Solar and Biomass Microgrid in Adjuntas, PR

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Can Biomass Gasification Help Increase Community Resilience? Design and Model of a Solar and Biomass Microgrid in Adjuntas, PR

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Abstract

In response to Hurricane Maria and inequities of the Puerto Rican power grid, communities in Puerto Rico are looking to transform the energy and agricultural landscape with the uses of biogasification in mini-grids. Excess biomass is a carbon-neutral resource readily available to many vulnerable communities that offers the potential to lower the cost to maintain a stable mini-grid while also increasing community autonomy and sustainability. This research aimed to model a small-scale grid that integrated solar PV and biomass gasification for a large community hospitality center to better understand the economic and technical effects of using biomass as a fuel source. This research also sought to design a gasifier using CAD to increase efficiency and usability to allow for future biomass gasification experimentation. HOMER Pro and Helioscope were used to model the microgrid, while Fusion 360 was used to design the CAD model of the prototype hybrid gasifier. The model demonstrated that a PV-biomass gasification installation would help increase community energy resilience and could lower the cost of energy from $0.234/kWh to $0.121/kWh for the local business. However, future investigation is needed to design a circular supply chain to process and store the excess biomass. The completed design of the new model gasifier will also contribute to future thesis work exploring biomass energy characteristics. This work is part of an ongoing engagement by UofM´s Sustainability Without Borders organization and thus will continue with the next master’s Project team.

Acknowledgments

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Special thanks to the University of Michigan’s School for Environment and Sustainability (SEAS), Sustainability Without Borders, Planet Blue and Rackham Graduate School.

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Lastly, we would like to show our gratitude to our friends and family that have supported us during this very unprecedented year.

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Introduction

Traditional energy systems are not well adapted to the warming climate, especially in island nations like Puerto Rico. With the increase of human-induced climate change, severe weather events are likely to become more frequent and more intense [1]. The effects of these events were seen after Puerto Rico was hit by the category 5 Hurricane Maria which devastated the Puerto Rican power infrastructure. The storm knocked out the island's power grid, shut down virtually all cellular communication, and destroyed nearly all traffic lights and road signs [2]. This was one of the largest blackouts in US history leaving 1.5 million people without power and some for over a year [3].

To exacerbate this issue, Puerto Rican residents experience significant energy burdens due to the island’s high electricity costs. Puerto Rico Electric Power Authority (PREPA) is the sole utility in Puerto Rico making them responsible for electricity generation, power distribution, and power transmission. Poor management and lack of maintenance has put PREPA in a severe financial crisis which is being passed on to their customers through their energy rates and poor service reliability [4]. These vulnerabilities are motivating the need for Puerto Rico to have an energy transformation to a more sustainable and resilient energy system.

At the heart of this transformation is the community of Adjuntas, Puerto Rico. This is a small town in a mountainous region on the island. In this town, there is a non-profit organization called Casa Pueblo who has been a champion in reimagining the Puerto Rican energy system. For the past four years the School for Environment and Sustainability has partnered with Casa Pueblo in this transition through the project Mini-grids from Biomass Residues for an Agricultural Circular Economy (MBRACE). This project focuses on reimagining the energy and agricultural systems in Puerto Rico through the use of agricultural residues, gasification, and biochar. Through this multi-year engagement with Casa Pueblo, past groups have begun demonstrating the feasibility of gasification for a circular economy. The goal of a circular economy is to eliminate waste by the continual reuse of resources [5].

To continue this work, our team has partnered with a local hospitality and ecotourism business, Parador Villas Sotomayor, following Casa Pueblo’s recommendation. Heavily impacted by Hurricane Maria, the parador was stranded without grid power for seven months and forced to rely on diesel generators. The owners of this business have committed both to sustainability and to assist in the transformation of Puerto Rico’s energy system. The parador is also an ideal location to further test the feasibility of biogasification as they are adjacent to an organic farm that produces an abundance of biomass which can be used in the gasification process. The facility could also act as a resilient hub for the Adjuntas community in a future natural disaster as they could provide critical services.

To further this work, our team focused on two main research questions:

1. How can we improve the biogasifier design to increase efficiency and usability?
2. Can biogasification increase community resilience through improved microgrid stability and financial viability?

Background

Biogasification

Biogasification is a thermochemical process that uses heat and oxygen to break down biomass—such as tree branches, coffee residues, or other carbon-rich plants—into hydrogen rich biogas that can be used as fuel to generate electricity. During this process carbon is sequestered in the charcoal creating biochar.

Figure 1 - Example of Biochar from gasification process. [6]

This biochar can be used in agricultural processes as a carbon soil amendment increasing soil health [7]. This technology has continued to evolve with the creation of several biogasifier designs that have proven to be useful in energy generation [8].

The gasification process (as shown in figure 2) starts with a multi-stage heating of the biomass starting with drying the fuel.

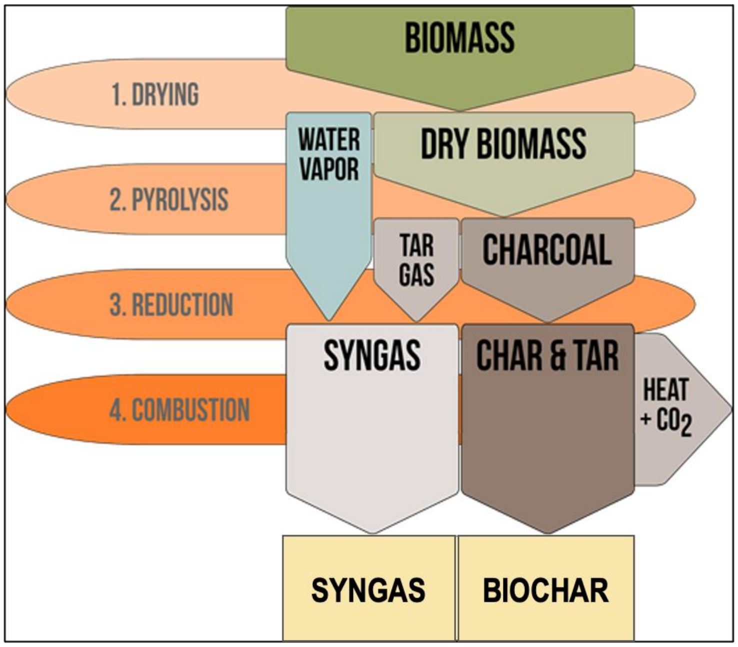

Figure 2 - Gasification Process Diagram [9]

This takes place in the uppermost area of the reactor removing excess moisture. When dried, the biomass then undergoes pyrolysis which is the process of the oils from the biomass evaporating leaving only carbon. The biomass then goes through combustion and the gas emitted passes over charcoal undergoing a reduction process turning water vapor into hydrogen and carbon gases [10]. This process produces biogas also known as syngas, biochar, and a tar residue. The syngas is then cooled, filtered and combusted in a generator to create electricity.

Although the gasification process still creates a small amount of carbon, there is a massive extraction of carbon from the atmosphere when the biomass is being produced that offsets this process. In order for biomass to be carbon neutral, we must make sure the land where the biomass is coming from continues to grow biomass to capture carbon [11]. An example of this is when residues of agricultural production are used as the feedstocks, particularly perennial crops. Another benefit of the gasification process is that it is fueled by biomass that was most likely used in composting or discarded as waste not reaping the potential benefits of the resource.

Biogasification can provide a resilient energy resource but has some limitations. The operation and maintenance of a biogasifier can be difficult and require many different disciplines, including facilities, electrical, and mechanical which need to be coordinated to an overall operation and maintenance strategy [12]. This burden of operation can create higher costs. The gasification process is also not 100% efficient, which means there are some waste products and impurities that can complicate this process. Additionally, biogasification relies on a well-established biomass supply chain in order to sustain operations of the biogasifier. When establishing the supply chain, accurate pricing can be difficult and can vary based on community while facing challenges of operational scaling.

As mentioned previously, there are a few different styles of biogasifiers. Past teams on this project have created two different types, a FEMA design and Imbert design. The FEMA design gasifier is cheaper, easier to build, and is better at producing biochar but produces more tar and less syngas. The Imbert design is more efficient at syngas production, decreasing tar residues, but also biochar production. This past work has laid the groundwork for our team's improved gasifier which combines advantages from both the FEMA and Imbert style biogasifiers.

Mini-grids

A mini-grid, sometimes referred to as a “micro grid”, can be defined as a group of electricity generators and storage systems that are interconnected to provide electricity to a localized area or group of people [13]. These mini-grids can be isolated or connected to a centralized power grid. The composition of a mini-grid can vary but most sustainable systems include renewable energy generation, some form of energy storage, and frequently other reserve power sources for grid stability.

The most important feature that mini-grids provide for this project is resiliency. Mini-grids generally are composed of several generation sources introducing redundancy over traditional systems that have a single point of failure, the power grid [12]. When constructing these mini-grids, solar photovoltaics (solar PV) are a common choice because of the resource abundance and lower lifetime energy costs. This high penetration of renewables can add uncertainty and variability to the energy supply. This problem is commonly mitigated by using battery storage which increases the cost of electricity. Biomass gasification can be an alternative generation source that does not rely on variable resources, like wind or solar, and can have a lower cost compared to other energy sources and storage. These benefits from biogasification can help create a more sustainable and resilient mini-grid.

Circular Economy with biogasification and mini-grids

With the use of biogasification in mini-grids, a circular economy can be achieved. The goal of a circular economy is to eliminate waste by the continual reuse of resources. This starts with the biomass supply chain that will be the source of fuel for the gasification process. Then the gasification occurs providing energy for the mini-grid and biochar for agriculture. The biochar increases the health of the soil improving the agricultural ecosystem. This improvement bolsters the biomass supply chain completing the circular economy. This system strives to reduce waste while also providing reliable low carbon energy to a mini-grid.

Methods

Literature Review

To begin the research, process an in-depth literature review was conducted on the biomass in Puerto Rico and biogasification. The goal of researching biomass was to provide information on the viability of a biomass supply chain to gain a deeper understanding of the feasibility of biogasification in rural communities of Puerto Rico. To inform the design of the improved gasifier, various studies and past project data of how each gasifier style differs was collected and analyzed.

Gasifier Design

With the data collected from the literature review, our team discussed what parts of each gasifier provided a net benefit to the overall design to increase efficiency and usability. Past members of MBRACE teams conducted several tests on operating gasifiers to better comprehend the gasifier operations and their net benefits. Using this knowledge gained from past designs, our team endeavored to design an improved biogasifier using Fusion360 3D modeling software. For every component of the complex gasification and filtration system, we followed a workflow of creating sketches, designing 3D bodies, and converting them to components and adding them to the full gasifier design. This design includes the main reactor chamber, primary filter, and secondary cyclone filter.

After completing the CAD design, the team created engineering drawings of each component and assembly diagrams when necessary. Lastly, we used that information to create a detailed build plan. This build plan provides a step by step process on how to construct each component utilizing fabrication techniques like welding, plasma cutting, and other metal working. The overarching goal of creating a digital design and associated build plan was to facilitate both future testing and eventual application of gasification technology across many of UofM's Sustainability Without Borders project portfolio.

Energy Modeling

Energy modeling was the most client-centered portion of our Master's work. Given the vulnerability of the populations in the region, approaching our project in an ethically and equitably sound manner was of the utmost importance. To ensure this, the multi-year MBRACE project has consistently operated using the Rural Livelihoods Framework [14], which emphasizes holistic, community-led assessment and action. Accordingly, the team repeatedly met with our energy modeling client, Parador Villas Sotomayor, to assess their existing assets and vulnerabilities and to better understand the business owner's desired livelihood outcomes.

After our client made it clear that their electricity costs were one of the business's chief financial burdens, we worked closely with Villas Sotomayor to holistically assess their energy consumption patterns, gather electrical demand data, explore potential locations for solar PV installations, and address other considerations necessary for accurate modeling.

We then worked with the microgrid modeling software, HOMER Pro, to model the performance of both an isolated and a grid-connected microgrid with a variety of different generation scenarios for each. To accomplish this, we first had to supply HOMER with detailed information about every generation resource under consideration as well as a detailed hourly demand curve.

Accurately modeling predicted electrical loads proved to be a significant challenge, as Villas Sotomayor only had monthly billing information for each of their two separate electrical meters. To construct a more detailed load curve, we correlated two years of combined monthly demand data with monthly occupancy information. This allowed us to better control for the drop in electrical demand associated with the low occupancy the parador has experienced during the COVID-19 pandemic. We then used information gained from interviews with the client to find well-studied load curves that could closely mirror the parador's own demand. Parador Villas Sotomayor has a wide variety of buildings and energy profiles, so we combined two demand curves from NREL's OpenEI database: a small restaurant and a small hotel [15]. We manually combined these curves and scaled them to reflect the actual level of demand by our client. These load curves can be seen in figure 3.

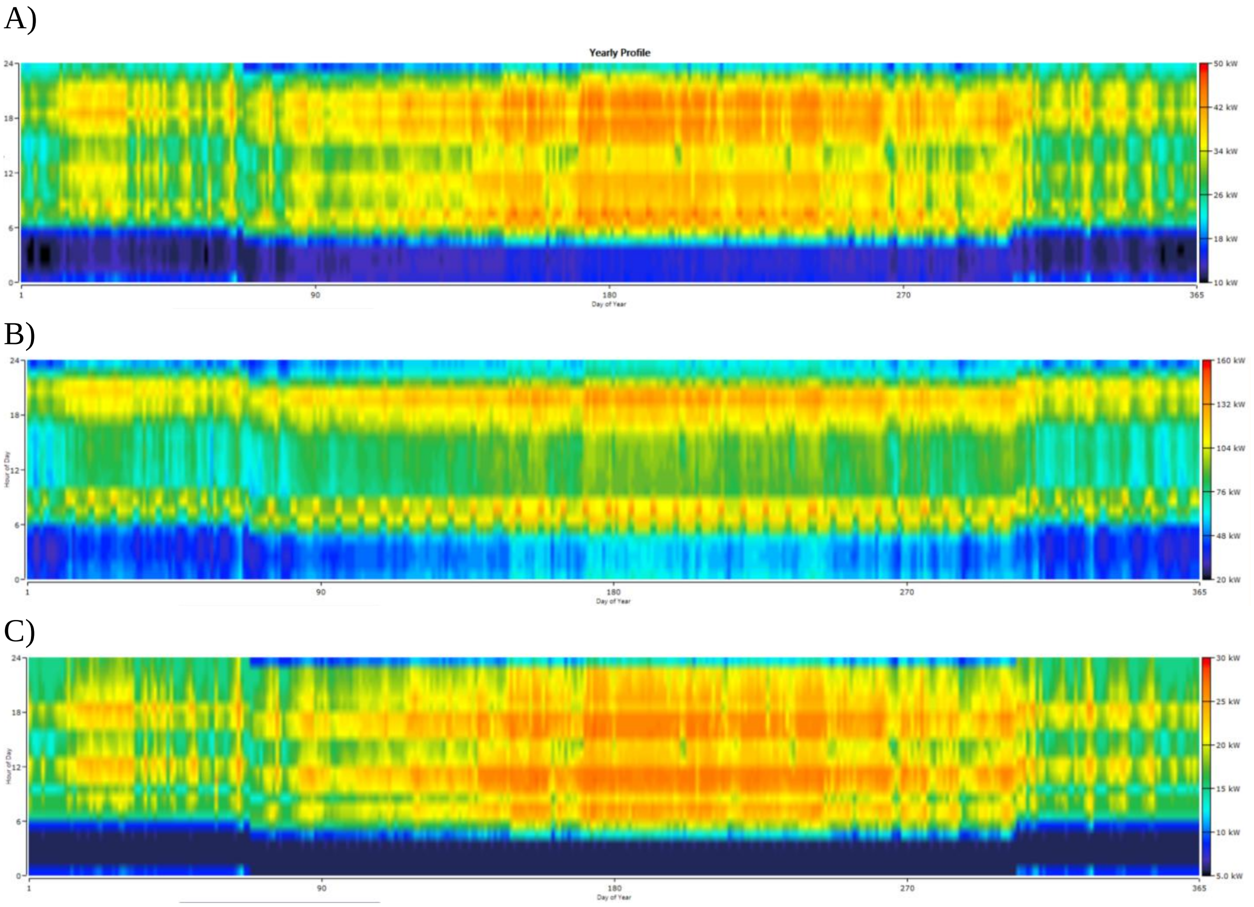

Figure 3: Load curve data for rooms, lobby, and a combined curve. A) Rooms B) Lobby C) Combined

Next, we input information about each generation component under consideration and its associated energy resource. The components that we assessed were diesel generation, biomass gasification, solar PV, battery storage, and grid-connected electricity.

The manually inputted assumptions and specifications for each of these are listed below.
For all capital costs, we assumed replacement costs to be 50% of original capital costs and operation and maintenance to be 1% of total capital cost annually.

Table 1: HOMER Pro Modeling Specifications (note that multiple values separated by commas represent multiple values used for sensitivity analysis)

Specification	Amount	Specification	Amount
Biomass Price ($/ton)[1]	$5, $25	Generator Replacement Costs ($/kW) [16]	$1050
PV System Lifespan (years)[2]	25	Scaled Annual Average Demand (kWh/day)[3]	763.73
Biomass Carbon content [17]	50%	Peak Demand (kW)[4]	49.88
LHV of biogas (MJ/kg) [16]	7.09	Li-ion battery storage capital costs ($/kWh)[5]	$550
Gasification ratio (kg/kg) [18]	2.84	Li-ion battery storage lifetime[1]	15 years / 3000kWh throughput
Available biomass per day (tons) [15]	2.0	Minimum state of Li-ion battery charge[1]	40%
Gasifier generator lifetime[1]	15000 hours	PR Grid electricity retail price ($/kWh)[6]	$0.234
Minimum runtime[1]	120 minutes	PR Grid excess electricity sell back price ($/kWh)[7]	$0.075
Minimum load ratio[1]	25%	Discount rate[1]	8%
Generator Capital Costs ($/kW)[8]	$2100	Biomass Fuel Consumption Slope (kg/hr/kW output) [16]	1.650

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[1] Biomass price sensitivities and daily availability estimated based on personal communications with Prof. Jose Alfaro and the ownership of Villas Sotomayor. More refined price estimates will be completed by future teams

[2] HOMER default value

[3] Calculated as a weighted average of the previous two years of monthly energy bills

[4] Calculated from HOMER Pro based off the load curve automatically created by HOMER from our input data

[5] Values estimated from consultation with Dr. Jose Alfaro

[6] PREPA retail rates vary. These are based off an average of actual prices paid by Parador Villas Sotomayor 2019-2020.

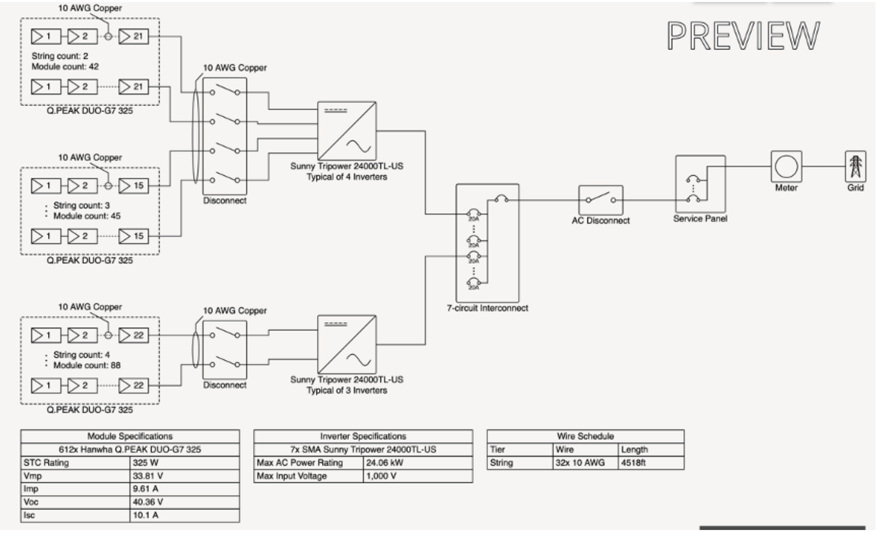
[7] Puerto Rico Act 114-2007. Accessed from: https://aeepr.com/es-pr/QuienesSomos/Ley57/Facturación/Tariff Book - Electric Service Rates and Riders Revised by Order 05172019 Approved by Order 05282019.pdf. Note that the actual sellback rate is $0.10, but it is only applied to 75% of excess kWh (as the rest is donated), which for modeling purposes was converted simply to a rate of $0.075.

[8] Estimated based on previous cost outcomes for SWB and from consultation with Dr. Jose Alfaro.

For solar generation, we used a separate solar PV system design software, Helioscope, to design a full PV system and model the expected hourly electrical output. We consulted with Villas Sotomayor about ideal panel locations and ultimately chose a design utilizing a large ground-mounted PV array in one of the businesses large open fields (see figure 4). Specifically, the design uses Sunny Tripower 24000TL inverters and Q.Peak DUO G7 325W solar modules.

Figure 4: Ground-mounted solar array siting

Helioscope converted our design information into a single-line diagram (SLD) showing the electrical blueprints for our solar PV system (see figure 5). This program is a highly technical engineering program that creates bankable designs which can be used to secure project funding and construction contracts.



Module Specifications	
612x Hanwha Q.PEAK DUO-G7 325	
STC Rating	325 W
Vmp	33.81 V
Imp	9.61 A
Voc	40.36 V
Isc	10.1 A

Inverter Specifications	
7x SMA Sunny Tripower 24000TL-US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	32x 10 AWG	4518ft

Figure 5: Single line diagram (SLD) of Helioscope design

Using satellite imagery, solar resource databases, local historical weather data, manually inputted shading sources (e.g. trees and buildings), and the performance specifications of the individual system components in order to simulate expected system AC electrical output for every hour in an average year. Although HOMER Pro can simulate this information, Helioscope provides more nuanced results, modeling things like interpanel shading losses and individual wiring losses, making it comparable in accuracy to other professional solar design tools [19].

HOMER Pro uses the possible system components, including the Helioscope output, and performs an economic optimization to find the lowest cost system architecture for our results.

We also created a separate model without including a grid resource to model what level of resilience and community services the parador could offer in the event of another extended blackout.

Results

Gasifier Design

Our hybrid design combined positive elements from past designs made from previous teams. This resulted in the full replicated visual model of our hybrid gasifier on Fusion 360. In addition, we crafted engineering drawings on each of the components as a resource for future teams. The following figures show the added modifications and justifications for implementing these changes for our hybrid design.

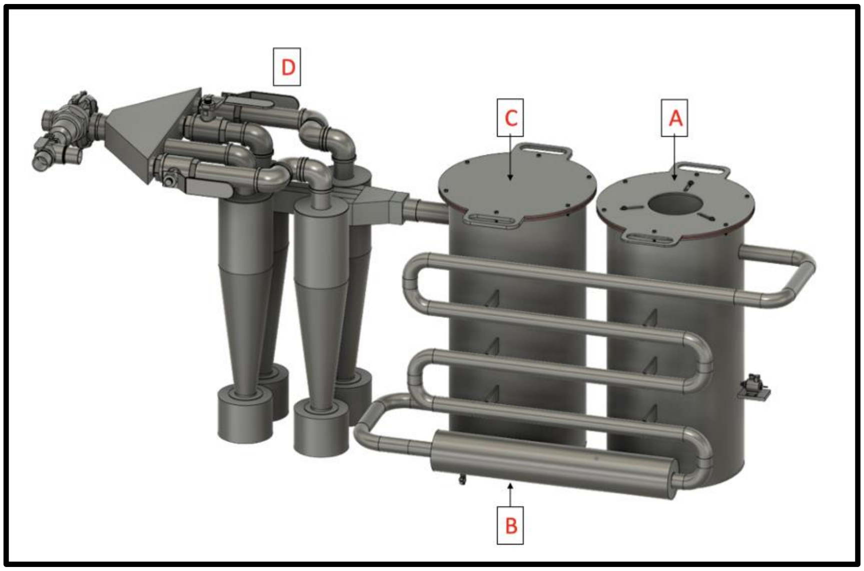


Figure 6 - Hybrid Gasifier Design. This diagram shows the main components for our new hybrid gasifier design Where A is the Reaction Chamber, B is the Condenser Tube, C is Primary Filter and D is the Cyclone Filter

Reaction Chamber

Figure 7 shows a cross-sectional diagram of the reaction chamber.

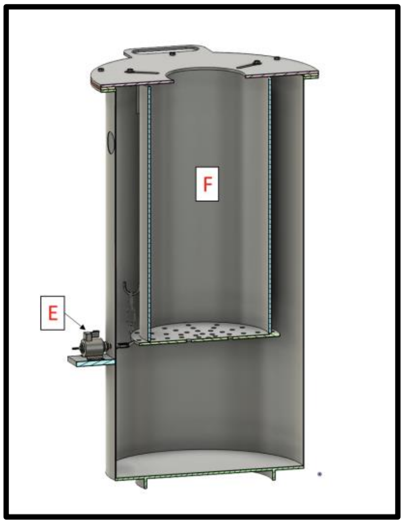


Figure 7 - Reaction Chamber. E) Solenoid. F) Fire tube.

For the reaction chamber we added the following changes that we believe would help improve the design:

Shaker Grate

In the previous version, the shaker grate was imperfect at reducing bridging and clearing debris for feedstock to travel down the fire tube. This was partially due to its slightly inefficient automated system. For our design, we used a linear actuator solenoid that will provide reciprocating motion causing the shaker grate to agitate the feedstock.

Fire Tube

The fire tube design and sizing is important as it changes the theoretical syngas production for the gasifier. We made the fire tube with a more flexible design to allow it to be removed and replaced by other fire tubes of different diameters and heights. As a result, this would make it more efficient at conducting future research on the gasifier’s performance.

Filtration System

The purpose of the filtration system is to extract out particulate matter from the syngas. Without this process, it would decrease the efficiency of our gasifier and increase the amount of tar buildup that could lead to generator failure. This stage is a two-step process which includes the primary filtration and secondary cyclone filtration. In figure 8, the primary filter on the left has an inner component that is filled with straw and other medium that removes large particles and tar. On the right, is a new addition to our design, cyclone filtration.

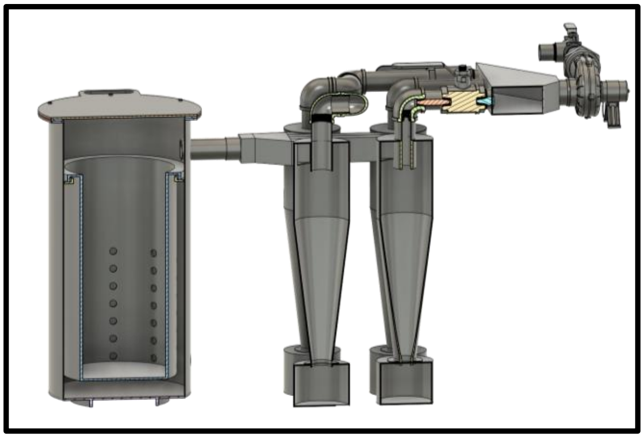


Figure 8 - Section Analysis of the Filtration Section

Cyclone filters are devices that use the principle of inertia and centrifugal force to separate heavier particles in a process called vortex separation [20]. This part of the design was a major modification that we added to provide more filtration. Syngas impurities enter the cyclone filter and the heavier particles will sink to the bottom whereas the clean syngas will escape up through the central pipe. After this process, the cleaner syngas will be sent to the generator for fuel to make electricity.

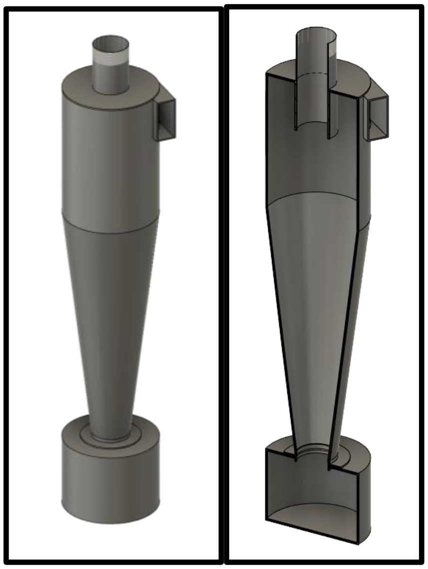
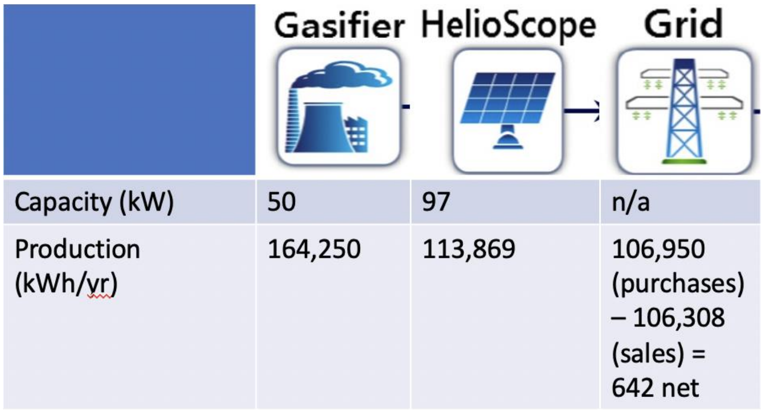


Figure 9 - Cyclone Filter and sectional analysis

Energy Modeling

We split our microgrid modeling into two main scenarios, grid-connected and grid-isolated.

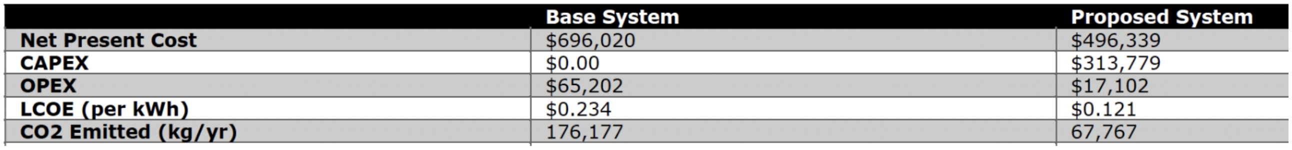
After considering tens of thousands of possible combinations and various sensitivities, results show that the grid-connected microgrid configuration with the lowest net present cost (NPC) utilized grid power, a large solar PV installation, and a 50kW biogasifier (see figure 9 for system architecture).



	Gasifier	HelioScope	Grid
Capacity (kW)	50	97	n/a
Production (kWh/yr)	164,250	113,869	106,950 (purchases) – 106,308 (sales) = 642 net

Figure 10: System components in lowest NPC grid-connected system

This system design has a NPC over $200,000 lower than the base case of only grid power over the 25-year project lifespan. Notably, this assumes no major grid disruptions nor the equity benefits from building a more resilient system that could significantly raise the true costs of the base case while lowering those of the microgrid. As seen in figure 10, this system brings the levelized cost of energy down from an average of $0.234/kWh to $0.121/kWh, has an IRR of 15.3% and a payback period of 6.38 years (discounted payback period is 8.73 years). However, this scenario requires an initial capital investment of over $300,000, which could prove to be a significant barrier given the difficulty of obtaining low cost financing throughout the Caribbean region [21]. Moreover, due to the significant reliance on gasification and its associated generator, the generator will likely need to be replaced about every 5 years, which negatively impacts NPC.



	Base System	Proposed System
Net Present Cost	$696,020	$496,339
CAPEX	$0.00	$313,779
OPEX	$65,202	$17,102
LCOE (per kWh)	$0.234	$0.121
CO2 Emitted (kg/yr)	176,177	67,767

Figure 11: Economic comparison between lowest NPC system and grid-connected base case

Lower biomass pricing of $5/ton—which might be possible given that the owners of Villas Sotomayor also own an adjacent farm—does not change the optimal system architecture, as the gasifier and 50kW generator run slightly over 3000 hours annually, but with slightly lower operating costs.

The large PV systems in these designs (nearly 100kW$_{peak}$) are economically viable under current Puerto Rican regulatory law due almost entirely to net metering which allows HOMER to essentially offset the entirety of overnight grid purchases with a combination primarily extra overnight biomass-powered generation, as well as some extra daytime solar generation. Figure

12, which shows purchases and sales to the PREPA grid, demonstrates the extent to which nighttime sales back to the grid are crucial to keeping grid costs down. This is made possible by the gasifier running at max capacity during these hours (as seen in figure 13).

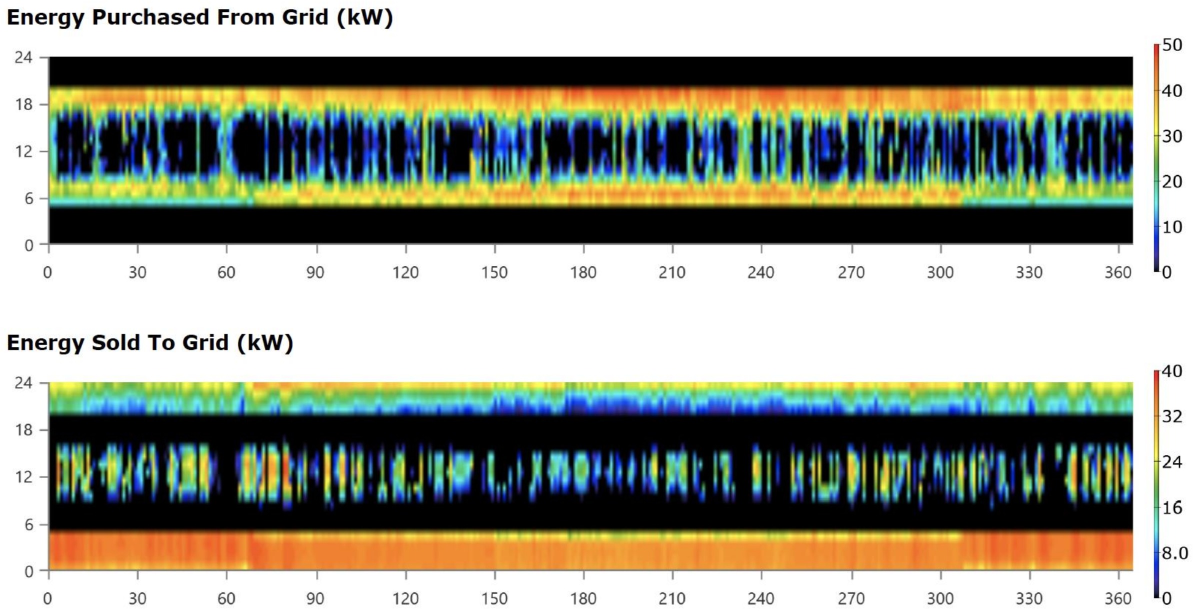


Figure 12: Grid Energy Net Sales

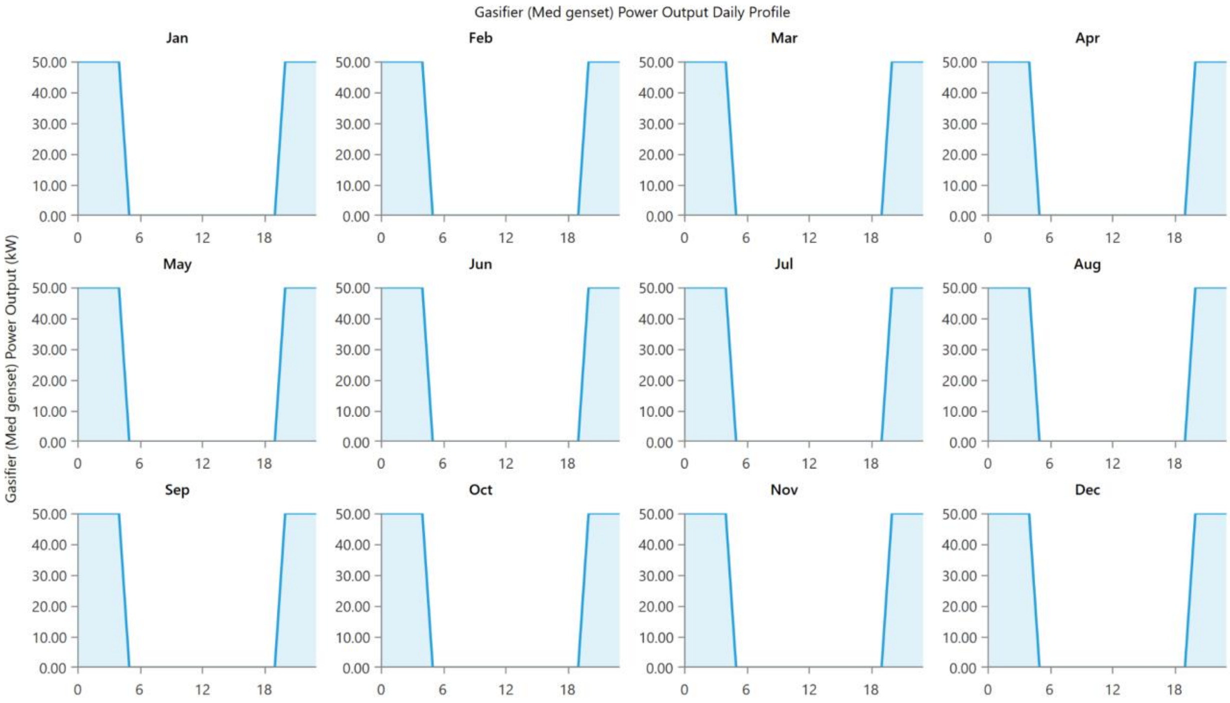


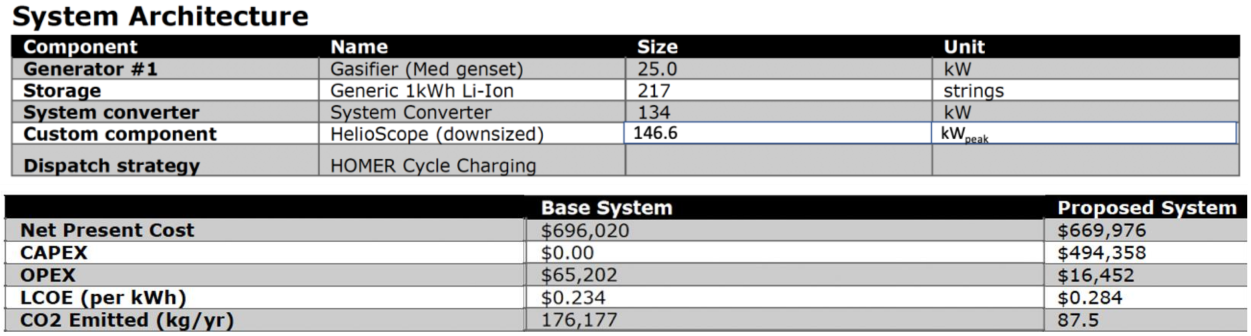
Figure 13: Hourly gasifier output profile, organized by month

Given the abundant space and excellent solar resource in the region, large PV installations could potentially be viable, although financing considerations might make the smaller PV array a more practical option. Because the grid is the highest cost source of energy in the system and because Puerto Rico allows for 100% net metering, HOMER runs the gasifier at full capacity nearly every night to feed excess energy to the grid and "roll back" the electricity meter (see figure 12). Without net metering policies this strategy would almost certainly be less viable and the gasifier would likely run less.

Grid-Isolated Model

The grid-isolated model inherently is more sensitive to stability and capacity issues, as it cannot rely on the grid to smooth out demand and generation extremes and mismatches. HOMER defaults to a maximum capacity shortage fraction of 5%.[9] With these settings, the lowest NPC system uses zero solar PV and relies on 55kW of diesel generation and 25kW of biogasification with a very small amount of battery storage (11kWh), achieving a renewable penetration of only 21.7%. This architecture has a cost of energy of $0.256, which is higher than current average grid pricing, meaning it would only be financially viable during serious sustained blackouts. Moreover, such a system fails to address the sustainability goals of Parador Villas Sotomayor, namely decreased environmental impacts and lower energy burdens.

However, as mentioned, in the livelihood context of our project client, grid isolation would likely only occur in the event of a disaster. During these emergency situations where the majority of the region is without power, larger capacity shortages would likely not be a major concern as non-essential loads would almost certainly be reduced. Accordingly, we considered a 25% maximum capacity shortage. In that case, the lowest NPC grid-isolated system costs were actually slightly lower than the grid-connected base case ($670k vs $696k). It relies on approximately 146kW solar PV installation and a gasifier with an associated 25kW generator, along with sufficient Li-ion battery capacity (217kWh) to provide over 4 hours of full system autonomy with 100% renewable energy penetration (see figure 14).



System Architecture

Component	Name	Size	Unit
Generator #1	Gasifier (Med genset)	25.0	kW
Storage	Generic 1kWh Li-Ion	217	strings
System converter	System Converter	134	kW
Custom component	HelioScope (downsized)	146.6	kW_{peak}
Dispatch strategy	HOMER Cycle Charging		

	Base System	Proposed System
Net Present Cost	$696,020	$669,976
CAPEX	$0.00	$494,358
OPEX	$65,202	$16,452
LCOE (per kWh)	$0.234	$0.284
CO2 Emitted (kg/yr)	176,177	87.5

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[9] Capacity shortage fraction is defined as the total annual capacity shortage divided by the total annual electrical demand. Capacity shortage is simply the difference between the required operating capacity (actual load + required operating reserve) and the actual system capacity.

Figure 14: a) Grid-isolated system architecture. b) Economic comparison between grid-connected base case and the lowest NPC grid-isolated system

Capacity shortages are seen during the “shoulder periods” of each day, that is, the early mornings and late evenings, when demand is high but solar generation is low (see figure 15). In the emergency scenarios in which this model would be relevant, those demand peaks could likely be smoothed by simply powering down large loads for a few hours or delaying other uses.

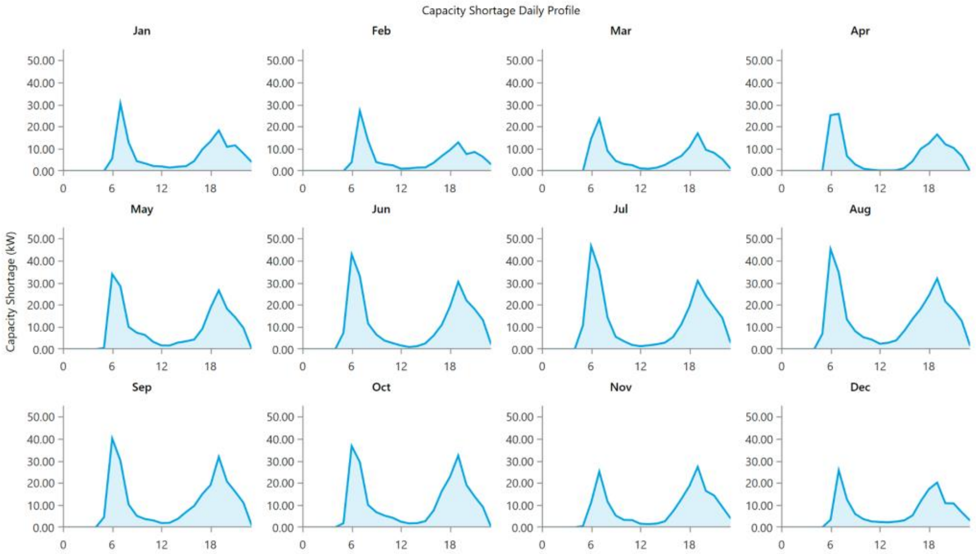

Figure 15: Daily system capacity shortages, averaged by month

Ultimately, neither of these models can fully capture the exact energy context facing Parador Villas Sotomayor. However, the differences between the two, most notably a large energy storage component in an isolated model but with less reliability, can help guide the owners to a solution that works best for them.

Discussion

Biogasification

Older gasifiers that were made by previous MBRACE teams encountered a few challenges that would hinder the gasifier's performance. For example, the gasifiers in Puerto Rico and Ann Arbor tend to build up more tar residues which decreases the gasifiers overall efficiency. This led us to create a hybrid model that is more adept at reducing tar production while increasing the production of syngas and biochar. A major addition to that hybrid design is the use of cyclone filtration in our model. Cyclone filters add another layer of filtration to further clean out all the heavy and fine impurities that could cause generator issues. This addition alone could play a key role in the gasifier's success into creating a more viable sustainable microgrid for rural communities. Additionally, the design incorporated several additions that will make testing and optimizing the gasifier much easier.

Using CAD to visually model our gasifier created a unique perspective that lays the groundwork to understand the makeup of the components in the biogasifier. In addition, creating the build plan further solidifies the foundation of creating a robust process that will provide ease into making changes, small or large, to improve the gasifier's performance. Creating the build plan synonymously with the presence of the CAD design creates a "troubleshooting" resource for future teams to use. Creating the build plan with the availability of a CAD design, gives future teams resources to troubleshoot when problems occur. Therefore, this can be used as a standard procedure that could be applied to improve our gasifier's performance in different environmental scenarios.

Biogasification is a promising technology that can transform rural communities into becoming more resilient against many threats from climate change. With the threat of more severe storms and hurricanes that could further damage a feeble energy infrastructure, gasification can provide a remedy to potential power shut offs. In addition, it can help Puerto Rico become less dependent on fossil fuels which accounts for a large percentage of its electricity mix. Although there is a lot of diesel generation, especially in rural areas, biogasification can help establish more hybrid renewable energy microgrids which are more cost competitive than their counterparts and make rural communities less energy insecure.

Energy Modeling

A grid-connected microgrid can be "islanded" to function independently from the grid when service is unreliable. Since the parador and the surrounding community all have access to the PREPA grid, this is likely the most accurate scenario for the parador. A financially optimized microgrid that has the ability to tap into grid electricity can achieve significant cost savings by reducing the amount of energy storage and decreasing the size of other components. This type of setup does have drawbacks though because the microgrid design will ultimately be less stable in the event of an extended grid outage. The seven-month power outage after Hurricane Maria demonstrated the possibility of such an occurrence and underscored the vulnerability of the parador and Adjuntas residents in general.

The threat of sustained energy outage is not something that can be easily modeled using HOMER Pro, but qualitative assessment of the risk might lead one to suggest incorporating more energy storage or increasing the biomass gasifier generation capacity. (Notably, diesel backup generators are only somewhat reliable in a sustained grid outage situation, as there is a high chance that diesel supply could become extremely scarce, as was observed during the beginning months of the post-Maria blackout). This would raise system costs (as seen from the significantly higher NPC from the isolated model) but could improve health and equity outcomes by improving community resilience.

There is significant literature on the importance of ensuring electricity supply for critical facilities during blackouts [22]. Basic community services like refrigeration, clean water supply, and air conditioning can lead to significant improvements in health outcomes for at-risk populations. Parador Villas Sotomayor is a perfect candidate to be considered a critical facility for the Adjuntas community, as it has food services, climate control, rooms that could be used for emergency housing, and other basic sanitation services. Thus, our team believes that at least some battery storage capacity would be a wise addition to the optimized model, as it could significantly stabilize the grid in a blackout situation. However, in that event the owners of the parador could easily cut their power consumption for most applications and thus reduce total system demand to a level that could be met with just a combination of battery storage, solar PV, and gasification. More investigation is needed to determine what exactly that optimal sizing would be.

It’s also important to note that the viability of this system is significantly dependent on the continuation of Puerto Rico’s net-metering policies. Currently PREPA reimburses excess electricity sold fed back to the grid at just over 40% of the retail price ($0.10 sellback price compared with $0.234 average cost). All of the lowest cost systems in our model relied heavily on that to offset the significant capital costs for the PV system and to alleviate overnight generation costs.

It is significant that our final grid-connected system achieves 70% renewable energy penetration while simultaneously increasing energy autonomy, decreasing cost, and increasing community resilience. There are still many considerations that affect system viability and performance, like barriers to financing such a large initial capital outlay and the significant uncertainty surrounding the future of Caribbean energy systems, but this modeling demonstrates clearly that biomass gasification can present a strong option for grid-connected rural businesses.

Finally, it should be noted that this model rests on many assumptions and uncertainties. Critically, we assume a fully established biomass supply chain, which implies a system that can provide up to two tons of dry biomass per day. Biomass would likely need to be processed, including drying and pelletization, depending on the specific feedstock before being used in the microgrid. Furthermore, biomass resources can differ significantly in carbon content, heating value, and levels of impurities. These can affect generator efficiency and shorten the lifespan. Finally, actual gasifier operation requires operation by a trained individual. Parador Villas Sotomayor has a 24hr staff presence and staff who are interested in learning how to operate the gasifier, which largely mitigates this barrier, but this may play a much larger role in applications to communities and/or businesses without 24/7 operations.

Overall, the optimal system likely lies somewhere between the optimal design for the grid-connected and grid-isolated scenarios. Increased autonomy and decreased reliance on generous net metering policies could offset initial PV capital costs while still achieving the equity and sustainability goals laid out by the owners of Villas Sotomayor. However, more work is needed to better understand biomass resource and supply chain details, real-world operability considerations, and more nuanced demand information.

Conclusion

The outcomes from this project have major implications for future teams and our community partners in Adjuntas. The hybrid gasifier design can be utilized as part of a mini-grid to continue the progress in creating a resilient community in Puerto Rico. Based on the energy modeling that was completed, future teams can work with the Parador Villas Sotomayor to create a pilot project to demonstrate the benefits of circular economy using biogasification in a mini-grid.

The current plan for the subsequent teams is to partner with the community of Adjuntas and utilize sustainable development techniques to construct a biomass supply chain. With this better understanding of the biomass resource availability and the hybrid gasifier design, optimization of the gasifier can be conducted to increase efficiency and usability of the design. Other aspects of the project that MBRACE will focus on includes biomass heat rate testing and assessing storage and processing capacities for the proposed supply chain.

This project further propels the goals of the MBRACE mission: stimulating a new path for sustainable development of Puerto Rico’s agriculture and energy sectors. Although this project focused on two somewhat disconnected ideas (reactor design and energy modeling) ideas, it builds upon the foundation from previous MBRACE groups and its overall purpose to create hybrid mini-grids that support community sustainability and resilience. .

References

[1] Climate Change Indicators: Weather and Climate. (2021, April 15). US EPA. https://www.epa.gov/climate-indicators/weather-climate#:%7E:text=Scientific%20studies%20indicate%20that%20extreme,storms%2C%20floods%2C%20and%20droughts.

[2] Scott, M. (2018, August 1). Hurricane Maria's devastation of Puerto Rico | NOAA Climate.gov. Climate.Gov. https://www.climate.gov/news-features/understanding-climate/hurricane-marias-devastation-puerto-rico

[3] Campbell, A. F. (2018, August 15). Puerto Rico power restored 11 months after Hurricane Maria. Vox. https://www.vox.com/identities/2018/8/15/17692414/puerto-rico-power-electricity-restored-hurricane-maria

[4] Kwasinski, Alexis & Andrade, Fabio & Castro-Sitiriche, Marcel & O'Neill-Carrillo, Efrain. (2019). Hurricane Maria Effects on Puerto Rico Electric Power Infrastructure. IEEE Power and Energy Technology Systems Journal. PP. 1-1. 10.1109/JPETS.2019.2900293.

[5] What is the circular economy? (2013). Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

[6] K.salo.85. (2013, December 2). Biochar [Photograph]. Wikipedia. https://upload.wikimedia.org/wikipedia/commons/7/76/Biochar.jpg

[7] Spears, S. (2018, October 15). What is Biochar? Regeneration International. https://regenerationinternational.org/2018/05/16/what-is-biochar/

[8] Biomass explained - U.S. Energy Information Administration (EIA). (2020, August 28). U.S. Energy Information. https://www.eia.gov/energyexplained/biomass/

[9] Alfaro,José. "Circular Economy Industrial Symbiosis and Gasification", University of Michigan, 2019

[10] Peterson, B. (2020). Wood Gasifier Builder's Bible: Off Grid Fuel for the Prepared Homestead: Wood Gas in Minutes. Independently published.

[11] Is biomass gasification carbon neutral? (2011, February 16). Middlebury. http://www.middlebury.edu/sustainability/carbon-neutrality/biomass/faq/node/243721

[12] Booth, S., Reilly, J., Butt, R., Wasco, M., & Mnohan, R. (2020, January). Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects. NREL. https://www.nrel.gov/docs/fy19osti/72586.pdf

[13] Mini Grids - energypedia.info. (2020, June). Energypedia.Info. https://energypedia.info/wiki/Mini_Grids

[14] 3.1 The sustainable livelihoods framework and the asset pentagon. (2012). SOAS. https://www.soas.ac.uk/cedep-demos/000_P528_RF_K3736-Demo/unit1/page_22.htm

[15] Commercial Reference Buildings. (2020). Energy.Gov. https://www.energy.gov/eere/buildings/commercial-reference-buildings

[16] Park, S., Kim, S. J., Oh, K. C., Cho, L. H., Kim, M. J., Jeong, I. S., ... & Kim, D. H. (2020). Characteristic analysis of torrefied pellets: Determining optimal torrefaction conditions for agri-byproduct. Energies, 13(2), 423.

[17] García, C. A., Peña, Á, Betancourt, R., & Cardona, C. A. (2018). Energetic and environmental assessment of thermochemical and biochemical ways for producing energy from agricultural solid residues: Coffee cut-stems case. Journal of Environmental Management, 216, 160-168. doi:10.1016/j.jenvman.2017.04.029

[18] Garcia-Freites, S., Welfle, A., Lea-Langton, A., Gilbert, P., & Thornley, P. (2019). The potential of coffee stems gasification to provide bioenergy for coffee farms: a case study in the Colombian coffee sector. Biomass Conversion and Biorefinery, 1-16.

[19] BEW Engineering. (2013, October). Performance Model Evaluation. https://s3.amazonaws.com/helpscout.net/docs/assets/5889260f2c7d3a7846304e89/attachments/5893a6962c7d3a7846308ee2/bew-model-evaluation.pdf

[20] J.M.K.C. Donev et al. (2018). Energy Education - Cyclone separator [Online]. Available: https://energyeducation.ca/encyclopedia/Cyclone_separator. [Accessed: April 30, 2021].

[21] Guarini Center on Environmental, Energy and Land Use Law, Spiegel-Feld, D., Bishop, N., Ross, P., Rudyk, B., & Wood, A. (2018, January). Clean and Resilient Power for Caribbean States. Guarini Center on Environmental, Energy and Land Use Law. https://guarinicenter.org/wp-content/uploads/2018/01/Clean-and-Resiliant-Power.pdf

[22] Critical Facilities: Where Government and Utility Services Redefine Resilience—Rocky Mountain Institute 2018; The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices—National Association of Regulatory Utility Commissioners, 2019