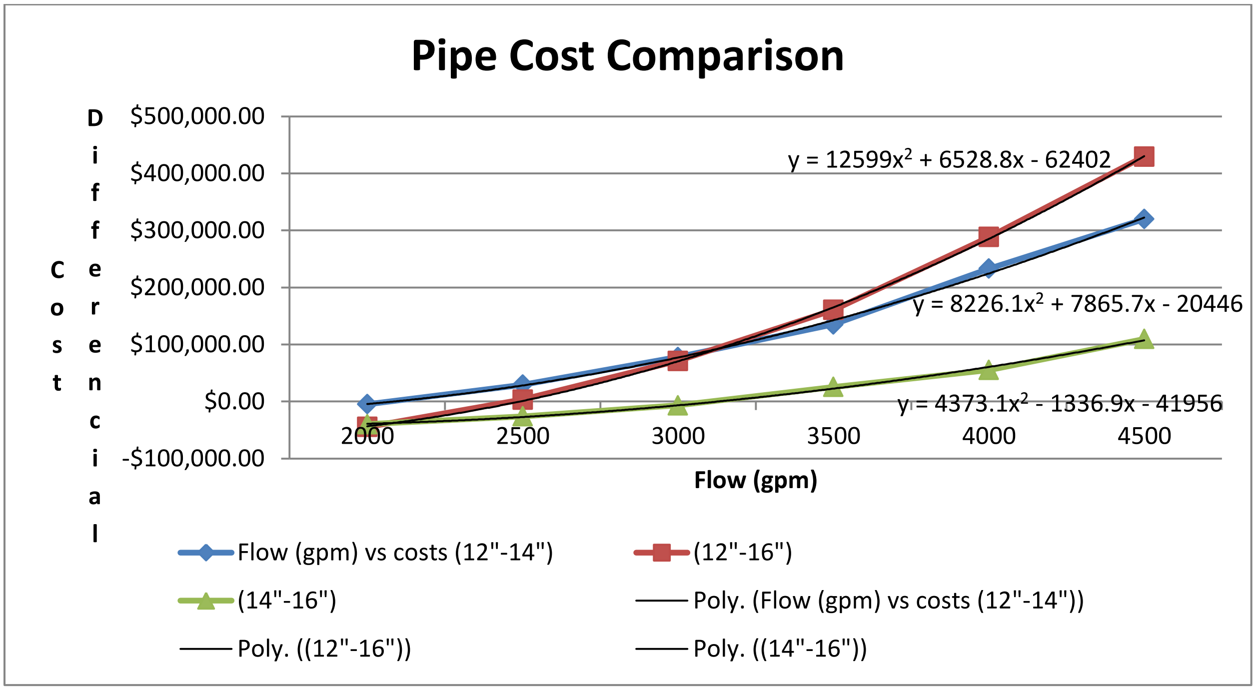

Figure 17: Pipe size comparison; flows vs. cost (Appendix I)

The graph in Figure 17 compares the cost of the pipe material plus the cost for the pumps required for the various flow rates versus the flow in gpm. It shows 3 lines, the blue line represents the costs of a 12 inch pipeline minus the costs of a 14 inch pipeline, red is 12 inch minus a 16 inch, and the green is a 14 inch minus a 16 inch. When the line is below zero on the y axis that means that you are saving money, and when the line is over zero that represents the increased costs of using that pipeline over the other. For example in the red line scenario once the line crosses the X-axis the 16 inch pipe becomes the more cost effective option.   So the 12 inch is only better than both other pipe sizes when the flows are lower than 2000 gpm. That flow is too low to supply the total current demand for chilled water even with improved efficiencies.

That ruled out a 12 inch pipe so a more detailed look at the 14 inch and the 16 inch were required. The comparison of 14 inch to 16 inch is shown in Figure 18:

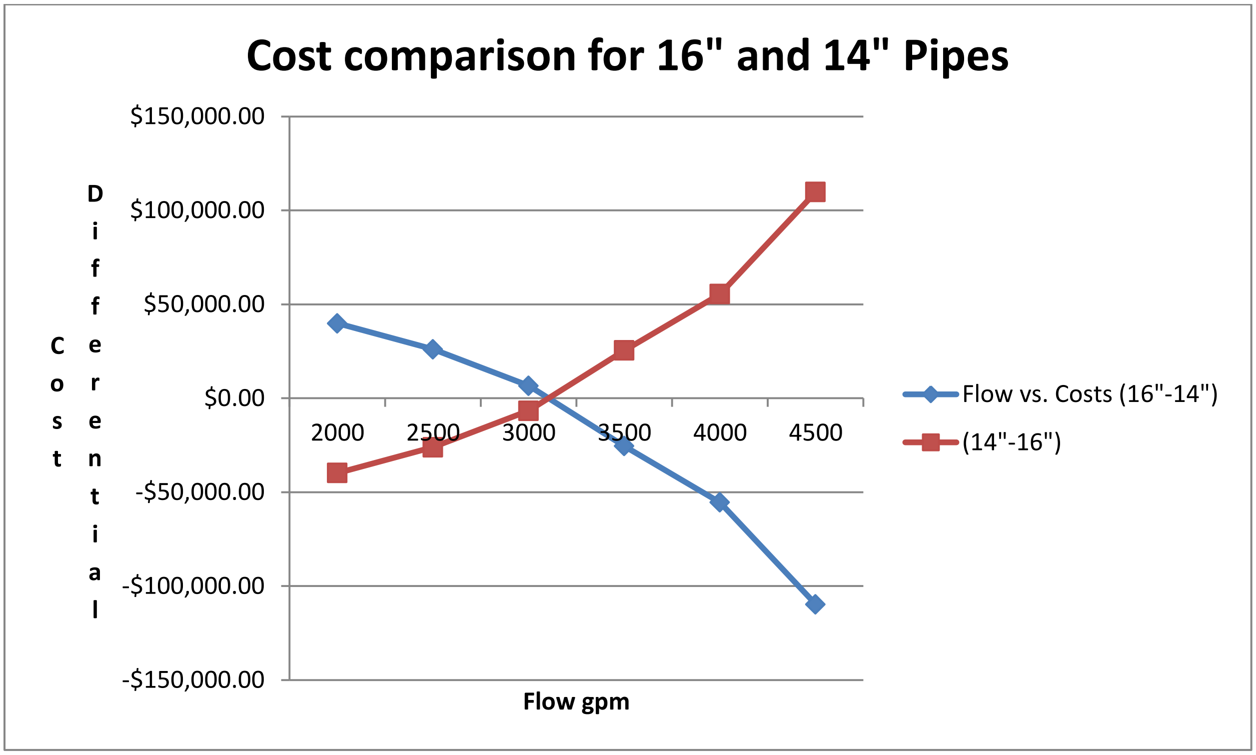

Figure 18: Comparison of Costs based on flow for 16" and 14" pipes (Appendix I)

Figure 18 shows visually that where the lines cross is the flow value were one becomes less expensive than the other. In this representation the blue is the 16 inch costs minus the costs of the 14 inch, and the red is the opposite. The location where they cross is slightly above 3000 gpm. And as mentioned before the total tonnage demand is 1125 tons of refrigeration per hour, which translates to just over 2600 gpm. So the 14 inch pipeline could provide the demand with room to spare, and would save the ACP money on material costs.

Now that we have determined a pipe diameter and a size for the storage tank the values can be determined to be put into the economic analysis. The factors that were used to determine the initial investment for alternative A are; pipe materials, thermal storage , absorption chiller, cooling towers, pipe insulation and pipe installation. The costs of these factors are shown in Figure 19:

Initial Investment									
Chiller tons	Pipe	Tank volume	Tank cost	Pump costs	Chillers	Cooling towers	Insulation	Installation	Total Cost
2400	$743,359.20	517616	$356,976.55	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,150,930.83

Figure 19: Alternative II Initial Investment (Appendix I)

The pipe material costs are the same as discussed previously as well as the tank costs. The pump costs were determined by using the pump HP with the capacity to pump 3000 gpm, which was approximately a 105 HP pump. This pump translates to approximately a $26,179.98 pump, but the system needs two pumps one to send the water down and one to pump it back. In addition to these pumps the system requires repetition for back up pumps so both pumps require a backup. This raises the pump costs to $105,000. The absorption chillers are priced $650 per ton (Appendix A), so with 2400 tons of refrigeration it comes to a cost of $1,560,000. The cooling towers are priced at $250 per ton from the chillers, which brings the cost to $600,000. (Appendix A) The insulation price is from a quote given to us by the ACP for a 5 kilometer pipeline, which costs $348,751. (Appendix F) The insulation is only needed for one direction because the cold water being delivered to the system is the only direction that needs insulation. The installation cost is 40 percent of the pipe material costs so it is 40 percent of $743,359.20, which is $436,844.08. This brings the total investment for this alternative to $4,150,930.83.

The next step is to determine the yearly expenses and costs. The expenses are going to be extremely reduced because the absorption chillers will be powered by cogeneration, which will reduce their electric consumption to essentially no costs. The expenses will consist of pumping electric consumption, and human resources. The pump cost will be based on the kWh consumption of the two pumps that will be running. The 105 HP pumps use 78 kW, this 78 kW will be used 24 hours a day and 365 days a year multiplied by a factor to take into account that the pump will not be running at full capacity all the time. We used .8 for our factor to make a conservative cost estimate for the pumps. And this number is multiplied by $.14/kWh to get a cost for the year, and then multiplied by 2 to represent costs for both pumps. This number ends up to be $153,231.32 per year. The human resources cost is $167,447.45 per year. (Appendix A) The total yearly expenses for alternative A are $320,678.77.

The income for this alternative is the same as for the status quo because it will be provided chilled water to the same buildings with the same demand and installed tonnage. This means the income for alternative A will be $1,975,763.43. The total expenses and income used for the economic analysis will be $320,678.77 and $1,975,763.43 respectively, with an initial investment of $4,150,930.83.

4.2 Economic Analysis

4.2.1 IRR and VAN of Alternative I: New Facility vs. Status Quo

Figures 20 and 21 are images of our Excel model, including investment, expense, and income inputs. The resulting IRR for the new facility scenario was 12%. With a minimum acceptable rate of return of 14%, this scenario proves to unfortunately be unworthy.

Fiscal Year	New Facility A Investment (-)	B Expenses	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value	Status Quo A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor
2013	(4,042)				(4,042)	1.0000	(4,042.15)	-	-		-	-	1.0000
2014	-	(726)	1,976		1,250	0.8772	1,096.36	-	(1,257)	1,976	-	719	0.8772
2015	-	(726)	1,976		1,250	0.7695	961.72	-	(1,257)	1,976	-	719	0.7695
2016	-	(726)	1,976		1,250	0.6750	843.61	-	(1,257)	1,976	-	719	0.6750
2017	-	(726)	1,976		1,250	0.5921	740.01	-	(1,257)	1,976	-	719	0.5921
2018	-	(726)	1,976		1,250	0.5194	649.13	-	(1,257)	1,976	-	719	0.5194
2019	-	(726)	1,976		1,250	0.4556	569.42	-	(1,257)	1,976	-	719	0.4556
2020	-	(726)	1,976		1,250	0.3996	499.49	-	(1,257)	1,976	-	719	0.3996
2021	-	(726)	1,976		1,250	0.3506	438.15	-	(1,257)	1,976	-	719	0.3506
2022	-	(726)	1,976		1,250	0.3075	384.34	-	(1,257)	1,976	-	719	0.3075
2023	-	(726)	1,976		1,250	0.2697	337.14	-	(1,257)	1,976	-	719	0.2697
2024	-	(726)	1,976		1,250	0.2366	295.74	-	(1,257)	1,976	-	719	0.2366
2025	-	(726)	1,976		1,250	0.2076	259.42	-	(1,257)	1,976	-	719	0.2076
2026	-	(726)	1,976		1,250	0.1821	227.56	-	(1,257)	1,976	-	719	0.1821
2027	-	(726)	1,976		1,250	0.1597	199.61	-	(1,257)	1,976	-	719	0.1597
2028	-	(726)	1,976		1,250	0.1401	175.10	-	(1,257)	1,976	-	719	0.1401
2029	-	(726)	1,976		1,250	0.1229	153.60	-	(1,257)	1,976	-	719	0.1229
2030	-	(726)	1,976		1,250	0.1078	134.73	-	(1,257)	1,976	-	719	0.1078
2031	-	(726)	1,976		1,250	0.0946	118.19	-	(1,257)	1,976	-	719	0.0946
2032	-	(726)	1,976		1,250	0.0829	103.67	-	(1,257)	1,976	-	719	0.0829
2033	-	(726)	1,976		1,250	0.0728	90.94	-	(1,257)	1,976	-	719	0.0728
Totals	(4,042)	(14,518)	39,515	-	20,955		4,236	-	(25,140)	39,515	-	14,375	

Figure 20: Excel Model, New Facility, Investment, Expenses, Income. (Appendix I)

	Alt. A vs. Status Quo	
Year (n)	Difference in Cash Flow	Difference in Present Values
0	(4,042.15)	(4,042.15)
1	531.09	465.87
2	531.09	408.65
3	531.09	358.47
4	531.09	314.45
5	531.09	275.83
6	531.09	241.96
7	531.09	212.24
8	531.09	186.18
9	531.09	163.31
10	531.09	143.26
11	531.09	125.66
12	531.09	110.23
13	531.09	96.69
14	531.09	84.82
15	531.09	74.40
16	531.09	65.27
17	531.09	57.25
18	531.09	50.22
19	531.09	44.05
20	531.09	38.64
Totals	6,580	(525)
	12%	(525)
	IRR	ANV

Figure 21: Excel Model, New Facility, IRR, VAN. (Appendix I)

4.2.2 IRR and VAN of Alternative II: Co-generation Pipeline and Storage Tank Scenario

Now that all of the factors have been determined the numbers can be put into the economic analysis to determine the potential for this alternative against the current operation. Here are the numbers for alternative II:

Fiscal Year	Alternative A A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value
2013	(4,151)	-	-	-	(4,151)	1.0000	(4,150.93)
2014	-	(321)	1,976	-	1,655	0.8772	1,451.83
2015	-	(321)	1,976	-	1,655	0.7695	1,273.53
2016	-	(321)	1,976	-	1,655	0.6750	1,117.14
2017	-	(321)	1,976	-	1,655	0.5921	979.94
2018	-	(321)	1,976	-	1,655	0.5194	859.60
2019	-	(321)	1,976	-	1,655	0.4556	754.03
2020	-	(321)	1,976	-	1,655	0.3996	661.43
2021	-	(321)	1,976	-	1,655	0.3506	580.21
2022	-	(321)	1,976	-	1,655	0.3075	508.95
2023	-	(321)	1,976	-	1,655	0.2697	446.45
2024	-	(321)	1,976	-	1,655	0.2366	391.62
2025	-	(321)	1,976	-	1,655	0.2076	343.53
2026	-	(321)	1,976	-	1,655	0.1821	301.34
2027	-	(321)	1,976	-	1,655	0.1597	264.33
2028	-	(321)	1,976	-	1,655	0.1401	231.87
2029	-	(321)	1,976	-	1,655	0.1229	203.40
2030	-	(321)	1,976	-	1,655	0.1078	178.42
2031	-	(321)	1,976	-	1,655	0.0946	156.51
2032	-	(321)	1,976	-	1,655	0.0829	137.29
2033	-	(321)	1,976	-	1,655	0.0728	120.43
Totals	(4,151)	(6,414)	39,515	-	28,951		6,811

Figure 22: Alt A Economic Analysis (appendix J)

The economic numbers shown in blue on Figure 22 are for the alternative and were compared to the status quo's numbers which are shown in Figure 23:

Status Quo						
A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value
-	-	-	-	-	1.0000	-
-	(1,257)	1,976	-	719	0.8772	630.53
-	(1,257)	1,976	-	719	0.7695	553.09
-	(1,257)	1,976	-	719	0.6750	485.17
-	(1,257)	1,976	-	719	0.5921	425.59
-	(1,257)	1,976	-	719	0.5194	373.32
-	(1,257)	1,976	-	719	0.4556	327.47
-	(1,257)	1,976	-	719	0.3996	287.26
-	(1,257)	1,976	-	719	0.3506	251.98
-	(1,257)	1,976	-	719	0.3075	221.04
-	(1,257)	1,976	-	719	0.2697	193.89
-	(1,257)	1,976	-	719	0.2366	170.08
-	(1,257)	1,976	-	719	0.2076	149.19
-	(1,257)	1,976	-	719	0.1821	130.87
-	(1,257)	1,976	-	719	0.1597	114.80
-	(1,257)	1,976	-	719	0.1401	100.70
-	(1,257)	1,976	-	719	0.1229	88.33
-	(1,257)	1,976	-	719	0.1078	77.49
-	(1,257)	1,976	-	719	0.0946	67.97
-	(1,257)	1,976	-	719	0.0829	59.62
-	(1,257)	1,976	-	719	0.0728	52.30
-	(25,139)	39,515	-	14,376		4,761

Figure 23: Status Quo Economic Analysis (appendix J)

The results for the comparison of the co-generation alternative and the status quo are shown in Figure 24, which provides the internal rate or return and the actual net value for the comparison:

	Alt. A vs. Status Quo	
Year (n)	Difference in Cash Flow	Difference in Present Values
0	(4,150.93)	(4,150.93)
1	936.29	821.30
2	936.29	720.44
3	936.29	631.97
4	936.29	554.36
5	936.29	486.28
6	936.29	426.56
7	936.29	374.17
8	936.29	328.22
9	936.29	287.92
10	936.29	252.56
11	936.29	221.54
12	936.29	194.33
13	936.29	170.47
14	936.29	149.53
15	936.29	131.17
16	936.29	115.06
17	936.29	100.93
18	936.29	88.54
19	936.29	77.66
20	936.29	68.13
Totals	14,575	2,050
	22%	2,050
	IRR	ANV

Figure 24: Alt A vs. Status Quo IRR and ANV (Appendix J)

These results show that alternative A is a profitable alternative. With an IRR of 22% which is 8% over 14%, which is breaking even, the project is economically feasible. And the ANV is $2,050,00 which is the present day value of this project to the ACP. With a sensitivity analysis done to see the maximum investment allowable and still have an IRR over 14%, it showed that the total investment could amount to $5,750,000 while still obtaining an IRR of 15%. (Appendix K) This further shows the profitability and stability of this project.

Chapter 5: Conclusion and Recommendations

Based on the alternative scenarios that were evaluated during this study, it was determined that recommendations would be based on current and future conditions. The first section will discuss the results of the new facility analysis and provide recommendations for the ACP to consider when seeking replacement of the current Balboa facility systems. The second section will discuss the results of implementing a cogeneration pipeline and storage tank from Miraflores to Balboa and provide recommendations that the ACP may consider when planning for projected future replacement and increases of the system.

5.1 Alternative I: New Facility Scenario

Our minimum acceptable rate of return was set at 14%. With a an internal rate of return of only 12%, Figure 21 tells us that over the next 20 years the ACP would actually lose many and has an actual net value of negative $525,000 if they were to pursue an investment in a new facility. A less conservative assessment can be made that would reduce the initial investment and expense calculations, but when we inputted this lower investment value as three million dollars, we still only get a rate of return that is not comparable to that of the cogeneration scenario. In our opinion this option is not worth further investigation, when there is a more profitable and over beneficial option available.

5.2 Alternative II: Co-generation Pipeline and Storage Tank Scenario

With a rate of return of 22% shown in Figure 24, a pipeline with the use of co-generation proves to be the best option for future analysis at the ACP. With an actual net value of $2,050,000 and a positive investment over the next twenty years the project looks to be a profitable and safe endeavor. A sensitivity analysis was also calculated for this scenario and initial investment cost of $5,750,000 would still net an internal rate of return of 15%. (Appendix L). This means that the project has a fairly high safety net for profitability, and further proved to us the potential in this project. The cost analysis shows that this project is a worthy investment but there are also other factors that contribute to make this an even better overall project.

The pipeline will be traversing an approximately 6 kilometer route through a fairly dense area that includes many complexes and other potential clients. Without the pipeline these clients are unreachable, but with the pipeline passing through the area, the possibility of new customers and further potential revenue generation becomes a factor. Because cogeneration is a highly efficient process and the absorption chillers require minimal electricity, the production of more chilled water just becomes a matter of capacity. If the facility is built with the three 800 ton chillers, that we have done our analysis for, the ACP will already have excess production available to provide for some new clientele. This requires further more detailed analysis but the potential is only provided with the construction of this pipeline. The other factor is the ACP will be using waste heat that currently is being released to the environment. This would be a positive environmentally conscious move for the ACP, and help show that ACP's commitment to improving the environment as well as significantly improving the efficiency of their operations. Our final recommendation is for the ACP to further investigate the Co-generation pipeline scenario to further economic gain and to improve the environmental impacts of their production.

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CANAL DE PANAMÁ

Chapter A ANÁLISIS DE PREFACTIBILIDAD PARA UNA PLANTA DE AGUA FRÍA

Índice de Contenidos

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Introducción

La Autoridad del Canal de Panamá genera energía eléctrica de fuentes hídricas y térmicas para autoconsumo y venta del excedente. A la vez produce y vende agua fría para sistemas de refrigeración en el área de Balboa. Sin embargo, en vista de la posibilidad de una reubicación de las instalaciones hacia el área de Red Tank, surge la necesidad de evaluar nuevas alternativas a los sistemas convencionales. Adicionalmente, en años anteriores se propuso y evaluó la conveniencia de un sistema central de agua fría para Corozal Oeste y posteriormente la alternativa de producir el agua fría por cogeneración con el calor residual de la Termoeléctrica de Miraflores.

Actualmente, Corozal Oeste cuenta con instalaciones que son refrigeradas mediantes sistemas convencionales, o de expansión directa. Esto representa un elevado consumo de electricidad lo cual reduce la cantidad de energía a vender en el mercado eléctrico nacional. Por esta razón es importante evaluar tecnologías a escala que permitan reducir el consumo de energía dando margen a una mayor venta de electricidad en el mercado eléctrico y a la vez una disminución en costos operativos.

Este informe analiza la viabilidad de incluir en el diseño de las nuevas instalaciones de la ACP en Red Tank, una planta de agua fría capaz de abastecer todas nuestras instalaciones en sitio, y a la vez vender agua fría a Ciudad del Saber.

Metodología del Análisis

Se realizó un análisis comparativo para evaluar un escenario convencional de refrigeración por expansión directa versus una red urbana de frío que brinda la posibilidad de desarrollar nuevas líneas de negocio. Además, que permita aprovechar las ventajas por cogeneración en la termoeléctrica de Miraflores. Con esta información, se podrá determinar la rentabilidad económica de integrar la planta de agua fría a las nuevas instalaciones.

El análisis se efectuó con los siguientes pasos:

Definición de varias alternativas de comparación.

Evaluación de costos unitarios en base a listados de precios de los principales fabricantes de equipos para redes urbanas de agua fría y expansión directa

Estimación de capacidades requeridas utilizando estándares de ASHRAE y otras fuentes de información como referencias.

Estimación de costos capitales, costos fijos y costos operativos.

Elaboración del análisis económico.

Conclusiones y recomendaciones.

Definición de alternativas

Se parte sobre la base de que la mejor opción para climatización en la ACP para un conjunto de edificios consiste en un sistema central de agua fría. Esto se contrasta con un escenario convencional hipotético (status quo) en el análisis económico utilizando sistemas de expansión directa tipo Split. Tal premisa se propone para Red Tank por muchas razones como la eficiencia, confiabilidad, control y economía de escala. Sin embargo, existen diversas alternativas para un sistema central de agua fría, resumidas en la **Tabla 1**. Además del status quo y la opción de mini plantas (Alternativa A), en este análisis, se han definido dos opciones para un sistema de agua fría central: (Alternativa B) Un sistema convencional con chillers eléctricos limitado al área de Red Tank, (Alternativa C) Un sistema central de frío con cogeneración desde Miraflores que abastezca a Red Tank. De estas opciones, cabe la posibilidad de crear (Alternativa D) una red urbana de frío con chillers eléctricos en Red Tank y con ventas a Ciudad del Saber o (Alternativa E) un sistema con chillers eléctricos y cogeneración desde la Termoeléctrica de Miraflores para Red Tank y con ventas a Ciudad del Saber.

Status Quo o escenario de comparación[1]	**Alternativa A**[2]	**Alternativa B**[3]	**Alternativa C**[4]	**Alternativa D**[5]	**Alternativa E**[6]
Escenario hipotético con Sistemas de Expansión Directa	Sistema de mini plantas de expansión directa refrigeradas por agua.	Sistema central de agua fría por chillers eléctricos para Red Tank	Sistema central de agua fría por cogeneración (100%) para Red Tank	Sistema de agua fría por chillers eléctricos para Red Tank con ventas a Ciudad del Saber	Sistema de agua fría por cogeneración (50/50 eléctrico y absorción) para Red Tank con ventas a Ciudad del Saber

Tabla A Alternativas para Red Tank

Notas:

Escenario hipotético con sistemas de expansión directa enfriado por aire (status quo). Se basa en la suposición hipotética de que todo el aire acondicionado se pueda abastecer con sistemas tipo Split.

Sistema de mini plantas de agua fría enfriadas por aire, por edificio o grupo de edificios.

Sistema convencional con chillers eléctricos enfriados por agua. Este sistema sólo proveería agua fría a las instalaciones de Red Tank y no ofrece la oportunidad de venta del excedente. Requiere electricidad, como fuente energética.

Sistema de agua fría por cogeneración con chillers de absorción o adsorción. Existen múltiples ejemplos en el mundo de estos sistemas y se sugiere como una prioridad en la estrategia energética de la Agencia Internacional de Energía[1] por su impacto positivo en la eficiencia energética y cambio climático. Esta opción se basa en ubicar una planta de producción de agua fría en la Termoeléctrica de Miraflores para aprovechar el calor residual en cogeneración. Como fuente energética se ha definido un 100% por cogeneración y equipos de back up capaces de proveer el 100% por electricidad.

[1] Cogeneration and District Energy - Sustainable Energy – IEA. www.iea.org/files/CHPbrochure09.pdf

Un sistema con chillers eléctricos con servicio a Red Tank y Ciudad del Saber. Esto permitiría generar ingresos con la planta de agua fría a ubicar en Red Tank, similar al caso de la planta de agua fría de Balboa.

Una red distrital por chillers eléctricos y cogeneración que proveería agua fría a Red Tank y vendería a Ciudad del Saber sin descartar la oportunidad de expansión a otros clientes. Como fuente energética, se asume 50% por cogeneración y 50% por electricidad.

Estimación de la Demanda de Aire Acondicionado

Para edificios de oficinas de media ocupación, la ASHRAE recomienda una tasa de climatización de 280 (Sq-ft / Ton) pies cuadrados por cada tonelada de capacidad instalada.[2] Este valor coincide cercanamente con la capacidad promedio del sistema de agua fría de Balboa. De acuerdo a la data de la Planta de Agua Fría de Balboa, se ha calculado que la ACP instala 1 tonelada por cada 270 ft^2 de superficie[3]. En este caso, la demanda estimada para el complejo de Red Tank es de 2,191.22 Tons de refrigeración; ya que, el plan maestro para Red Tank, estima que se deben climatizar 57,000 m^2 (aproximadamente 614,000 ft^2) de área, que se desglosa en la **Tabla 3.** No obstante, el análisis se realizará con una capacidad instalada de 3,000 toneladas asumiendo la oportunidad de futuras expansiones y capacidad de respaldo.

Cálculos de Toneladas de refrigeración a instalar			
Según ASHRAE, para oficinas de ocupación media se necesitan			
280 ft2 / Ton de superficie climatizada			
Sitio	**Area m2**	**Area ft2**	**Toneladas**
Complejo Administrativo	25,000.00	269,097.75	961.06
Almacénes y Depósitos	24,000.00	258,333.84	922.62
Talleres, Producción y Laboratorios	8,000.00	86,111.28	307.54
Total	**57,000.00**	**613,542.87**	**2,191.22**

Tabla B Capacidad de refrigeración estimada para Red Tank

Valores de referencia para el cálculo de costos, eficiencias de equipos y vida útil

La **Tabla 2** resume los costos de referencia para equipos. Para realizar los cálculos de consumo, eficiencia y costos de las diversas alternativas, se utilizaron varias referencias de proveedores y normas vigentes. En el caso de los sistemas de bombeo y torres de enfriamiento, se utilizaron los precios de

[2] HVAC Refresher Refresher – Facilities Standard for the Building Services (Part 1) http://www.trane.com/commercial/uploads/pdf/865/ctv-trt-001-en.pdf

[3] Email enviado a Eric Admade por Urho Gonzal, 23/3/2012, Tema: pie2/ton refrig -- RE: facturación, toneladas instaladas por edificio. Ver anexo G.

referencia provistos por TRANE[4], para la tubería se obtuvo una cotización de OTEK-Internacional y para los chillers se utilizaron los precios de referencia RETSCREEN International[5]. En base a una demanda estimada de 3000 Tons de refrigeración para Red Tank y 3000 para Ciudad del Saber, se selecciona una tubería de 16 pulgadas para abastecer de agua fría a cada circuito. El cálculo para Ciudad del Saber se debe a un análisis preliminar ejecutado por un consultor que estimó que la capacidad instalada es de 1,600 Toneladas y que con el tiempo, esta puede crecer hasta 2,800 Toneladas.

Equipos	**Costos**
Tubería de 16 pulgadas[6]	B/.63.33/ m lineal
Bombas	B/.250.00 / HP
Chillers	
Centrifugo (600 – 1400 Tons)	B/. 600 / Ton
Absorción (350-1000 Tons)	B/. 1,200 / Ton
Torres de Enfriamiento	B/.55.00 / GPM
Expansión Directa (aire)	B/. 522.94
Expansión Directa (agua)	B/. 1,172.10

Tabla C Costos de inversión para equipos

Para los sistemas por expansión directa enfriados por aire, se estiman unos precios de mercado de B/.522.94por Tonelada.[7] Para los sistemas de expansión directa enfriados por agua, el costo por Tonelada es de B/. 1,172.10.[8] La capacidad instalada se obtiene con la superficie de trabajo que será climatizada.

En el caso de la nueva planta de agua fría, se ha optado por establecer una diferencia de temperatura (Delta T, ΔT) de 14°F ya que a mayor diferencia de temperatura (salida vs retorno), menor es el diámetro requerido para la tubería y mayor eficiencia se obtiene en los sistemas. Además a mayor Delta T, menor es el flujo de agua requerido ya que hay un mayor intercambio de calor, y por ende, menores son los costos en bombeo e inversiones en tubería.

Para el análisis técnico de los sistemas es importante notar que no se incluyen los costos en ductos internos para ninguno de los casos ya que los mismos varían de acuerdo a la edificación y se puede asumir que sus costos son similares, independientemente del tipo de tecnología a utilizar.

En cuanto a las eficiencias, la norma ASHRAE 90.1 -2007 establece los requisitos mínimos para la eficiencia de los sistemas de aire acondicionado **(Tabla 4)**. Para sistemas de expansión directa por aire, igual o de más de 63 Toneladas, deberán tener un EER mínimo de 9.7. Haciendo la conversión a COP (COP = EER/3.412), este debe ser de al menos 2.84. Para sistemas de expansión directa por agua, igual o de más de 20 Toneladas, deberán tener un EER mínimo de 11.0 o un COP de 3.22. Para una planta de agua fría con chillers eléctricos centrífugos, el COP mínimo debe ser de 6.10. En el caso de la planta de

[4] Trane Quick Reference for Efficient Chiller System Design. http://www.trane.com/commercial/uploads/pdf/865/ctv-trt-001-en.pdf
[5] RETSCREEN INTERNATIONAL desarrollado por Natural Resources Canada.
~~[6] Cotización provista por O-Tek Internacional S.A.~~
[7] Cifras provistas por Angélica Wong, Contrato Corporativo para unidades minisplit.
[8] Cotización presentada por Alex Villarreta, LG Electronics Panamá, 16/04/2012.

agua fría por cogeneración, el COP para los chillers eléctricos es de 6.10 mientras que para los de absorción es de un mínimo de 1.00.

Tecnología	**Minimum Coefficient of Performance (COP)**
Expansión directa por aire.	2.84
Expansión directa por agua	3.22
Planta central de agua fría con chillers eléctricos	6.10
Planta central de agua fría con chillers de absorción o adsorción.	1.00

Tabla D COP para diversas tecnologías según norma ASHARE 90.1-2007

A pesar de que el COP de los chillers de absorción es menor, estos son más convenientes ya que utilizan energía o calor residual, cuya energía no tiene costo debido a que de otra manera dicho calor se vierte al ambiente. Este ahorro se refleja en los costos de energía anuales detallados en este documento. Es importante señalar que los chillers de absorción, al igual que los de adsorción, tienen un funcionamiento muy similar, lo que hace ambas tecnologías factibles. Además, ambas presentan costos de inversión iniciales muy similares. Queda analizar a un nivel técnico más profundo, cuál de las dos alternativas es más viable para la ACP.

Es importante tomar en cuenta que estudios realizados por ASHRAE[9] señalan que los sistemas por expansión directa pierden entre el 14 a 16% de su eficiencia luego de 4 años de uso y pueden llegar a un pico de entre el 30 a 40% en un período de 20 años puesto que a partir del 3 año pierden el 2% anual de su eficiencia original. Esto se debe a que los compresores de dichos equipos utilizan aceites que eventualmente escapan de su circuito y se mezclan con el refrigerante el cual recorre todo el sistema de refrigeración. Este causa acumulaciones de aceite y escorias (fouling) y obstruye las líneas lo cual reduce significativamente el desempeño de dichos equipos. Esta pérdida se refleja en el análisis económico de las alternativas Status Quo y A.

Información relevante para el Análisis Económico

La comparación de los sistemas de agua fría versus los de expansión directa requiere de un análisis por consumo de energía para períodos de vida similares. En un análisis de este tipo, las variables de mayor importancia, además de la inversión inicial, son:

Los costos de operación relacionados con el consumo de energía eléctrica para ambos sistemas.

Los costos de mantenimiento que incluyen mano de obra, piezas y limpieza.

La eficiencia de los sistemas a gran escala como una planta de agua fría, cuyo COP (Coefficient of Performance) se encuentra en torno a 6.0, mientras que para los sistemas de expansión directa típicos el COP es de 2.7. Debido a que la ACP está comprando unidades de expansión directa con inverter, el COP e de 3.52. El COP indica la eficiencia energética de los equipos de refrigeración; mientras mayor el COP,

[9] Air Conditioning and Refrigeration Systems Oil Fouling, ASHARE Newsletter 11-24-2005.

mejor desempeño[10]. Adicionalmente, se realiza una corrección progresiva por la pérdida de eficiencia en los sistemas de expansión directa.

Debido a que el futuro de Red Tank aún es incierto, se plantean varios escenarios para análisis a fin de determinar cuál es el más beneficioso para la ACP. Los escenarios identificados se detallan en la **Tabla 1**.

Para los sistemas de agua fría, es importante tomar en cuenta que los mayores costos en la inversión se darán en tres elementos que son:

Tuberías

Bombas

Chillers

Los costos de la tubería dependerán de la distancia así como del diámetro de las mismas. Además, se incluyen costos adicionales como el aislamiento y la obra civil para enterrar las mismas. Los costos para las bombas dependen igual de la distancia a la cual se desea enviar el agua así como el flujo deseado. Todos estos valores se determinan con parámetros de diseño.

Las distancias estimadas para los sitios de interés (partiendo de Miraflores) son:

Tramo interno en Red Tank: 1 km

Tramo hacia Red Tank: 2.5km

Tramo hacia Ciudad del Saber: 0.42 km

La **Tabla 5** establece los criterios para la selección de caudales y diámetros de tubería, en base a la demanda de refrigeración calculada[11].

[10] ASHRAE 90.1 -2007, pág. 43-44, 46.
[11] Trane Quick Reference for Efficient Chiller System Design.
http://www.trane.com/commercial/uploads/pdf/865/ctv-trt-001-en.pdf

TRANE

Water Piping Capacity (Tons)

Pipe Size	GPM Price* Pump**	Chilled Water 20°ΔT 1.2 GPM/Ton	18°ΔT 1.33 GPM/Ton	16°ΔT 1.5 GPM/Ton	14°ΔT 1.7 GPM/Ton	12°ΔT 2 GPM/Ton	10°ΔT 2.4 GPM/Ton
48	60,000 GPM	50,000	45,000	40,000	35,000	30,000	25,000
	$450/ft 195 HP	40,000	36,000	32,000	28,000	24,000	20,000
42	40,000 GPM	33,300	30,000	26,600	23,300	20,000	16,600
	$400/ft 115 HP	26,600	24,000	21,300	18,600	16,000	13,300
36	30,000 GPM	25,000	22,500	20,000	17,500	15,000	12,500
	$350/ft 110 HP	20,000	18,000	16,000	14,000	12,000	10,000
30	20,000 GPM	16,600	15,000	13,300	11,600	10,000	8,300
	$300/ft 80 HP	13,300	12,000	10,650	9,300	8,000	6,600
24	12,000 GPM	10,000	9,000	8,000	7,000	6,000	5,000
	$250/ft 45 HP	8,000	7,200	6,400	5,600	4,800	4,000
20	8,000 GPM	6,650	6,000	5,300	4,650	4,000	3,300
	$225/ft 32.2 HP	5,300	4,800	4,250	3,700	3,200	2,650
18	7,000 GPM	5,800	5,250	4,650	4,050	3,500	2,900
	$200/ft 37.6 HP	4,650	4,200	3,700	3,250	2,800	2,300
16	6,000 GPM	5,000	4,500	4,000	3,500	3,000	2,500
	$175/ft 43.5 HP	4,000	3,600	3,200	2,800	2,400	2,000

Tabla E Capacidades, en toneladas, para Tuberías de Agua Fría

Es importante notar que la tabla nos indica el flujo o caudal permisible en base al diámetro de la tubería así como el costo estimado por pie de tubería instalado. Para la tubería de 16 pies, el caudal es de 6,000 GPM (galones por minuto) mientras que el costo cotizado para tubería de fibra de vidrio con O-Tek Internacional es de B./ 63.33 por metro lineal (ver **Anexo A**). Este costo no incluye los materiales y soterramiento de la tubería. La tubería soterrada implica un 35% del costo de la misma.

En cuanto a la potencia necesaria para bombeo, esta se obtiene calculando las perdidas por fricción en la tubería además de las perdidas en altura por el recorrido de la misma. Estas pérdidas dependen del diámetro de la tubería, la distancia, la aspereza interna de la misma y el caudal. Para los sitios de interés se realizaron estos cálculos obteniendo diversas potencias de bombeo (estimando una eficiencia global de 76% (80% mecánica, 95% eléctrica). Las potencias de bombeo dependen de la configuración del sistema (ver **Anexo D**).

Para los chillers, los cálculos se hacen en base al tonelaje de la planta. Debido a que estos se venden por tonelaje, calcular el número de chillers necesarios depende del modelo y fabricante de los mismos. Como referencia se escogieron chillers centrífugos eléctricos de 1,000 Toneladas cada uno y chillers de absorción por cogeneración de 1,000 Toneladas cada uno. Eso equivaldría a:

Red Tank aislado: 3 chillers centrífugos eléctricos de 1,000 Tons cada uno para un total de 3000 Tons instaladas.

Red Urbana de frío entre Red Tank –Ciudad del Saber (sin cogeneración): 6 Chillers eléctricos de 1,000 Tons cada uno para un total de 6,000 Tons instaladas.

Red Tank Aislado (Cogeneración): 3 Chillers de absorción de 1000 Tons para un total de 3,000 Tons instaladas.

Red Tank – Ciudad del Saber Distrital (50% Eléctrico y 50% Cogeneración): 3 chillers eléctricos centrifugos de 1,000 Tons y 3 chillers de absorción de 1,000 Tons para un total de 6,000 Tons instaladas.

Finalmente, para los costos e ingresos por energía, se utilizan como referencia las actuales tarifas por potencia y demanda de electricidad y agua fría. Los cargos son los siguientes:

Costo de la electricidad: B/. 0.10 / kWh en base al costo de oportunidad de la energía eléctrica de la ACP.

Cargo por tonelada Instalada de agua fría por mes: B./ 15.81 / Ton.

Cargo por consumo medido de agua fría: B./ 0.1221 Ton-hr.

En adición a los costos de equipos, se incluye el costo de instalación, expresado como un 40% del total de los mismos.

Análisis Económico

La Tabla 6 **resume el análisis económico (ver** Anexo F**) de las Alternativas presentadas y seguidamente se discuten los detalles de cada escenario.** Me gustaría que esta tabla desglose todos los costos renglón por renglón para cada columna (costo por equipos, bombas, tubería; y, electricidad por bombas y chillers, etc.)

	Alternativas						
	Status Quo	A	B	C	D	E	F
	Expansión directa enfriada por aire	Mini centrales de agua fría enfriadas por agua	Planta Central de Agua fría por chillers eléctricos	Planta Central de Agua fría por cogeneración	Red Urbana de frío con chillers eléctricos Red Tank/CDS	Red Urbana de frío con 50% cogeneración Red Tank /CDS	Red Urbana de frío con 100 % cogeneración Red Tank /CDS
Costos Capitales							
Inversión	**B/. 1,568,820.00**	**B/. 3,516,295.13**	**B/. 3,529,766.30**	**B/. 6,055,315.60**	**B/. 7,861,350.07**	**B/. 8,786,311.95**	**B/. 10,080,061.95**
Costos Operativos							
Electricidad	B/. 1,039,903.22	B/. 731,467.68	B/. 436,379.83	B/. 47,450.47	B/. 888,623.49	B/. 424,302.19	B/. 58,641.48
Mantenimiento	B/. 39,750.00	B/. 39,750.00					
Recurso Humano			B/. 167,447.45	B/. 167,447.45	B/. 167,447.45	B/. 167,447.45	B/. 167,447.45
Depreciación							
Total	**B/. 1,079,653.22**	**B/. 771,217.68**	**B/. 603,827.28**	**B/. 214,897.92**	**B/. 1,056,070.94**	**B/. 591,749.64**	**B/. 226,088.93**
Ingresos							
Por Demanda					B/. 569,160.00	B/. 569,160.00	B/. 569,160.00
Por Consumo					B/. 808,790.40	B/. 808,790.40	B/. 808,790.40
Total					**B/. 1,377,950.40**	**B/. 1,377,950.40**	**B/. 1,377,950.40**
Rentabilidad							
TIR		23%	39%	26%	27%	30%	30%
VAN (miles)		1,130	3,702	3,753	5,502	7,652	8,780
Toneladas	3000	3000	3000	3000	6000	6000	6000
Costo por Tonelada	B/. 522.94	B/. 1,172.10	B/. 1,176.59	B/. 2,018.44	B/. 1,310.23	B/. 1,464.39	B/. 1,680.01

Tabla F Tabla comparativa por escenario

Alternativa A:

El escenario compara un sistema de expansión directa con mini plantas de expansión directa enfriadas por agua. Ambos sistemas tendrían el mismo tonelaje (3,000 Tons). La diferencia entre ellos recae en que las mini plantas son agrupadas por edificios mientras que las unidades de expansión directa son independientes cada una. Además los costos de instalación de los equipos de expansión directa suelen ser mayores debido a las modificaciones hay que hacer para instalar cada una a la edificación. La inversión inicial para un sistema de expansión directa es de B/. 1,568,820.00, repetitiva a cada 4 años mientras que para las mini plantas de agua fría es de B/. 3,516,295.13 Tomando en cuenta los gastos operativos anuales y la inversión requerida, se obtiene una TIR del 35 % y el VAN es de B/. 2,198,000.00. Esto se debe a que la inversión inicial es más significativa que el ahorro en energía. Es importante tener en cuenta que los equipos de expansión directa deben ser reemplazados cada 4 años ya que empiezan a presentar fallas productos del uso excesivo y su eficiencia ha disminuido considerablemente. Estos ciclos de uso son consistentes con la experiencia de la ACP en los contratos de aires tipo split y la garantía de dichos equipos. Para las mini plantas, se estima una pérdida de eficiencia de hasta el 40% a los 8 años de operación. Su reemplazo se estima será a los 20 años.

Por simplicidad, se asume que el costo eléctrico del enfriamiento por agua es similar al costo eléctrico de una torre de enfriamiento.

Alternativa B:

El escenario compara una planta de agua fría convencional (3,000 Tons) ubicada en Red Tank (circuito aislado) contra un sistema de expansión directa. Debido a que es un sistema convencional, la planta en Red Tank lleva torres de enfriamiento. Todos estos equipos representan una inversión de B./ 3,529,766.30. Tomando en cuenta los gastos operativos y mantenimiento, en comparación los sistemas de expansión directa, la TIR es de 56% y el VAN de B/. 4,691,000.00.

En este escenario falta calcular el costo de electricidad de la torre de enfriamiento (incluye el bombeo y los abanicos).

Alternativa C:

Para este escenario, se contempla una planta de agua fría (3,000 Tons) con cogeneración al 100% en Miraflores, que abastezca Red Tank. Se utilizan los mismos equipos con la única diferencia de que no hay torres de enfriamiento ya que el agua para refrigerar los chillers sería mediante gravedad. Para este sistema, la planta conllevaría una inversión inicial de B./ 6,764,065.60. La diferencia en costos se debe a aumentos significativos en tubería debido a una mayor distancia desde el punto de entrega así como en los sistemas de bombeo. Además, este sistema por cogeneración es más costoso ya que utiliza una tecnología que aprovecha el calor residual de las máquinas a combustión de la termoeléctrica y lleva un sistema de chillers eléctricos de backup en caso tal haya problemas con las máquinas térmicas. Los chillers por cogeneración de 2 etapas cuestan el doble de los eléctricos (B./ 1,200.00 / Ton). Aquí es mejor usar el costo de AD que es de $1031 por ton segun cotizacion de HIJC USA, Inc. Cabe resaltar que los costos operativos de una planta por cogeneración son menores debido al menor uso de electricidad (ver **Anexo B**). No obstante, la elevada inversión inicial de esos sistemas, el menor costo energético hace que la TIR sea del 28% y tenga un VAN de B/. 3,993,000.00.

En cuanto a costos operativos, el sistema convencional de agua fría utiliza más energía ya que necesita de electricidad para los chillers y torres de enfriamiento. Anualmente los costos operativos en energía se estiman en aproximadamente B./ 380,219.83. En cambio, el sistema al 100% en cogeneración solo consume cerca de B./ 47,450.47 que son gastos producto del sistema de bombeo.

Alternativas D y E:

Estos escenarios contemplan incluir clientes externos. Puesto que la infraestructura ya estaría disponible y un aumento en la escala de los sistemas solo representa una inversión adicional en los equipos más no en el personal. Por lo tanto, cabe evaluar que ganancias o beneficios generaría un cliente externo para ambos sistemas de agua fría, tanto por chillers eléctricos como por cogeneración.

Ampliando el segundo escenario (Alternativa C) a una red distrital con chillers eléctricos, similar a la actual planta de agua fría de Balboa, se obtiene una mayor rentabilidad en la producción de agua fría. Si usamos la tarifa actual de B/. 15.81 / Ton instalada y B/. 0.1221 Ton –hr, se obtienen ingresos anuales estimados en B/. 1,377,950.40 para 3,000 (ver **Anexo C**) Toneladas comercializadas. La inversión requerida para la red distrital sería de B/. 7,861,350.07 lo que implica una inversión adicional de B/. 4,331,583.77. Esto resulta en una TIR del 33% y VAN de B/. 3,573,000.00 para la inversión adicional a realizar.

En el escenario D falta calcular el costo de electricidad de la torre de enfriamiento (incluye el bombeo y los abanicos).

En el caso del tercer escenario, se propone convertirlo a una red distrital con cogeneración. Utilizando la tarifa vigente, los ingresos anuales serían de B/. 1,377,950.40 para 3,000 Toneladas comercializadas. La inversión requerida para una red distrital por cogeneración sería de B/. 9,495,061.95 que representa una inversión adicional de B/. 2,730,996.35. Esta inversión genera una TIR del 79% y VAN de B/. 5,358,000.00 por la inversión adicional requerida para la red distrital.

Conclusiones

Luego de un minucioso análisis de las alternativas presentes para un sistema de refrigeración para las nuevas instalaciones en Red Tank, se ha determinado que varias opciones son beneficiosas para la ACP, dependiendo del enfoque a tomar. En caso de que se trate un escenario que solo contempla el generar agua fría para consumo propio, una planta de agua fría por chillers eléctricos en Red Tank es la inversión más conveniente. Esto se debe a que la misma se encuentra dentro de las instalaciones lo cual reduce el número de tubería necesaria para el proyecto. Esto produce una TIR del 45% sobre el escenario base siendo la mejor opción para autoconsumo.

En el caso de producir agua fría con fines de comercialización, la opción de una planta de agua fría por cogeneración provee mejor rendimiento que la alternativa de chillers eléctricos. Esto se debe a que se aprovecha el calor residual de la termoeléctrica disminuyendo los gastos anuales en energía. Para este escenario se obtiene una TIR del 65% que es la mejor opción.

En base al VAN la mejor opción resulta ser una red distrital de agua fría por cogeneración ya que el VAN es de B/. 5,358,000.00. La segunda mejor opción es una red aislada de agua fría por chillers eléctricos para Red Tank, que genera un VAN de B/. 3,573,000.00.

Anexo A

Costos de equipos

Table 1: Chiller Selection Criteria

	Centrifugal	**Reciprocating**	**Rotary**	**Absorption**
Description	Variable-volume compression using centrifugal force	Piston-type com-pression, suitable for small and variable loads	Positive displacement compression using two machined rotors	Uses heat in the cycle instead of mechanical compression
Initial cost (per Ton[1] of cooling)	$500–$700	$450–$600	$500–$800	$1,000–$1,400
Maintenance cost	Medium	Higher	Lower	Lower
Appropriate size (Tons of cooling)	90–1000	3–100	20–2000	100–5000
Space requirements, noise, vibration	Small, high-pitched noise, no vibration	Small, high-pitched noise, no vibration	Small, quiet, no vibration	Large, low noise and vibration
1 One Ton of cooling = 12 000 Btu/hr or 3.5 kW of cooling output.				

Tabla A- 1 Costos de inversión para equipos de planta de agua fría (RETSCREEN)

Many chiller manufacturers, including Trane, Carrier, McQuay, Dunham-Bush and York, are well-established companies that produce quality equipment. Before you select a new chiller, ensure that the equipment has the appropriate capacity to handle the desired load.

Chilled Water Plant Costs Estimated

Water chillers (with starters)		
Centrifugal:		
300 to 600 tons		$250/ton
600 to 1400 tons		$240/ton
1500 to 2500 tons		$230/ton
Absorption		
1 stage	90 to 1600 tons	$350/ton
2 stage	350 to 1000 tons	$500/ton
direct-fired	100 to 1100 tons	$525/ton
Rotary Screw		
water cooled	70 to 130 tons	$300/ton
water cooled	150 to 450 tons	$240/ton
air cooled	70 to 400 tons	$420/ton
Setting, rigging, installation		$60/ton
Add 4160 volt motor		$25/kW
Add 0.035 tubes		$7/ton
Add Gas Engine		$450/kW - $500/kW

Pumps (not including VFD or starter)	$200/HP - $300/HP
Cooling Tower	
Normal	$20/gpm - $40/gpm
Permanent	$40/gpm - $75/gpm
Piping	see chart
Controls	$30/ton - $60/ton
Electrical	$130/kW - $360/kW
Plate and Frame Heat exchanger	
unit only	$30/ton - $60/ton
complete installation with piping and simple auto control	$80/ton - $140/ton

Note: These prices are typical construction costs for normal access applications. For total project cost, add fees, testing and contingencies.

Useful Formulas

Pump Hp = (GPM x Total Head in ft. water) / (Pump Eff.x 3960)

kW/ton = 3.516/COP
kW/ton = 12/EER

1 Ton = 12,000 BTU/HR
Tons = (GPM x Δ T x specific heat* x specific gravity*) / 24
* for fluids other than water

GPM $\propto$ RPM
Head $\propto$ RPM^2
Power $\propto$ RPM^3 $\propto$ GPM^3

Example:
Pump HP @ 5,000 gpm = 26.1 HP* x (5,000GPM / 4,000GPM)^3
* pump hp @ 4,000 gpm from water piping capacity chart

Specification Bid Form

Energy cost savings of a high efficiency chiller can be accredited to the chiller in the bid process. The lifetime (or any other span of time) can be used to calculate cost savings for every 0.01 kW/ton better than the base bid chiller.

kW/ton	Purchase Price	Cost Savings	Comparative Cost	
.60 kW/Ton	From vendor	none	base bid	Choose the Best Value
.59 kW/Ton	*	$ savings	(base bid) - ($ savings)	
.58 kW/Ton	*	2 x $ savings	(base bid) - (2 x $ savings)	
.57 kW/Ton	*	3 x $ savings	(base bid) - (3 x $ savings)	
*	*	*	*	
*	*	*	*	
.50 kW/Ton	From vendor	9 x $ savings	(base bid) - (9 x $ savings)	

Energy Cost Savings = 0.01 kW/ton x Chiller Tons x $ / kWh x Equivalent Full Load Hours (per year) x Chiller Lifetime (years)

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TRANE®

Quick Reference for Efficient Chiller System Design

Tabla A- 2 Costos de inversión para planta de agua fría (TRANE)

Costo para mini plantas de agua fría			
Capacidad Instalada		3000.00	Tons
Costo / Ton	Enfr. Agua	B/. 1,500.00	/ Ton
Costo / Ton	Man.	B/. 800.00	/ Ton
Costos Total		**B/. 6,900,000.00**	

Tabla A- 3 Costos de equipos para miniplantas de expansión directa enfriadas por agua.

Costo total para 3000 Toneladas de refrigeración en aislado	
Tuberías	
Red Tank	$ 126,660.00
Aislamiento	$ 188,325.54
Uniones	$ 15,517.24
Chillers 3000 Tons	
Centrifugo	$ 2,100,000.00
Torres de Enfriamiento	$ 372,000.00
Bombas	$ 18,758.86
Subtotal	***$ 2,821,261.64***
Total (Inst. al 40%)	**$ 3,949,766.30**

Tabla A- 4 Costos de una planta de agua fría por chillers eléctricos.

Costo total para 3000 Toneladas de refrigeración por cogeneración en aislado		
Tuberías		
Red Tank		$ 443,310.00
Aislamiento		$ 823,924.24
Uniones		$ 67,887.93
Chillers	3000 Tons	
Centrifugos		
Absorción	3000 Tons	$ 3,600,000.00
Torres de Enfriamiento		$ -
Bombas		$ 61,138.11
SubTotal		***$ 4,996,260.28***
Total (incl. inst. y sot.)		**$ 6,994,764.39**

Tabla A- 5 Costos de una planta de agua fría por cogeneración.

Costo total para 6000 Toneladas en red distrital		
Tuberías		
Red Tank-CDS		$ 496,507.20
Aislamiento		$ 659,139.39
Uniones		$ 60,827.59
Chillers	6000 Tons	
Centrifugo		$ 4,200,000.00
Absorción		$ -
Torres de Enfriamiento		$ 744,000.00
Bombas		$ 54,775.88
SubTotal		***$ 6,215,250.05***
Total (Inst. Al 40%)		**$ 8,701,350.07**

Tabla A- 6 Costo de una red distrital de agua fría por chillers eléctricos.

Costo total para 6000 Toneladas de refrigeración por cogeneración en red		
Tuberías		
Red Tank-CDS		$ 496,507.20
Aislamiento		$ 922,795.15
Uniones		$ 76,034.48
Chillers	6000 Tons	
Centrifugo	3000 Tons	$ 1,800,000.00
Absorción	3000 Tons	$ 3,600,000.00
Torres de Enfriamiento		$ -
Bombas		$ 71,409.31
SubTotal		***$ 6,966,746.14***
Total (Inst. al 40%)		**$ 9,753,444.59**

Tabla A- 7 Costo de una red distrital de agua fría por cogeneración.

Anexo B

Costos Operativos

Consumo de Energía para Sistemas de Expansión Directa							
EER =	12						
COP =	3.52		1 Ton =	12000	BTU/hr		
Días Laborales		260	días				
kW = BTU/hr / 3413*COP							
	Capacidad	**Potencia Elec.**	**Horas de Uso**		**Consumo Elec.**	**Costo**	**Costo Anual**
	Tons	***kW***	***Pico***	***Media Carga***	***kWh***	***B/. / kWh***	***B/.***
Exp. Directa	3000	2999.12	5	3	6238171.70	B/. 0.1667	**B/. 1,039,903.22**

Tabla B- 1 Costo anual de energía para sistema de expansión directa.[12]

Consumo de Energía para Mini plantas enfriadas por agua.							
EER =	11						
COP =	5.00		1 Ton =	12000	BTU/hr		
Días Laborales		260	días				
kW = BTU/hr / 3413*COP							
	Capacidad	**Potencia Elec.**	**Horas de Uso**		**Consumo Elec.**	**Costo**	**Costo Anual**
	Tons	***kW***	***Pico***	***Media Carga***	***kWh***	***B/. / kWh***	***B/.***
Exp. Directa	3000	2109.58	5	3	4387928.51	B/. 0.1667	**B/. 731,467.68**

Tabla B- 2 Costo anual de energía para miniplantas enfriadas por agua.

Consumo de Energía para Chillers Eléctricos							
COP =	6		1 Ton =	12000	BTU/hr		
Días Laborales		260	días				
kW = BTU/hr / 3413*COP							
	Capacidad	**Potencia Elec.**	**Horas de Uso**		**Consumo Elec.**	**Costo**	**Costo Anual**
	Tons	***kW***	***Pico***	***Media Carga***	***kWh***	***$ / kWh***	***$***
Chillers	3000	1757.98	5	3	3656607.09	$ 0.1000	**$ 365,660.71**

Tabla B- 3 Costo anual de energía para chillers eléctricos.

[12] Costo de energía para el año inicial. A partir de este, la eficiencia cae un 7% luego del primer año de uso; 5% el segundo y del tercero en adelante, un 2% anual.

Consumo Eléctrico Bombeo						
Red Tank						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	72795.58	kWh	Costos	$ 7,279.56
50%	10		72795.58	kWh	Anuales	$ 7,279.56
Total			***145591.16***	***kWh***		***$ 14,559.12***
Distrital						
Red Tank						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	181988.96	kWh	Costos	$ 18,198.90
50%	10		181988.96	kWh	Anuales	$ 18,198.90
Subtotal			***363977.91***	***kWh***		***$ 36,397.79***
Ciudad del Saber						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	42921.40	kWh	Costos	$ 4,292.14
50%	10		42921.40	kWh	Anuales	$ 4,292.14
Subtotal			***171685.58***	***kWh***		***$ 8,584.28***

Tabla B- 4 Costo de energía por bombeo para planta de agua fría por chillers eléctricos.

Consumo Eléctrico Bombeo						
Red Tank						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	94900.94	kWh	Costos	$ 9,490.09
50%	10		94900.94	kWh	Anuales	$ 9,490.09
Total			***189801.88***	***kWh***		***$ 18,980.19***
Cogeneración						
Red Tank						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	237252.35	kWh	Costos	$ 23,725.24
50%	10		237252.35	kWh	Anuales	$ 23,725.24
Subtotal			***474504.71***	***kWh***		***$ 47,450.47***
Ciudad del Saber						
	Horas uso	Costo por kWh =	$ 0.1000	/kWh		
Pico	5	Consumo	55955.06	kWh	Costos	$ 5,595.51
50%	10		55955.06	kWh	Anuales	$ 5,595.51
Subtotal			***223820.22***	***kWh***		***$ 11,191.01***

Tabla B- 5 Costo de energía por bombeo para planta de agua fría por cogeneración.

Anexo C

Ingresos Económicos

Ventas a Ciudad del Saber				
Cargo por Tonelada Instalada por mes			$ 15.81	/ Ton
Cargo por consumo medido			$ 0.1221	/ Ton-hr
Demanda Mensual			3000	
Venta por Demanda Mensual			$ 47,430.00	
Venta por Demanda Anual			***$ 569,160.00***	
Consumo Mensual		Pico	345000	
		Media Carga	207000	
Venta por Consumo Mensual			$ 67,399.20	
Venta por Consumo Anual			***$ 808,790.40***	
Venta Total			**$ 1,377,950.40**	

Tabla C- 1 Ingresos anuales por venta de agua fría a Ciudad del Saber

Anexo D

Cálculos de Sistemas de Bombeo

Cálculos para Caudales y Bomba							
	Diametro Tubería	16.00	in				
		0.4064	m				
	Área	0.130	m^2				
	Caudal	4960	GPM	1 GPM =	6.31E-05	m^3/s	
		3.13E-01	m^3/s	1.13E+03	m^3/hr		
	Velocidad =	Caudal / Area					
		2.41	m/s	7.91	ft/s		
Utilizando la tabla 1 de Engineering Piping Design							
Por cada 100 pies hay 0.3 psi en perdidas por fricción				0.3	psi/100ft	Tramos de 100 ft	
	Red Tank Interno	1	km	3,280.83	ft	66	
	Hacia Red Tank	2.5	km	8,202.08	ft	164	
	CDS	0.42	km	1,377.95	ft	28	
Calculando las perdidas por fricción				h = P*2.31/ SG		en metros (m)	
	Red Tank Interno	19.68	psi	45.47	ft	13.9	
	Hacia Red Tank	49.21	psi	113.68	ft	34.6	
	CDS	8.27	psi	19.10	ft	5.8	
Perdidas por Altura (psi)							
Red Tank	0	CDS	0.0	Red Tank Distrital		0.0	
Perdidas Totales							
	Red Tank Interno	19.7	psi				
	Hacia Red Tank	49.2	psi				
	CDS	8.3	psi				
Teniendo el coeficiente se cálcula las perdidas por fricción							
$\Delta h = \lambda*(L*V^2)/(d_h * 2g)$		Δh_{RT} (m) =	13.9	Δh_{CDS} (m) =	5.8	$\Delta h_{RTCoGen}$ (m) =	34.6
Para calcular la potencia necesaria para bombeo, se debe tomar en cuenta las perdidas y diferencial de altura							
$P_h = q*\rho*g*h/3.6*10^6$		**Red Tank Aisl.**		**CDS**		**Red Tank Distrital**	
$h = \Delta h + h_{alt}$		h_{altRT} (m) =	0	h_{altCDS} (m) =	0	h_{altRT} (m) =	0
		h_{RT} (m) =	13.9	h_{CDS} (m) =	5.8	h_{RT} (m) =	34.6
Potencia		P_{hRT} (kW) =	42.56	P_{hCDS} (kW) =	17.87	P_{hRT} (kW) =	106.39
Potencia Eléctrica 3000 T		η_{mec} =	80%	η_{elec}=	95%	η_{elec}=	95%
$P_{elec} = P_h / (\eta_{mec} * \eta_{elec})$		**P_{elecRT} (kW) =**	**56.00**	**$P_{elecCDS}$ (kW) =**	**23.52**	**P_{elecRT} (kW) =**	**139.99**

Tabla D- 1 Potencia de bombeo de planta de agua fría por chillers eléctricos.

Cálculos para Caudales y Bomba							
	Diametro Tubería	16.00	in				
		0.4064	m				
	Área	0.130	m^2				
	Caudal	4850	GPM	1 GPM =	6.31E-05	m^3/s	
		3.06E-01	m^3/s	1.10E+03	m^3/hr		
	Velocidad =	Caudal / Area					
		2.36	m/s	7.74	ft/s		
Utilizando la tabla 1 de Engineering Piping Design							
Por cada 100 pies hay 0.4 psi en perdidas por fricción				0.4	psi/100ft	Tramos de 100 ft	
	Red Tank Interno	1	km	3,280.83	ft	66	
	Hacia Red Tank	2.5	km	8,202.08	ft	164	
	CDS	0.42	km	1,377.95	ft	28	
Calculando las perdidas por fricción				h = P*2.31/ SG		en metros (m)	
	Red Tank Interno	26.25	psi	60.63	ft	18.5	
	Hacia Red Tank	65.62	psi	151.57	ft	46.2	
	CDS	11.02	psi	25.46	ft	7.8	
Perdidas por Altura (psi)							
Red Tank	0	CDS	0.0	Red Tank Distrital		0.0	
Perdidas Totales							
	Red Tank Interno	26.2	psi				
	Hacia Red Tank	65.6	psi				
	CDS	11.0	psi				
Teniendo el coeficiente se cálcula las perdidas por fricción							
$\Delta h = \lambda*(L*V^2)/(d_h * 2g)$		Δh_{RT} (m) =	18.5	Δh_{CDS} (m) =	7.8	$\Delta h_{RTCoGen}$ (m) =	46.2
Para calcular la potencia necesaria para bombeo, se debe tomar en cuenta las perdidas y diferencial de altura							
$P_h = q*\rho*g*h/3.6*10^6$		**Red Tank Aisl.**		**CDS**		**Red Tank Cogen**	
$h = \Delta h + h_{alt}$		h_{altRT} (m) =	0	h_{altCDS} (m) =	0	h_{altRT} (m) =	0
		h_{RT} (m) =	18.5	h_{CDS} (m) =	7.8	h_{RT} (m) =	46.2
Potencia		P_{hRT} (kW) =	55.48	P_{hCDS} (kW) =	23.30	P_{hRT} (kW) =	138.70
Potencia Eléctrica 3000 T		η_{mec} =	80%	η_{elec}=	95%	η_{elec}=	95%
$P_{elec} = P_h / (\eta_{mec} * \eta_{elec})$		**P_{elecRT} (kW) =**	**73.00**	**$P_{elecCDS}$ (kW) =**	**30.66**	**P_{elecRT} (kW) =**	**182.50**

Tabla D- 2 Potencia de bombeo de planta de agua fría por cogeneración.

Anexo E

Balance Energético de Chimeneas

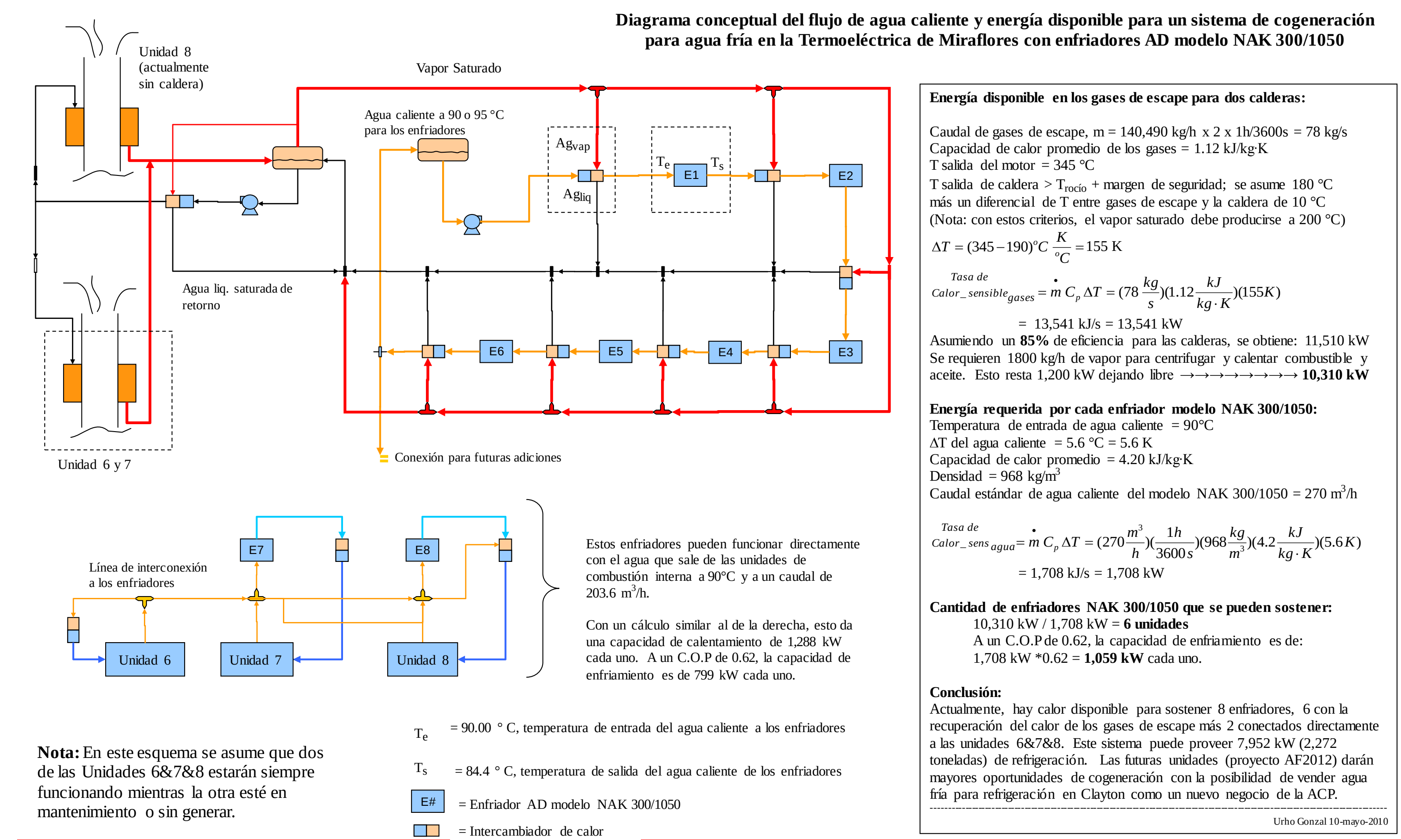
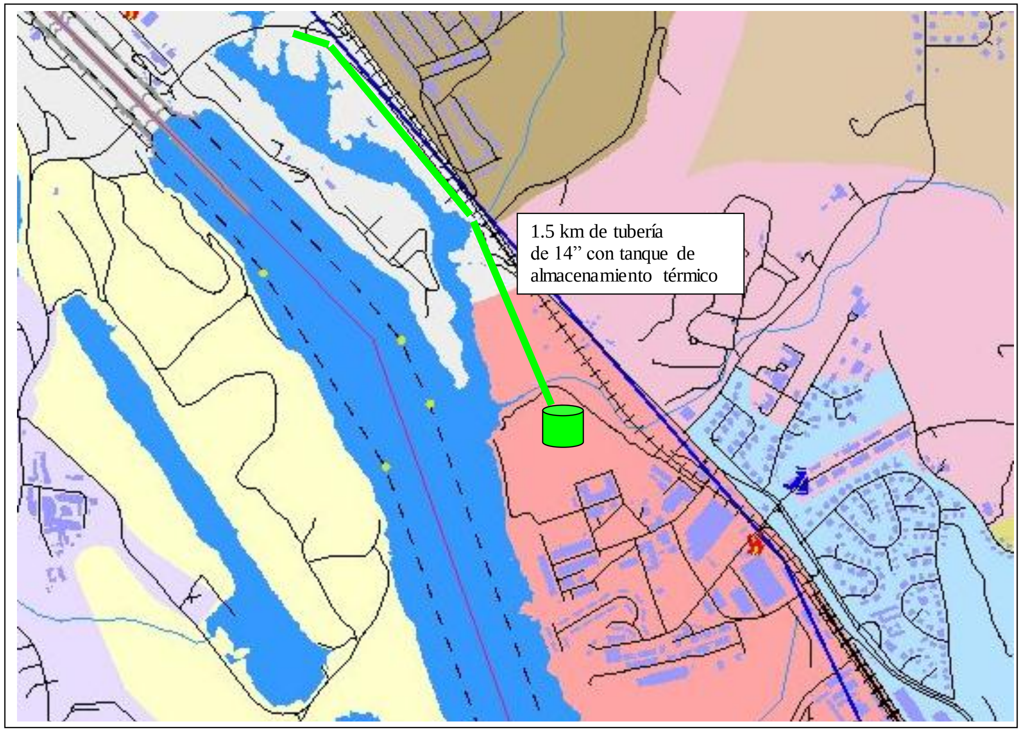


Figura 1 Flujo y energía disponible para un sistema de cogeneración en la termoeléctrica.



Tanques de Almacenamiento Térmico

Estos tanques ofrecen la capacidad de generar agua fría a un ritmo constante las 24 horas para su consumo durante el día. Con esto se requiere una menor cantidad o tamaño de unidades de enfriamiento.

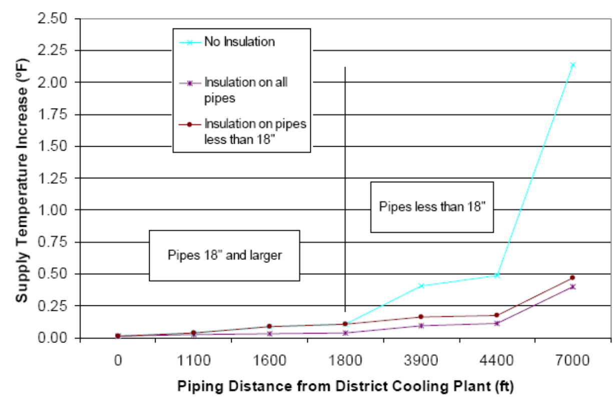
Un tanque con capacidad de 2,000,000 galones provee 12 horas de flujo a 2,778 gal/min (10.5 m^3/min = 631 m^3/h). Esto equivale a la producción de agua fría de **3.5 unidades** NAK 300/1050 (cada una genera 181 m^3/h de agua fría a 9 o 6°C).

El uso de estos tanques reducirá el tamaño de tubería de la Termoeléctrica de Miraflores a un tanque en Corozal; por ejemplo, en vez de una tubería de 20" se podría usar una tubería de 14".

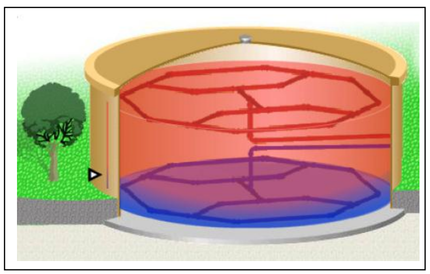
Alternativamente:
El uso de estos tanques se podría incluir en un diseño con enfriadores por compresión (eléctricos). Así, el consumo eléctrico puede ser nocturno o a ritmo constante las 24 horas, lo que proveería un mejor uso de la capacidad y demanda eléctrica.

En tuberías con aislamiento prefabricado, la ganancia de calor de la Termoeléctrica de Miraflores a un tanque en Corozal sería de solo 0.25 °C.

Aumento de Temperatura en Tuberías de Enfriamiento Distrital



Fuente: www.fvbenergy.com



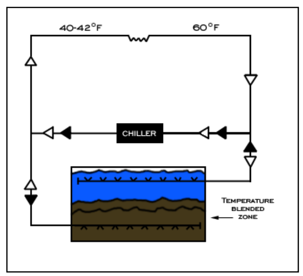


Figura 2 Tanques de almacenamiento térmico.

Anexo F

Análisis Económico

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

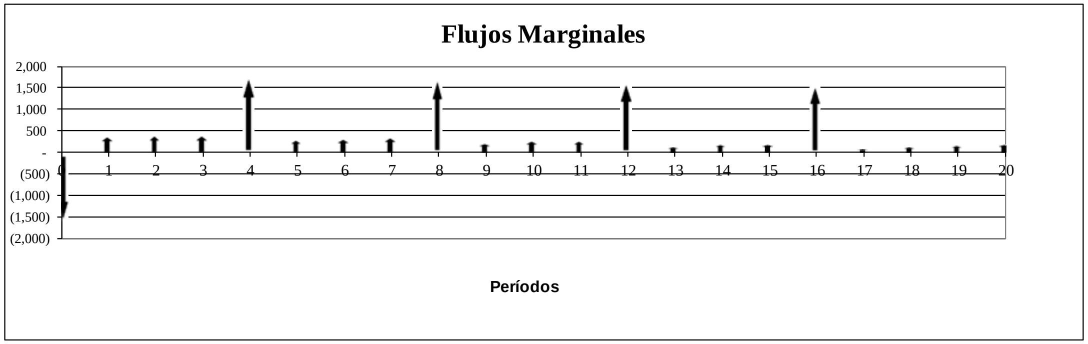
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario	**AF-2013**
Tasa mínima de retorno	14%

Alternativa A: Nombre del proyecto



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

		Alternativa A						
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente
0	2013	(3,516)	(731)			(4,248)	1.0000	(4,247.76)
1	2014	-	(783)			(783)	0.8772	(686.55)
2	2015	-	(822)			(822)	0.7695	(632.35)
3	2016	-	(838)			(838)	0.6750	(565.79)
4	2017	-	(855)			(855)	0.5921	(506.23)
5	2018	-	(872)			(872)	0.5194	(452.94)
6	2019	-	(890)			(890)	0.4556	(405.27)
7	2020	-	(907)			(907)	0.3996	(362.61)
8	2021	-	(925)			(925)	0.3506	(324.44)
9	2022	-	(944)			(944)	0.3075	(290.29)
10	2023	-	(963)			(963)	0.2697	(259.73)
11	2024	-	(982)			(982)	0.2366	(232.39)
12	2025	-	(1,002)			(1,002)	0.2076	(207.93)
13	2026	-	(1,022)			(1,022)	0.1821	(186.04)
14	2027	-	(1,042)			(1,042)	0.1597	(166.46)
15	2028	-	(1,063)			(1,063)	0.1401	(148.94)
16	2029	-	(1,084)			(1,084)	0.1229	(133.26)
17	2030	-	(1,084)			(1,084)	0.1078	(116.89)
18	2031	-	(1,084)			(1,084)	0.0946	(102.54)
19	2032	-	(1,084)			(1,084)	0.0829	(89.95)
20	2033	-	(1,084)			(1,084)	0.0728	(78.90)
Totales		(3,516)	(20,063)	-	-	######		(10,197)

		Status Quo							Alt. A vs. Status Quo		Gráfica	
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
0	2013	(1,569)	(1,080)			(2,648)	1.0000	(2,648.47)	(1,599.29)	(1,599.29)	-	(1,599.29)
1	2014		(1,152)	-	-	(1,152)	0.8772	(1,010.92)	369.78	324.36	369.78	-
2	2015		(1,204)	-	-	(1,204)	0.7695	(926.78)	382.64	294.43	382.64	-
3	2016		(1,225)	-	-	(1,225)	0.6750	(827.00)	387.00	261.21	387.00	-
4	2017	(1,569)	(1,080)	-	-	(2,648)	0.5921	(1,568.11)	1,793.47	1,061.88	1,793.47	-
5	2018		(1,152)	-	-	(1,152)	0.5194	(598.54)	280.34	145.60	280.34	-
6	2019		(1,204)	-	-	(1,204)	0.4556	(548.73)	314.89	143.46	314.89	-
7	2020		(1,225)	-	-	(1,225)	0.3996	(489.65)	317.90	127.05	317.90	-
8	2021	(1,569)	(1,080)	-	-	(2,648)	0.3506	(928.45)	1,722.99	604.01	1,722.99	-
9	2022		(1,152)	-	-	(1,152)	0.3075	(354.39)	208.45	64.10	208.45	-
10	2023		(1,204)	-	-	(1,204)	0.2697	(324.89)	241.57	65.16	241.57	-
11	2024		(1,225)	-	-	(1,225)	0.2366	(289.91)	243.11	57.52	243.11	-
12	2025	(1,569)	(1,080)	-	-	(2,648)	0.2076	(549.71)	1,646.70	341.79	1,646.70	-
13	2026		(1,152)	-	-	(1,152)	0.1821	(209.83)	130.64	23.78	130.64	-
14	2027		(1,204)	-	-	(1,204)	0.1597	(192.36)	162.19	25.90	162.19	-
15	2028		(1,225)	-	-	(1,225)	0.1401	(171.65)	162.15	22.72	162.15	-
16	2029	(1,569)	(1,080)	-	-	(2,648)	0.1229	(325.48)	1,564.12	192.22	1,564.12	-
17	2030		(1,152)	-	-	(1,152)	0.1078	(124.23)	68.09	7.34	68.09	-
18	2031		(1,204)	-	-	(1,204)	0.0946	(113.89)	120.09	11.36	120.09	-
19	2032		(1,225)	-	-	(1,225)	0.0829	(101.63)	140.89	11.69	140.89	-
20	2033		(1,246)	-	-	(1,246)	0.0728	(90.64)	161.40	11.74	161.40	-
Totales		(7,844)	(24,555)	-	-	(32,399)		(12,395)	8,819	2,198	10,418	(1,599)
									35%	2,198		
									TIR	VAN		

Tabla F- 1 Análisis económico para mini plantas enfriadas por agua.

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

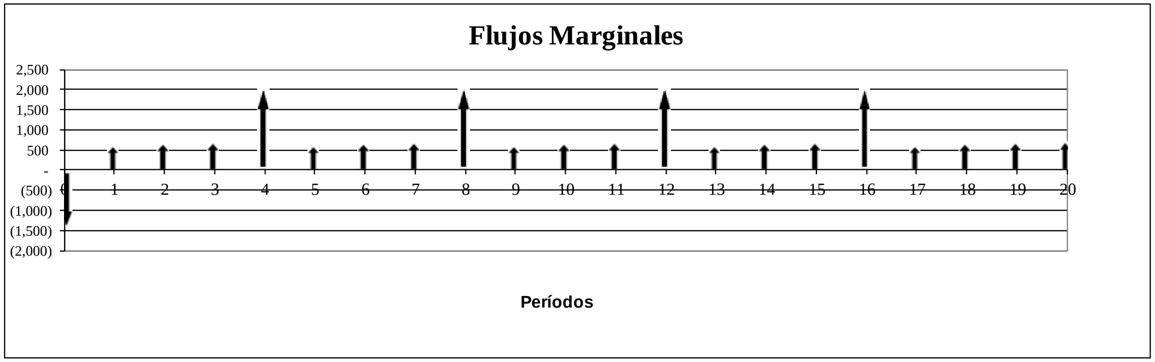
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario	AF-2013
Tasa mínima de retorno	14%

Alternativa A: Nombre del proyecto



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

		Alternativa A							Status Quo							Alt. A vs. Status Quo		Gráfica	
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
0	2013	(3,530)	(548)		-	(4,077)	1.0000	(4,077.43)	(1,569)	(1,080)			(2,648)	1.0000	(2,648.47)	(1,428.96)	(1,428.96)	-	(1,428.96)
1	2014		(548)		-	(548)	0.8772	(480.41)		(1,152)	-	-	(1,152)	0.8772	(1,010.92)	604.78	530.51	604.78	-
2	2015		(548)		-	(548)	0.7695	(421.41)		(1,204)	-	-	(1,204)	0.7695	(926.78)	656.77	505.37	656.77	-
3	2016		(548)		-	(548)	0.6750	(369.66)		(1,225)	-	-	(1,225)	0.6750	(827.00)	677.57	457.34	677.57	-
4	2017		(548)		-	(548)	0.5921	(324.26)	(1,569)	(1,080)	-	-	(2,648)	0.5921	(1,568.11)	2,100.81	1,243.85	2,100.81	-
5	2018		(548)		-	(548)	0.5194	(284.44)		(1,152)	-	-	(1,152)	0.5194	(598.54)	604.78	314.10	604.78	-
6	2019		(548)		-	(548)	0.4556	(249.51)		(1,204)	-	-	(1,204)	0.4556	(548.73)	656.77	299.22	656.77	-
7	2020		(548)		-	(548)	0.3996	(218.87)		(1,225)	-	-	(1,225)	0.3996	(489.65)	677.57	270.78	677.57	-
8	2021		(548)		-	(548)	0.3506	(191.99)	(1,569)	(1,080)	-	-	(2,648)	0.3506	(928.45)	2,100.81	736.46	2,100.81	-
9	2022		(548)		-	(548)	0.3075	(168.41)		(1,152)	-	-	(1,152)	0.3075	(354.39)	604.78	185.97	604.78	-
10	2023		(548)		-	(548)	0.2697	(147.73)		(1,204)	-	-	(1,204)	0.2697	(324.89)	656.77	177.16	656.77	-
11	2024		(548)		-	(548)	0.2366	(129.59)		(1,225)	-	-	(1,225)	0.2366	(289.91)	677.57	160.33	677.57	-
12	2025		(548)		-	(548)	0.2076	(113.67)	(1,569)	(1,080)	-	-	(2,648)	0.2076	(549.71)	2,100.81	436.04	2,100.81	-
13	2026		(548)		-	(548)	0.1821	(99.71)		(1,152)	-	-	(1,152)	0.1821	(209.83)	604.78	110.11	604.78	-
14	2027		(548)		-	(548)	0.1597	(87.47)		(1,204)	-	-	(1,204)	0.1597	(192.36)	656.77	104.89	656.77	-
15	2028		(548)		-	(548)	0.1401	(76.73)		(1,225)	-	-	(1,225)	0.1401	(171.65)	677.57	94.93	677.57	-
16	2029		(548)		-	(548)	0.1229	(67.30)	(1,569)	(1,080)	-	-	(2,648)	0.1229	(325.48)	2,100.81	258.17	2,100.81	-
17	2030		(548)		-	(548)	0.1078	(59.04)		(1,152)	-	-	(1,152)	0.1078	(124.23)	604.78	65.19	604.78	-
18	2031		(548)		-	(548)	0.0946	(51.79)		(1,204)	-	-	(1,204)	0.0946	(113.89)	656.77	62.11	656.77	-
19	2032		(548)		-	(548)	0.0829	(45.43)		(1,225)	-	-	(1,225)	0.0829	(101.63)	677.57	56.20	677.57	-
20	2033		(548)		-	(548)	0.0728	(39.85)		(1,246)	-	-	(1,246)	0.0728	(90.64)	698.08	50.79	698.08	-
Totales		(3,530)	(11,501)	-	-	(15,031)		(7,705)	(7,844)	(24,555)	-	-	(32,399)		(12,395)	17,368	4,691	18,797	(1,429)
																56%	4,691		
																TIR	VAN		

Tabla F- 2 Análisis económico para planta de agua fría por chillers eléctricos.

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

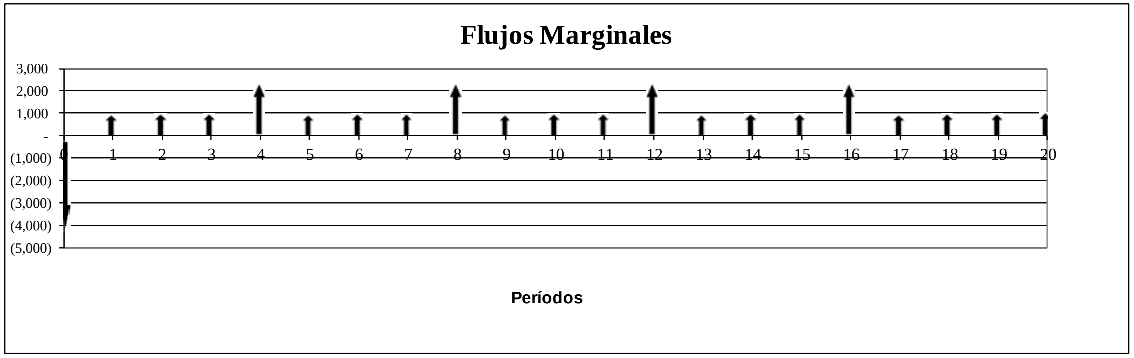
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario	AF-2013
Tasa mínima de retorno	14%

Alternativa A: Nombre del proyecto



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

Año	AF	Alternativa A: A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente
0	2013	(6,764)	(215)			(6,979)	1.0000	(6,978.96)
1	2014		(215)		-	(215)	0.8772	(188.51)
2	2015		(215)		-	(215)	0.7695	(165.36)
3	2016		(215)		-	(215)	0.6750	(145.05)
4	2017		(215)		-	(215)	0.5921	(127.24)
5	2018		(215)		-	(215)	0.5194	(111.61)
6	2019		(215)		-	(215)	0.4556	(97.90)
7	2020		(215)		-	(215)	0.3996	(85.88)
8	2021		(215)		-	(215)	0.3506	(75.33)
9	2022		(215)		-	(215)	0.3075	(66.08)
10	2023		(215)		-	(215)	0.2697	(57.97)
11	2024		(215)		-	(215)	0.2366	(50.85)
12	2025		(215)		-	(215)	0.2076	(44.60)
13	2026		(215)		-	(215)	0.1821	(39.13)
14	2027		(215)		-	(215)	0.1597	(34.32)
15	2028		(215)		-	(215)	0.1401	(30.11)
16	2029		(215)		-	(215)	0.1229	(26.41)
17	2030		(215)		-	(215)	0.1078	(23.17)
18	2031		(215)		-	(215)	0.0946	(20.32)
19	2032		(215)		-	(215)	0.0829	(17.83)
20	2033		(215)		-	(215)	0.0728	(15.64)
Totales		(6,764)	(4,513)	-	-	(11,277)		(8,402)

Año	Status Quo: A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente
0	(1,569)	(1,080)			(2,648)	1.0000	(2,648.47)
1		(1,152)	-	-	(1,152)	0.8772	(1,010.92)
2		(1,204)	-	-	(1,204)	0.7695	(926.78)
3		(1,225)	-	-	(1,225)	0.6750	(827.00)
4	(1,569)	(1,080)	-	-	(2,648)	0.5921	(1,568.11)
5		(1,152)	-	-	(1,152)	0.5194	(598.54)
6		(1,204)	-	-	(1,204)	0.4556	(548.73)
7		(1,225)	-	-	(1,225)	0.3996	(489.65)
8	(1,569)	(1,080)	-	-	(2,648)	0.3506	(928.45)
9		(1,152)	-	-	(1,152)	0.3075	(354.39)
10		(1,204)	-	-	(1,204)	0.2697	(324.89)
11		(1,225)	-	-	(1,225)	0.2366	(289.91)
12	(1,569)	(1,080)	-	-	(2,648)	0.2076	(549.71)
13		(1,152)	-	-	(1,152)	0.1821	(209.83)
14		(1,204)	-	-	(1,204)	0.1597	(192.36)
15		(1,225)	-	-	(1,225)	0.1401	(171.65)
16	(1,569)	(1,080)	-	-	(2,648)	0.1229	(325.48)
17		(1,152)	-	-	(1,152)	0.1078	(124.23)
18		(1,204)	-	-	(1,204)	0.0946	(113.89)
19		(1,225)	-	-	(1,225)	0.0829	(101.63)
20		(1,246)	-	-	(1,246)	0.0728	(90.64)
Totales	(7,844)	(24,555)	-	-	(32,399)		(12,395)

Año	Alt. A vs. Status Quo: Flujo marginal	Valor Presente Marginal	Gráfica: Flujos Positivos	Flujos Negativos
0	(4,330.49)	(4,330.49)	-	(4,330.49)
1	937.55	822.41	937.55	-
2	989.54	761.42	989.54	-
3	1,010.34	681.95	1,010.34	-
4	2,433.58	1,440.87	2,433.58	-
5	937.55	486.93	937.55	-
6	989.54	450.82	989.54	-
7	1,010.34	403.77	1,010.34	-
8	2,433.58	853.11	2,433.58	-
9	937.55	288.30	937.55	-
10	989.54	266.92	989.54	-
11	1,010.34	239.06	1,010.34	-
12	2,433.58	505.11	2,433.58	-
13	937.55	170.70	937.55	-
14	989.54	158.04	989.54	-
15	1,010.34	141.55	1,010.34	-
16	2,433.58	299.07	2,433.58	-
17	937.55	101.07	937.55	-
18	989.54	93.57	989.54	-
19	1,010.34	83.81	1,010.34	-
20	1,030.85	75.01	1,030.85	-
Totales	21,122	3,993	25,452	(4,330)
	28%	3,993		
	TIR	VAN		

Tabla F- 3 Análisis económico para planta de agua fría por cogeneración.

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

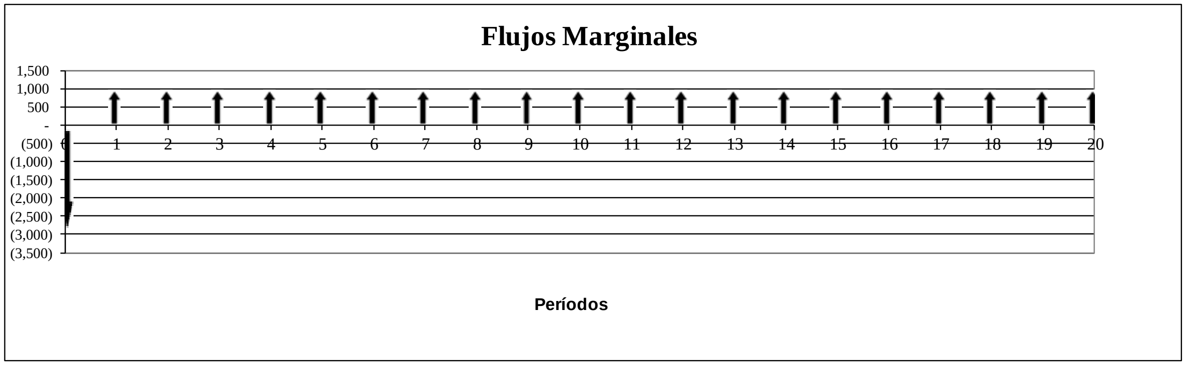
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario AF-2013
Tasa mínima de retorno 14%

Alternativa A: Nombre del proyecto



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

		Alternativa A							Status Quo							Alt. A vs. Status Quo		Gráfica	
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
0	2013	(7,861)	(944)	1,378		(7,427)	1.0000	(7,427.15)	(3,950)	(548)			(4,497)	1.0000	(4,497.43)	(2,929.72)	(2,929.72)	-	(2,929.72)
1	2014		(944)	1,378	-	434	0.8772	380.88	-	(548)	-	-	(548)	0.8772	(480.41)	981.87	861.29	981.87	-
2	2015		(944)	1,378	-	434	0.7695	334.10	-	(548)	-	-	(548)	0.7695	(421.41)	981.87	755.51	981.87	-
3	2016		(944)	1,378	-	434	0.6750	293.07	-	(548)	-	-	(548)	0.6750	(369.66)	981.87	662.73	981.87	-
4	2017		(944)	1,378	-	434	0.5921	257.08	-	(548)	-	-	(548)	0.5921	(324.26)	981.87	581.34	981.87	-
5	2018		(944)	1,378	-	434	0.5194	225.51	-	(548)	-	-	(548)	0.5194	(284.44)	981.87	509.95	981.87	-
6	2019		(944)	1,378	-	434	0.4556	197.82	-	(548)	-	-	(548)	0.4556	(249.51)	981.87	447.33	981.87	-
7	2020		(944)	1,378	-	434	0.3996	173.52	-	(548)	-	-	(548)	0.3996	(218.87)	981.87	392.39	981.87	-
8	2021		(944)	1,378	-	434	0.3506	152.21	-	(548)	-	-	(548)	0.3506	(191.99)	981.87	344.20	981.87	-
9	2022		(944)	1,378	-	434	0.3075	133.52	-	(548)	-	-	(548)	0.3075	(168.41)	981.87	301.93	981.87	-
10	2023		(944)	1,378	-	434	0.2697	117.12	-	(548)	-	-	(548)	0.2697	(147.73)	981.87	264.85	981.87	-
11	2024		(944)	1,378	-	434	0.2366	102.74	-	(548)	-	-	(548)	0.2366	(129.59)	981.87	232.33	981.87	-
12	2025		(944)	1,378	-	434	0.2076	90.12	-	(548)	-	-	(548)	0.2076	(113.67)	981.87	203.80	981.87	-
13	2026		(944)	1,378	-	434	0.1821	79.05	-	(548)	-	-	(548)	0.1821	(99.71)	981.87	178.77	981.87	-
14	2027		(944)	1,378	-	434	0.1597	69.35	-	(548)	-	-	(548)	0.1597	(87.47)	981.87	156.81	981.87	-
15	2028		(944)	1,378	-	434	0.1401	60.83	-	(548)	-	-	(548)	0.1401	(76.73)	981.87	137.56	981.87	-
16	2029		(944)	1,378	-	434	0.1229	53.36	-	(548)	-	-	(548)	0.1229	(67.30)	981.87	120.66	981.87	-
17	2030		(944)	1,378	-	434	0.1078	46.81	-	(548)	-	-	(548)	0.1078	(59.04)	981.87	105.84	981.87	-
18	2031		(944)	1,378	-	434	0.0946	41.06	-	(548)	-	-	(548)	0.0946	(51.79)	981.87	92.85	981.87	-
19	2032		(944)	1,378	-	434	0.0829	36.02	-	(548)	-	-	(548)	0.0829	(45.43)	981.87	81.44	981.87	-
20	2033		(944)	1,378	-	434	0.0728	31.59	-	(548)	-	-	(548)	0.0728	(39.85)	981.87	71.44	981.87	-
Totales		(7,861)	(19,819)	28,937	-	1,257		(4,551)	(3,950)	(11,501)	-	-	(15,451)		(8,125)	16,708	3,573	19,637	(2,930)
																33%	3,573		
																TIR	VAN		

Tabla F- 4 Análisis económico para red distrital de agua fría por chillers eléctricos.

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

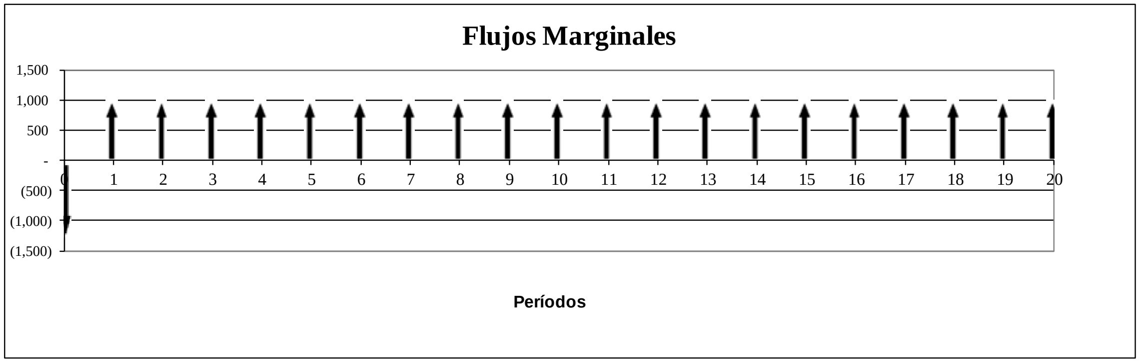
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario	**AF-2013**
Tasa mínima de retorno	14%

Alternativa A: Nombre del proyecto



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

		Alternativa A							Status Quo							Alt. A vs. Status Quo		Gráfica	
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
0	2013	(9,495)	(592)	1,378	-	(8,709)	1.0000	(8,708.86)	(7,222)	(215)	-	-	(7,437)	1.0000	(7,436.83)	(1,272.04)	(1,272.04)	-	(1,272.04)
1	2014		(592)	1,378	-	786	0.8772	689.65	-	(215)	-	-	(215)	0.8772	(188.51)	1,001.10	878.16	1,001.10	-
2	2015		(592)	1,378	-	786	0.7695	604.96	-	(215)	-	-	(215)	0.7695	(165.36)	1,001.10	770.31	1,001.10	-
3	2016		(592)	1,378	-	786	0.6750	530.66	-	(215)	-	-	(215)	0.6750	(145.05)	1,001.10	675.71	1,001.10	-
4	2017		(592)	1,378	-	786	0.5921	465.49	-	(215)	-	-	(215)	0.5921	(127.24)	1,001.10	592.73	1,001.10	-
5	2018		(592)	1,378	-	786	0.5194	408.33	-	(215)	-	-	(215)	0.5194	(111.61)	1,001.10	519.94	1,001.10	-
6	2019		(592)	1,378	-	786	0.4556	358.18	-	(215)	-	-	(215)	0.4556	(97.90)	1,001.10	456.09	1,001.10	-
7	2020		(592)	1,378	-	786	0.3996	314.20	-	(215)	-	-	(215)	0.3996	(85.88)	1,001.10	400.08	1,001.10	-
8	2021		(592)	1,378	-	786	0.3506	275.61	-	(215)	-	-	(215)	0.3506	(75.33)	1,001.10	350.94	1,001.10	-
9	2022		(592)	1,378	-	786	0.3075	241.76	-	(215)	-	-	(215)	0.3075	(66.08)	1,001.10	307.85	1,001.10	-
10	2023		(592)	1,378	-	786	0.2697	212.07	-	(215)	-	-	(215)	0.2697	(57.97)	1,001.10	270.04	1,001.10	-
11	2024		(592)	1,378	-	786	0.2366	186.03	-	(215)	-	-	(215)	0.2366	(50.85)	1,001.10	236.88	1,001.10	-
12	2025		(592)	1,378	-	786	0.2076	163.18	-	(215)	-	-	(215)	0.2076	(44.60)	1,001.10	207.79	1,001.10	-
13	2026		(592)	1,378	-	786	0.1821	143.14	-	(215)	-	-	(215)	0.1821	(39.13)	1,001.10	182.27	1,001.10	-
14	2027		(592)	1,378	-	786	0.1597	125.56	-	(215)	-	-	(215)	0.1597	(34.32)	1,001.10	159.89	1,001.10	-
15	2028		(592)	1,378	-	786	0.1401	110.14	-	(215)	-	-	(215)	0.1401	(30.11)	1,001.10	140.25	1,001.10	-
16	2029		(592)	1,378	-	786	0.1229	96.62	-	(215)	-	-	(215)	0.1229	(26.41)	1,001.10	123.03	1,001.10	-
17	2030		(592)	1,378	-	786	0.1078	84.75	-	(215)	-	-	(215)	0.1078	(23.17)	1,001.10	107.92	1,001.10	-
18	2031		(592)	1,378	-	786	0.0946	74.34	-	(215)	-	-	(215)	0.0946	(20.32)	1,001.10	94.66	1,001.10	-
19	2032		(592)	1,378	-	786	0.0829	65.21	-	(215)	-	-	(215)	0.0829	(17.83)	1,001.10	83.04	1,001.10	-
20	2033		(592)	1,378	-	786	0.0728	57.21	-	(215)	-	-	(215)	0.0728	(15.64)	1,001.10	72.84	1,001.10	-
Totales		(9,495)	(12,427)	28,937	-	7,015		(3,502)	(7,222)	(4,513)	-	-	(11,735)		(8,860)	18,750	5,358	20,022	(1,272)
																79%	5,358		
																TIR	VAN		

Tabla F- 5 Análisis económico para red distrital de agua fría por cogeneración.

Anexo G

Comunicados

LDeVega

From: UGonzal
Sent: Friday, March 23, 2012 4:09 PM
To: EAdmade; LDeVega
Subject: pie2/ton refrig -- RE: facturación, toneladas instaladas por edificio

Estimado Eric,

Abajo están los m2 de los edificios en Balboa con agua fría, según los datos que tenemos. Puede ser que no toda el área tiene aire acondicionado, por lo que serían cifras aproximadas.

Laurentino,

Creo que habíamos quedado en que para el informe usáramos el valor de 280 pie2/ton. Favor cita que en Balboa el promedio en edificios de oficinas es de 269 pie2/ton según la tabla de abajo, lo cual es cercano a lo que dice ASRHAE.

Usuario/Dueño	Edificio	Toneladas Instaladas		Área m2	pie2	
División de Electricidad y Acueductos	66-A	27.3		1531.7	16487.2188	
Central de Telecomunicaciones	69	15.2		520.3	5600.5092	
Escuela de Aprendices	74	130.0		1243.95	13389.8778	
Edificio de Administración	101	331.7		15373.6	165481.4304	
Centro de Capacitación Ascanio Arosemena	701/702	93.7		1751.37	18851.74668	
Centro de Capacitación Ascanio Arosemena	704	246.7		5218.01	56166.65964	
Auditorio del CCAA	705	118.4		1701.53	18315.26892	
Departamento de Recursos Humanos	706/707	222.1		4589.17	49397.82588	
Div. de Contratos/ Div. de Políticas Contables y Financieras	710	132.0		4129.16	44446.27824	
Gimnasio de Balboa	713-X	62.6		1419.75	15282.189	
Departamento de Informática	721	40.7		514.28	5535.70992	
Depto. de Operaciones Marítimas, Sección de Prácticos	726	12.6		2269.23	24425.99172	
Depto de Operaciones Marítimas/Subest. Eléctrica de Balboa	729/731	103.8		3712.82	39964.79448	
TOTAL		1,536.80				

Saludos,

Urho Gonzal P. | Especialista en Control Ambiental y Conservación de Energía | Sección de Evaluación Ambiental | Tel. (507) 276-2141 | Email: ugonzal@pancanal.com

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From: EAdmade
Sent: jueves, 22 de marzo de 2012 09:48 a.m.
To: LDeVega; UGonzal
Subject: facturación, toneladas instaladas por edificio

1

Anexo H

Cotizaciones

OTEK INTERNACIONAL S.A.
Oficina: Calle 19 A # 43-B-41 El Poblado
PBX: +(57 4) 444 4242
Oficina: Calle 90 # 19 A 13 Bogotá
PBX: +(57 1) 608 21 98
Apartado Aéreo: 82159
Medellín, Colombia

COTIZACIÓN INTERNACIONAL N°. 9032012

Empresa:	CANAL DE PANAMA
NIT	
Contacto:	LAURENTINO DE VEGA JOLY
Email:	ldevega@pancanal.com
Ciudad:	PANAMA
Dirección:	
Teléfono:	507-2724670
Fax:	

PROYECTO: ACP - Panama

ÍTEM	DESCRIPCIÓN	UND	CANTIDAD	VALOR UNITARIO (US$)	VALOR PARCIAL (US$)
1	Tubería GRP DN800 PN10 SN2500	ml	2.000.00	$ 144.44	$ 288.880.00
2	Acople GRP DN800 PN10	un	178.00	$ 186.36	$ 33.172.00
3	Tubería GRP DN400 PN6 SN5000	ml	5.000.00	$ 63.33	$ 316.650.00
4	Acople GRP DN400 PN6	un	453.00	$ 90.00	$ 40.770.00
5	Tubería GRP DN350 PN6 SN5000	ml	5.000.00	$ 54.44	$ 272.200.00
6	Acople GRP DN350 PN6	un	445.00	$ 85.56	$ 38.074.00

DN=Diámetro Nominal (mm), PN=Presión Nominal (bar), SN=Rigidez Nominal (N/m²), L=Longitud (m)

Subtotal	$ 989.746.00
Transporte	$ 163.626.20
Seguros	$ 11.533.72
TOTAL	$ 1.164.905.93

La tubería se suministra para sistemas a flujo libre y a presión hasta 32 bar (470 psi), en diámetros entre 300 y 3700mm, cumpliendo con todas las normas de fabricación AWWA C-950 y las NTC 3826, NTC 3870 y NTC 3871.

Términos Comerciales

* Forma de pago: 30% anticipo y el saldo respaldado mediante carta de credito confirmada e irrevocable pagadera contra documentos de embarque B/L
* Los precios están dados en dólares americanos, además son tentativos para estudios de factibilidad. Tanto el precio del flete como el de los tubos deben ser revisados al momento de acercarse la negociación. Solo deben ser tomados como referencia
*El costo del transporte incluye embalaje, seguro, transporte terrestre y marítimo CIF Puerto Balboa, no se incluye descargue en Puerto Balboa, gastos de aduana o nacionalización ni transporte interno dentro de Panamá.
* La tubería se suministrará en los siguientes tramos: DN800 tramos de 11.8 metros, DN400 en longitud de 11,6 y DN350 en longitud de 11,8 para efectos de anidamiento en le momento del cargue de la tubería. Los acoples se consideraron con un 5% adicional para cortes en obra
* Tiempo de entrega: sujeto a instalación en obra y fabricación en planta
*Estas cantidades son generales y están sujetas a cambios según diseño definitivo del proyecto

Fecha de elaboración: 9 de marzo de 2012
Vencimiento: Treinta (30) días
Plazo de entrega: Ver términos comerciales
Sitio de entrega: CIF Puerto Balboa - Panamá

Siempre estaremos atentos para asistirlos técnica y comercialmente
Otek Internacional S.A

Sergio Llano
Elaboró: MV Estructuración de Proyectos

Código: F-300-03 | Aprobado por: Coordinador Comercial | Vigente desde: 2011 - 05-18 | Revisión: 02

2

Aislante térmico Thermaflex, producto ThermaSmart PRO

ACP

Atención: **Ing. Urho Gonzal** **22-03-12**

Proyecto: Aislante térmico Thermaflex, producto ThermaSmart PRO

Referencia: **2012-065-DP**

Codigo Producto	Clave Thermaflex	Unidad	Cantidad	Contenidos por empaque	Precio Unitario USD	Descuento de	Precio con descuento	Sub total en USD
3100025	TS 25 mm	Rollo	420	39 M2	$ 1.427,84	45%	$ 785,31	$ 329.832,10
8001004	Glue 30 L	Lata	65	30 Ltr	$ 529,20	45%	$ 291,06	$ 18.918,90
					Total		$	348.751,00

**Condiciones comerciales generales

-Precios en USD
-Precios sujetos a cambio sin previo aviso

- Inlcuye descuento de: **45%**
- Condiciones de Pago: **50% contra Orden de Compra, 50% contra arribo a Puerto**
-Incoterm: **CIF Puerto Balboa**
- Propuesta valida por: **30 días**
- Tiempo de Entrega: **Aprox. 4 semanas**

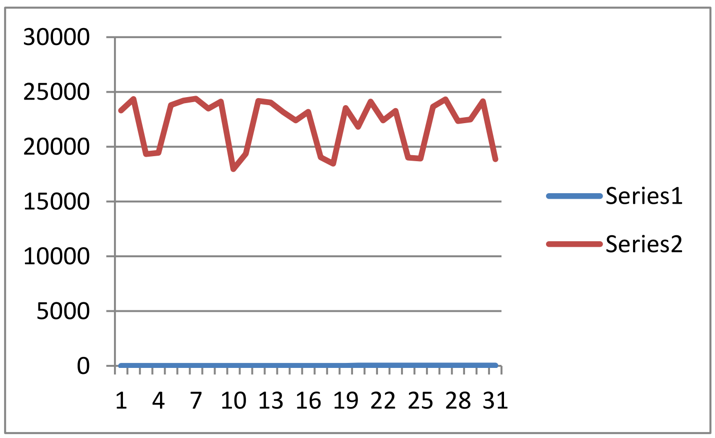
En espera de su confirmación, y agradeciendo su preferencia, me reitero a sus ordenes para cualquier duda al respecto de la presente cotización.

Adobe Acrobat Document

Appendix B- Chilled Water Demand per day

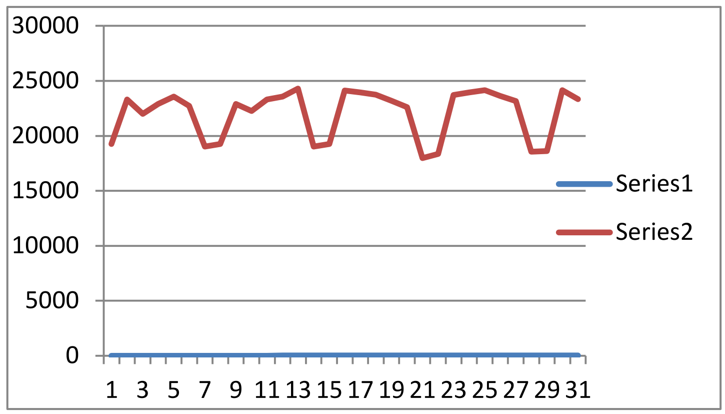
Diciembre

fecha	Día	Ton-h
1	j	23308.67
2	v	24346.58
3	s	19329.68
4	d	19438.68
5	l	23803.77
6	m	24185.95
7	mi	24389.14
8	j	23459.58
9	v	24119.48
10	s	17944.28
11	d	19340.99
12	l	24156.51
13	m	24032.12
14	mi	23157.45
15	j	22387.87
16	v	23163.05
17	s	19036.59
18	d	18442.37
19	l	23540.52
20	m	21817.25
21	mi	24122.31
22	j	22389.1
23	v	23263.45
24	s	19012.73
25	d	18918.06
26	l	23639.77
27	m	24316.12
28	mi	22334.89
29	j	22487.13
30	v	24136.85
31	s	18853.34
		686874.3



Enero

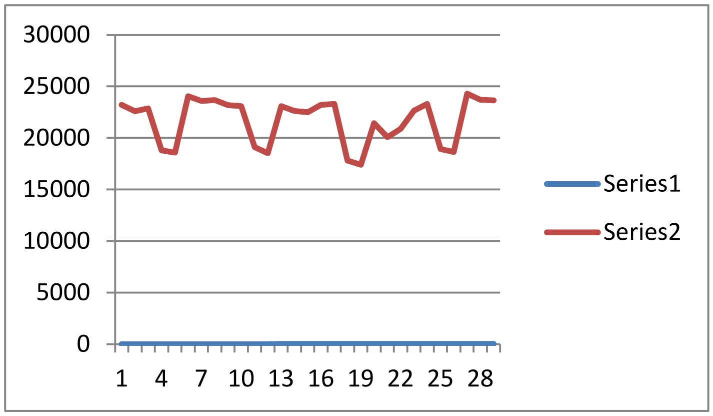
fecha	Día	
1	d	19262.42
2	l	23299.43
3	m	22009.34
4	mi	22900.16
5	j	23561.96
6	v	22729.21
7	s	19019.83
8	d	19262.42
9	l	22904.87
10	m	22248.34
11	mi	23299.43
12	j	23561.96
13	v	24293.09
14	s	19019.83
15	d	19262.42
16	l	24129.77
17	m	23945.32
18	mi	23763.22
19	j	23183.43
20	v	22616.76
21	s	17972.75
22	d	18363.77
23	l	23711.14
24	m	23938.96
25	mi	24156.99
26	j	23645.62
27	v	23171.62
28	s	18559.41
29	d	18632.46
30	l	24142.97
31	m	23351.11
		683920



Febrero

fecha	Día	
1	mi	23225.48
2	j	22575.66
3	v	22872.12
4	s	18799.83
5	d	18573.4

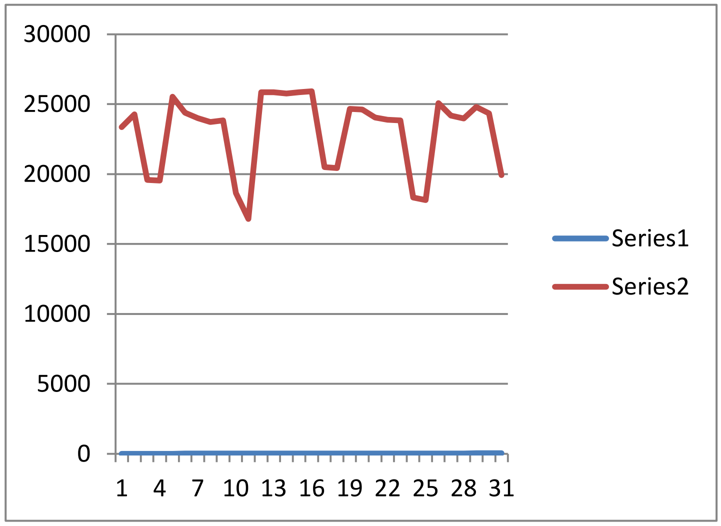
6	l	24050.78
7	m	23578.23
8	mi	23673.64
9	j	23166.12
10	v	23096.04
11	s	19096.71
12	d	18525.48
13	l	23084.47
14	m	22609.22
15	mi	22492.73
16	j	23221.84
17	v	23289.32
18	s	17801.09
19	d	17394.72
20	l	21439.8
21	m	20080.78
22	mi	20870.97
23	j	22651.37
24	v	23295.33
25	s	18922.15
26	d	18642.6
27	l	24304.64
28	m	23709.97
29	mi	23644.68
		628689.2



Marzo

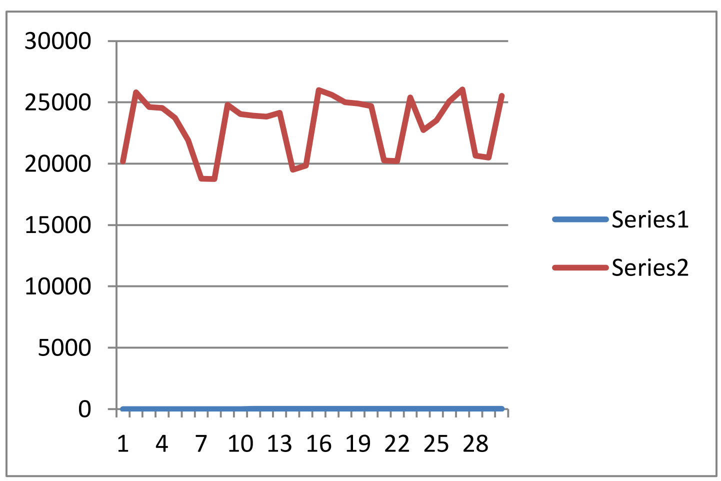
fecha	Día	
1	j	23358.35
2	v	24260.6
3	s	19576.89
4	d	19541.93
5	l	25528.21
6	m	24378.97
7	mi	24003.47
8	j	23721.3
9	v	23835.38
10	s	18645.95
11	d	16783.19
12	l	25836.85
13	m	25856.82

14	mi	25758.23
15	j	25843.69
16	v	25905.53
17	s	20492.62
18	d	20415.46
19	l	24665.35
20	m	24603.72
21	mi	24038.13
22	j	23888.23
23	v	23831.43
24	s	18329.67
25	d	18136.29
26	l	25068.2
27	m	24175.94
28	mi	23969.79
29	j	24787.33
30	v	24338.79
31	s	19922.69
		713499

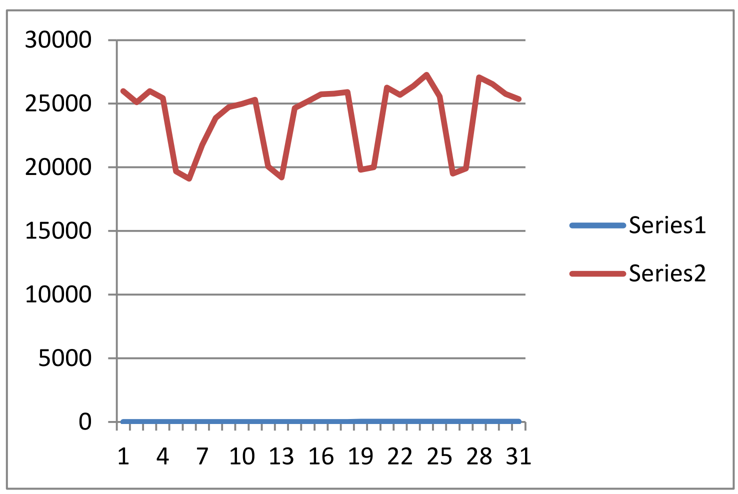


Abril

fecha	Día	
1	d	20177.01
2	l	25815.03
3	m	24606.14
4	mi	24525.69
5	j	23734.49
6	v	21900.6
7	s	18767.87
8	d	18741.73
9	l	24795.26
10	m	24035.35
11	mi	23920.07
12	j	23826.34
13	v	24154.43
14	s	19498.05
15	d	19856.08
16	l	26005.95
17	m	25608.71
18	mi	25012.51
19	j	24911.99



20	v	24692.63
21	s	20258.86
22	d	20207.59
23	l	25398.64
24	m	22734.08
25	mi	23510.47
26	j	25072.37
27	v	26049.12
28	s	20653.4
29	d	20503.38
30	l	25523.01
		694496.9
Mayo		
fecha	Día	
1	m	25983.58
2	mi	25103.27
3	j	25982.23
4	v	25442.66
5	s	19676.86
6	d	19101.95
7	l	21765.54
8	m	23880.33
9	mi	24732.21
10	j	24989.91
11	v	25308.54
12	s	20066.33
13	d	19204.26
14	l	24651.17
15	m	25191.31
16	mi	25747.65
17	j	25803.47
18	v	25922.88
19	s	19819.02
20	d	20010.7
21	l	26265.48
22	m	25698.57
23	mi	26393.16
24	j	27263.01
25	v	25573.39
26	s	19498.43



27	d	19901.78
28	l	27076.85
29	m	26549.33
30	mi	25764.78
31	j	25368.01
		743736.7

Appendix C- Economic Analysis Model

ACP (1716)
v. 21-10-2009

AUTORIDAD DEL CANAL DE PANAMÁ

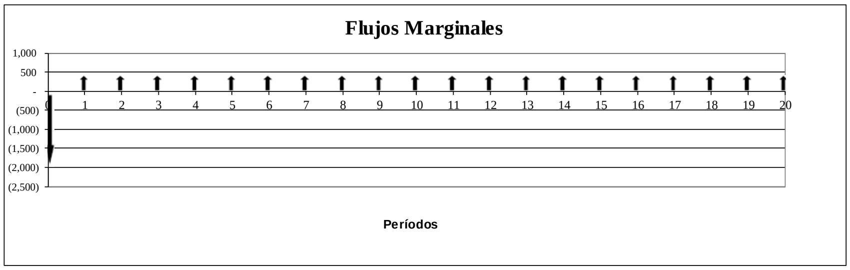
ANÁLISIS ECONÓMICO DEL FLUJO DE EFECTIVO

Nombre del proyecto: (NIP- XXXX)

(en miles de balboas)

Ciclo presupuestario	AF-2013
Tasa mínima de retorno	14%

Alternativa A: Tercera Línea



Método del Valor Actual Neto (VAN) y Tasa Interna de Retorno (TIR)

		Alternativa A							Status Quo							Alt. A vs. Status Quo		Gráfica	
Año	AF	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	A Inversión (-)	B Gastos (-)	C Ingresos (+)	D Pérdida (-)	Flujo total	Factor Valor Presente	Valor Presente	Flujo marginal	Valor Presente Marginal	Flujos Positivos	Flujos Negativos
0	2013	(2,000)			-	(2,000)	1.0000	(2,000.00)		-				1.0000	-	(2,000.00)	(2,000.00)	-	(2,000.00)
1	2014		(981)		-	(981)	0.8772	(860.88)		(1,402)	-	-	(1,402)	0.8772	(1,229.82)	420.60	368.95	420.60	-
2	2015		(981)		-	(981)	0.7695	(755.16)		(1,402)	-	-	(1,402)	0.7695	(1,078.79)	420.60	323.64	420.60	-
3	2016		(981)		-	(981)	0.6750	(662.42)		(1,402)	-	-	(1,402)	0.6750	(946.31)	420.60	283.89	420.60	-
4	2017		(981)		-	(981)	0.5921	(581.07)		(1,402)	-	-	(1,402)	0.5921	(830.10)	420.60	249.03	420.60	-
5	2018		(981)		-	(981)	0.5194	(509.71)		(1,402)	-	-	(1,402)	0.5194	(728.15)	420.60	218.45	420.60	-
6	2019		(981)		-	(981)	0.4556	(447.11)		(1,402)	-	-	(1,402)	0.4556	(638.73)	420.60	191.62	420.60	-
7	2020		(981)		-	(981)	0.3996	(392.20)		(1,402)	-	-	(1,402)	0.3996	(560.29)	420.60	168.09	420.60	-
8	2021		(981)		-	(981)	0.3506	(344.04)		(1,402)	-	-	(1,402)	0.3506	(491.48)	420.60	147.45	420.60	-
9	2022		(981)		-	(981)	0.3075	(301.79)		(1,402)	-	-	(1,402)	0.3075	(431.13)	420.60	129.34	420.60	-
10	2023		(981)		-	(981)	0.2697	(264.73)		(1,402)	-	-	(1,402)	0.2697	(378.18)	420.60	113.45	420.60	-
11	2024		(981)		-	(981)	0.2366	(232.22)		(1,402)	-	-	(1,402)	0.2366	(331.74)	420.60	99.52	420.60	-
12	2025		(981)		-	(981)	0.2076	(203.70)		(1,402)	-	-	(1,402)	0.2076	(291.00)	420.60	87.30	420.60	-
13	2026		(981)		-	(981)	0.1821	(178.68)		(1,402)	-	-	(1,402)	0.1821	(255.26)	420.60	76.58	420.60	-
14	2027		(981)		-	(981)	0.1597	(156.74)		(1,402)	-	-	(1,402)	0.1597	(223.91)	420.60	67.17	420.60	-
15	2028		(981)		-	(981)	0.1401	(137.49)		(1,402)	-	-	(1,402)	0.1401	(196.42)	420.60	58.92	420.60	-
16	2029		(981)		-	(981)	0.1229	(120.61)		(1,402)	-	-	(1,402)	0.1229	(172.29)	420.60	51.69	420.60	-
17	2030		(981)		-	(981)	0.1078	(105.79)		(1,402)	-	-	(1,402)	0.1078	(151.14)	420.60	45.34	420.60	-
18	2031		(981)		-	(981)	0.0946	(92.80)		(1,402)	-	-	(1,402)	0.0946	(132.57)	420.60	39.77	420.60	-
19	2032		(981)		-	(981)	0.0829	(81.41)		(1,402)	-	-	(1,402)	0.0829	(116.29)	420.60	34.89	420.60	-
20	2033		(981)		-	(981)	0.0728	(71.41)		(1,402)	-	-	(1,402)	0.0728	(102.01)	420.60	30.60	420.60	-
Totales		(2,000)	(19,628)	-	-	(21,628)		(8,500)	-	(28,040)	-	-	(28,040)		(9,286)	6,412	786	8,412	(2,000)
																21%	786		
																TIR	VAN		

Método del Costo Anual Uniforme Equivalente (CAUE)

Años	Factor A/P	CAUE
20	0.1510	118.63

Instrucciones

Información General

1. Complete the information highlighted in blue: project name, PIN, budget cycle (year of preparation).

2. Check for the number of periods or years is enough, according to the estimated useful life of the investment. In case you missed it, including trying to insert lines between the last and penultimate line to avoid having to change the formulas for total internal rate of return and the data that feed the graph.

3. Verify that the columns of "year" and "AF" are correct.

4. Check the number of periods in the formula CAUE to agree to last flow (number of periods must equal the number of years in the "year").

Detail of the estimated

I Alternative A

a Initial Investment

Enter in negative (-) the estimated investment, which must contain all costs associated with the implementation (operation, implementation) of a good or service. This amount is the same that has been approved on Form 1680 - Project Charter. The initial investment amount is placed in year zero (year budgeting) and corresponds to a specific time when the investment occurs.

b Operational costs or maintenance

Enter in negative (-) the estimated operating expenses or maintenance (preventive and corrective) associated with the proposed investment. The expenditure budget of the project identified on Form 1715 - Project Budget, must match the flow of costs of alternative A. The flow of operating expenses or maintenance stands from year 1.

c Income

Enter in positive (+) direct revenue estimated to be generated from the proposed investment. Income should not be considered internal transfers between units of ACP. The revenue stream is placed from the year 1.

d Losses

Enter in negative (-) the estimated potential losses of income, such as the interruption of a service or system, among others. The leakage flux is placed from the year 1.

II Status quo (situación actual)

a Initial Investment

Enter in negative (-) the estimated investment, if applicable, current status (status quo). The initial investment amount is placed in year zero (budgeting) and corresponds to the specific time when the investment occurs.

b Operational costs or maintenance

Enter in negative (-) the estimated operating expenses or maintenance (preventive and corrective) of the current condition. The flow of operating expenses or maintenance of the status quo (current situation) is placed after the year 1.

c Income

Enter in positive (+) the estimated direct revenue generated from the existing condition (status quo).

d Loses

Estimated direct revenue losses from the interruption of a service or system, among others, of the existing condition (status quo).

III Other Considerations

This is relevant aspects that have not been quantified or not be quantified as part of the economic evaluation:

1. Improvements to current processes.
2. Teams higher capacity and efficiency, which will lead to lower maintenance costs, increase in the estimated useful life
3. Change in technology
4. Standardization of equipment and spare parts, among others.

IV Conclusión

If Alternative A (proposed investment) has a positive NPV and CAUE marginally when compared to the status quo (current condition), we recommend alternative A.

If Alternative A (proposed investment) has an internal rate of return (IRR) of____% above the minimum expected return rate of 14%, we recommend alternative A.

Write a brief conclusion of why (from their point of view and according to the favorable results), Alternative A is the best alternative for the ACP from the economic standpoint.

Note: If you require alternative assessment is required to copy to another tab of the same document and in turn compared against the status quo.

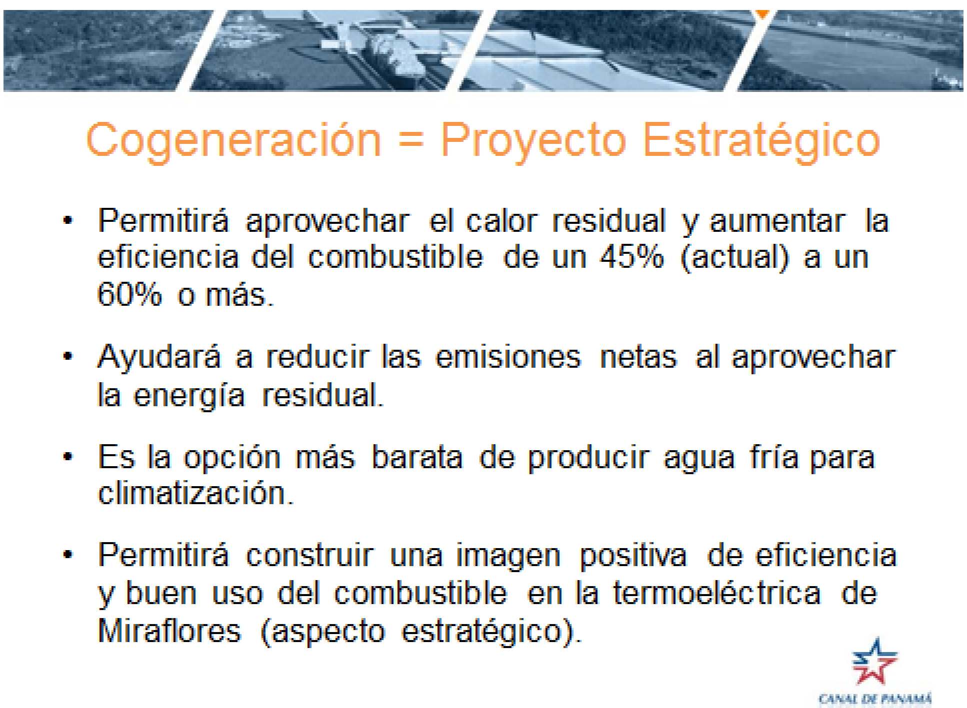
Factores de Interés Compuesto Discreto

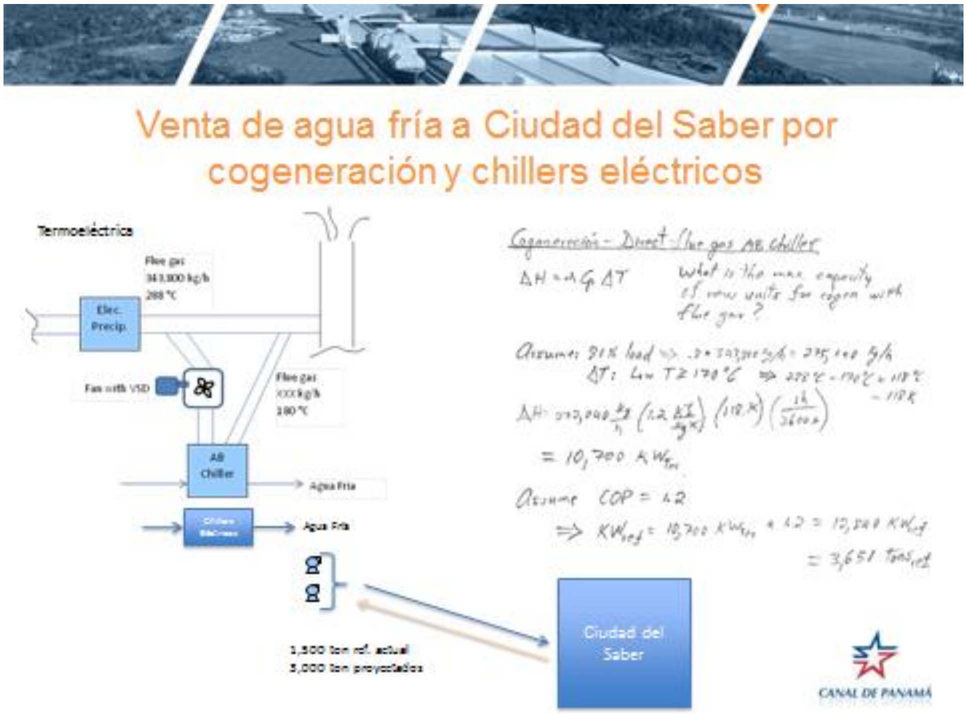
i = tasa efectiva por período = **14%**

N= períodos

N	Factor del Valor Presente *P/F*	Recuperación de Capital *A/P*
0	1.0000	
1	0.8772	1.1400
2	0.7695	0.6073
3	0.6750	0.4307
4	0.5921	0.3432
5	0.5194	0.2913
6	0.4556	0.2572
7	0.3996	0.2332
8	0.3506	0.2156
9	0.3075	0.2022
10	0.2697	0.1917
11	0.2366	0.1834
12	0.2076	0.1767
13	0.1821	0.1712
14	0.1597	0.1666
15	0.1401	0.1628
16	0.1229	0.1596
17	0.1078	0.1569
18	0.0946	0.1546
19	0.0829	0.1527
20	0.0728	0.1510
21	0.0638	0.1495
22	0.0560	0.1483
23	0.0491	0.1472
24	0.0431	0.1463
25	0.0378	0.1455
30	0.0196	0.1428
35	0.0102	0.1414
40	0.0053	0.1407
45	0.0027	0.1404
50	0.0014	0.1402

Appendix D- Chilled Water Distribution Power Point




Venta de agua fría a Ciudad del Saber por cogeneración y chillers eléctricos
Termoeléctrica
Flue gas
343,800 kg/h
288 °C
Elec. Precip.
Fan with VSD
Flue gas
xxx kg/h
180 °C
AB Chiller
Agua Fria
Agua Fria
1,500 ton ref. actual
5,000 ton proyectados
Ciudad del Saber
CANAL DE PANAMÁ


Proyecto de red urbana de frío
Termoeléctrica con cogeneración y chillers eléctricos
Ciudad del Saber
Otros clientes potenciales en Corozal y Albrook
Tubería 16" fibra de vidrio
Almacenamiento térmico en Balboa
Red de distribución de Balboa
Se propone el siguiente orden:
1. Instalar cogeneración y chillers eléctricos para vender a Ciudad del Saber.
2. Instalar una línea de Miraflores a Balboa, almacenamiento térmico en Balboa y aumentar la cogeneración.
3. Mudar los chillers de Balboa a Miraflores (se reduce la inversión en equipos nuevos).
4. Captar otros clientes potenciales entre Corozal y Albrook. Otros clientes en Clayton y Ciudad Hospitalaria.
CANAL DE PANAMÁ

Viabilidad y ventajas

- En varios estudios de la ACP se ha determinado que una planta central de agua fría es la opción más eficiente para climatización.
- Las tecnologías de cogeneración están bien desarrolladas (+100 años) y existen diversas opciones como ADsorción y Absorción.
- Las tuberías de fibra de vidrio han reducido los costos a tan solo B/.65K por kilómetro (tuberías de 16").
- Los equipos de agua fría por cogeneración están por el orden de B/.600 a 900 por tonelada, cercano al costo de chillers eléctricos.
- La cogeneración permitirá el aprovechamiento de la energía residual en la termoeléctrica y la reducción equivalente de emisiones.

CANAL DE PANAMÁ

Resumen económico para una red urbana de frío: Caso de ACP y Ciudad del Saber

	A = Status Quo	B	C	D
Cifras en miles	Planta Central de Agua fria por chillers eléctricos	Red Urbana de frio con chillers eléctricos Red Tank/CDS	Red Urbana de frio con 50% cogeneración Red Tank /CDS	Red Urbana de frio con 100 % cogeneración Red Tank/CDS
Toneladas	3000	6000	6000	6000
Costos Capitales				
Inversión	3,530	7,861	8,786	10,080
Costos Operativos				
Electricidad	436	889	424	59
Mantenimiento				
Recurso Humano	167	167	167	167
Depreciación				
Total Operat.	604	1,056	592	226
Ingresos				
Por Demanda		569	569	569
Por Consumo		809	809	809
Total Ingresos		1,378	1,378	1,378
Rentabilidad				
TIR		21%	26%	27%
VAN		1,799	3,950	5,078

CANAL DE PANAMÁ

Appendix E- Pipe Cost Quote

OTEK INTERNACIONAL S.A.
Oficina: Calle 19 A # 43-B-41 El Poblado
PBX: +(57 4) 444 4242
Oficina: Calle 90 # 19 A 13 Bogotá
PBX: +(57 1) 508 21 96
Apartado Aéreo: 62159
Medellín, Colombia

COTIZACIÓN INTERNACIONAL Nº. 9032012

Empresa:	CANAL DE PANAMA
NIT	
Contacto:	LAURENTINO DE VEGA JOLY
Email:	ldevegas@pancanal.com
Ciudad:	PANAMA
Dirección:	
Teléfono:	507-2726670
Fax:	

PROYECTO: ACP - Panama

ÍTEM	DESCRIPCIÓN	UND	CANTIDAD	VALOR UNITARIO (US$)	VALOR PARCIAL (US$)
1	Tuberia GRP DN800 PN10 SN2500	ml	2.000,00	$ 144,44	$ 288.880,00
2	Acople GRP DN800 PN10	un	178,00	$ 186,36	$ 33.172,00
3	Tuberia GRP DN400 PN6 SN5000	ml	5.000,00	$ 63,33	$ 316.650,00
4	Acople GRP DN400 PN6	un	453,00	$ 90,00	$ 40.770,00
5	Tuberia GRP DN350 PN6 SN5000	ml	5.000,00	$ 54,44	$ 272.200,00
6	Acople GRP DN350 PN6	un	445,00	$ 85,56	$ 38.074,00
	DN=Diámetro Nominal (mm), PN=Presión Nominal (bar), SN=Rigidez Nominal (N/m²), L=Longitud (m)			Subtotal	$ 989.746,00
				Transporte	$ 163.626,20
				Seguros	$ 11.533,72
				TOTAL	$ 1.164.905,93

La tubería se suministra para sistemas a flujo libre y a presión hasta 32 bar (470 psi), en diámetros entre 300 y 3700mm, cumpliendo con todas las normas de fabricación AWWA C-950 y las NTC 3826, NTC 3870 y NTC 3871.

Términos Comerciales

* Forma de pago: 30% anticipo y el saldo respaldado mediante carta de credito confirmada e irrevocable pagadera contra documentos de embarque B/L
* Los precios están dados en dólares americanos, además son tentativos para estudios de factibilidad. Tanto el precio del flete como el de los tubos deben ser revisados al momento de acercarse la negociación. Solo deben ser tomados como referencia
*El costo del transporte incluye embalaje, seguro, transporte terrestre y marítimo CIF Puerto Balboa, no se incluye descargue en Puerto Balboa, gastos de aduana o nacionalización ni transporte interno dentro de Panamá.
* La tubería se suministrará en los siguientes tramos: DN800 tramos de 11.8 metros, DN400 en longitud de 11,6 y DN350 en longitud de 11,8 para efectos de anidamiento en le momento del cargue de la tubería. Los acoples se consideraron con un 5% adicional para cortes en obra
* Tiempo de entrega: sujeto a instalación en obra y fabricación en planta
*Estas cantidades son generales y están sujetas a cambios según diseño definitivo del proyecto

Fecha de elaboración: 9 de marzo de 2012	**Plazo de entrega:** Ver términos comerciales
Vencimiento: Treinta (30) días	**Sitio de entrega:** CIF Puerto Balboa - Panamá

Siempre estaremos atentos para asuntos técnicos y comercialmente

Otek Internacional S.A

Sergio Llano
Elaboró: MV Estructuración de Proyectos

Código:	Aprobado por:	Vigente desde:	Revisión:
F-300-03	Coordinador Comercial	2011 - 05-18	02

Appendix F- Insulation Quote

ACP

Atención: Ing. Urho Gonzal — 22-03-12

Proyecto: Aislante térmico Thermaflex, producto ThermaSmart PRO

Referencia: 2012-065-DP

Codigo Producto	Clave Thermaflex	Unidad	Cantidad	Contenidos por empaque	Precio Unitario USD	Descuento de	Precio con descuento	Sub total en USD
3100025	TS 25 mm	Rollo	420	39 M2	$ 1.427,84	45%	$ 785,31	$ 329.832,10
8001004	Glue 30 L	Lata	65	30 Ltr	$ 529,20	45%	$ 291,06	$ 18.918,90
					Total		$	348.751,00

**Condiciones comerciales generales

-Precios en USD
-Precios sujetos a cambio sin previo aviso

- Inlcuye descuento de:	**45%**
- Condiciones de Pago:	**50% contra Orden de Compra, 50% contra arribo a Puerto**
-Incoterm:	**CIF Puerto Balboa**
- Propuesta valida por:	**30 días**
- Tiempo de Entrega:	**Aprox. 4 semanas**

Appendix G- Storage Tank Quote

Estimate

COMPANY	BlueScope Water	
MODEL	BH Highline BH45R7	
STEEL	ZINCALUME® zinc-aluminum coated steel	
ROOF TYPE	Dome Roof – 90 mph wind load per ASCE7.05	
DIAMETER	37'4"	
SEISMIC	No allowance made for seismic	
HEIGHT	19'1"	
GROSS TANK CAPACITY	155,800 Gallons	
DELIVERY SCHEDULE	60 TO 90 days after completion of accepted engineering drawings	
Fittings & Accessories		
1 EA	Industratex® Tank Liner NSF61 Certified for potable water	
1 EA	Heavy-duty external ladder (Hot dipped galvanized)	
1 EA	Roof access hatch, hinged, lockable 30"-	
1 EA	Hinged side access hatch, 30"	
1 EA	Mechanical external level gauge	
1 SET	Tank bolt down brackets	
1 EA	Roof vent	
1 EA	Geo-Tex layer (Under Liner)	
1 SET	Magnesium anodes for cathodic protection	
Nozzles		
1 EA 4"	PVC outlet nozzle with ANSI flange external connection and anti-vortex internal - Insulation by others	
1 EA 4"	PVC Inlet nozzle with ANSI flange external connection and deflector internal - Insulation by others	
1 EA 6"	PVC overflow w/bell-mouth, down-pipe, pipe Brackets and flapper closure - Insulation by others	
1 EA 2"	PVC steel sidewall drain outlet with valve- NPT - Insulation by others	
		Price per Tank
Total	GALVALUME® zinc-aluminum coated steel	Total $92,800.00*

*Ring beam foundation and site work is not included. Standard engineering drawings for the ring beam will be supplied by BlueScope Water. Adjustments to the ring beam drawing may be required for site specifics. Geological engineering report not included. Applicable customs charges, taxes and permits not included

Estimate for ring beam installation...$15,000.00

Appendix H- kWh consumption and Chilled Water taxes

Electr. Balboa Plant Chill Water

UGonzal

You forwarded this message on 11/21/2012 3:55 PM.

Sent: Wed 11/21/2012 3:54 PM

To: EST-KBlack; EST-MReed

OCTUBRE	NOVIEMBRE	DICIEMBRE	ENERO	FEBRERO	MARZO	ABRIL	MAYO	JUNIO	JULIO	AGOSTO	SEPTIEMBRE
818,377	858,833	674,432	763,277	766,399	780,341	815,600	826,132	768,409	765,845	737,600	781,891

In kWh every month

The production of electricity costs B/.0.140 per kWh
And is sold at B/.0.183 per kWh

Chill water tariff:

Renglón	Descripción	Tarifa
2040.0020	Cargo por demanda, por tonelada instalada, por mes	B/.29.59
2040.0030	Cargo por consumo medido, por tonelada-hora	B/.0.1225

Saludos,

Urho Gonzal P. | Especialista en Control Ambiental y Conservación de Energia | Sección de Evaluación Ambiental | Tel. (507) 276-2141 | Email: ugonzal@pancanal.com

Appendix I- Model Calculations

Flow (gpm)	Length (m)	diameter 1 (m)	diameter 2 (m)	diameter 3 (m)	Flow (m^3/s)
1000	5973.81	0.3	0.35	0.4	0.063083523
1500	5973.81	0.3	0.35	0.4	0.094625284
2000	5973.81	0.3	0.35	0.4	0.126167045
2500	5973.81	0.3	0.35	0.4	0.157708806
3000	5973.81	0.3	0.35	0.4	0.189250568
3500	5973.81	0.3	0.35	0.4	0.220792329
4000	5973.81	0.3	0.35	0.4	0.25233409
4500	5973.81	0.3	0.35	0.4	0.283875852
2646.01	5973.81	0.3	0.35	0.4	0.166919632

Flow (gpm)	Velocity 1 (m/s)	Velocity 2 (m/s)	Velocity 3 (m/s)	Reynolds Number 1	Reynolds Number 2	Reynolds Number 3
1000	0.892450038	0.655677579	0.502003146	186705.0289	160032.8819	140028.7717
1500	1.338675057	0.983516368	0.75300472	280057.5433	240049.3228	210043.1575
2000	1.784900076	1.311355158	1.004006293	373410.0577	320065.7638	280057.5433
2500	2.231125095	1.639193947	1.255007866	466762.5722	400082.2047	350071.9291
3000	2.677350114	1.967032737	1.506009439	560115.0866	480098.6457	420086.315
3500	3.123575133	2.294871526	1.757011012	653467.601	560115.0866	490100.7008
4000	3.569800152	2.622710316	2.008012585	746820.1155	640131.5275	560115.0866
4500	4.016025171	2.950549105	2.259014159	840172.6299	720147.9685	630129.4724
2646.01	2.361431725	1.734929431	1.328305345	494023.3734	423448.6058	370517.5301

Flow (gpm)	Friction Factor 1	Friction Factor 2	Friction Factor 3	Friction loss (DW) 1	Friction loss (DW) 2	Friction loss (DW) 3
1000	0.015	0.0155	0.016	12.12523687	5.796912199	3.069200584
1500	0.014	0.0145	0.015	25.46299743	12.20156519	6.474094981
2000	0.0135	0.0135	0.014	43.65085275	20.19569411	10.74220204
2500	0.013	0.013	0.0135	65.6783664	30.38703975	16.18523745
3000	0.0125	0.0125	0.013	90.93927655	42.07436273	22.44352927
3500	0.012	0.0125	0.0125	118.8273214	57.26788261	29.37320871
4000	0.012	0.012	0.0125	155.203032	71.8069124	38.3650073
4500	0.0115	0.012	0.012	188.2443025	90.88062351	46.61348386
2646.01	0.0113	0.013	0.013	63.95291997	34.04014011	17.45949203

Flow (gpm)	Pressure loss (DW) 1	Pressure loss (DW) 2	Pressure loss (DW) 3	Pressure loss (DW) 1 (PSI)	Pressure loss (DW) 2 (PSI)	Pressure loss (DW) 3 (PSI)
1000	133243.1891	86705.18893	59959.43509	19.32529075	12.57552448	8.696380837
1500	186540.4647	121666.9587	84317.95559	27.05540705	17.64630047	12.22928555
2000	239837.7404	151034.8452	104929.0114	34.78552335	21.90575231	15.21866646
2500	288693.5763	181801.2026	126476.9334	41.87146329	26.36803519	18.34392833
3000	333107.9727	209770.6184	146151.123	48.31322687	30.42465599	21.19742829
3500	373080.9294	244732.3881	163951.5803	54.1108141	35.49543199	23.77916635
4000	426378.2051	268506.3915	187373.2346	61.8409304	38.94355967	27.17619012
4500	459689.0023	302069.6905	202363.0934	66.67225308	43.81150462	29.35028532

Flow (gpm)	Mass Flow rate (kg/s)	Delta H (kW)	Tons of Refrigeration (RT)	Volume (Gal)	Power (HP)
1000	63.29113924	1329.113924	377.927385	66972.77778	1782.371013
1500	94.93670886	1993.670886	566.8910775	100459.1667	2673.55652
2000	126.5822785	2658.227848	755.8547701	133945.5556	3564.742026
2500	158.2278481	3322.78481	944.8184626	167431.9445	4455.927533
3000	189.8734177	3987.341772	1133.782155	200918.3334	5347.113039
3500	221.5189873	4651.898734	1322.745848	234404.7222	6238.298546
4000	253.164557	5316.455696	1511.70954	267891.1111	7129.484053
4500	284.8101266	5981.012658	1700.673233	301377.5	8020.669559
2646.01	167.4689873	3516.848734	999.9996401	177210.6397	4716.171524

Flow (gpm)	Pump power (kW) 1	Pump power (kW) 2	Pump power (kW) 3	Pump (HP) 1	Pump (HP) 2	Pump (HP) 3	Pump Cost 1	Pump Cost 2	Pump Cost 3
1000	7.501443929	3.58633916	1.898802994	10.05960134	4.809359714	2.54633659	$2,514.90	$1,202.34	$636.58
1500	23.62954838	11.32299823	6.00793135	31.68774423	15.18438974	8.056768117	$7,921.94	$3,796.10	$2,014.19
2000	54.01039629	24.98868576	13.29162096	72.42912967	33.51037736	17.82435613	$18,107.28	$8,377.59	$4,456.09
2500	101.5820532	46.99839625	25.03304729	136.2237682	63.02588335	33.56986715	$34,055.94	$15,756.47	$8,392.47
3000	168.7824884	78.08964299	41.65499069	226.3410302	104.7199293	55.86025894	$56,585.26	$26,179.98	$13,965.06
3500	257.2995268	124.0034609	63.60248312	345.0443261	166.2913691	85.29232914	$86,261.08	$41,572.84	$21,323.08
4000	384.0739292	177.6973209	94.94014972	515.0515888	238.2960168	127.3168295	$128,762.90	$59,574.00	$31,829.21
4500	524.0696265	253.0104433	129.7713172	702.7888988	339.2925708	174.0261913	$175,697.22	$84,823.14	$43,506.55
2646.01	104.6903123	55.72338058	28.58101982	140.392012	74.7262793	38.32777637	$35,098.00	$18,681.57	$9,581.94

Constants	
Gravity Constant (m/s^2)	9.8
Fluid Density supply (kg/m^3)	999.7
Fluid Density return (kg/m^3)	999.7
specific weight (N/m^3)	
Kinematic Viscosity supply (m^2/s)	0.000001434
Kinematic Viscosity return (m^2/s)	0.000001186
Length (m)	5973.81
Hazen William Constant	150
Manning's Coefficient	0.009
Area 1 (m^2)	0.070685775
Area 2 (m^2)	0.096211194
Area 3 (m^2)	0.1256636
Absolute roughness (in)	0.00021
Absolute roughness (m)	5.334*10^(-6)

Pipe Pricing

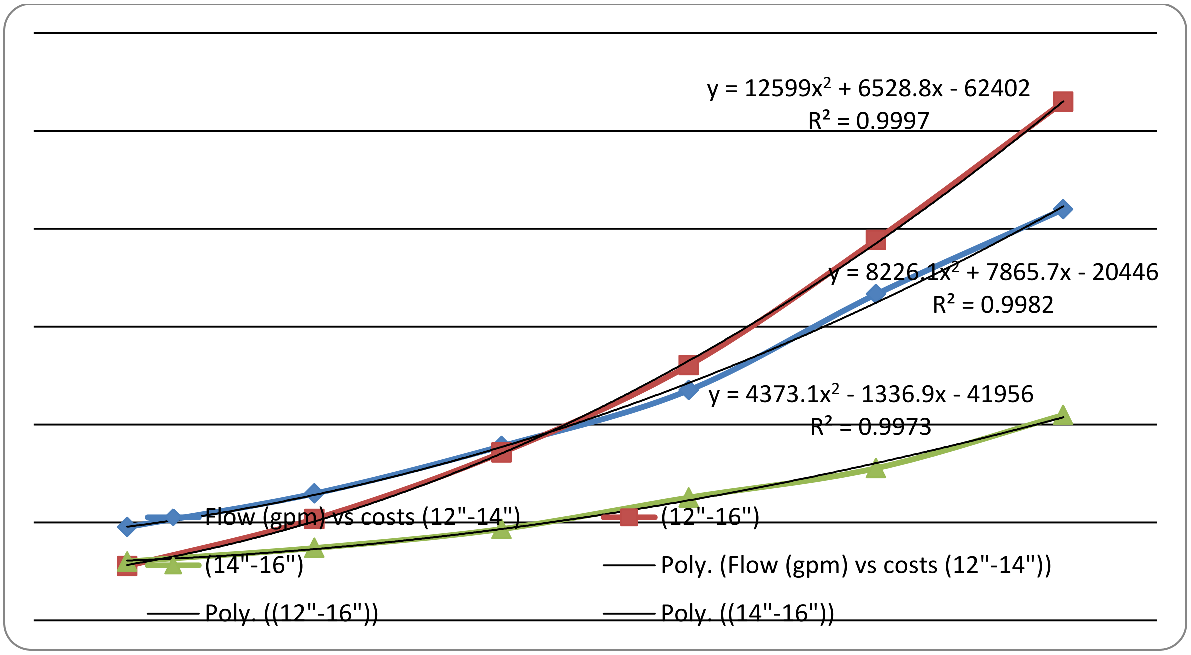
Item		Material	Diameter (mm)	Diameter (in)	Pressure (Bar)	Normal Stiffness (N/m2)	Length (m)	# units	Unit Price/m	% of highests cost	Unit price/part	% of highests cost	Partial Price
1		Tuberia GRP	DN800	32	PN10	SN2500	2.000.00		144.44	100			288.880.00
2		Acople GRP	DN800	32	PN10			178			186.36	100	33.172.00
3		Tuberia GRP	DN400	16	PN6	SN5000	5.000.00		63.33	43.8			316.650.00
4		Acople GRP	DN400	16	PN6			453			90	48.3	40.770.00
5		Tuberia GRP	DN350	14	PN6	SN5000	5.000.00		54.44	37.7			272.200.00
6		Acople GRP	DN350	14	PN6			445			85.56	45.8	38.074.00
7		Tuberia GRP	DN300	12	PN6	SN5000	5000		47.71	33			238550
8		Acople GRP	DN300	12	PN6			445			79.29	42.5	35284.05
9													
	Length (m)	**Diameter (m)**	**Pipe Costs**	**Coupling Costs**	**Total Costs**								
	11947.62	0.3	$570,020.95	$86,120.62	$656,141.57								
	11947.62	0.35	$650,428.43	$92,930.76	$743,359.19								
	11947.62	0.4	$756,642.77	$97,753.25	$854,396.03								

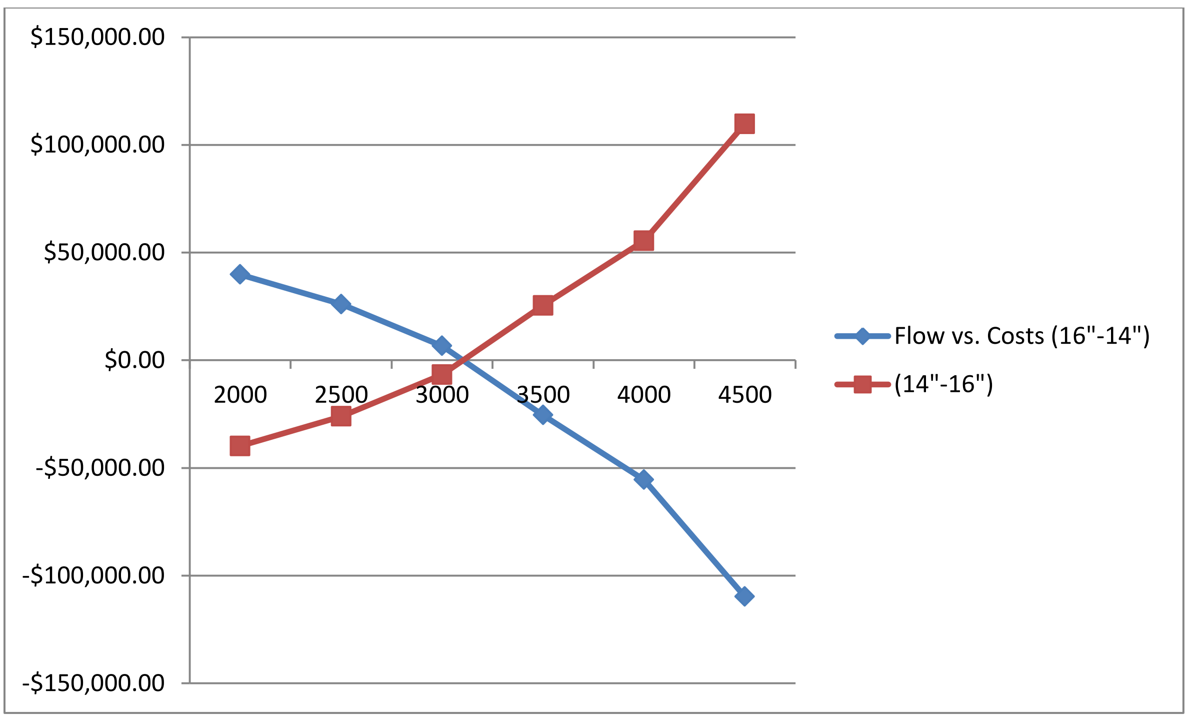
Thermal Storage Tank

Tank volume	Tank tons	tank cost	tons/hr for 8 hrs	Tank Diameter	Height to Diameter ratio
517616	2920.907088	$356,976.55	365.113386	27.99563382	0.357198557
500000	2821.5	$344,827.59	352.6875	27.51512311	0.363436498
475000	2680.425	$327,586.21	335.053125	26.81842464	0.37287798
450000	2539.35	$310,344.83	317.41875	26.10313774	0.383095707
425000	2398.275	$293,103.45	299.784375	25.36769008	0.39420223
400000	2257.2	$275,862.07	282.15	24.61027428	0.406334358
375000	2116.125	$258,620.69	264.515625	23.82879561	0.41966032
350000	1975.05	$241,379.31	246.88125	23.02080363	0.434389701
325000	1833.975	$224,137.93	229.246875	22.18340145	0.450787496
300000	1692.9	$206,896.55	211.6125	21.31312272	0.469194502
275000	1551.825	$189,655.17	193.978125	20.40576144	0.490057675
250000	1410.75	$172,413.79	176.34375	19.45613014	0.513976825
225000	1269.675	$155,172.41	158.709375	18.45770571	0.541779144
200000	1128.6	$137,931.03	141.075	17.40209183	0.57464356

Pipe Diameter Optimization

Cost of Pipe	Flow (gpm)	Cost of Pumps	Difference in pump cost (12"-14")	Difference in pump cost (12"-16")	Difference in pipe cost (12"-14")	Difference in pipe cost (12"-16")	Total diff (12"-14")	Total diff (12"-16'
328070.79	2000	$72,430.00	$38,919.62	$54,605.64	-43608.81	-99127.23	-$4,689.19	-$44,521.59
328070.79	2500	$136,220.00	$73,194.12	$102,650.13	-43608.81	-99127.23	$29,585.31	$3,522.90
328070.79	3000	$226,340.00	$121,620.07	$170,479.74	-43608.81	-99127.23	$78,011.26	$71,352.51
328070.79	3500	$345,040.00	$178,748.63	$259,747.67	-43608.81	-99127.23	$135,139.82	$160,620.44
328070.79	4000	$515,050.00	$276,753.98	$387,733.17	-43608.81	-99127.23	$233,145.17	$288,605.94
328070.79	4500	$702,790.00	$363,497.43	$528,763.81	-43608.81	-99127.23	$319,888.62	$429,636.58
			14"-16" pump costs	**14"-16" pipe cost**	**Total Difference**	**14"-12" pump costs**	**14"-12" pipe costs**	**Total diff (14"-12'**
371679.6	2000	$33,510.38	$15,686.02	-$55,518.42	-$39,832.40	-$38,919.62	43608.81	4689.187361
371679.6	2500	$63,025.88	$29,456.02	-$55,518.42	-$26,062.40	-$73,194.12	43608.81	-29585.30665
371679.6	3000	$104,719.93	$48,859.67	-$55,518.42	-$6,658.75	-$121,620.07	43608.81	-78011.26075
371679.6	3500	$166,291.37	$80,999.04	-$55,518.42	$25,480.62	-$178,748.63	43608.81	-135139.8209
371679.6	4000	$238,296.02	$110,979.19	-$55,518.42	$55,460.77	-$276,753.98	43608.81	-233145.1732
371679.6	4500	$339,292.57	$165,266.38	-$55,518.42	$109,747.96	-$363,497.43	43608.81	-319888.6192
			16"-14" Pump costs	**16"-14" pipe cost**	**total difference**	**16"-12" pump costs**	**16"-12" pipe costs**	**Total diff (16"-12'**
427198.02	2000	$17,824.36	-$15,686.02	$55,518.42	$39,832.40	-$54,605.64	99127.23	$44,521.59
427198.02	2500	$33,569.87	-$29,456.02	$55,518.42	$26,062.40	-$102,650.13	99127.23	-$3,522.90
427198.02	3000	$55,860.26	-$48,859.67	$55,518.42	$6,658.75	-$170,479.74	99127.23	-$71,352.51
427198.02	3500	$85,292.33	-$80,999.04	$55,518.42	-$25,480.62	-$259,747.67	99127.23	-$160,620.44
427198.02	4000	$127,316.83	-$110,979.19	$55,518.42	-$55,460.77	-$387,733.17	99127.23	-$288,605.94
427198.02	4500	$174,026.19	-$165,266.38	$55,518.42	-$109,747.96	-$528,763.81	99127.23	-$429,636.58





Initial Investment

Initial Investment										
Chiller tons	**Pipe**	**Tank volume**	**Tank tons**	**tank cost**	**pump costs**	**chillers**	**cooling towers**	**insulation**	**Installation**	**total**
2400	$743,359.20	517616	2920.90709	$356,976.55	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,150,930.83
3000	$743,359.20	517616	2920.90709	$356,976.55	$105,000.00	$1,950,000.00	$750,000.00	$348,751.00	$436,844.08	$4,690,930.83
2400	$743,359.20	500000	2821.5	$344,827.59	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,138,781.87
2400	$743,359.20	475000	2680.425	$327,586.21	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,121,540.49
2400	$743,359.20	450000	2539.35	$310,344.83	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,104,299.11
2400	$743,359.20	425000	2398.275	$293,103.45	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,087,057.73
2400	$743,359.20	400000	2257.2	$275,862.07	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,069,816.35
2400	$743,359.20	375000	2116.125	$258,620.69	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,052,574.97
2400	$743,359.20	350000	1975.05	$241,379.31	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,035,333.59
2400	$743,359.20	325000	1833.975	$224,137.93	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,018,092.21
2400	$743,359.20	300000	1692.9	$206,896.55	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$4,000,850.83
2400	$743,359.20	275000	1551.825	$189,655.17	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$3,983,609.45
2400	$743,359.20	250000	1410.75	$172,413.79	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$3,966,368.07
2400	$743,359.20	225000	1269.675	$155,172.41	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$3,949,126.69
2400	$743,359.20	200000	1128.6	$137,931.03	$105,000.00	$1,560,000.00	$600,000.00	$348,751.00	$436,844.08	$3,931,885.31

Annual Expenses and Income at Balboa

Baseline at Balboa	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Sum
Expenses													
Energy (kWh)	818377	858611	674432	753277	766399	750341	818500	525132	758409	765648	737600	751591	8978317
Cost ($)	$114,573	$120,206	$94,420	$105,459	$107,296	$105,048	$114,590	$73,518	$106,177	$107,191	$103,264	$105,223	$1,256,964
Income													
ton-hr sold			686874	683920	628689	713499	694496	743736					8302428
$$			$84,142	$83,780	$77,014	$87,404	$85,076	$91,108					$1,017,047
installed tons (assumed)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	32400
$$	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$79,893	$958,716
													$1,975,763

Appendix J- Alternative A Vs. Status Quo Cost Analysis

	Alternative A							Status Quo						
Fiscal Year	A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value	A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value
2013	(4,151)	-	-	-	(4,151)	1.0000	(4,150.93)	-	-	-	-	-	1.0000	-
2014	-	(321)	1,976	-	1,655	0.8772	1,451.83	-	(1,257)	1,976	-	719	0.8772	630.53
2015	-	(321)	1,976	-	1,655	0.7695	1,273.53	-	(1,257)	1,976	-	719	0.7695	553.09
2016	-	(321)	1,976	-	1,655	0.6750	1,117.14	-	(1,257)	1,976	-	719	0.6750	485.17
2017	-	(321)	1,976	-	1,655	0.5921	979.94	-	(1,257)	1,976	-	719	0.5921	425.59
2018	-	(321)	1,976	-	1,655	0.5194	859.60	-	(1,257)	1,976	-	719	0.5194	373.32
2019	-	(321)	1,976	-	1,655	0.4556	754.03	-	(1,257)	1,976	-	719	0.4556	327.47
2020	-	(321)	1,976	-	1,655	0.3996	661.43	-	(1,257)	1,976	-	719	0.3996	287.26
2021	-	(321)	1,976	-	1,655	0.3506	580.21	-	(1,257)	1,976	-	719	0.3506	251.98
2022	-	(321)	1,976	-	1,655	0.3075	508.95	-	(1,257)	1,976	-	719	0.3075	221.04
2023	-	(321)	1,976	-	1,655	0.2697	446.45	-	(1,257)	1,976	-	719	0.2697	193.89
2024	-	(321)	1,976	-	1,655	0.2366	391.62	-	(1,257)	1,976	-	719	0.2366	170.08
2025	-	(321)	1,976	-	1,655	0.2076	343.53	-	(1,257)	1,976	-	719	0.2076	149.19
2026	-	(321)	1,976	-	1,655	0.1821	301.34	-	(1,257)	1,976	-	719	0.1821	130.87
2027	-	(321)	1,976	-	1,655	0.1597	264.33	-	(1,257)	1,976	-	719	0.1597	114.80
2028	-	(321)	1,976	-	1,655	0.1401	231.87	-	(1,257)	1,976	-	719	0.1401	100.70
2029	-	(321)	1,976	-	1,655	0.1229	203.40	-	(1,257)	1,976	-	719	0.1229	88.33
2030	-	(321)	1,976	-	1,655	0.1078	178.42	-	(1,257)	1,976	-	719	0.1078	77.49
2031	-	(321)	1,976	-	1,655	0.0946	156.51	-	(1,257)	1,976	-	719	0.0946	67.97
2032	-	(321)	1,976	-	1,655	0.0829	137.29	-	(1,257)	1,976	-	719	0.0829	59.62
2033	-	(321)	1,976	-	1,655	0.0728	120.43	-	(1,257)	1,976	-	719	0.0728	52.30
Totals	(4,151)	(6,414)	39,515	-	28,951		6,811	-	(25,139)	39,515	-	14,376		4,761

	Alt. A vs. Status Quo	
Year (n)	Difference in Cash Flow	Difference in Present Values
0	(4,150.93)	(4,150.93)
1	936.29	821.30
2	936.29	720.44
3	936.29	631.97
4	936.29	554.36
5	936.29	486.28
6	936.29	426.56
7	936.29	374.17
8	936.29	328.22
9	936.29	287.92
10	936.29	252.56
11	936.29	221.54
12	936.29	194.33
13	936.29	170.47
14	936.29	149.53
15	936.29	131.17
16	936.29	115.06
17	936.29	100.93
18	936.29	88.54
19	936.29	77.66
20	936.29	68.13
Totals	14,575	2,050
	22%	2,050
	IRR	ANV

Appendix K-Alternative A vs Status Quo Sensitivity Analysis

Year (n)	Fiscal Year	Alternative A: A Investment (-)	B Expenses	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value
0	2013	(5,750)	-	-	-	(5,750)	1.0000	(5,750.00)
1	2014	-	(321)	1,976	-	1,655	0.8772	1,451.83
2	2015	-	(321)	1,976	-	1,655	0.7695	1,273.53
3	2016	-	(321)	1,976	-	1,655	0.6750	1,117.14
4	2017	-	(321)	1,976	-	1,655	0.5921	979.94
5	2018	-	(321)	1,976	-	1,655	0.5194	859.60
6	2019	-	(321)	1,976	-	1,655	0.4556	754.03
7	2020	-	(321)	1,976	-	1,655	0.3996	661.43
8	2021	-	(321)	1,976	-	1,655	0.3506	580.21
9	2022	-	(321)	1,976	-	1,655	0.3075	508.95
10	2023	-	(321)	1,976	-	1,655	0.2697	446.45
11	2024	-	(321)	1,976	-	1,655	0.2366	391.62
12	2025	-	(321)	1,976	-	1,655	0.2076	343.53
13	2026	-	(321)	1,976	-	1,655	0.1821	301.34
14	2027	-	(321)	1,976	-	1,655	0.1597	264.33
15	2028	-	(321)	1,976	-	1,655	0.1401	231.87
16	2029	-	(321)	1,976	-	1,655	0.1229	203.40
17	2030	-	(321)	1,976	-	1,655	0.1078	178.42
18	2031	-	(321)	1,976	-	1,655	0.0946	156.51
19	2032	-	(321)	1,976	-	1,655	0.0829	137.29
20	2033	-	(321)	1,976	-	1,655	0.0728	120.43
	Totals	(5,750)	(6,414)	39,515	-	27,352		5,212

Year (n)	Fiscal Year	Status Quo: A Investment (-)	B Expenses (-)	C Income (+)	D Loss (-)	Total Cash Flow	Present Value Factor	Present Value
0	2013	-	-	-	-	-	1.0000	-
1	2014	-	(1,257)	1,976	-	719	0.8772	630.53
2	2015	-	(1,257)	1,976	-	719	0.7695	553.09
3	2016	-	(1,257)	1,976	-	719	0.6750	485.17
4	2017	-	(1,257)	1,976	-	719	0.5921	425.59
5	2018	-	(1,257)	1,976	-	719	0.5194	373.32
6	2019	-	(1,257)	1,976	-	719	0.4556	327.47
7	2020	-	(1,257)	1,976	-	719	0.3996	287.26
8	2021	-	(1,257)	1,976	-	719	0.3506	251.98
9	2022	-	(1,257)	1,976	-	719	0.3075	221.04
10	2023	-	(1,257)	1,976	-	719	0.2697	193.89
11	2024	-	(1,257)	1,976	-	719	0.2366	170.08
12	2025	-	(1,257)	1,976	-	719	0.2076	149.19
13	2026	-	(1,257)	1,976	-	719	0.1821	130.87
14	2027	-	(1,257)	1,976	-	719	0.1597	114.80
15	2028	-	(1,257)	1,976	-	719	0.1401	100.70
16	2029	-	(1,257)	1,976	-	719	0.1229	88.33
17	2030	-	(1,257)	1,976	-	719	0.1078	77.49
18	2031	-	(1,257)	1,976	-	719	0.0946	67.97
19	2032	-	(1,257)	1,976	-	719	0.0829	59.62
20	2033	-	(1,257)	1,976	-	719	0.0728	52.30
	Totals	-	(25,139)	39,515	-	14,376		4,761

Year (n)	Alt. A vs. Status Quo: Difference in Cash Flow	Difference in Present Values
0	(5,750.00)	(5,750.00)
1	936.29	821.30
2	936.29	720.44
3	936.29	631.97
4	936.29	554.36
5	936.29	486.28
6	936.29	426.56
7	936.29	374.17
8	936.29	328.22
9	936.29	287.92
10	936.29	252.56
11	936.29	221.54
12	936.29	194.33
13	936.29	170.47
14	936.29	149.53
15	936.29	131.17
16	936.29	115.06
17	936.29	100.93
18	936.29	88.54
19	936.29	77.66
20	936.29	68.13
Totals	12,976	451
	15%	451
	IRR	ANV

Appendix L- Chiller and Cooling Tower Quote

Uninstalled Equipment Replacement Cost Guidelines (Cost Per Ton)

Service	Tonnage	Price Per Ton
Air-cooled Chiller (recip.)	40 - 60	**$575.00 - $650.00**
Air-cooled Chiller (recip.)	70 - 180	**$450.00 - $525.00**
Water-cooled Chiller (recip.)	40 - 60	**$525.00 - $575.00**
Water-cooled Chiller (recip.)	70 - 180	**$450.00 - $515.00**
Water-cooled Centrifuged Chiller	100 - 300	**$375.00 - $675.00**
Water-cooled Centrifuged Chiller	400 - 1600	**$300.00 - $365.00**
Cooling Towers, Induced Draft, assembled	10.0 - 40	**$225.00 - $265.00**
Cooling Towers, Induced Draft, assembled	50 - 150	**$175.00 - $215.00**
Cooling Towers, Counter-flow, Forced Draft	100 - 300	**$155.00 - $175.00**
RTU Gas Heat, DX	3.0 - 15	**$695.00 - $800.00**
RTU Gas Heat, DX	20 - 60	**$465.00 - $695.00**
RTU Multizone	3.0-15	**$1050.00 - $1195.00**
RTU Multizone	20 - 60	**$1125.00 - $1195.00**
Heat Pump: Water to Air	3.0 - 20	**$475.00 - $575.00**
Heat Pump: Air to Air Par.	3.0 - 7	**$675.00 - $735.00**
Heat Pump: Air to Air Split	2.0 -10	**$750.00 - $850.00**

*** NOTE**
Prices reflect cost-per-tonnage of uninstalled equipment.