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INVESTIGACIÓN

SUSTAINABLE DESIGN SOLUTIONS
for BATIPA FIELD INSTITUTE

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Sustainable Design Solutions for Batipa Field Institute

An Interactive Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
Degree of Bachelor of Science

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Resumen

El Batipa Field Institute tiene la visión de convertirse en una estación de investigación que prospera en la comunidad científica y en el ecoturismo. El objetivo de este proyecto fue proponer diseños para la energía sostenible y la utilización de recursos para su implementación en el instituto. Los diseños finales incluyeron la instalación de un sistema fotovoltaico y conectividad a Internet, la utilización de madera de teca en exceso y el desarrollo de un concepto para la recolección de agua de lluvia y la estructura de soporte fotovoltaico. Esto se logró a través de un proceso iterativo de diseño orientado a las partes interesadas donde la comunicación permitió el estrechamiento de la investigación para lograr recomendaciones finales detalladas.

Abstract

The Batipa Field Institute has a vision to grow into a research station that thrives in the scientific community and in ecotourism. The goal of this project was to propose designs for sustainable energy and resource utilization for implementation at the institute. The final designs included installing a photovoltaic system and internet connectivity, utilizing excess teak wood, and developing a concept for a rainwater harvesting and photovoltaic support structure. This was accomplished through an iterative stakeholder oriented design process where communication allowed for the narrowing of research to achieve detailed final recommendations.

Acknowledgements

This project was only able to be completed thanks to the help of our sponsor and all the people we met in the field. Our team would like to take this space to thank them.

First we would like thank our primary sponsor, *Dr. Francisco Ugel*. Dr. Ugel coordinated our stay in David in addition to all of our meetings and visits to both Oteima University and the Batipa Field Institute. Dr. Ugel was constantly in contact with us, answering any questions we had, and helping us to organize anything we needed.

We would also like to thank the president of Oteima University, *Mr. Luis Ríos Espinosa*, for hosting our team as a sponsor and for taking the time to explain the past, present, and future goals of the Batipa Field Institute.

The son of Mr. Luis Ríos Espinosa and the manager of the current practices at Batipa, *Mr. Luis Antonio Ríos Gnaegi*, was also instrumental in the completion of this project. Our team wants to make sure to not only thank him for giving us a tour of Batipa, but also for explaining each function of Batipa.

Our thanks go to *Mr. Héctor Palacios* as well, Mr. Palacios presented to us his future vision of the Batipa Field Institute in great detail. He constantly stayed in contact with us and answered all questions that we had. He even gave us permission to use the photographs of his conceptual designs in our presentations.

We would also like to thank two of our tour guides from our time spent in David, *Jerry* and *Pablo*, who gave us transportation and answered all of our questions.

Last but not least, we would like to thank our advisors, *Prof. James Chiarelli* and *Prof. Stephen McCauley*. They were invaluable assets to the completion of our projects including aiding in formulating the concepts and organization of our project, and proofreading our paper.

EXECUTIVE SUMMARY

This report provides recommendations of sustainable designs for the use of solar power and Wi-Fi internet connectivity in addition to the utilization of excess teak wood at the Batipa Field Institute. Oteima University, officially known as Universidad Technólogica Oteima, is a private university that is an affiliate to multiple companies located on the Batipa Peninsula. Batipa is the collection of affiliated enterprises that are responsible for the reforestation of teak trees, genetic modification of cattle, and preservation of biodiversity on the peninsula. The pursuit of Batipa's profitable management practices and biodiversity conservation represents a cutting edge integration of land use.

One of Batipa's enterprises, the Batipa Field Institute, is a tropical research station focused on preserving the peninsula's natural environment while providing opportunities for scientists and students to research the unique ecosystems present. The institute includes a recreational area called Cabimos consisting of a structure with sleeping quarters and a kitchen as well as separate accommodations for bathrooms and showers. They plan to expand through the construction of modernized facilities that promote ecotourism, agricultural education, and environmental research. To facilitate expansion across the peninsula, outpost stations, depicted below in Figure ES 1 will be located in remote areas throughout Batipa. All of the proposed facilities are planned to be sustainable, off the grid, and have a low environmental impact.

Figure ES 1: Rendering of an Outpost Station (Palacios, 2017)

Our recommendations were developed through a stakeholder oriented design process with our main objectives targeting communication with our sponsor, gathering information, and presenting preliminary designs for iteration and feedback. Over our seven weeks in Panama, ten days were spent with our sponsor, Oteima University, in the city of David, the capital city of the Chiriquí Province. Three of our days in David were dedicated to on site excursions with the objective of learning about Batipa's current operations and resource management practices through observations and interviews. Throughout the remainder of our time in Panama, we had ongoing discussions with our sponsor to determine how to best deliver meaningful designs for implementation at Batipa.

After an iterative process of working to determine our sponsor's key priorities, depicted above in Figure ES 2, we identified the primary needs for which we could propose design solutions.

1. Photovoltaic System for Cabimos
2. Wi-Fi Internet Connectivity at Cabimos
3. Utilization of Excess Teak Wood

Figure ES 2: Graphic depicting Stakeholder Oriented Design Approach

Photovoltaic System for Cabimos

Proposing a photovoltaic system to implement at Cabimos required a careful selection of a solar panel, batteries, charge controller, and inverter to ensure a cost effective solution. The solar panel size had to be considered first because the size has to satisfy the daily power demand of Cabimos. Three different scenarios of Cabimos were investigated to demonstrate how the system's size and cost fluctuates due to certain appliances for lighting, internet, and a charging station. The lowest power scenario for Cabimos, shown in Table ES1, calculates that the energy needed to power the listed devices is 624 Watt hours per day.

Table ES 1: A potential scenario of appliances to be implemented at Cabimos

Appliance	Power Demand	Daily Hours of Use	Energy Needed
Three LED Light Bulbs	30 W	12 Hours	360 Wh
One Wi-Fi Hotspot	4.5 W	24 Hours	108 Wh
Two Phone Chargers with phones	12 W	12 Hours	144 Wh
Two Phone Chargers without phones	1 W	12 Hours	12 Wh
Total Energy	-	-	624 Wh

In order for the photovoltaic system to power these appliances up to one and a half days without sunlight, one 24 Volt, 200 Watt panel in conjunction with a 24 Voltage, 94 Amp hour battery bank and a 9 Amp charge controller is required.

Once the correct solar panel size was selected, the next step was to create a battery bank that stores the collected energy. A large battery bank is essential to not only store the daily demand of energy, but to also store enough energy to power the system without sunlight. As deep cycle batteries are the most expensive component of the photovoltaic system, it is essential to invest in a higher quality, longer lasting product such as lithium batteries. Over 28 years, it was determined that lithium batteries were a more cost effective option than the standard flooded lead acid batteries.

The next two required components of the photovoltaic system included a charge controller and an inverter. Each of these components have a more expensive, efficient option and a cheaper, less efficient option. For the charge controller and the inverter, it was determined that it was more profitable to invest in the more expensive Maximum Power Point Tracking Charge Controller and the Pure Sine Wave Inverter because the benefits of increased system efficiency surpass the initial cost.

Wi-Fi Internet Connectivity at Cabimos

The implementation of Wi-Fi at Cabimos would make progress towards achieving a connection throughout the Peninsula allowing visitors to complete tasks requiring internet. There are two main options providing off the grid solutions for wireless internet: mobile Wi-Fi hotspots and satellite internet dishes. Both options provide sufficient connectivity to fulfil the expected internet demands at Cabimos and can solely run off solar power. However, the benefits of each option differ mobile Wi-Fi hotspots are a small-scale, minimal power solution while satellite internet is a large-scale, extensive power solution. We concluded that the most viable option would be mobile Wi-Fi hotspots because they can accommodate the current internet demands as well as being a financially safe option without as many contracts and components as a satellite. A satellite internet dish would provide a more stable and robust connection, however its bandwidth and signal exceed the current demands at Batipa. Another aspect of satellite internet to consider is the limited signal during rainfall. These factors result in satellite internet connections not being a viable option against mobile Wi-Fi hotspots.

Utilization of Excess Teak Wood

One of the final goals of our team was to propose a means for the elimination and utilization of excess teak wood. This is a critical resource management for Batipa as trees are harvested every year. Thousands of tons of wood that are not commercially profitable in their current state must be removed before reforestation can begin. Despite the fact that our sponsor expressed interest in avoiding the purchase of a wood chipper, we determined after extensive research that the most viable option was to recommend one.

Potential uses for the created wood chips are:

- Landscaping (Pathways, Mulch, etc.)
- Selling as Non-Timber Products (Dairy farms, Particleboard makers, etc.)
- Energy Production (Combustion and Anaerobic Digestion)
- Composting

Table ES 2: Important components to consider when purchasing a wood chipper

Component	Recommendation	Advantages
Feed System	Hydraulics	Requires less effort for feeding Gives variable feeding speeds
Cutting System	Drum	More common Creates more uniform chips
Portability	Tires -Potential Trailer Attachment	Easier for maintenance Smaller and simpler design
System Controls	Remote control (Optional)	Increased Operator Safety
Loading System	Cab with loading arm (Optional)	Increased Operator Safety Increased Speed
Chipping Capacity	Larger than recommended	Increased lifetime of machine

An example of a wood chipper that our team thinks would be a good fit for Batipa's needs is the Morbark Beever™ M20R Forestry Chipper, seen in Figure ES 3 below. This is an smaller scale, efficient industrial drum chipper that is portable and optimal for in-woods chipping. In addition, it is reinforced in critical wear areas and creates wood chips that have the potential to be used for the biomass industry.

Figure ES 3: Morbark Beever™ M20R Forestry Chipper

Conceptual Design for a Structure Utilizing Teak

Our team developed a conceptual design for an elevated structure that maximizes the potential for rainwater harvesting and the use of a photovoltaic system at the outpost stations, depicted in Figure ES 4. The structure is surrounded by a teak facade which contributes to our sponsor's goal of utilizing excess teak wood. An objective of this design is to provide a large enough catchment surface for rainwater collection to be a viable water source at the outpost stations. A solar panel positioned at the top of the structure would maximize energy collection in more remote, wooded areas. To develop this, we conducted research into rainwater harvesting systems, power demand, and created detailed models of our concept.

In order to determine the feasibility of a rainwater harvesting system at the outpost stations, we evaluated the stations' water demands by using the Rainwater Calculation Formula (Novak, Van, & DeBusk, 2014). Assuming the water demand is 1200 gallons per year, we ascertained that a structure with a 36 ft^2 catchment surface area would fulfill the need at each outpost station. This catchment surface would provide almost 3000 gal per year, assuming Batipa's average annual rainfall.

In order to prove the effectiveness of providing solar power at the outpost stations, we estimated daily energy demand at each station. The appliances needed to satisfy our sponsor's needs had a demand of 1.240 kWh fulfilled by implementing two 24 Volt, 160 Watt panels.

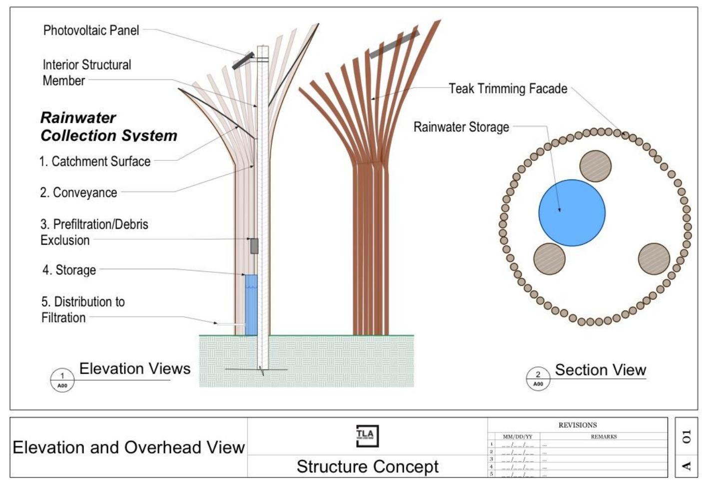

Figure ES 4: Elevation and section views of structure concept

In our time working with Oteima University and the Batipa Field Institute, our team provided thoughtful recommendations based on a stakeholder oriented design approach. Batipa's stakeholders comprised of multiple individuals with varying backgrounds and fields of expertise. We were able to successfully propose designs to advance Batipa's unique vision to not only be sustainable and off the grid, but also environmentally friendly and economically feasible. In all of our proposals, we adopted design principles for larger capacity with higher initial investments in the interests of sustainability. Our recommendations gave our sponsor a large base of information to potentially implement any of these designs.

Authorship

All team members contributed to all the written work in the Executive Summary, Methodology Chapter, and Findings Chapter and assisted in editing. In addition, we all conducted interviews of faculty and staff at both Oteima University and Batipa.

Theresa Cloutier: Primary author of the Environmental Research Stations and Ecotourism section in the Background chapter, the Abstract, and the Introduction. Gathered research and presented final deliverable for the utilization of excess teak wood. Co-Editor of the entire report. Main translator.

Alyssa Konsko: Primary author of the Land Use and Biodiversity in Panama section in the Background chapter, conducted research of rainwater harvesting systems and presented final deliverable of teak wood structure concept, photographed Batipa.

Dominic Palermo: Primary author for the Sustainable Opportunities section in the Background Chapter, gathered research of photovoltaic system components, solar power, solar maintenance, and power demands, presented final deliverable for a photovoltaic system at Cabimos. Co-Editor of the entire report.

Jonathan Scammon: Primary author of the Oteima University and Batipa background sections. Photographed Batipa and was the main graphic designer including the 3D modeling and rendering of Cabimos in addition to 2D infographic designs. Researched and presented final deliverable for Wi-Fi connectivity at Cabimos.

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Introduction

Climate change, deforestation, and other human-induced environmental changes threaten biodiversity in tropical ecosystems. Preserving these ecosystems throughout the world is a task that many government and private organizations are becoming involved with. In many tropical regions, the most prominent ecosystems are the rainforest as it is estimated that they contain about 50% of the world's species (University of Michigan, 2016). Therefore, organizations that perform independent studies of the resources existing in tropical areas are crucial to the preservation of ecosystems.

Tropical research stations, often situated in protected habitats, represent some of the organizations that conduct research and educate the public about biodiversity and natural resources. In the Chiriquí province of Panama, Universidad Tecnológica Oteima, or Oteima University, has an affiliate company called Batipa comprised of many specialized enterprises. One of these enterprises is the Batipa Field Institute; a research station dedicated to the creation of biological corridors and the preservation of biodiversity. It is located on the Batipa peninsula just outside the city of David. In addition to the institute, there are two other enterprises on the peninsula: a teak tree plantation dedicated to reforestation and harvesting for profit and a cattle genetics laboratory committed to the artificial insemination of cows. Through the multidimensional use of their land, Batipa constantly strives for improvement to remain a leader in innovation.

Currently, Batipa has a vision to broaden their institute through ecological research and ecotourism. The Batipa peninsula is a very remote location that must perform all energy functions off the grid as access to the power and water grids is too expensive. Batipa wishes to promote biodiversity while reducing their impact on the environment. This expansion in the mission of the field institute would attract a great deal of publicity. As a private, for profit company, Batipa has many intricate land management approaches. They would like to find ways for their existing and future agricultural practices to enhance the use of natural resources and promote biodiversity while remaining economical. The pursuit of Batipa's profitable management practices and biodiversity conservation represents a cutting edge integration of land use that could be a model for other institutes.

Out of the vision for integrating ecological research and ecotourism, concepts for new infrastructure have been developed. Our project proposes design options and resource utilization strategies for Batipa. To complete this, we created methods for solar power and Wi-Fi internet connectivity implementation, utilization of excess teak wood, and designs for a future rainwater harvesting and photovoltaic support structure. These designs were developed through communication and extensive research in a stakeholder-oriented approach to ensure our final proposal would be as useful as possible. Our recommendations detail options framed to help Batipa achieve their goals of operating sustainably while remaining off the grid in a way that is economically feasible. These proposals are ready for near term implementation at the Batipa Field Institute site while also having the capability of being easily adapted for future enterprises.

Background

In this section, we discuss the challenges around land use management in Panama and opportunities for implementing land protection policies. The impact protected areas and environmental research stations have in maintaining biodiversity are discussed in addition to the role of ecotourism. We explain how Oteima University through the Batipa Field Institute, the sponsor of this project, aims to preserve biodiversity through the development of biological corridors and reforestation. In addition, we examine the goals of the sponsor for the future development of the Batipa Field Institute site.

Land Use and Biodiversity in Panama

The story of Panama over the last few decades is one of economic growth and development of new opportunities for its citizens. However, economic development, and the urbanization that often accompanies it, is not without its problems. In a country where settlement patterns are shifting rapidly, the movement of citizens from rural to urbanized area can spur problems that threaten biodiversity in the unique ecosystems in the region.

One of the largest problems facing Panama is the disparity between the growing economic prosperity in urbanized areas, versus the poverty that has become a staple of rural areas. There has been a trend over the last 50 years of populations moving to the most urban areas of the country, specifically the canal zone, in order to take advantage of the economic opportunities present there (World Bank, 2017). The trend of urbanization has left the remaining rural populace with less opportunities for economic growth than the rest of the country. Because of this, Panama is faced with a large disparity in the poverty rate of individuals living in rural versus urban areas. Urban areas see a 4% poverty rate, while rural populations see a 27% poverty rate (World Bank, 2017).

The poor enforcement of the legislation intended to protect land has led to a complicated land use dynamic between struggling rural populations and the ecosystems they live in close proximity to. The rural populace is expanding the amount of land used for agriculture to counter economic hardships, despite the protected status of the land that is often encroached upon (CCAD (Central American Commission on Environment and

Development, El Salvador) CAC (Central American Agricultural Council, El Salvador) 2014). These protected areas are unable to be maintained properly due the inability to integrate and organize government institutions designed to preserve and manage natural ecosystems. This has led to the poor enforcement of environmental legislation and lack of effective policy to protect these lands (Programa Estado de la Nación - Región, 2011). The conflicting use of protected areas coupled with the poor enforcement of conservation legislation resulted in the loss of more than 250,000 hectares of forests over the past decade in Panama alone (Gobierno Nacional, 2014).

The problem of deforestation is not unique to Panama. In fact, expanding agricultural lands is one of the most prominent contributors to deforestation across Central America (Programa Estado de la Nación - Región, 2011). One of the biggest contributors to deforestation is expanding agricultural areas (CCAD & CAC, 2014). Massive amounts of native vegetation across the region has already been converted to agricultural land (Garen, et al., 2011). The native ecosystems of Central America is home to more than 200 ecosystems and over 20,000 different plant and animal species, as well as serving as an important migratory path between the North and South American Continents (CCAD & CAC, 2014). Although Central America only makes up a 2% of the world's landmass, it is home to 12% of the world's biological wealth (CCAD & CAC, 2014). Taking steps to reduce the effects of deforestation in such an ecologically dense region is essential to protecting the wealth of biodiversity that exists there.

Steps have been made to combat deforestation throughout Central America. The development of the Mesoamerican Biological Corridor across the isthmus of Central America and Mexico is one of the conservation efforts combating threats to biodiversity in the region. The Mesoamerican Biological Corridor, depicted in Figure 1, is a land use planning system that, with the help of organizations such as the World Bank and other NGO's to engage regional governments in promoting and implementing land protection strategies (Independent Evaluation Group (IEG), 2011). The Joint Declaration signed by Central American government officials defined the Mesoamerican Biological Corridor as:

> A territorial planning system consisting of natural protected areas under a special regime whereby core, buffer, multiple use and corridor zones are organized and

consolidated to provide an array of environmental goods and products to the Central American and the global society, offering spaces for social harmonization to promote investments in the conservation and the sustainable use of natural resources, with the aim of contributing to the improvement of the quality of life of the inhabitants of the region. (IEG, 2011, p. xv)

Although the rate of deforestation in Central America has decreased from 1.6% loss between 1990 and 2000, to 1.2% loss from 2000 to 2010, there is still a long way to go in mitigating the effects of this this problem.

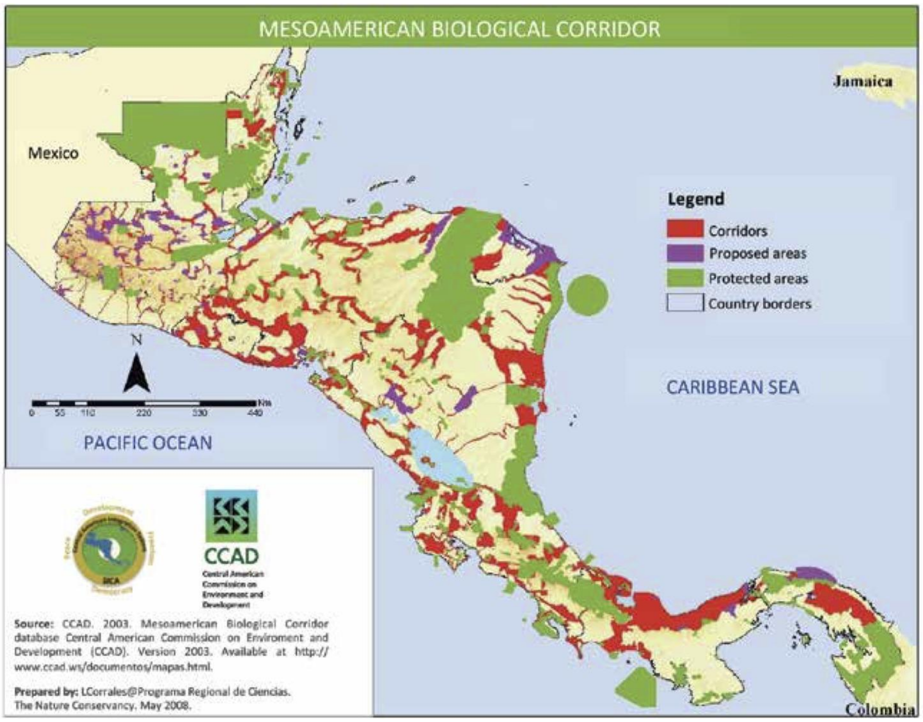

Figure 1: Map depicting the Mesoamerican Biological Corridor (CCAD & CAC, 2014)

The Panamanian government recognizes deforestation is still a significant threat to the environment that the country faces (Gobierno Nacional, 2014). In addition to participating in the development of the Mesoamerican Biological Corridor, Panama has previously engaged in programs combating deforestation in the country. From 2011 to 2015, Panama utilized the resources provided by the United Nations Joint Program for the Reduction of Emissions from Deforestation and Forest Degradation (UN-REDD) to organize steps to implement infrastructure to fulfill the REDD+ initiative. The REDD+ initiative works to eliminate deforestation by creating financial incentives for sustainable land development practices. The program, upon its final evaluation in 2015, was considered highly effective and it was concluded that it “generated a series of products for the preparation of the country so that it implements REDD + mechanisms and public policy of forest management,” (“Programa Conjunto De Las Naciones Unidas Para La Reducción De Emisiones Provenientes De Deforestación y De Degradación De Los Bosques”).

The Panamanian government believes that the fiscal incentives for reforestation efforts are a huge driver in ensuring the success of reforestation programs (Gobierno Nacional, 2014). In Estratégico de Gobierno de Panamá, which outlines the current state of Panama and the biggest problems facing the country, the government released a detailed plan for the implementation of territorial development and environmental sustainability strategies. Through strengthening political institutions and creating strategies for environmental management policies, they hope to meet their objective of creating a long term plan for sustainable land management, and mitigating the effects of environmental degradation that stem from inappropriate land use (Gobierno Nacional, 2014). Reaffirming the commitment to environmental preservation creates opportunities for organizations like the Batipa Field Institute to commit resources to reforestation and conservations practices, ensuring dedication to preservation efforts.

Oteima University

Oteima University focuses on the use of technology and the promotion of sustainable development. It was founded in 1985 with the aspiration to become an innovative and leading university through its unique combination of academics and hands on field experience. Mr. Luis Ríos Espinosa, one of the primary stakeholders, is the president of the university. Oteima has grown from an Educational Training Center into an officially recognized university only twenty years after they were founded. Their mission is “[to] form professional leaders and entrepreneurs committed to the sustainable human development of the country through the generation, diffusion, and application of knowledge in areas of teaching, research extension and production*”* (Oteima University, 2017).

Oteima's main campus is located in the city of David. This campus hosts a student body of around 1000, with most students pursuing studies in English. Their secondary location is in the town Santiago, located 160km east of David in the Veraguas Province (Jerry, personal communication, August 31, 2017).

Batipa & Affiliated Companies

The Batipa Peninsula is home to Batipa, a family owned business focused on preserving the peninsula's rare tropical environment while also operating successfully. Two thousand hectares of the peninsula are home to three main enterprises of Batipa, including 1000 hectares for the reforestation and harvesting of teak trees, 400 hectares for cattle pasture and a genetics laboratory, and 600 hectares dedicated to the preservation of biodiversity and wildlife. Batipa is located 40km southeast of David, bordering the Pacific Ocean at the Gulf of Chiriquí. Figure 2 below shows a map of Batipa's location, labeled as the Proyecto (project) site. This location is home to a jungle wilderness encapsulating low coastal hills, mesas, and mountains with an abundance of surrounding habitats including island reefs, mangroves, and rivers. Because Batipa is located in a tropical environment, it important for them to implement business practices that do not adversely affect the ecosystems to stay true to their focus (Oteima University, 2017).

Figure 2: Map of the Batipa Peninsula in relation to the surrounding area (Palacios, 2017)

Prior to 2000, The Batipa Peninsula experienced the effects of heavy logging practices. When Batipa acquired the peninsula, they originally set a goal of reforesting 1000 hectares of the region. This goal was achieved through the strategic founding and operation of their teak tree plantation, Dabsa. Dabsa successfully reforested 1100 hectares with teak trees through strategically managing the planting and harvesting of these trees (Oteima University, 2017).

The second affiliate of Batipa that utilizes a large portion of their land is their cattle operation, Cattle Batipa. This business is focused on the breeding and sale of cattle through genetic modification and cross-breeding.

Another affiliate of Batipa is the Batipa Field Institute. This institute is a tropical research station focused on preserving 198 species that live on the Batipa Peninsula (Espinosa, Personal Communication, 2017). Methods implemented to preserve the biodiversity at Batipa include establishing around 20 biological corridors to connect Batipa to the Mesoamerican Biological Corridor. These corridors promote the biodiversity at Batipa while also allowing animals to reach the human-created reservoirs. The reservoirs were built to hedge against the dehydration of wildlife during the dry season.

The Batipa Field Institute was proposed to Oteima University by Dr. Russ Mullen from Iowa State University to serve as a place for hands-on research and education through the global interchange of foreign visitors. This institute provides an opportunity for visiting scientists and students to partake in ongoing long-term studies focused on preserving the unique environment of the Batipa Peninsula, all while integrating biodiversity protection with the rural economic activities of the Batipa company (Mullen, "Batipa Field Institute", 2014).

Batipa’s implementation of an area called Cabimos provides accommodations for visitors. A small building offers enclosed sleeping corridors, a kitchen, flushable toilets, and showers. Figures 3 and 4 below show photos of Cabimos. It is located on a small hill overlooking the Gulf of Chiriquí presenting a beautiful environment to any resident. Figure 5 below shows a bird’s eye view of Cabimos. Here scientists can stay and experience Batipa within a safe building and study the environment.

Figure 3: Sleeping quarters at Cabimos (Scammon, 2017)

Figure 4: Sitting area at Cabimos (Scammon, 2017)

Batipa aspires to advance by incorporating modernized facilities on the peninsula, bringing in aspects of ecotourism and new research to their location. The main architect of Batipa, Mr. Héctor Palacios, developed an overall site plan and designs for building facilities at Batipa, including: a welcome center located at the entrance of Batipa, small outpost stations, a large research facility, a garden center, and a dormitory. Each of the buildings includes a unique architecture that derives from Panamanian culture, demonstrating the cultural identity of Batipa. All of the buildings will have some level of interaction to educate visitors about Batipa's unique history and environment, as well as the sustainable practices Batipa has implemented. The general concept of the plan has been embraced by the Batipa leadership, which is now seeking funding and taking other steps toward implementation.

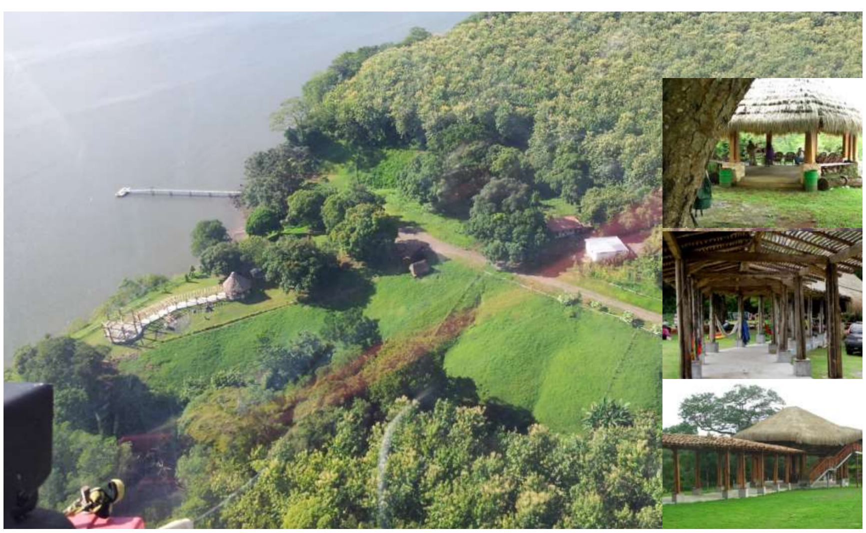

Figure 5: A bird's eye view and images during the construction of Cabimos (Mullen, 2014)

Environmental Research Stations & Ecotourism

Around the world, research stations have been created as ways to protect environments. The vision for Batipa's future mirrors other state-of-the-art research stations in similar regions. The stations conduct research on maintaining the ecosystem and teaching the public about the flora and fauna, while working to reduce their impacts on the environment and demonstrate sustainable resource management practices.

Specifically in the Central American region, a number of tropical research stations create opportunities for academics to study unique ecosystems in close proximity. Researchers at these stations work in identifying, understanding, and protecting endangered tropical species in the vast, biodiverse regions in which they live.

The Smithsonian Tropical Resource Center began in 1923 in the Panama Canal zone, with the intention of conducting environmental research, and has since grown to include nine different facilities around Panama. Multiple facilities are now located on the coast of Panama depicted in Figure 6. The center hosts 38 staff working in the facilities and over 900 scientists and academics visit year round. The institute strives for long term research and invests in training biologists from around the world every year (About STRI, 2017).

Figure 6: Bird's eye view of the Panama coastline (Etched99, 2012)

Las Cruces is an environmental research station located in Costa Rica with the main purpose of studying and protecting rare and endangered plant species from around the country. The station protects over 300 hectares of forest habitat and is also home to the most famous botanical garden in Central America, the Wilson Botanical Garden. Las Cruces was originally founded as an experimental farm in 1962, and today is an internationally recognized research station. Over 740 scientific publications in the last few decades have been made from research performed there (Biological Stations: Las Cruces, 2016).

Oftentimes research stations are very secluded, and while this makes them hard to reach, it also allows for a multitude of ecological systems to remain relatively unaffected by human infrastructure. The stations are then able to study the systems that have progressed with minimal interference from the outside world. For example, Palo Verde is a research station located outside of San Jose, Costa Rica. No buses will go directly to the station, it is located in a unique, dry area of the forest and only has enough equipment and resources for a few groups of researchers. The area of the forest tends to attract a great deal of rare migratory birds and is an excellent place to study species that are only found in remote areas (Biological Stations: Palo Verde, 2015).

In other parts of the world, many research stations and their partnered universities have found that one of the better ways to educate the public on the ecosystems is through ecotourism. Ecotourism is defined as "tourism to places having unspoiled natural resources, with minimal impact on the environment being a primary concern," (Ecotourism Definition, 2017). Figure 7 below shows an example of the aesthetics of ecotourism.

Fowlers Gap Research Station is located in the outback of Australia with deep ties to ecotourism, which partners with The University of New South Wales. It has a heavy focus on research, environmental monitoring, and teaching. Established in 1966, the station performs many diverse activities, such as research on kangaroos, reptiles, birds, and monitoring of the arid climate, soil conservation, and solar power. The station has a well-established site with many eco-trails and wildlife viewing platforms which attracts not only scientists from around the world, but tourists, and artists as well. Fowlers Gap works with as many groups as possible for the education of the public. They allow visitors to book excursions through local tour companies and have given permission for many documentaries to be filmed on site. However, driving and camping are not permitted on the site due to the dangerous interference with ecosystems that they could cause. For any visitors who would like to stay on site, accommodations such as cottages are available at the center or hub of the station (Fowlers Gap Research Station Ecotourism, 2013).

Figure 7: Ecotourism Docks in Chiapas, Mexico (Thelmadatter, 2011)

Heron Island is located off the coast of Australia in the Great Barrier Reef zone. The island houses a resort for travelers in addition to a research station associated with The University of Queensland, and a Queensland Parks and Wildlife ranger station. The station is the largest island-based research station in the Southern Hemisphere with over 60 domestic and international institutions using it for research and education. The resort on the island has close ties to the research station. It runs tours daily with the goal of teaching the public about the ecosystems that they then go diving and snorkeling in. In order to protect the ecosystems, the resort is running its own power generator, producing potable water, and treating wastewater, all of which is shared with the research and ranger stations. The island's commitment to sustainability was recognized when they were awarded the Advanced Eco-Certification by Ecotourism Australia (Heron Island: Ecotourism & Research Station, 2011).

Batipa's vision is to be similar to these stations, making it an innovator in the region. While each station works to preserve and research the environment, it is important for the institutes to operate without harming the environment as well. This is where the idea of being a sustainable research institute appeals to many of the scientists who work at the centers. In addition, the remote locations of many of these stations make it hard to transport materials and even to obtain water and electricity. As such, remaining off the electric and water grids is often not a choice, but a necessity.

Sustainability Opportunities for Batipa

Because the Batipa peninsula is a remote location, sustainable, off the grid resource management methods are required. Sustainability practices involve any process that avoids the depletion of natural resources in order to maintain an ecological balance (Sustainability Definition, 2017). The Batipa Field Institute has many sustainability opportunities that range from using renewable energy sources, to using localized materials, to using low carbon output construction methods with the goal of minimizing negative environmental impact.

A sustainable energy option for Batipa to implement is solar power because of government incentives and Batipa's optimal location. The incentive programs were created in response to "a prolonged drought in 2014 … [that caused Panama] to depend on thermoelectric sources and electricity imports to meet their power needs," (Bloomberg New Energy Finance, 2016). The 2014 drought dealt a significant blow to Panama because 57.3% of their total energy collection came from hydroelectric plants. The incentives from the Panamanian Government called for the installation of solar and wind power to promote the diversification of the energy matrix to hedge against future dependence on imported energy (Bloomberg New Energy Finance, 2016). It is also geographically feasible to implement solar energy on the Batipa peninsula due to the high solar irradiation, seen in Figure 8, at the site. Because the Batipa peninsula is located just south of the city of David, Batipa is exposed to the highest energy sunlight in all of Panama.

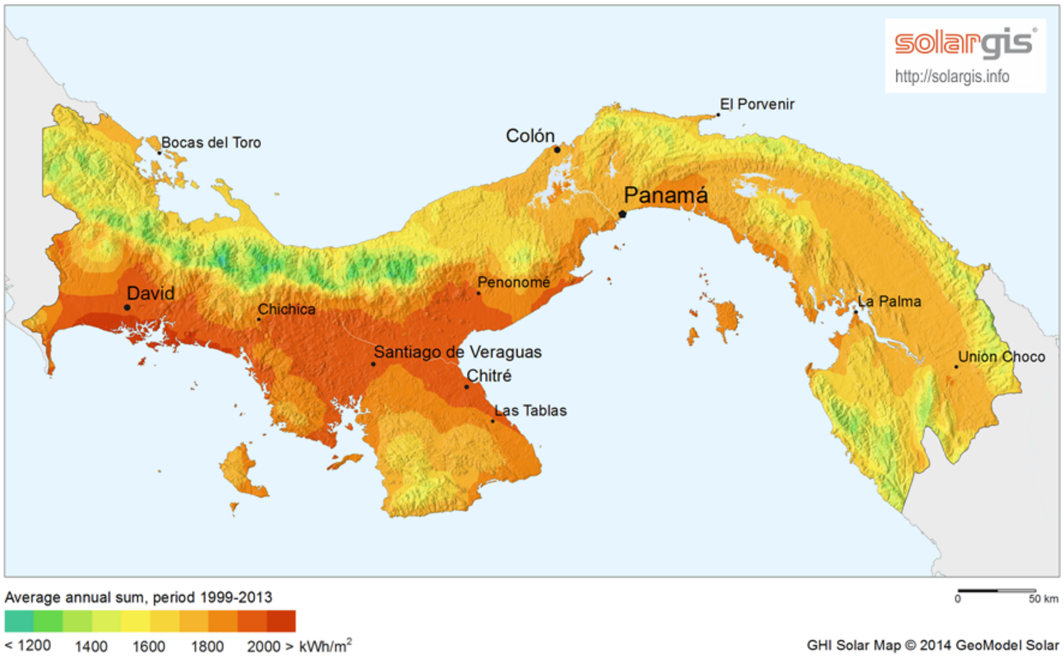

Figure 8: Map depicting Panama's Solar Irradiation (Solargis, 2014)

One of the ongoing projects at Batipa is the teak tree plantation. This project provides Batipa with another unique sustainable opportunity because they have localized building materials readily available. Teak is a luxurious wood that can be used for "ship and boatbuilding, veneer, furniture, exterior construction, carving, turnings, and other small wood objects" (Meier, 2015). The unique properties of decay and termite resistance compose the qualities that make teak very expensive and a sought out resource. If Batipa used their on-site teak, they would eliminate the carbon impact and the total cost accrued over importing and manufacturing other building materials. Other factors like labor and time need to be taken into account before an educated decision to use their teak over imported goods can be made.

The information discussed in this section explores the potential of the Batipa Field Institute and sets the stage for our work to propose sustainable practices through the utilization of renewable energy and localized resources.

METHODOLOGY

The overall goal of our project was to present Batipa with sustainable design options that could be implemented to take advantage of on-site resources. Understanding who we were working for, how they functioned, and what they envisioned for the future of their institute was a key part of being able to present viable solutions. Our team spent 10 days living in the city of David. Three of those days were spent visiting Batipa to investigate the site. The other days we used for research at Oteima University and conversations with our sponsor.

We were able to research broad options for sustainable energy, waste disposal, water collection, natural debris removal, and more for Batipa. Discussing all of our research and recommendations ensured that our designs were centered around our sponsor's needs. As laid out in Figure 9, our project followed a stakeholder-oriented design which included ongoing discussions and presentations to focus our recommendations to be as useful as possible.

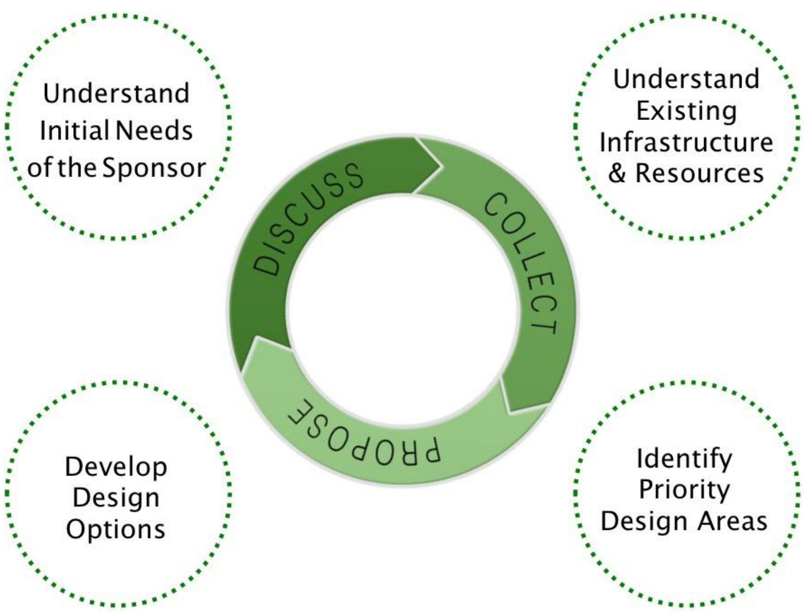

Figure 9: Graphic depicting Stakeholder Oriented Design Approach

Objective 1: Understand the Initial Needs of the Sponsor

Our sponsor was comprised of multiple parties invested in the development of Batipa Field Institute. By consulting with all of them, we gathered as much information about Batipa as possible to understand their goals and plans for the future. When interpreting their plans for development, establishing gaps was critical to define the consulting work we provided for them. Reaching this understanding ensured that our final conclusions and deliverables were well informed and relevant. An orientation meeting held on our first day in David included a presentation by Héctor Palacios, the architect hired to design and develop Batipa's vision for new construction. Through conversations with Mr. Luis Ríos Espinosa, the president of Oteima University, Dr. Francisco Ugel the vice-president of the University, and Mr. Héctor Palacios, we addressed the following questions.

- What is their timeline for development?
- What is their highest priority?
- Where were the gaps in their work where we could provide the most assistance?

Objective 2: Understand Existing Infrastructure and Resources at Batipa

It was essential to understand Batipa's existing infrastructure and resource usage in order to develop designs that are compatible with the site. Oteima University provided us with the opportunity to visit Batipa for three days. We were driven to the project site every morning by a local knowledgeable driver in a 4x4 vehicle that allowed us to traverse the rough gravel roads. Being shown points of interest such as Cabimos and the teak tree plantation, gave our team an understanding of the full scope of the Batipa Field Institute. Cabimos can be seen on Figure 10 below.

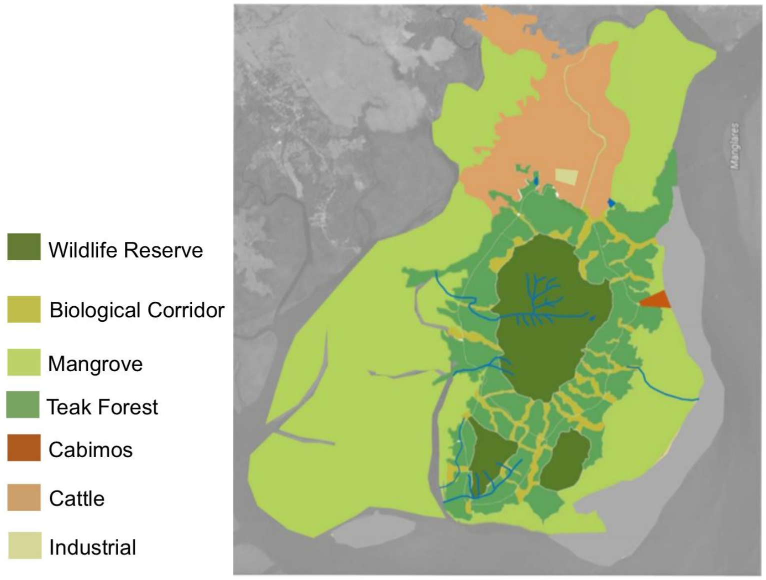

Figure 10: Map showing land use breakdown of the Batipa Peninsula (Palacios, 2017)

We knew that our proposed designs would have to be compatible with this off the grid site and feasibly implemented in the middle of the jungle. Keeping these limitations in mind, we investigated existing structures and evaluated their purpose. Because our driver knew the entire peninsula, we were able to ask him specific questions about each building. This allowed our team to explore the entirety of Batipa's infrastructure and their use of resources including water, waste, biomass, power, and connectivity.

We evaluated water at Batipa by assessing the way individual buildings used, collected, and purified it. Waste management was investigated by determining the current system in place and if a septic system was being used. Given the teak tree plantation and many animals present at Batipa, we assessed the amount of plant and animal biomass on the peninsula and the current system in place to deal with it. Batipa's power opportunities were investigated by determining the site's current energy sources as well as surveying the area for potential utilization of energy generation methods such as wind turbines, mini-hydroelectric, solar, and biomass. Connectivity at Batipa was evaluated by testing the strength of the cellular signal over the peninsula and the availability of internet access through a mobile data plan.

Objective 3: Identify Priority Design Areas

Our team identified the most beneficial options for Batipa to satisfy their ideas of sustainable ecological research and ecotourism. This was accomplished by researching potential technologies to provide a range of options in different domains to generate more discussion with stakeholders at Oteima and further refine the scope.

Our research followed three specific design criteria in the initial exploration of technologies. The designs had to be sustainable, accessible off the grid, and economically feasible. We initially narrowed the scope of our research to only focus on the small outpost stations that will be located throughout the peninsula. Doing so allowed us to investigate every concern our sponsor had on a manageable scale while also having the potential to be applicable to larger scale projects at Batipa. Limitations of Batipa being off the grid and very remote were taken into account to provide viable options to ensure everything proposed could be implemented. We considered the limitations by researching the advantages and disadvantages in terms of implementation, cost, and significance for specifically: water, waste, power, connectivity, and biomass.

In our role as acting as consultants for Batipa, it was necessary to maintain clear communication with the stakeholders. To do this, our group presented our initial findings at Oteima University about off the grid water, energy, and waste design options at the end of our 10 day visit. In this presentation, we discussed the preliminary proposals along with in-depth explanations of the benefits of implementation.

Following our presentation, we held a discussion of our sponsor's perceptions of our research to learn what interested them and what they wanted us to research more in-depth. Two of the key stakeholders were present, Dr. Francisco Ugel and Mr. Luis Antonio Ríos Gnaegi, so we were able to immediately hear their opinions. We reached out to Mr. Héctor Palacios later to inform him of our research direction. The stakeholders discussion defined the scope of our project.

Objective 4: Develop Design Options for Batipa

Our team spent the next few weeks finding and recording as much in-depth research as possible with the intention of delivering specific design solutions to be implemented on the peninsula of Batipa. The targeted areas of design were:

- The necessary photovoltaic system at Cabimos
- Implementation of Wi-Fi at Cabimos
- Utilization of excess teak wood

Cabimos required a photovoltaic system to power appliances that could provide lighting, internet, and outlets for a charging station. There were various appliances that could satisfy these goals, so the daily energy demand of multiple options were investigated. Once the energy demand was quantified, we researched the most cost effective solar panel size, charge controller type, battery type, battery quantity, and inverter type. Each of these components impacted the total cost and efficiency of the photovoltaic system at Cabimo; therefore, a rough cost-benefit analysis was required to make a complete recommendation.

Our next goal was to develop design recommendations for an off the grid, wireless internet connectivity option. In order to implement this, we researched options with minimal power use, ease of installation, and ability to function off the grid. Our first task involved looking into general methods of creating a wireless internet network off the grid. Once we had a basic understanding of what method would benefit Batipa most, a market analysis was performed looking for a product available within Panama that meets Batipa's design constraints.

For the research and design of the utilization of the excess teak wood we needed to learn of possible methods for the disposal of the wood. We accomplished this through two major data collection tasks: market analysis of tree plantation scraps and interviews with wood chipper companies. With this information, we decided to investigate the feasibility of a wood chipper. For our proposal, we analyzed what factors Batipa should consider when purchasing a wood chipper and potential options for usage of the chips.

Our team developed a concept of a teak structure in order to provide water and electricity to the proposed outpost stations. To ascertain the feasibility of the structure concept, our team conducted research into rainwater harvesting systems and the power demand of the outpost stations. To justify the implementation of a rainwater harvesting system, we estimated the water demand of each outpost station, calculated the amount of water that could be accumulated through a catchment surface, and calculated the size of a water storage tank. We estimated energy demand of a station to make a recommendation for the size of solar panel necessary to fulfill the energy needs of each station.

FINDINGS

Finding 1: Goals and Plans of Batipa Stakeholders

Understanding the needs of our sponsor was crucial to making our final recommendations relevant and useful. All parties encouraged the advancement of the Batipa Field Institute through the future development of modern research and ecotourism facilities. Our sponsor consisted of multiple stakeholders with diverse goals for the development of Batipa. Mr. Luis Ríos Espinosa has aspirations of introducing more opportunities for ecotourism at Batipa, as well as maintaining their existing commitment to improving biodiversity in the region through conservation efforts. As manager of business operations at Batipa, Mr. Luis Antonio Ríos Gnaegi hopes to maximize efficiency and profits for both short term operations and long term plans of development. Figure 11 below shows a photo of Mr. Luis Antonio Ríos Gnaegi. Mr. Hector Palacios also maintained an important perspective to consider as the architect of Batipa's plan for development.

Figure 11: Mr. Luis Antonio Ríos Gnaegi showing the area for the new dormitories (Scammon, 2017)

From our initial orientation at Oteima University, we gathered information about the current functions of Batipa and future plans to modernize it for ecotourism and education. The plan for future development includes design concepts by Mr. Héctor Palacios for an entrance station, small outpost stations, an investigation center, a dormitory, and a garden center. In addition to the new facilities, Batipa is planning the construction of bird cages to reintroduce macaws in Panama.

Figure 12: Rendering of Entrance Station (Palacios, 2017)

An entrance station, depicted in Figure 12, intends to make the Batipa Field Institute more visible from the Pan-American Highway. This entrance will include an interactive touch screen highlighting the work being done at Batipa. A more visible and engaging entrance station will provide a stronger link between Batipa and the community.

Figure 13: Rendering of Investigation Center (Palacios, 2017)

The investigation center, as depicted above in Figure 13, will be located at the tip of the peninsula and will include a classroom space. The space will encourage Batipa's goal of education while having the technology to facilitate research on the peninsula.

Figure 14: Rendering of Dormitories (Palacios, 2017)

Dormitories, which are depicted in Figure 14 above, will facilitate the extended stay of researchers, students, and tourists. They will be located on a hill that overlooks the existing Cabimos and the Gulf of Chiriquí. The site was "strategically chosen to create an atmosphere of total peace and spirituality" (Plan Maestro Centro Batipa, 2017, slide 45).

Figure 15: Rendering of an Outpost Station (Palacios, 2017)

The implementation of outpost stations, as depicted above in Figure 15, across the peninsula intends to promote ecotourism and research in the more remote areas of Batipa. The stations will all include restroom facilities and an area for individuals to sleep overnight if necessary. Batipa is interested in including potable drinking water and Wi-Fi internet connection for researchers and tourists to utilize.

Our sponsor's first goal for development is to continue to raise monetary funds for the project. One of the most costly aspects of the plan, creating roads and other infrastructure, is already in place to support future development. They plan to complete construction of the entrance station first followed by the macaw cages. In order maximize utilization of the structures, our sponsor expressed interest in ideas that followed specific design criteria outlined in Table 1 below.

Table 1: Stakeholder Design Criteria

Stakeholder's Needs	Design Criteria
• Power • Waste • Water • Connectivity	• Sustainable • Off the Grid • Economically feasible • Able to be maintained in remote areas • Will not adversely impact environment

During the discussion of our preliminary presentation, Mr. Luis Antonio Ríos Gnaegi also expressed interest in expanding some our research to develop solutions for current operations at Batipa. He was particularly interested in creating a plan to install solar panels on the main sleeping and living structures at Cabimos. We discussed basic appliances for implementation of lighting, Wi-Fi internet connectivity, and charging electronic devices. In addition, Mr. Luis Antonio Ríos Gnaegi explained that after annual teak tree harvesting, Batipa can only commercially sell the wood below where the branches start to grow. The company can then try to sell the rest to local farmers or companies that do not need the wood to be as pristine. Because of this, he expressed interest in finding a method to utilize or eliminate the excess wood sustainably and economically while still allowing the plantation to remain off the grid.

From this discussion, Mr. Luis Antonio Ríos Gnaegi laid out three clear objectives for our group to research and deliver plans for. These objectives were:

- How to deliver energy to existing structures via solar panels
- How to establish Wi-Fi at existing structures
- Proposing one or more options for removing teak tree trimmings

Because Mr. Luis Ríos Espinosa and Mr. Héctor Palacios were not present during this presentation and discussion of deliverables, our team proceeded with the objectives defined by Mr. Luis Antonio Ríos Gnaegi, while keeping in mind the positions of our other stakeholders in developing our final deliverables.

Finding 2: Existing Infrastructure and Resources at Batipa Field Institute

Our three trips to Batipa involving conversations with personnel and our sponsor led to the understanding of current usage of resources at Batipa, including water, waste, biomass, power, and connectivity.

Water

Batipa has implemented a few different systems in order to utilize water. Mr. Luis Antonio Ríos Gnaegi mentioned that all of the buildings at Batipa are supplied with water by gravity fed pipes being led down from the mountains into water storage containers depicted in Figure 16 below. At Cabimos, there is a well with a pump implemented to provide running water for a bathroom and shower. Mr. Luis Antonio Ríos Gnaegi informed us that the collected water was chemically treated with chlorine to kill harmful bacteria and microorganisms so employees and visitors could drink the water.

Figure 16: Water storage tanks located near Cabimos (Konsko, 2017)

Waste

We explored an operational toilet, depicted below in Figure 17 and Figure 18, while we were at Cabimos. This system used a septic tank to capture the waste from the flushing toilet as well as the shower and sink drains.

Figure 17: Exterior of bathroom facilities at Cabimos (Scammon, 2017)

Figure 18: Interior of bathroom facilities at Cabimos (Scammon, 2017)

Biomass

Batipa fulfils their goal of reforestation while also operating as a plantation by allocating their land into sections which are planted in yearly increments. After about 20 years, when a teak tree has grown to a sufficient height, it is harvested and reforested. Figures 19 and 20 below show photos of the teak trees. He stressed that they have many branches and poor quality wood pieces both from thinnings and from the major harvest that need to be removed before re-planting can begin, and there is currently no system in place to handle the removal.

Figure 19: Two year old teak trees at Batipa plantation (Scammon, 2017)

Figure 20: Measuring teak tree density at plantation (Scammon, 2017)

The Batipa peninsula also functions as a farm for five different species of genetically manipulated cows. The three-main types of cattle at Batipa are Senepol, Gyr, and Brangus, each of which have different benefits and originate from different parts of the world. Figures 21 and 22 below show photos of the lab space and the cows. Through crossbreeding, Batipa aims to create an offspring that survives within the tropics and have beneficial traits for either milking or meat. This is an ongoing project, so there are always many cows roaming around the pastures. As such, there is a great deal of manure produced.

Figure 21: Batipa's cattle genetics lab (Scammon, 2017)

Figure 22: Cows in holding pen at genetics lab (Scammon, 2017)

Touring the peninsula allowed us to view wood and manure biomass and we could see that the removal of such was not only necessary, but very critical. We discussed with Mr. Luis Antonio Ríos Gnaegi that there were possibilities to use this biomass to Batipa's advantage.

Power

The power demands of many buildings at Batipa are minimal; therefore, making a connection to the energy grid through power lines would be extremely expensive and unreasonable. Challenges we considered when determining viable off the grid energy sources for Batipa were proximity to the water sources, tall trees blocking sunlight, current energy sources, and the distance between each building.

We came to the conclusion that the ocean is too calm nearby to harvest energy through any form of hydroelectric generation. Mini hydroelectric generation was also not feasible because there were no streams or waterfalls on the Batipa peninsula that would last through the dry season.

Figure 23: Solar Panels mounted on structure at Batipa (Konsko, 2017)

By investigating the existing structures depicted above in Figure 23, we developed an understanding of the current solar panel sizes being used and the daily energy demands. Some areas had no trees shading them due to existing structures already implementing solar panels, but other areas marked out for future development were still overgrown. Currently, solar power is mainly used for lighting and charging batteries in these smaller buildings. The only other energy generation source we found at Batipa was a diesel generator, seen below in Figure 24, that was used to power high wattage appliances such as a washing machine.

Figure 24: Diesel generator stored at Cabimos (Konsko, 2017)

The distance between the current buildings at Batipa is too significant to implement one major generation source of renewable energy such as biomass combustion. If a major generation source like biomass combustion were to be implemented, the required landscaping labor and cost to install wires to various buildings in Batipa would cost roughly $16,000 dollars per kilometer (Keefe, 2001). That estimate does not include the cost to maintain and repair damaged lines. If a storm occurs and a tree falls on one of the power lines, the entire system could lose power until the required maintenance could be completed.

Connectivity

During our three trips to Batipa, we assessed the cellular and Wi-Fi signals currently implemented. There is not a high demand for internet at Batipa in its present state, so signal varied significantly depending on our location. Within Cabimos a 3G connection could be achieved although the speeds and consistency were limited. Another location where a cellular signal could be achieved was on the road connecting Batipa to the main highway. Here there was an extended cellular signal that could access the internet, although far from any other buildings. Around other parts of the peninsula there was generally no service or connection to the internet.

Analysis and Recommendations

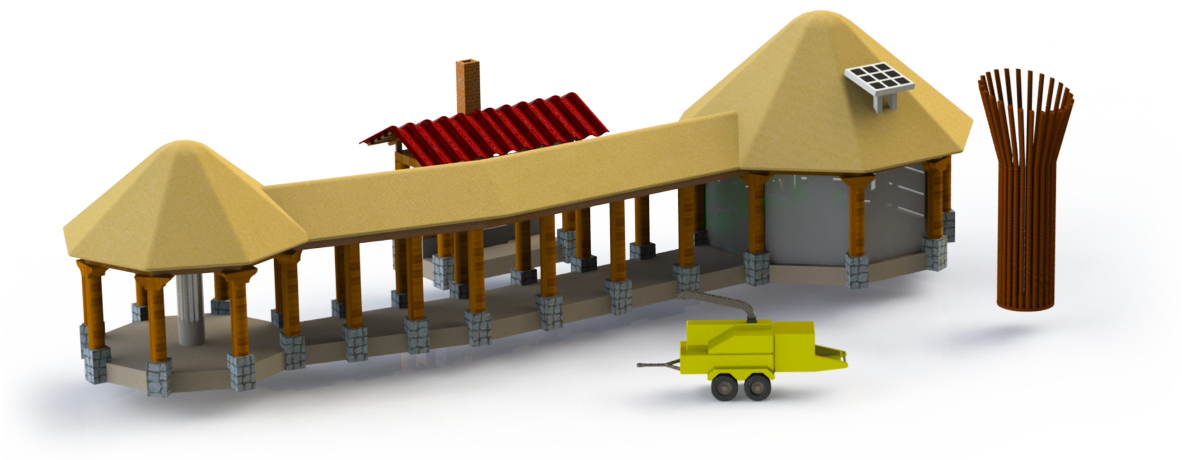

Figure 25: Graphic showing proposed solutions for Batipa (Scammon, 2017)

This section presents our final design recommendations as depicted above in Figure 25. We came to these recommendations after performing extensive research and analyzing what we had learned about our sponsor's goals. We have listed our final recommendations for the implementation of a photovoltaic system and Wi-Fi internet connectivity as well as the utilization of the excess teak wood. In addition, we have laid out the concept idea for a rainwater catchment and solar panel housing structure.

Implementation of Solar at Cabimos

Proposing a photovoltaic system to implement at Cabimos required a careful selection of a solar panel, batteries, charge controller, and inverter to ensure a cost effective solution. The solar panel size had to be considered first because the size has to satisfy the daily power demand of Cabimos. The next important component to select are the deep cycle batteries. There are two types of deep cycle batteries, flooded lead acid and lithium, that are analyzed in this section to show which types provides the most benefit over time. Once the solar panel size and battery bank is determined, then a charge controller can be selected. Charge controllers come in two forms, either pulse width modulation (PWM) or maximum power point tracking (MPPT). Both types have their pros and cons and can greatly impact the efficiency of the system at a cost. Lastly, an inverter needs to be either a modified sine wave or a pure sine wave. Similar to the charge controller, both types have their pros and cons that greatly influence the capabilities of the photovoltaic system.

The total size of the photovoltaic system is dependent upon the budget available. In this section, there are three scenarios investigated to enlighten how the total system size and cost fluctuates to satisfy the same goals.

Figure 26: Rendering of Cabimos implementing a potential photovoltaic system (Scammon, 2017)

Sizing the Solar Panel

We needed to determine the correct size of solar panel for Cabimos given its intended electrical use. Three scenarios were analyzed and categorized as a low, medium, and high power demand based off of different combinations of technology that could be implemented at Cabimos. An example a potential scenario can be seen in Figure 26 above. In each of these scenarios, the recommended solar panel size is able to support a system that provides lighting, internet, and a charging station for either phones or laptops for a day and a half of no sunlight. These three options shed light on how drastically system demands fluctuate when using different appliances to accomplish the same goal. The total required energy needed to power the full photovoltaic system in each of these cases is dependent upon each appliance's wattage and the time of expected hours of daily use. To be safe, the amount of power estimated for each appliance is rounded upwards to provide a guard band.

Table 2: The low power scenario appliance daily energy demand

Appliance	Power Demand	Daily Hours of Use	Energy Needed
Three LED Light Bulbs	30 W	12 Hours	360 Wh
One Wi-Fi Hotspot	4.5 W	24 Hours	108 Wh
Two Phone Chargers with phones	12 W	12 Hours	144 Wh
Two Phone Chargers without phones	1 W	12 Hours	12 Wh
Total Energy	-	-	624 Wh

The low power option for Cabimos in Table 2 above shows that the daily energy demand to power the listed devices is 624 Watt hours. In order to provide power for a worst case scenarios of one and a half days without sunlight, a 24 Volt, 200W panel will need to be used in conjunction with a 24 Voltage, 94 amp hour battery bank and a charge controller that can support up to 9 amps.

Table 3: The medium power scenario appliance daily energy demand

Appliance	Power Demand	Daily Hours of Use	Energy Needed
Three LED Light Bulbs	30 W	12 Hours	360 Wh
One Wi-Fi Hotspot	4.5 W	24 Hours	108 Wh
Two Laptop Chargers	140 W	4 Hours	560 Wh
Total Energy	-	-	1028 Wh or 1.028 kWh

The medium power option for Cabimos in Table 3 above shows that the daily energy demand to power the listed devices is 1,028 Watt hours. In order to provide power for a worst case scenarios of one and a half days without sunlight, either two 24 Volt, 150 Watt or one 24 Volt, 300 Watt panel will need to be used in conjunction with a 24 Voltage, 154 amp hour battery bank and a charge controller that can support up to 18 amps.

Table 4: The high power scenario appliance daily energy demand

Appliance	Power Demand	Daily Hours of Use	Energy Needed
Three LED Light Bulbs	30 W	12 Hours	360 Wh
Satellite Dish	70 W	24 Hours	1680 Wh
Router	6 W	24 Hours	144 Wh
Modem	9 W	24 Hours	216 Wh
Two Laptop Chargers	140 W	4 Hours	560 Wh
Total Energy	-	-	2,960 Wh or 2.96 kWh

The high power option for Cabimos in Table 4 above shows that the daily energy demand to power the listed devices is 2,096 Watt hours. In order to provide power for a worst case scenarios of one and a half days without sunlight, four 24 Volt, 215 Watt panels will need to be used in conjunction with a 24 Voltage, 443 amp hour battery bank and a charge controller that can support up to 36 amps.

The daily energy demands can vary by approximately 5 times between the low and high power scenarios. Each of the scenarios above were determined using the altEStore website's Off-Grid Solar Panel System Calculator to get the recommended size of solar panel, size of the battery bank, and current capacity of a charge controller given the daily energy demand and how many days without sunlight (Beaudet, 2017).

Deep Cycle Batteries

There are five types of deep cycle batteries (lithium, flooded lead acid, sealed AGM, sealed gel, and saltwater batteries) that could potentially work in a photovoltaic system. We learned through research that the flooded lead acid batteries and lithium batteries are the most used and cost effective options. The flooded lead acid batteries are much cheaper than the lithium batteries, but they only last, on average, a third of the time. The flooded lead acid batteries' lifespan solely depends on the percentage they are discharged. The longest lifespan can be obtained by discharging them down a maximum of 20%. Even though this prolongs the lifespan, it is not always the most economical choice because this means you will require more batteries in your total system (Beaudet, 2017). . Lithium batteries can be discharged down 100% multiple times, but it is more cost effective to discharge them down to 80%. So not only do the lithium batteries last three times longer than lead, they can also use more of their stored power without damaging the battery. This has extreme economic benefits for systems built to last for many years.

Table 5: Analysis of lead and lithium batteries storage of power in a system with a PWM charge controller

Battery Name	Number	Lifespan	Price	Price Per Year
Lead T105	4	8.22 yrs	$632.48	$76.94
Lithium SimpliPhi 1310Wh	1	27.4 yrs	$1745.00	$63.69

Table 5 above shows that even though the flooded lead batteries are cheaper, they end up being more expensive over time because all four batteries will be replaced three times before needing to replace the lithium battery once. In order to get the 8.22 years of life out of the flooded lead acid batteries, constant maintenance and upkeep of the batteries is required. The lithium battery requires no maintenance to ensure it survives its 27.4 years. For these reasons, we would recommend investing more money initially to get the lithium batteries.

Charge Controllers:

When installing a full photovoltaic system, it is essential to install a charge controller in order "to optimize the charging of your deep cycle batteries [and to] prevent electricity from the batteries from going through the solar panels when there is no sun" (Beaudet, 2017). Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) charge controllers are the two options for a charge controller. The PWM charge controller is less efficient and cheaper than the MPPT. Even though they are more expensive, the MPPT controllers detect the optimum operating voltage and amperage of the solar panel array and match that with the battery bank. This more exclusive system results in an additional 15% to 30% more power collected from the full solar array.

The example above in Table 5 showed the total number of lead and lithium batteries for a system using a PWM charge controller. Table 6 below shows the same system with the only difference being a MPPT charge controller. Comparing these two tables shows how using a MPPT charge controller can reduce the amount of batteries, and therefore cost, required to power the same system.

Table 6: Analysis of lead and lithium batteries storage of power in a system with a MPPT charge controller

Battery Name	Number	Lifespan	Price	Price Per Year
Lead T105	2	8.22 yrs	$316.24	$38.47
Lithium SimpliPhi 655Wh	1	27.4 yrs	$1155.00	$42.15

Using a MPPT charge controller would cut the cost of lead batteries needed in the system by half and it also would reduce the cost of lithium batteries per year by approximately 33%. It is also apparent when comparing Table 5 and Table 6 that the utilization of a MPPT charge controller could optimize a solar system enough to make flooded lead acid batteries more cost effective than lithium batteries.

The price difference between a MPPT and PWM charge controllers on altEStore's website is anywhere from $60 to $100 dollars. The money saved by purchasing a PWM charge controller does not save money in the long run because more batteries are required due to its inefficiency. Therefore, the most cost effective option is the MPPT charge controller.

Inverters

The last component that needs to be considered for a full photovoltaic system is an inverter that converts the batteries' DC power into usable, AC power (Beaudet, 2017). Like the charge controllers, there are two options for inverters: pure sine wave and modified sine wave inverter as seen below in Figures 27 and 28, respectively. The modified sine wave inverter is best for simplistic systems that consist of appliances such as older TVs, incandescent lights, and motors with brushes. These inverters are not recommended for systems that include electronics, audio, induction motors, rechargeable batteries, or digital clocks (Beaudet, 2017). The pure sine wave inverters are typically more expensive, but they are necessary for electronics, florescent lights and dimmers, and inductive loads. The pure sine wave inverter is recommended because it has a higher efficiency and it is a more versatile inverter. The price gap between the modified sine wave inverters and the pure sine wave inverters have been closing as new solar technologies continue to develop and photovoltaic systems become more cost effective.

Figure 27: Example of a pure sine wave inverter (Dambis, 2016)

Figure 28: Example of a modified sine wave inverter (Zuzu, 2008)

Final Recommendations for an off the grid photovoltaic system at Cabimos include:

- 24 Volt Solar Panel and a 24 Volt Battery Bank Sized to Meet Cabimos' Needs
- MPPT Charge Controller
- Lithium Deep Cycle Batteries
- Pure Sine Wave Inverter

Achieving Connectivity at Cabimos

After researching possible methods for the implementation of Wi-Fi at Cabimos, we concluded there are two main options to provide an off the grid solution: mobile Wi-Fi hotspots and satellite internet dishes. Both options provide sufficient connectivity to fulfil Batipa's current internet demand and can run off solar power. However, the benefits of each option differ as mobile Wi-Fi hotspots are a small-scale solution while satellite internet is a large-scale option.

Internet Demands

The first step we took into consideration for implementing Wi-Fi at Cabimos was estimating the demands for internet. For the current state of the Batipa Field Institute, we made some assumptions shown in Table 7 below to get a rough estimate of the required internet speeds. These assumptions included the amount of activity for the Wi-Fi, the reliability, and the number of users expected at Cabimos. Using an online bandwidth calculator, we obtained an estimated value of 1-6 Mbps ("Bandwidth Calculator", 2017). This gave us a general understanding of a sufficient download speed that would fulfil the demands at Cabimos.

Table 7: Assumptions made to calculate Cabimos internet demands

Activity	Reliability	Users
Web Browsing Moderate Emailing Minimal Download Minimal Streaming	Should meet demands Not much maintenance	Minimum: 1 User Average: ~4 Visitors Overnight: 8 Bunks
Light	Decent	*Low*

Mobile Wi-Fi Hotspot

A mobile Wi-Fi Hotspot is a small device that creates a wireless signal by connecting to a cellular signal, such as 3G or 4G, and converting it into wireless internet. They run off a battery that can be plugged in for continuous use and require a SIM card with a Data Plan. There are two main aspects to implementing a mobile Wi-Fi hotspot at Cabimos: the cellular signal provider and mobile device. Each aspect has several options that provide different benefits, explained throughout this section.

Cellular Provider

The main factors to consider when selecting a cellular provider consist of the signal coverage and offered data plans. Within Panama there are four main cellular providers being +Movil, Claro, Digicel, and Movistar. Our research focused on finding a cellular provider whose coverage is available at Batipa with a sufficient speed and reasonable data plans.

For cellular coverage, we analyzed the coverage maps provided by AT&T of each provider to get an understanding of which would offer the strongest signal at Batipa. Out of the four providers, the one who fully covers the Batipa Peninsula is Digicel. Although the coverage maps analyzed are only representative of a 2G signal, they can be used to get a general understanding of which signal would provide the most strength at Batipa. Digicel's abundant coverage indicates they have the most infrastructure and resources to provide a stable connection for Batipa ("GSM Coverage Maps", 2015).

The next factor when considering a cellular provider is the data plan. There are two main payment methods for data plans, prepaid and postpaid. Based upon data plans offered as of October 5th, 2017, postpaid methods are the most beneficial as they offer better pricing for every gigabyte and larger amounts of data. The full list of every data plans offered by these four providers is featured in Appendix E while a summarized table of the most applicable plans is featured below in Table 8.

Table 8: A summarized list of the most beneficial data plans offered within Panama

Provider	Data Limit	Price	$ / GB	Time	Type
Digicel	6 GB	$14.95	$2.49 / GB	Data All Used	Postpaid
Digicel	10 GB	$24.95	$2.50 / GB	Data All Used	Postpaid
Digicel	12 GB	$29.99	$2.50 / GB	Data All Used	Postpaid
Digicel	7 GB	$19.95	$2.85 / GB	Data All Used	Postpaid
Digicel	14 GB	$39.99	$2.86 / GB	Data All Used	Postpaid
Digicel	20 GB	$59.99	$3.00 / GB	Data All Used	Postpaid
Digicel	16 GB	$49.99	$3.12 / GB	Data All Used	Postpaid
Claro	3 GB	$14.99	$5.00 / GB	Data All Used	Prepaid
Digicel	3 GB	$14.99	$5.00 / GB	30 Days	Prepaid
Claro	4 GB	$19.99	$5.00 / GB	Data All Used	Prepaid
Claro	5 GB	$24.99	$5.00 / GB	Data All Used	Prepaid
Claro	6 GB	$29.99	$5.00 / GB	Data All Used	Prepaid
Claro	10 GB	$49.99	$5.00 / GB	Data All Used	Prepaid

Based upon the analysis of the two main aspects for cellular providers, Digicel stands out as being able to provide the most benefits for the current state of Batipa. Their coverage for a 2G signal covers all of the Batipa Peninsula; therefore, it can be assumed that they have the most infrastructure for cellular service within Chiriquí. Out of all data plans, Digicel is the best option because their price per gigabyte is the least of all competitors while providing a sufficient amount of data that can be fully used without a time limit.

Hotspot Device

The second step of consideration for implementing a mobile Wi-Fi hotspot is the device itself. When purchasing this device, many specifications of the unit must be taken into consideration to get the most beneficial purchase.

First, a unit can either be locked or unlocked depending on where it is bought from. Locked units are typically purchased through a cellular provider and can only function through this provider. This is generally a strategy used by providers to keep customers a part of their brand and away from competitors. Customers must buy a data plan through the cell provider that their device is locked to and cannot utilize another providers signal. Unlocked units are more common and can be purchased nearly anywhere. These units can utilize any provider's data plan and are more abundant throughout the market. We suggest that Batipa purchases an unlocked device to provide freedom in choosing their provider and data plan.

The next factor to consider when purchasing a hotspot is if certain signals are limited based on geography. For example, some products can only function in certain parts of the world depending on the manufacturer's limits for 4G and 3G. Huawei's E5577 has limitations that only allow 4G LTE to function within Europe, Asia, Middle East, & Africa while 3G is available globally (Amazon, 2017). In terms of Batipa, the main signal present is a 3G signal which can meet the current needs of Batipa. Making certain the unit implemented can function within the geographic location of Panama with not only 3G, which is generally offered globally, but with 4G LTE would be beneficial to provide faster speeds.

The third factor to consider when selecting a mobile hotspot is the type of Wi-Fi signal generated by the unit. There is a large variety of different signals for Wi-Fi that are beneficial for different aspects and demands, ranging from 802.11 a/b/g/n/ac which have progressed in relation to the advancement of technology. The current cutting-edge technology, 802.11ac, would be excessive for Batipa as an 802.11n network would meet their benefits. By taking into consideration the range of connectivity at Batipa, we concluded that a strong connection within and around Cabimos is sought after. This can be implemented by utilizing a wireless signal consisting of a 2.4GHz and 5GHz. The 5GHz signal travels a short distance of only 15m indoors and 30m outdoors, but offers a stronger connection that would act as the main network used within Cabimos, represented by the red range within Figure 29. The second signal at 2.4GHz travels a further distance of around 45m indoors and 90m outdoors, but consists of slower speeds that are only beneficial for small demanding devices outside Cabimos, shown by yellow within Figure 29 (Mitchell, 2017). Batipa would benefit most by implementing a device that provides but a

2.4GHz and 5GHz signal to provide a stronger connection within Cabimos and a lighter connection that can be access and used outside Cabimos.

The last factor to consider is any additional specifications that would provide advantages to Batipa's connectivity. The one prevalent feature that some hotspots offer is external connectors that allow an antenna to be used. For Batipa, having an antenna installed on the top of Cabimos would produce a stronger connection to cellular signals and result in a better wireless signal.

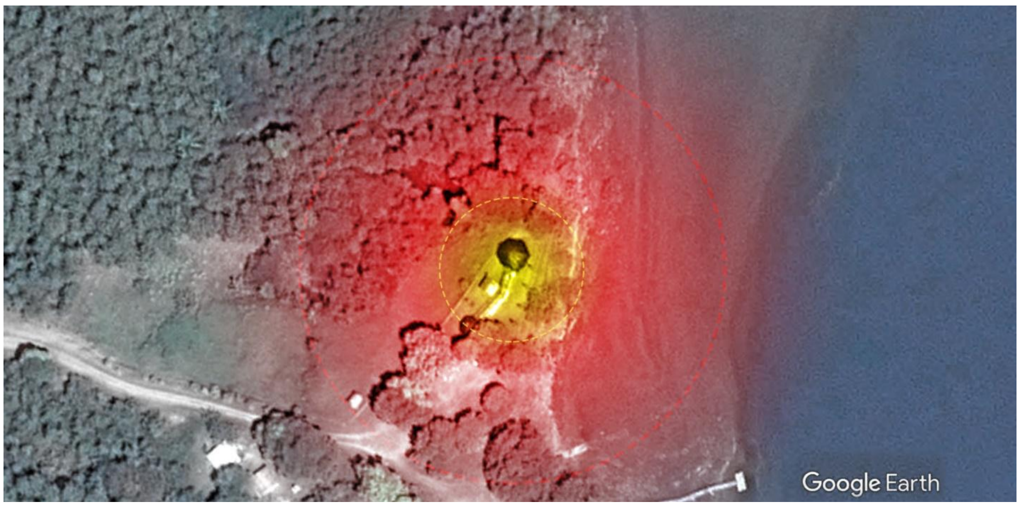

Figure 29: Heat map showing the estimated Wi-Fi range at Batipa (Google Earth, 2017)

Satellite Internet

A satellite internet dish is the second method for implementing a wireless connection. It offers a better and more consistent connection by obtaining its signal from a satellite orbiting Earth. This connection can be obtained nearly anywhere a satellite dish can be mounted and would benefit Batipa most in areas with demand high internet speeds or no cellular service. This option features a more complicated installation as more components are required to convert the signal obtained from the satellite dish into a wireless connection. Consisting of a modem and router, these additional steps increase the power demands required causing the need for more solar panels to be implemented. This type of connection is more robust and would be more beneficial for higher internet demands. Satellite dishes, however, are known to experience reduced connectivity during heavy rainfall (Torres, 2017). This creates an issue during rainy weather. For instance if researchers relocated to Cabimos with the intent of completing tasks requiring internet, they would suffer from slower connection speeds and their work would be hindered due to the limited connectivity.

For the current state of Batipa, a satellite internet connection is inefficient and would be excessive for their current internet demands. It is recommended that Batipa considers implementing a satellite internet connection for their future facilities. The demands at these buildings will be significantly larger than at Cabimos, and a satellite connection would fulfil these needs. In addition to these satellite dishes, network expanders could be utilized to provide complete connection across the Batipa peninsula.

Utilization of Excess Teak Wood

It was quite difficult to find information on the utilization or elimination of excess wood in an industrial setting, as no tree plantation was able to respond to us and there was limited information to be found through market research. However, after extensive research we determined that the best method for us to propose was for the scraps to be put through a wood chipper. Our team decided to propose this solution even knowing that a wood chipper represents an upfront investment and that our sponsor stated interest in avoiding the purchase of a chipper, as it emerged from our analysis as the best option.

Options for Use of Wood Chips

The use of a wood chipper allows for the mass of excess teak trees to be broken down into very small chips. Depending on the chip size and composition, there are many different options on what to do with them. There are ways for them to be used on the peninsula to aid in the future productions, ways to make money off of them, and ways to use them in the production of energy.

Figure 31: Man walking over a woodchip pathway (Pink Sherbert Photography, 2010)

Figure 30: Wood chips utilized as mulch for planting (Staff Sgt. Peasinger, 2011)

The simplest option is to use the newly created wood chips as a base for pathways or for aesthetic purposes around buildings. All this would require would be moving the wood chips from the area where the chipper deposited them to the area where they would be laid. Figures 30 and 31 above show photos of wood chips being laid for landscaping purposes. However, with the quantity of teak wood that needs to be chipped every year, it is very likely that more wood chips would be produced than would be needed for this solution.

Another simple option would be to sell them. Many companies such as dairy farmers, particleboard makers, and biomass energy plants need wood chips and sawdust (Canfield, 2008). The disadvantage to this option is that there are not many companies near Batipa that are ready to buy them so they must be shipped to buyers. It might be possible to negotiate selling chips and sawdust to local sawmills so that they may then sell it to customers, but there is no guarantee that they will always need a large shipment.

Energy production through the use of the wood chips is appealing because it is a sustainable option for Batipa. There are a few ways to produce energy from the chips. The most common method is combustion, which is a type of biomass energy that involves burning the chips with excess air to heat water in a boiler. Figure 32 below shows a photo of a wood burning furnace. The boiler creates steam used to power a turbine which then in turn powers a generator to create electricity (U.S. Department of Energy, 2016). This method allows for the consumption of many wood chips year round.

Figure 32: Wood furnace used to burn wood chips (Joseph, 2006)

Wood chips also have the option to produce energy through anaerobic digestion, which involves the breaking down of the chips by bacteria and the use of the gas created by this chemical reaction for energy production. For more detail on anaerobic digestion, refer to Appendix B. The anaerobic digestion of wood chips and sawdust needs other materials as well. Wood is very high in carbon, so to balance that it must be paired with a material that is very high in nitrogen in order for it to digest (Mark M., 2013). Materials such as manure and plant greens would be very useful. The bacteria would be enticed to break down the cellulose in the wood with it (Feedstocks for Biogas, 2014). An issue is that not many wood chips can be used this way as it takes time for the wood to be completely digested.

There are other means of the breaking down of wood chips other than that of energy production for their use and removal. Composting wood chips, while fairly time consuming, allows for the chips to become part of the ecosystem again. Figure 33 below shows a photo of a common compost pile. The wood chips can be used to create mulch, which is very useful for any sort of planting process. The mulch covers the soil and aids in suppressing weeds, conserving soil moisture and temperature, and aesthetics. However, mulch cannot be made directly out of wood chips as wood is made up of mostly carbon compounds and very little nitrogen. The carbon compounds take a great deal of time to be broken down so the bacteria would take up nitrogen from the soil around the chips instead (Compost Wood and Woodchip, 2017).

Figure 33: A compost pile (Catkin, 2014)

The composting process breaks down the carbon releasing carbon dioxide. For large quantities of wood chips, composting in heaps of up to 2 meters wide and 1.5 meters high can be very effective if done right. Bacteria for breaking down the chips should naturally occur and as long as the heap does not exceed the maximum dimensions air should still be able to flow allowing oxygen to reach all of the bacteria. During the dry season, water may need to be added manually. Thirty litres of water per cubic meter of chips is recommended and cupping the top of the heap can help retain the water. Following this method, the pile should be turned every two weeks to ensure that oxygen reaches all of the compost. The composting is complete when the temperature of the pile does not rise after being turned. Adding greens that are high in nitrogen, or manure will aid in increasing the decomposition time, but are not completely necessary. Depending on the chips size and composition, the composting can take between 3 and 12 months (Webber and Gee, 1996). The composted wood chips could now be used for mulching or even a softer base for pathways. While it is time consuming, this option allows for the continuous removal of large quantities of wood chips and allows for the final product to be used back in the ecosystem either on site or sold somewhere else.

The solutions presented all propose different ways to eliminate the wood chips. Some eliminate a greater quantity of chips and some eliminate them faster than others. As such, each solution is probably best used in conjunction with another solution as opposed to being used alone.

Options for a Wood Chipper

There are many elements that need to be taken into consideration when choosing a wood chipper. For Batipa's needs our team only looked at industrial wood chippers. Electric, Gas, and Power Take-Off (PTO) wood chippers are common for roadside work and households, but were determined to be too small. Our recommendations for components to include in the wood chipper are presented below.

Feed System: A hydraulic feed system on a wood chipper may increase the initial cost of purchasing a wood chipper, but the advantages over a gravity or mechanically fed system are significant (How to choose…, 2015).

- Requires less effort for feeding
- Often gives feeding speed and reversible feeding options
- Controlled feed rate produces more uniform chips
- Often eliminates the need for a clutch

Cutting System: There are two options to cut wood chips on an industrial scale, drum and disk. Our team recommends a drum chipper, which is the most common chipper for large operations as a disk chipper requires that the disk be at least twice the size of the material that is being cut (Drum or Disk Chipper, 2012). In addition, drum chippers create more uniform chips.

Portability: Industrial sized wood chippers come in a few different transportation modes, stationary, track mounted, or with tires. Each year a new area of the plantation needs to be harvested; therefore, being able to move the chipper would be a great advantage and would reduce the man labor needed to move all of the scraps. Most wood chippers are transported by attachment to something else such as a car, but there are some with self-driving functions. Having a chipper that is transported by an attachment results in a simpler and smaller chipper. Whether it is transported by attachment or self-driving, tires are recommended because they are easier to service than treads for a track mounted chipper.

System Controls: Some wood chippers, usually those with variable feeding speeds, can have the option to be controlled remotely. This increases the operator's safety by allowing them to remain farther away from the chipper as it is functioning. Our team presents investing in a wood chipper with the ability for remote operation as a benefit. However, in the interest of minimizing cost it is optional.

Loading System: Some wood chippers have the option to be equipped with a large loading arm. This arm is operated from a cab on top of the chipper and is able to grab large piles of wood scraps at a time and load them into the chipper. Our team presents investing in a loading system as a benefit as it almost completely eliminates the need for hand feeding resulting in a safer working environment. However, in the interest of minimizing cost it is optional.

Chipping Capacity: The size of the wood that needs to be chipped determines the chipping capacity. Chipping capacity can be affected by the size of the drum, and by the size of the feeding inlet. It is also affected by power, which is generally determined by the engine size. Our team recommends getting a wood chipper that has a slightly higher chipping capacity than Batipa needs. Running the machine lower than the limit will increase life expectancy and decrease maintenance needs.

Engine: The engine size determines how much wood can be chipped and how quickly. The more power, the faster the wood chipping rate and the higher load the chipper can handle. Our team recommends getting an engine with more horsepower than needed. Running the machine slower or not at maximum output will increase life expectancy and decrease maintenance needs.

Woodchip Production: Different wood chippers output different types of wood chips, such as wood chips specifically for biomass energy production, or wood chips for landscaping. Our team recommends investing in a wood chipper with multiple options for chip creation to leave opportunities open for the future.

An example of a wood chipper that our team thinks would be a good fit for Batipa's needs is the Morbark Beever™ M20R Forestry Chipper. Figure 34 below shows a photo of the chipper. This is an efficient drum chipper on the smaller scale for industrial chippers. It is portable and optimal for in-woods chipping. In addition, it is reinforced in critical wear areas and creates wood chips that could be used for the biomass industry. The standard model includes hydraulics and remote control feed speed for safety. (See Appendix F for a specifications sheet.)

Figure 34: Morbark BeeverTM M20R Forestry Chipper (Morbark, 2017)

The lifespan of any given wood chipper will vary depending on how often it is maintenanced. The more often the engine, bearings, and other internal mechanisms are maintenanced, the longer a wood chipper will last.

A future option for a more sustainable wood chipper would be to use biodiesel. Biodiesel is defined as "renewable, biodegradable fuel manufactured… from vegetable oils, animal fats, or recycled restaurant grease," (U.S. Department of Energy, 2017). It is a cleaner fuel than regular petroleum diesel and can be used in any compression ignition engine. The biodiesel would greatly decrease the wood chipper's impact on the environment, however, it is harder to obtain than diesel, therefore more expensive.

Conceptual Design for a Structure Utilizing Teak

Our team developed a conceptual design for an elevated structure that maximizes the potential for rainwater harvesting and the use of a photovoltaic system at the outpost stations. This structure, depicted in Figure 35, also contributes to our sponsor's goal of utilizing excess teakwood.

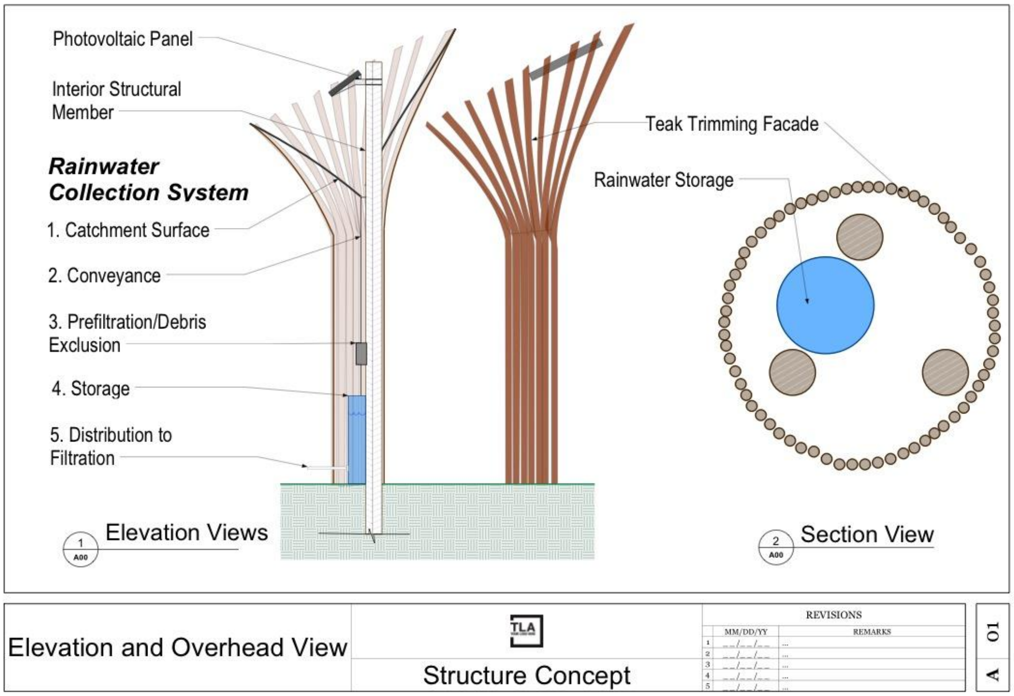

Figure 35: Elevation and Section Views of structure concept. (Konsko, 2017)

The structure is surrounded by a teak facade which contributes to our sponsor's goal of utilizing excess teak wood. An objective of this design is to provide a large enough catchment surface for rainwater collection to be a viable water source at the outpost stations. A solar panel positioned at the top of the structure would maximize energy collection in more remote, wooded areas. To develop this, we conducted research into rainwater harvesting systems, power demand, and created detailed models of our concept.

Rainwater Harvesting Components of Structure Concept

Providing potable drinking water at the outpost stations was a major goal for our sponsor. The facilities at Batipa field Institute are remote, so they utilize off the grid water sources. They currently have wells around Cabimos structures on the peninsula, however, digging individual wells at the more remote locations for the outpost stations would prove challenging. One of the solutions for providing water at the outpost stations would be to implement a rainwater harvesting system. This solution is motivated through the incentives and green building rating systems that encourage rainwater harvesting. If the new development for Batipa plans to obtain a LEED certification, rainwater harvesting could be used to accumulate credits. In most regions, the applicable codes and standards would need to be followed to ensure code compliant design. The Codes and Standards that are typically applicable to rainwater harvesting systems are listed in Appendix G.

A Rainwater collection system consists of five basic components displayed in Figure 36. The information and calculations below are to show the feasibility of rainwater harvesting to meet the demand of the outpost station needs.

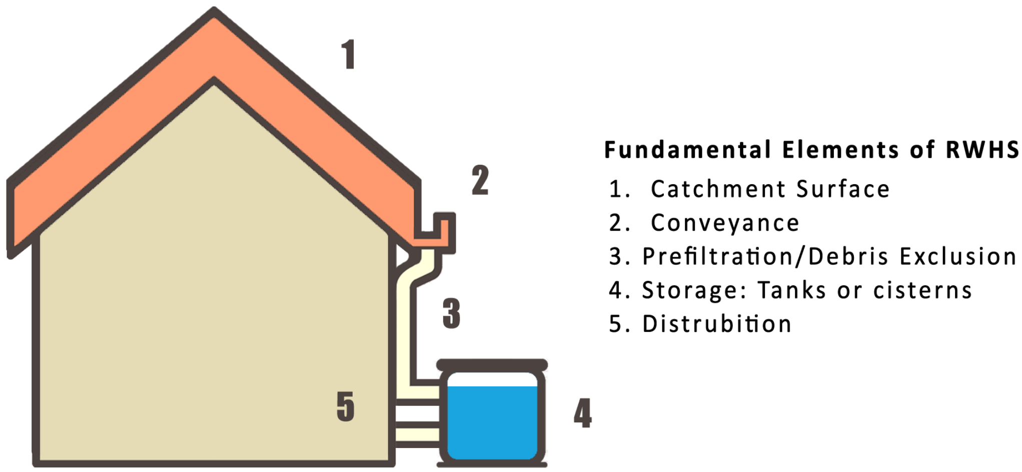

Figure 36: Fundamental elements of an integrated rainwater harvesting system (Scammon, 2017)

1. Catchment Surface: The catchment surface is the most important component of a rainwater harvesting system because it provides a surface for the rain to be diverted from for reuse. In a typical rainwater harvesting system, the catchment surface is usually the roof of a building. In this concept, the catchment surface is almost cone shaped, and completely encompassed by the teak facade. This is depicted in Figure 35.

Two considerations for the catchment surface are the size of the surface and the material to be used. The material used for the catchment surface will affect the runoff coefficient, which gives an indication of how much water can be collected from a specific material. Different materials can also accumulate different types of contaminates that will need to be filtered out to be used for drinking water (Frankel, 2012). Ensuring the catchment surface is large enough to capture enough rainwater to fulfill Batipa's needs is crucial. Detailed below are the steps we took to determine the monthly water supply from a 36 ft^2 catchment surface area.

To determine the water demand on each harvesting system would need to fill, we made some assumptions for the water demand at a single outpost station. If this structure were to be implemented, more detailed data would be needed to size the components of the rainwater harvesting system. We assumed the monthly demand on each structure would be 100 gallons/month given all water would be used solely to refill an individual's drinking water supply. However, the stations situated in highly trafficked areas on the peninsula will likely have a higher water demand.

In order to determine how much rainfall can be collected by a 36 ft^2 catchment surface area, we used the Rainwater Calculation formula seen below. (Novak, Van, & DeBusk 2014).

Rainwater Calculation Formula

$$V_{supply} = A \times P \times C \times 0.623$$

V_{supply} = volume of available water (gal)

P = precipitation (in)

A = collection surface (ft2)

C = runoff coefficient (dimensionless)

In our calculations, we used precipitation data from ETESA's San Lorenzo Station located on the Batipa Peninsula to determine the yearly volume of water available as well as the amount of water available per month. We also assumed that the catchment surface used would be metal, due to the use of corrugated steel in the stations, and the availability of data for a runoff coefficient. Another option for a catchment surface would be a UV resistant, non-toxic tarp. If a tarp were to be used, a runoff coefficient for the surface would have to be determined in order to have a more accurate calculation of the amount of rainwater to be stored. Assuming the demand for water at each outpost station is 1200 gallons per year, a 36 ft^2 catchment surface area could provide almost 3000 gal per year, given the annual average rainfall of 140 in is met. These calculations are shown in Appendix G.

Using the rainwater calculation formula to determine the amount of water collected per month gives an indication of how much water will be available in the rainy season (May - October) and the dry season (November - April) (Empresa de Transmisión Eléctrica, 1998). The results are depicted below in Table 9 . The value calculated for the volume available (V_{supply}) will be used to size the rainwater storage system.

Table 9: Calculated water supply at Batipa by month. Monthly rainfall data retrieved from http://www.hidromet.com.pa/clima_historicos.php?sensor=2

Month	P(in)	C (metal)	A (ft^2)	V_{supply} (gal)
Jan.	1.5	0.95	36	32.0
Feb.	0.5	0.95	36	10.7
March	2.5	0.95	36	53.3
April	5	0.95	36	106.5
May	16.5	0.95	36	351.6
June	17	0.95	36	362.2
July	15	0.95	36	319.6
Aug.	19	0.95	36	404.8
Sept.	21	0.95	36	447.4
Oct.	24.5	0.95	36	522.0
Nov.	14.6	0.95	36	311.1
Dec.	3.3	0.95	36	70.3

2. *Conveyance:* The conveyance system is usually comprised of gutters and a downspout, and directs the water from the catchment surface to the storage unit (Novak, Van, & DeBusk, 2014). In the proposed design, there would be no gutters leading to the downspout of the system. The catchment surface, especially if tarp was used, could be configured in such a way to lead directly into the downspout. Local plumbing codes should be used to determine the size of the downspout of the system. Because the water needs to be potable, copper, zinc and wood should not be used in the conveyance system (Frankel, 2012).

3. *Debris Exclusion:* Water directly from the catchment surface needs to be filtered before storage to remove debris like leaves, dirt, catchment surface particulates, and other contaminants (Novak, Van, & DeBusk, 2014). A variety of primary filtrations systems can be used dependent on the number of storage containers, the type of contaminants likely to be present, and how much water will need to be stored. Figure 37 depicts a vortex filter, which is commercially available. The vortex filter has a combination of coarse and fine screens, which filter out the majority of contaminates.

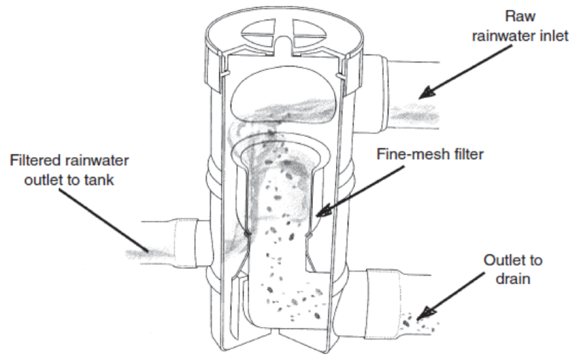

Figure 37: Vortex rainwater filter and roof washer (Frankel, 2012)

4. Storage: The storage unit is where water will be stored before use. A variety of configurations and tanks could be used to fulfill the demand for water at the outpost stations. For example, two storage tanks could be installed, to separate non potable water, and purified water for drinking use. There are a wide variety of cisterns available ranging in size, material, and cost. The next step for choosing a cistern would be to analyze the type of water storage system appropriate for the outpost station sites based on these factors.

An 800 gal rainwater storage tank could be used to fulfill Batipa's estimated demand through the dry season with little to no supplemental water being added. A harvesting system installed at the end of the rainy season in October could retain enough water to sustain an outpost station's demand for the dry season. The calculations for this are shown in Appendix G.

5. Distribution and Purification: The next step for providing accessible drinking water at the outpost stations would be to design a delivery and filtration system. The delivery system would need to transfer water from the structure to the outpost station, and would be designed on a case by case basis. Local plumbing codes would need to be consulted to ensure the fixtures used are able to deliver an appropriate amount of flow and pressure. In order for the rainwater to be converted into drinkable water, it would have to go through a final filtration phase.

Whatever filtration system Batipa chooses will have to filter the contaminants present to meet drinking water standards. There is currently a SAF H2O Survivor emergency electric filter at Batipa that can filter 180 gph and draws 14 Watts. Something like this could be implemented at each of the stations. The solar panel incorporated into the structure could be sized to meet the power demand for the filter.

Solar Component of Structure Concept

In order to maximize the potential for solar power at the outpost stations, the solar panel would need to be elevated enough to reduce the amount of shade from tree cover. In our structure concept, a solar panel could be mounted above the catchment surface, to the side or on top of one of the internal structural members. A consideration for further development of this concept would be to determine an efficient method for performing maintenance on the panel at this location.

In order to prove the effectiveness of providing solar power at the outpost stations, we determined the estimated energy demand at each station, which is shown in Table 10.

Table 10: Estimated Energy Demand at Outpost Stations

Item	Power Draw	Time Used	Energy Demand
LED Light Bulb	10 W	10 hours	100 Wh
Wi-Fi Hotspot	4.5 W	24 hours	108 Wh
Tablet	12 W	8 hours	96 Wh
Compost Fan	4 W	24 hours	96 Wh
3 Laptop Chargers	210 W	4 hours	840 Wh
Total	240.5 w	-	1.240 kWh

The items included in these calculations would help facilitate the comfort and connectivity for individuals using the outpost stations. It includes a tablet and Wi-Fi hotspot to allow personnel to upload research or data materials while in the field. The tablet would also be used to provide an interactive map with data and information about the site. A composting fan was included to take into consideration the energy demand for maintaining a waterless, composting toilet to eliminate waste at the stations. Using the calculator on altEstore's website, we were able to determine that two 24 Volt 180 Watt panels would meet these needs under a worst case scenario of a day and a half of no sunlight.

Teak Facade Component of Structure Concept

The internal systems would be enclosed by a façade of teak tree trimmings to provide an aesthetically pleasing appearance, as well as utilize the abundance of teak scraps left behind each harvesting season. The size of the teak scraps for the façade is flexible, and can be adjusted depending on the size of trimmings available. Some next steps for developing this concept could be to determine how the teak trimmings could be connected or woven together to form a uniform facade as well as how the teak facade could be connected or hung to the internal members.

CONCLUSION

All of the designs and resource management strategies were proposed for use at Batipa. In our time working with Oteima University, our team provided thoughtful recommendations based on a stakeholder oriented design approach. Batipa's stakeholders comprised of multiple individuals with varying backgrounds and fields of expertise.

When proposing a photovoltaic system for Cabimos, we recommended a solar panel size and its accompanying batteries, charge controller, and inverter. We presented various options for short and long term systems dependent upon the batteries selected. The flooded lead acid system will need new batteries roughly every 8 years whereas the lithium system will need its batteries replaced once every 27 years. As part of the photovoltaic system we suggested options for implementing internet connectivity. The first option of a Wi-Fi hotspot was more feasible for near-term application. The second option of a satellite was shown to be better for the future when there would be a greater connectivity need.

Proposing a wood chipper to aid in the utilization of the excess teak wood was a solution that would have both immediate and future impacts. Our team laid out many options for the use of chips from selling them for money to long-term energy production. In addition, we discussed using biodiesel to increase the sustainability of the chipper.

The last proposed design was a concept of a combined rainwater harvesting system and photovoltaic support structure. This structure would be useful for implementation at the future outpost stations to provide energy and water.

Our team was able to successfully propose designs for implementation at Batipa that were sustainable, off the grid, environmentally friendly, and economically feasible. In all of our proposals, we adopted design principles for larger capacity with higher initial investments in the interests of sustainability. Our recommendations gave our sponsor a large base of information to potentially implement any of these designs.

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Appendix A: Renewable Energy Sources

A comparison chart of advantages and disadvantages of different types of renewable energy sources for the Batipa Peninsula.

Type of Energy Sources	Advantages	Disadvantage
Wind	• Inexhaustible • Precedence in Panama • Doesn't need water to run • Fairly cost-effective	• Danger to wildlife, especially aerial • Large, could be considered an eyesore • Causes loud noises • Wind speeds not high enough near Batipa
Hydro (Water)	• Common around the world • Energy conversion is easy • Safe	• No running water in Batipa in dry season • Can harm aquatic habitats • Many parts • Expensive
Solar	• Already implemented at Batipa • Cheapest small-scale option • Easy to maintain	• Shade from leaves can greatly limit efficiency • Needs to be monitored
Geothermal	• Useful in large plant settings • Potent in volcanic regions	• Expensive • Many parts • Digging can be harmful to habitats • Small-scale is not yet common
Biomass	• Useful in a variety of sizes • Eliminates biowastes around the farm • Many different options for how to implement • Commercially proven technology	• Can be expensive • Potentially dangerous • Can have many parts

APPENDIX B: SUPPLEMENTAL ENERGY RESEARCH

Geothermal Energy:

Geothermal energy is energy created from use of the heat inside the surface of the Earth. There are two types of geothermal power plants, one is called hydrothermal or flash steam and the other is called binary cycle. Both are very similar, the only significant difference is that hydrothermal plants use heated water pools from underneath the Earth's surface, while binary cycle uses water to heat to heat another fluid with a lower boiling point in pipes underneath the surface. Both plants use the heated fluid to create steam which powers a steam turbine which in turn is then used to run a generator, creating electricity that can be sent out of the plant through wires. Figure 38 below shows a diagram of a plant. Creating enough steam to generate electricity is easier the hotter the water or rock is, and these are usually found at greater depths (National Geographic Society, 2012). In addition, volcanic regions are considered to be very useful for geothermal energy. In areas with less heat it is often common water to be heated underground and then either used directly or in conjunction with a heat pump to heat buildings.

Unfortunately, there has not been much research into geothermal technology in Central America, and hydrothermal remains the most common form as it is the least difficult to create the steam for energy production.

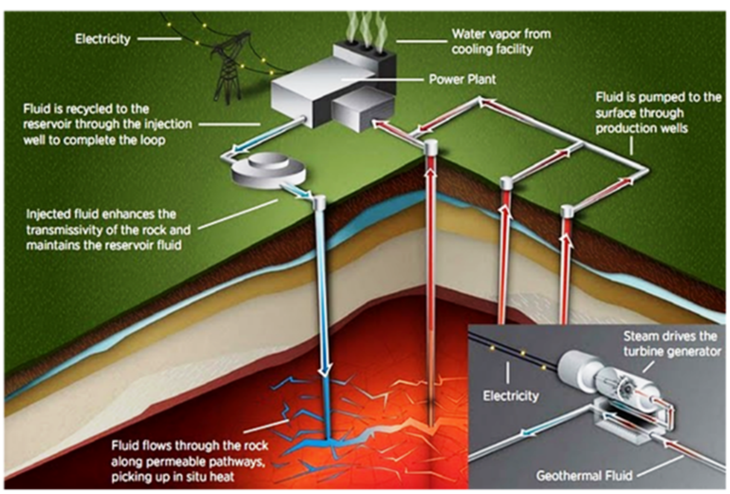

Figure 38: Diagram showing geothermal energy (University of Washington, 2016)

Biomass Energy:

Biomass energy or bioenergy is the energy harnessed from the breaking down of organic debris, generally from plants. There are four main types of bioenergy, combustion, gasification, anaerobic digesters, and pyrolysis (U.S. Department of Energy, 2016).

Combustion:

Combustion biomass energy is the simplest type to produce electricity. It is most common to use dry wood chips as the fuel. The bio-waste is fed into the combustor or furnace where it is burned alongside excess air to heat water in a boiler. The steam that is created in this boiler is fed into a turbine which in turn powers a generator to create electricity (U.S. Department of Energy, 2016).

Gasification:

Gasification is very similar to combustion and is often referred to as a cleaner form of combustion. The downside is that it is often more expensive (U.S. Department of Energy, 2016). Gasification is described as the conversion of solid fuel into gas by partial oxidation at elevated temperatures. Wood chips or other usable bio-waste are superheated in a low oxygen container until they emit a gas. The gas flows into a boiler where more oxygen is introduced causing the gas to ignite. Water vapor is produced from the ignited gas causes the water in the boiler to heat. Like combustion, the water vapor is used to power a turbine which in turn runs a generator to create electricity. It is cleaner because the exhaust from the wood gas circulates through a separator where it is filtered a few times before being released into the environment (Biomass at Middlebury, 2017). Unfortunately a few studies have been performed on the feasibility of a small-scale gasification plant and have been found to be economically unreasonable (Fracaro, Souza, Medeiros, and Marques, 2011).

Anaerobic Digesters:

Anaerobic digesters are a form of bioenergy with much variety. All types of anaerobic digesters convert bio-waste to biogas and a combination of solid and liquid effluents, otherwise known as bio-slurry. The biogas that is produced is usually composed of methane and carbon dioxide and can then be used for heating or combusted to create electricity. However, methane when exposed to air is potentially flammable. The bio-slurry is often vary fibrous and can be used for cattle bedding.

The digesters are all fairly simple in design. The most common bio-waste that is used is manure, food-processing waste, plant residues, and waste water. The bio-waste is fed into the digester where it is mixed with various types of bacteria and sometimes water. Figure 39 below shows a diagram of a digester. What type of bacteria and what type of digester to use depends on the amount of bio-waste being broken down and what percentage of that bio-waste is solid. Digesters can vary in capacity from simple one-family units to entire power plants.

Anaerobic digesters have many advantages, especially for farming communities. Not only do they eliminate excess bio-waste, but they also protect groundwater quality by reducing pathogens in manure. This is turn improves manure nutrient availability for plant life (Chen and Niebling, 2014).

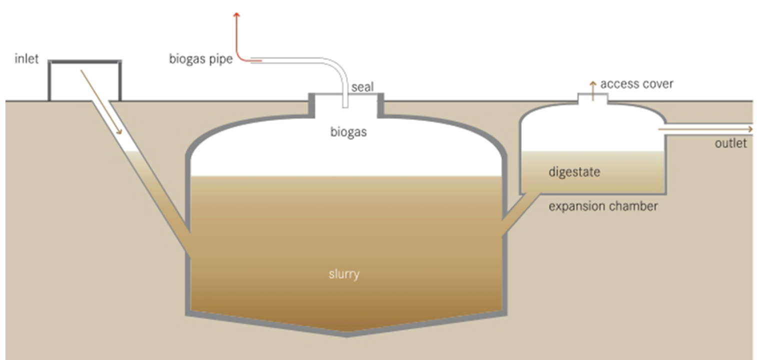

Figure 39: A diagram of a biogas reactor (Tilley, Ulrich, Lüthi, Reymond, Zurbrügg, 2014)

Pyrolysis:

Pyrolysis is a form of bioenergy that is most often used in industrial settings. The biomass or biowaste is rapidly heated in the absence of oxygen. This process yields a bio-oil which is often used as a form of fuel (U.S. Department of Energy, 2016).

Appendix C: Options for Future

AquaFresco

In 2014, the winning team of the Massachusetts Institute of Technology MADMEC competition started a company called AquaFresco, Inc. with the intention of taking their lab prototype to a commercialized product. The MADMEC competition involves teams of MIT students designing and building prototypes for societal needs such as energy storage, building efficiency, and transportation. The AquaFresco team prototyped a laundry washing machine that recycled over 90% of its wastewater and soup used. After winning the competition, the team received funding to share its product with the world. The machine was pilot tested in three hotels and three other commercial laundry facilities. Now, the team is looking to spread the machine worldwide to make washing laundry as sustainable as possible (AquaFresco, 2017).

After learning about Batipa's future plans to have dormitories on site for visiting students and researchers, our team decided to contact AquaFresco. We knew that their sustainable washing machine would be a great help to Batipa not only in reducing the amount of water used, but also as publicity and a learning experience. The AquaFresco team was very receptive to our idea of installing one or two of their machines at Batipa. However, they were unable to tell us if it would be feasible because the buildings are not yet in place at Batipa. In the future, when Batipa's plans for the dormitories have come to life, we hope that Oteima University can reach out again to AquaFresco and MIT and make a collaborative effort with them to take sustainability in Panama to the next level.

Appendix D: Solar Maintenance & Information

The purpose of this appendix is to make our sponsor and other readers aware of the necessary maintenance and safety measures a photovoltaic system requires. If these factors are taken into consideration, the efficiency and lifespan of the full photovoltaic system can be optimized.

Solar Panel

There are two types of solar panels that are mass produced today: monocrystalline and polycrystalline. Polycrystalline panels have been looked down on due to their lower efficiency ratings and higher losses due to heat when compared to monocrystalline panels. With the advancement of modern technology, the efficiency of producing polycrystalline panels has increased significantly. There is only on average a 2% efficiency difference between the types of panels currently. Polycrystalline panels are typically the ideal choice for solar panels now because they are cheaper to produce, they result in less production waste, and efficiency differences are no longer significant (Beaudet, 2017).

Some important tips to optimize your solar panels are: cleaning off the panel, checking the voltage output, mounting them over a light surface. Cleaning off the panel regularly is essential to the photovoltaic system because a dirty or shaded solar cell deals a significant blow to the amount of energy allowed to be collected. Checking the voltage output constantly during the same time of day ensures that your solar panel is functioning correctly. If there is an unexpected reading, then maintenance can be performed on the panel before any permanent damage occurs. Lastly, mounting a solar panel on top and around a light colored surface allows for the panel to collect more energy. Light colored surfaces reflect sunlight whereas dark colored surfaces absorb sunlight. Simply placing a white sheet underneath your solar panel can improve your solar panel's energy output.

Charge Controllers:

The maintenance and upkeep of charger controllers are specific to each device. This is mainly true because charge controllers have a wide range of extra functionalities. Some of the added functionalities include an interactive monitoring system that can display charge flow information about the solar panel. Another contributing factor to monitor is the current capacity the charge controller can handle. On a very hot and sunny day, the solar panel is going to collect more power than usual resulting in a higher current value. The wires resistance value also drops as heat increases, allowing a higher than usual voltage value. The charge controller needs to be able to handle the increased current and voltage values while performing its intended functions.

Batteries:

The two deep cycle battery types investigated in this paper are the flooded lead acid batteries and the lithium batteries. The lithium batteries require virtually zero maintenance and they have no major safety hazards if used correctly. The flooded lead acid batteries, however, require constant maintenance and cleaning to reach their advertised lifespans. Distilled water must be readily available in order to refill the battery cells to ensure full usage. Baking soda also needs to be readily available for cleaning and safety reasons. The baking soda neutralizes any acid the batteries leak. Acid builds up on the terminals and needs to be removed regularly to ensure clean connections can be made. If the batteries tip over or leak accidentally, baking soda needs to be used as soon as possible to neutralize the corrosive acids before they cause significant damage. For this reason, it is advised to keep flooded lead acid batteries in a non-corrosive plastic container on the floor and away from any hazard such as coat hangers, loose objects, etc.

Inverters:

If a correctly sized inverter is selected, the only maintenance required for these components is replacing the internal fuses. These fuses will blow if there is an appliance plugged in that draws too much power. This fuse burns out and cuts off the connection between the battery bank and the appliances to prevent damage to the batteries and to the appliance.

Wiring:

Wiring of the photovoltaic system is something that can be overlooked easily. Making sure the selected wiring is the correct size is essential to maximize efficiency and safety. Every component listed on altEStore's website comes with an intended wire gauge and the type of wire specified by either the manufacturer or sales representative. Aside from purchasing and using the correct wires, maintenance should be performed on the full system to ensure all wires are still intact and are making good connections with every used component.

APPENDIX E: DATA PLANS

All data plans offered by the four providers in Panama as of October, 2017.

Mobile Internet Data Plans						
Provider	Data Limit	Price	$ / UNIT	Time	Type	Type of Plan
Claro	350 MB	$ 2.99	$ 8.543 / GB	Data All Used	Prepaid	Mobile internet
Claro	750 MB	$ 4.99	$ 6.653 / GB	Data All Used	Prepaid	Mobile internet
Claro	1.5 GB	$ 9.99	$ 6.660 / GB	Data All Used	Prepaid	Mobile internet
Claro	3 GB	$ 14.99	$ 4.997 / GB	Data All Used	Prepaid	Mobile internet
Claro	4 GB	$ 19.99	$ 4.998 / GB	Data All Used	Prepaid	Mobile internet
Claro	5 GB	$ 24.99	$ 4.998 / GB	Data All Used	Prepaid	Mobile internet
Claro	6 GB	$ 29.99	$ 4.998 / GB	Data All Used	Prepaid	Mobile internet
Claro	10 GB	$ 49.99	$ 4.999 / GB	Data All Used	Prepaid	Mobile internet
Movistar	1.5 GB	$ 10.00	$ 6.667 / GB	15 days	Prepaid	Data w/ minutes
Movistar	1.1 GB	$ 5.00	$ 4.545 / GB	7 days	Prepaid	Data w/ minutes
Movistar	525 MB	$ 3.00	$ 5.714 / GB	4 days	Prepaid	Data w/ minutes
Movistar	250 MB	$ 2.00	$ 8.000 / GB	2 days	Prepaid	Data w/ minutes
Digicel	225 MB	$ 0.99	$ 4.400 / GB	1 days	Prepaid	Data plan
Digicel	400 MB	$ 1.99	$ 4.975 / GB	2 days	Prepaid	Data plan
Digicel	600 MB	$ 2.99	$ 4.983 / GB	3 days	Prepaid	Data plan
Digicel	1 GB	$ 4.99	$ 4.990 / GB	7 days	Prepaid	Data plan
Digicel	1.5 GB	$ 8.99	$ 5.993 / GB	15 days	Prepaid	Data plan
Digicel	3 GB	$ 14.99	$ 4.997 / GB	30 days	Prepaid	Data plan
Digicel	6 GB	$ 14.95	$ 2.492 / GB	Data All Used	Postpaid	Data plan
Digicel	7 GB	$ 19.95	$ 2.850 / GB	Data All Used	Postpaid	Data plan
Digicel	10 GB	$ 24.95	$ 2.495 / GB	Data All Used	Postpaid	Data plan
Digicel	12 GB	$ 29.99	$ 2.499 / GB	Data All Used	Postpaid	Data plan
Digicel	14 GB	$ 39.99	$ 2.856 / GB	Data All Used	Postpaid	Data plan
Digicel	16 GB	$ 49.99	$ 3.124 / GB	Data All Used	Postpaid	Data plan
Digicel	20 GB	$ 59.99	$ 3.000 / GB	Data All Used	Postpaid	Data plan
+Movil	1 GB	$ 19.95	$ 19.950 / GB	Data All Used	Prepaid	Mobile internet
+Movil	2 GB	$ 29.95	$ 14.975 / GB	Data All Used	Prepaid	Mobile internet
+Movil	5 GB	$ 39.95	$ 7.990 / GB	Data All Used	Prepaid	Mobile internet

Appendix F: Morbark Beever™ M20R Forestry Chipper Specifications Sheet

MORBARK® BEEVER™ M20R FORESTRY

FEATURES

- TorqMax Plus compression system, hydraulic lift assist, Variable Force constant hydraulic down pressure system with additional manually applied hydraulic down pressure at the valve handle and sprocket driven bottom feed wheel
- Directional flow discharge system with horizontal and vertical hydraulic positioning manufactured from abrasion resistant steel
- Hydraulic front and dual rear stabilizers
- 36" (91.44 cm) diameter x 33⅜" (84.77 cm) wide drum with front pocket and six Babbitt-style knives with removable knife holders
- Discharge clean out door on bottom
- Steel guard enclosing valve bank and automatic feed system components
- Live hydraulic system including: ball valve, pump, motor, and valve bank
- Spanish and English safety decals

OTHER SPECIFICATIONS

- Drum diameter: 36" (91.44 cm)
- Drum width: 33⅜" (84.77 cm)
- Infeed Opening: 65" wide x 43" high (165 cm x 109.22 cm)
- Throat Opening: 28" wide x 20" high (71.12 cm x 50.8 cm)
- Frame: 2" x 10" tubular (5.08 cm x 25.4 cm)

OPTIONS

- 4" x 4" (10.16 cm x 10.16 cm) grate system
- Forestry, rotating or top load discharge
- Grate System
- Custom paint and logo packages
- Electronic fuel gauge
- Variable speed flow control
- Tracks

A 6' (1.83 m) infeed bed with live WDH-110 chain drive

Advantage 3™ Drum creates more uniform chips

Remote Control

SPECIFICATIONS	US	METRIC
Chipping Capacity	20"	50.8 cm
Length	26'8"	8.12 m
Height	10'10"	3.3 m
Width	7'8"	2.34 m
Gross Weight (approx.)	18,000 lbs	8,165 kg
Suspension (Torsion)	20,000 lbs	9,071 kg
Tandem Axle	36,000 lbs leaf spring suspension	
Engine	CAT	
Horsepower	350 to 400 HP	260 to 300 kW
Fuel Capacity (tank)	65 gallons	246 litres
Hydraulic Oil	52 gallons	197 litres
Tires	(4) 235/75x17 ½" super singles	
Hitch	3" Pintle	7.62 cm Pintle

MORBARK www.morbark.com 800.831.0042

SPECIFICATIONS MAY VARY WITH EQUIPMENT OPTIONS 2/15/17

Appendix G: Rainwater Harvesting Supplemental Information

The following is a list of the Codes and Standards that are typically applicable to rainwater harvesting systems from (Frankel, 2012)

1. NSF International Protocol P151, Health Effects From Rainwater Catchment Systems
2. NSF/ANSI 6.1, Drinking Water System Health Effects
3. NSF—various standards for Drinking Water Treatment
4. National Weather Service, Hydro 35
5. NOAA, Technical Memorandums regarding rainfall
6. Applicable sections of model plumbing codes such as provisions of the UPC and IPC
7. Environmental Protection Agency, National Pollutant Discharge Elimination System
8. Rainwater Catchment Design and Installation Standards, ARSCA and ASPE
9. NSF Standard 53

The calculations below show that a 36 ft^2 catchment surface would easily fill the estimated demand for water at each outpost station, assuming the yearly water demand at each outpost station is 1200 gal per year.

V_{supply} = 36 ft^2 * 140 inches of rain/year * 0.95 * 0.623 = 2983 gal/year

Demand: 100 gal/mo * 12 months = 1200 gal/yr

On average, 1783 gallons leftover per year

The calculations below show that a reasonably sized (800 gal) rainwater storage tank could be used to fulfill Batipa's estimated demand through the dry season (December - April) with little no supplemental water being added. In this scenario, a harvesting system installed in the final month of the dry season (October) could retain enough water to sustain an outpost station's demand for the dry season.

	water available from previous month (gal)	+	V_{supply}	-	Demand per month (gal)	=	leftover per month (gal)
Oct.	0	+	520	-	100	=	420
Nov.	420	+	311	-	100	=	631
Dec.	631	+	70	-	100	=	601
Jan.	601	+	32	-	100	=	533
Feb.	533	+	11	-	100	=	444
March	444	+	53	-	100	=	397
April	397	+	106	-	100	=	403

Appendix H: Photovoltaic System Component Analysis

This table holds the information for all the used batteries in the following analysis.

				Lifespan Based off of DoD				
Lead Batteries	Voltage	Ah	Weight	20% DoD	40% DoD	50% DoD	80% DoD	Price
T105	6	225	62	3000	1500	1200	-	158.12
T145	6	260	72	5000	3500	2800	-	213.51
J305P	6	330	96	3000	1500	1200	-	279.84
J200	12	200	132	4000	2000	1700	-	297.77
Lithium Batteries	Voltage	Ah	Weight	20% DoD	40% DoD	50% DoD	80% DoD	Price
BattleBorn	12	100	30	-	-	-	5000	899
S.P. 655Wh 12V	12	51.2	16.2	-	-	-	10000	1155
S.P. 655Wh 24V	24	25.6	16.2	-	-	-	10000	1155
S.P. 1310Wh 12V	12	102.4	32.65	-	-	-	10000	1745
S.P. 1310Wh 24V	24	51.2	32.65	-	-	-	10000	1745
S.P. 2.6kWh 24V	24	102.4	57.5	-	-	-	10000	2775

The next two tables hold information comparing: The difference in energy requirements and cost for 2 days vs 1.5 days without sunlight using a Modified Sine Wave inverter, the total cost of using Lead vs Lithium per year using a PWM charge controller vs a MPPT charge controller.

	MSW Calculations										
	Daily Energy	737.14		PWM CC							
Days of Autonomy	2	Total Wh for Batteries	Total Ah for Batteries	Battery Name	Voltage	Ah	How Many	Price	Lifespan (Years)	Recommendation	$ per Year
	0.20	7371.40	307.14	J305P	6	330	4	1119.36	8.22	Lead	
	0.40	3685.70	153.57	T105	6	225	4	632.48	4.11	2 J200 at 40%DoD. Costs $595.54 and lasts 5.48 years. You spend less replacing these more often than the	$108.68/yr
				J200	**12**	**200**	**2**	**595.54**	**5.48**		
	0.50	2948.56	122.86	T105	6	225	4	632.48	3.29		
				J200	12	200	2	595.54	4.66		
	0.80	1842.85	76.79	BattleBorn	12	100	2	1798.00	13.70	Lithium	
				S.P. 1310Wh 12V	12	102.4	2	3490.00	27.40	S.P. 2.6kWh 24V. Costs $2775 and last 27.4 years	$101.28/yr
				S.P. 2.6kWh 24V	**24**	**102.4**	**1**	**2775.00**	**27.40**		
	1.5									Recommendation	$ per Year
	0.20	5528.55	230.36	**T145**	**6**	**260**	**4**	**854.04**	**13.70**	Lead	
				T105	6	225	4	632.48	8.22	4 T145 at 20%DoD. Costs $854.04 and lasts for 13.7 years	$62.34/yr
	0.40	2764.28	115.18	T105	6	225	4	632.48	4.11		
				J200	12	200	2	595.54	5.48		
	0.50	2211.42	92.14	T105	6	225	4	632.48	3.29		
				J200	12	200	2	595.54	4.66		
	0.80	1382.14	57.59	BattleBorn	12	100	2	1798.00	13.70	Lithium	
				S.P. 1310Wh 24V	24	51.2	1	1745.00	27.40	S.P. 2.6kWh 24V. Costs $2775 and last 27.4 years	$101.28/yr
				S.P. 2.6kWh 24V	**24**	**102.4**	**1**	**2775.00**	**27.40**		

	Daily Energy	737.14		MPPT CC							
	2	Total Wh for Batteries	Total Ah for Batteries	Battery Name	Voltage	Ah	How Many	Price	Lifespan (Years)	Recommendation	$ per Year
Days of Autonomy	0.20	7371.40	307.14	J305P	6	330	2	559.68	8.22	Lead	
	0.40	3685.70	153.57	T105	6	225	2	316.24	4.11	1 J200 at 40%DoD. Costs $297.77 and lasts 5.48 years. You spend less replacing these more often than the	$54.34/yr
				J200	12	200	1	297.77	5.48		
	0.50	2948.56	122.86	T105	6	225	2	316.24	3.29		
				J200	12	200	1	297.77	4.66		
	0.80	1842.85	76.79	BattleBorn	12	100	1	899.00	13.70	Lithium	
				S.P. 1310Wh 12V	12	102.4	1	1745.00	27.40	1 S.P. 1310Wh 12V. Costs $1745 and lasts 27.4 years.	$63.69/yr
				1.5						Recommendation	$ per Year
	0.20	5528.55	230.36	T145	6	260	2	427.02	13.70	Lead	
				T105	6	225	2	316.24	8.22	2 T145 at 20%DoD. Costs $427.02 and lasts for 13.7 years	$31.17/yr
	0.40	2764.28	115.18	T105	6	225	2	316.24	4.11		
				J200	12	200	1	297.77	5.48		
	0.50	2211.42	92.14	T105	6	225	2	316.24	3.29		
				J200	12	200	1	297.77	4.66		
	0.80	1382.14	57.59	BattleBorn	12	100	1	899.00	13.70	Lithium	
				S.P. 1310Wh 12V	12	102.4	1	1745.00	27.40	1 S.P. 1310Wh 12V. Costs $1745 and lasts 27.4 years.	$63.69/yr
				S.P. 655Wh 12V	12	51.2	1	1155.00	27.40		

The next two tables hold information comparing: The difference in energy requirements and cost for 2 days vs 1.5 days without sunlight using a Pure Sine Wave inverter, the total cost of using Lead vs Lithium per year using a PWM charge controller vs a MPPT charge controller.

	PSW Calculations										
	Daily Energy	653.33		PWM CC							
	2	Total Wh for Batteries	Total Ah for Batteries	Battery Name	Voltage	Ah	How Many	Price	Lifespan (Years)	Recommendation	$ per Year
Days of Autonomy	0.20	6533.33	272.22	J305P	6	330	4	1119.36	8.22	Lead	
				T145	6	260	4	854.04	13.70	4 T145s at 20% DoD. Costs $854.04 for 13.7 years	($854.04/ 13.7 years) $62.34/yr
	0.40	3266.67	136.11	T105	6	225	4	632.48	4.11		
				J200	12	200	2	595.54	5.48		
	0.50	2613.33	108.89	T105	6	225	4	632.48	3.29		
				J200	12	200	2	595.54	4.66		
	0.80	1633.33	68.06	BattleBorn	12	100	2	1798.00	13.70	Lithium	
				S.P. 2.6kWh 24V	24	102.4	1	2775.00	27.40	S.P. 2.6kWh 24V. Costs $2775 and last 27.4 years	$101.28/yr
				1.5						Recommendation	$ per Year
	0.20	4900.00	204.17	T105	6	225	4	632.48	8.22	Lead	
				J200	12	200	2	595.54	10.96	4 T105s at 20% DoD. Costs $632.48 and lasts 8.22 years	$76.94/yr
	0.40	2450.00	102.08	T105	6	225	4	632.48	4.11		
				J200	12	200	2	595.54	5.48		
	0.50	1960.00	81.67	T105	6	225	4	632.48	3.29		
				J200	12	200	2	595.54	4.66		
	0.80	1225.00	51.04	BattleBorn	12	100	2	1798.00	13.70	Lithium	
				S.P. 655Wh 24V	24	25.6	2	2310.00	27.40	1 S.P. 1310Wh 24V. Costs $1745 and lasts 27.4 years.	$63.69/yr
				S.P. 1310Wh 24V	24	51.2	1	1745.00	27.40		
				S.P. 655Wh 12V	12	51.2	2	2310.00	27.40		

	Daily Energy	737.14		MPPT CC							
	2	Total Wh for Batteries	Total Ah for Batteries	Battery Name	Voltage	Ah	How Many	Price	Lifespan (Years)	Recommendation	$ per Year
Days of Autonomy	0.20	7371.40	307.14	J305P	6	330	2	559.68	8.22	Lead	
	0.40	3685.70	153.57	T105	6	225	2	316.24	4.11	1 J200 at 40%DoD. Costs $297.77 and lasts 5.48 years. You spend less replacing these more often than the	$54.34/yr
				J200	12	200	1	297.77	5.48		
	0.50	2948.56	122.86	T105	6	225	2	316.24	3.29		
				J200	12	200	1	297.77	4.66		
	0.80	1842.85	76.79	BattleBorn	12	100	1	899.00	13.70	Lithium	
				S.P. 1310Wh 12V	12	102.4	1	1745.00	27.40	1 S.P. 1310Wh 12V. Costs $1745 and lasts 27.4 years.	$63.69/yr
				1.5						Recommendation	$ per Year
	0.20	5528.55	230.36	T145	6	260	2	427.02	13.70	Lead	
				T105	6	225	2	316.24	8.22	2 T145 at 20%DoD. Costs $427.02 and lasts for 13.7 years	$31.17/yr
	0.40	2764.28	115.18	T105	6	225	2	316.24	4.11		
				J200	12	200	1	297.77	5.48		
	0.50	2211.42	92.14	T105	6	225	2	316.24	3.29		
				J200	12	200	1	297.77	4.66		
	0.80	1382.14	57.59	BattleBorn	12	100	1	899.00	13.70	Lithium	
				S.P. 1310Wh 12V	12	102.4	1	1745.00	27.40	1 S.P. 1310Wh 12V. Costs $1745 and lasts 27.4 years.	$63.69/yr
				S.P. 655Wh 12V	12	51.2	1	1155.00	27.40		

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