FEASIBILITY STUDY OF A RURAL ELECTRIC MICROGRID WITH BIOMASS AS A DISTRIBUTED ENERGY RESOURCE

BY

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ABSTRACT

The widespread introduction of renewable energy systems has changed the nature of the electrical power grid. Alfred University is exploring the use of biomass as a distributed energy resource (DER) for a microgrid. A successful microgrid design can pave the way to an energy independent rural America with more dependable electric power and, in the long run, lower energy costs. Focusing on Western New York State, this thesis will cover the difficulties rural biomass microgrids must overcome in an area where maintaining a sustainable flow of feedstock can be a problem. First is an overview of a 25-year biomass-fueled microgrid model designed using HOMER Pro™ Analysis Software to simulate loads, DERs, energy storage, and calculated costs. An abundance of biomass as feedstock is necessary in reducing costs for the system as well as providing a more reliable fuel than solar or wind, both of which require a more robust energy storage system to compensate for power fluctuations. We also consider the increased biomass utilization via Combined Heat and Power (CHP). Microgrid integration is a necessary step in the dependability aspect of this project given its islanding capability and the various built-in protection schemes used to trigger it. This capability can serve as an additional layer of cybersecurity as islanding becomes a potential way of quarantining cyberattacks. We also examine the carbon neutrality question and possible greenhouse gas reduction that comes with biomass use as a DER. Other challenges biomass DER face for rural microgrids involve the sheer inertia of traditional fuels; capital cost; and fuel-like logistics, such as feedstock transportation and processing. This thesis will also address how New York State's "50 by 30" initiative may shape biomass energy usage for our area and make biomass a more attractive investment.

I. INTRODUCTION

Blackouts still exist. Hurricane Sandy reminded the people of NYC that such outages are still possible. Meanwhile, less urban areas of New York State are aware of just how possible, prominent even, blackouts are.[1] The combination of aging infrastructure with more erratic weather means this problem is here to stay, if not get worse. Rural areas have another problem that is a potential source for a solution; organic waste. There is currently an abundance of organic waste that rural citizens are paying to dispose of; in Steuben County some dairy farmers pay a premium of $1 million annually to dispose of manure from 2000 cows. This disposal method often comes in the form of spreading the manure, thereby practically optimizing greenhouse gas, namely methane, emission.

The disposal of human (municipal solid) waste too comes at a cost in the form of tipping/landfill fees. Though primarily not paid directly, these services still ultimately come with an ever more concerning environmental cost. Wood waste such as logs, chips, bark, and sawdust as well as waste from saw mills and paper mills provide additional biomass feedstock. Utilizing this waste is the goal of biomass energy. Implementing said energy usage with a microgrid addresses the issue of reliability and furthermore serves as an opening for a much-needed infrastructure update and overhaul. As global temperatures continue to rise, as extreme weather becomes more common, as aging infrastructure ages further, the need for reliable renewable energy becomes more and more evident.

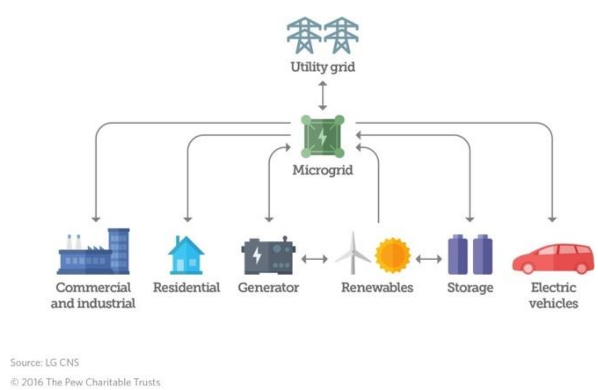

Figure 1: A microgrid and its potential components.[2]

This energy is arguably better managed by a system akin to Figure 1 shown above. The integration or establishment of a microgrid provides a more resilient form of power delivery as a localized fault can be contained and prevented from propagating by the microgrid's various protection schemes and power quality assurances. This does not mean that current power delivery methods have no way of preventing cascade failure. The new technology of microgrids, however, does mean an easier integration with other new technologies such as electric vehicles, distributed renewable energy sources, and a level of cyber security that traditional power delivery could not have been designed for. As seen in Figure 2 below, a vast majority of power infrastructure was built before the 1980s.

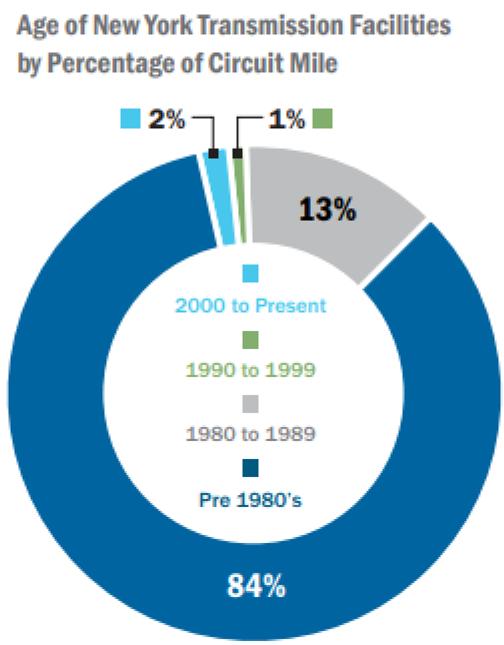

Figure 2: NY State transmission infrastructure over the years.[3]

Much of the feasibility of a project centers on economics. HOMER Pro™ was used to calculate a baseline cost for several test cases given biomass availability in Western New York with varying load data simulating Alfred University and Village as well nearby Hornell City to see how much the available biomass can support. Figure 3 below shows the location of Alfred in relation to NY State. The cost component involves the cost of power generation, control, and storage as well as the cost of fuel, operation, and maintenance.

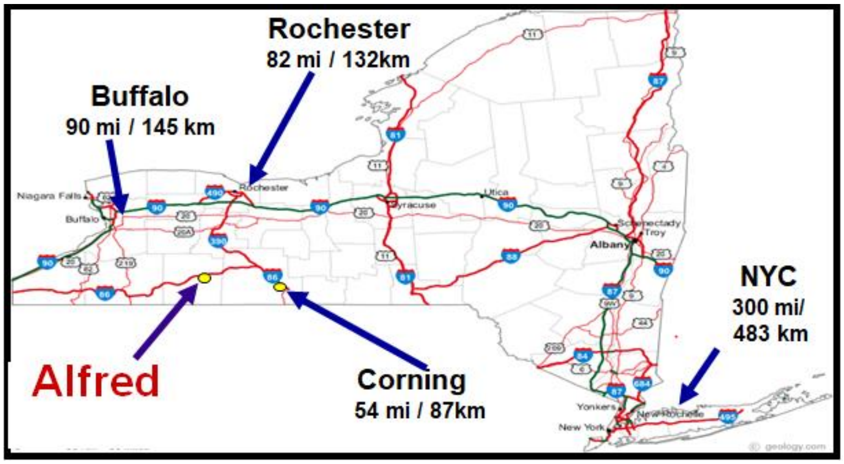

Figure 3: NY State map.

Biomass-powered microgrids have seen some implementation in places such as West Bengal, Bihar, and Borneo. All of these sites focus on rural areas for their energy production and consumption. The rural focus allows for easier access to biomass as well as a generally lower electrical load than a more urban setting. These microgrids are in large part primarily islanded and must therefore enforce strict load limits lest the architecture itself impose its own in the form of blackouts due to either an overload or complete power drain.

II. REVIEW OF LITERATURE

A microgrid is a cluster of small distributed energy resources (DER), storage systems and loads that can present itself to the main grid as a single controllable entity. Microgrids have a typical range of 1 to 30 MW while main utility grids are around 6 to 8 orders of magnitude greater in the TWs range. However, having a millionth of the power output of a main utility grid is not the sole criterion for a microgrid. With the implementation of DERs comes also the problem of harmonics. To combat this, a well-designed microgrid must have sufficient power quality assurance with several codes and standards that state acceptable levels of harmonic distortion as well as active harmonic filters to prevent faults. Moreover, if a fault does occur, a microgrid must have protection schemes in place to isolate the problem and prevent cascade failure or further equipment damage. An additional fault problem that microgrids must withstand is the potential redirection of fault current paths. This is because of the microgrids interacting with established electrical distribution systems built to handle unidirectional power flow, while microgrids by nature must be capable of bidirectional power flow.[4]

Equally essential is a microgrid's ability to isolate itself if the fault occurs in the utility grid and poses a threat to the microgrid. In this scenario, as opposed to isolating the non-functioning, it quarantines the functional. This is made possible by the arguably defining trait of the microgrid: islanding. A microgrid must be able to function with the main grid in grid-connected mode, and without it in island mode. These two states dictate whether microgrid control is merely used as an optimizer for DERs or the main frequency and voltage regulator. A microgrid must also be able to switch between these two states quickly and with minimal power disruption under intentional and, more importantly, unintentional conditions. To accomplish this microgrids employ remote and local methods. Remote methods communicate with the grid and monitor circuit breakers. Local methods monitor voltage and frequency within the microgrid.[4]

The distribution component of DERs implies a certain bias toward having a variety of feedstocks. However, as shown in a feasibility study for a community microgrid for SUNY Geneseo, adding food waste from campus dining in an effort to power the village's wastewater treatment plant, despite being the impetus for the study, was financially nonviable with an estimated cost "between $600k and $1M for approximately $57k worth of annual energy."[5]

Biomass energy has been humanity's fuel for most of its history. Recently it has been overshadowed by more energy-dense fossil fuels. But as the harmful effects of burning fossil fuels come to light, we must once more look to our past to see our future. Given a rural environment, biomass is an easily abundant source of energy: whether it's rice husk in Bihar, India; the timber in Pennsylvania; or cow manure in Western New York. Biomass comes in many forms. For simplification purposes, these forms can be categorized into the process required to harvest energy: combustion, cofiring, gasification, and anaerobic digestion.

Combustion is the oldest form of harvesting biomass energy and requires the least amount of system complexity. This process produces heat that is ready to use for keeping buildings warm or drying crops. For more versatile applications, the rest is used to boil water, producing steam to run a turbine to produce electricity. It is important to meet thermal loads prior to electricity production to avoid needless conversion losses from using heat to produce electricity to produce heat. This combustion can take either raw materials or ones preprocessed into pellets. Although production of the pellets may reduce overall efficiency as the process requires energy, the added versatility of transportation and automatic feeding make it an attractive option; not to mention that wood pellets, with their extreme density and low moisture content, can be burned with a higher combustion efficiency mitigating the efficiency reduction.[6]

Cofiring is a decades-old process wherein a biomass fuel is combusted simultaneously with another type of fuel. This method allows biomass to be introduced into established coal plants replacing some of the coal use without needing to create a biomass plant.

Gasification is the process of steam reacting with a carbon-based fuel such as charcoal, wood pellets, or wood chips. This produces hydrogen, carbon dioxide, and carbon monoxide. Despite the greenhouse gas byproduct, gasification can still be used for renewable energy given a renewable feedstock. Due to the gasification process' need for a carbon-heavy feedstock, gasifiers involve several steps before the gasification itself. First the feedstock is dehydrated. Then it goes through pyrolysis to begin the breakdown of the organic material. Pyrolysis is a form of heat decomposition of organic material in a low oxygen environment. The low oxygen indicates a lack of combustion as the primary chemical reaction. Combustion occurs at a later stage and provides heat for the gasification process to produce syngas: a mixture of hydrogen, carbon dioxide, and carbon monoxide.

Anaerobic digestion is the use of bacteria breaking down feedstock to produce biogas. Ideal feedstocks for anaerobic digestion are putrescible such as leftover food, sewage, and animal waste. High putrescibility means higher biogas production yield. This gas can then be combusted, and the heat produced treated in the same manner as heat from direct combustion or pellet combustion. This presents a potential to reduce costs in areas planning to use both flora and fauna biomass sources; the same water, steam turbine, and generator can be used provided the heat from the different fuel sources can be directed properly. The generators modeled in HOMER Pro™ will be utilizing combustion for MSW, Oak, and anaerobic digestion for cow manure.

Microgrid technology and biomass power individually have a history of application in power systems. Their combined application, however, has been limited to very low capacity applications such as a 30 to 150 kW generator in Bihar, India. This thesis asks the question of whether or not a biomass powered microgrid is feasible in Western New York. More specifically, what are or would be the biggest challenges toward establishing one.

"The obtained results show that the integration of renewable energy sources technologies has a beneficial effect on the levelized cost of electricity (LCOE) of isolated microgrids. The introduction of PV panels allows, in the optimal case, a LCOE reduction of 19% in comparison with system based only on Diesel engine. A further, twice as much, decrease (up to 38%) is attainable using biomass as main energy source: both Gasifier-based and Organic Rankine Cycle (ORC)-based systems show similar economic performances and ensure a share of electricity generated by renewables of about 95%."[7] (Bihar, India). LCOE reduction may primarily be due to a high starting point. The presence of hydroelectric and established infrastructure with competing power generation drives the baseline cost of energy in Western New York lower.

Q. Wang et al. studied the economic profitability of cow manure power production. A combined effort between dairy farmers, Central Vermont Public Service (CVPS), CVPS customers paying electricity premiums, and government agencies showed that cow manure usage leads to a reduction of 79 kg CO_2 equivalent per kWh of energy produced.[8]

M. Stadler et al. studied the major technical challenges that contribute to increasing microgrid cost as well as the most relevant revenue streams that increase microgrid worth. These technical challenges include islanding detection, relaying and protection, and power quality monitoring. The relevant revenue streams are demand response, power exports, local energy markets, and resiliency.

Demand response creates revenue by influencing consumer electricity usage patterns using variable pricing and utilizing energy storage to increase effectiveness. Power exports i.e. selling power to the grid as a revenue stream depends upon local markets and regulations e.g. feed-in tariffs. Local energy markets are a potential revenue stream predicated on microgrids trading energy between each other, outside the main electrical grid. Resiliency as a revenue stream is calculated in terms of how much loss of load will cost. This value varies heavily depending on the nature of operations the microgrid supports and therefore requires site-specific study.[4]

Thoma et al. conducted a cradle-to-grave life cycle assessment of greenhouse gas (GHG) emissions from milk production and consumption circa 2008 and concluded with 90% confidence "the GHG footprint of milk lies between 1.77 and 2.4 kg CO_2e kg^{-1} milk consumed" and proposed methane digesters as a way to capture and utilize methane available for larger systems. A potential concern they noted with this approach is the additional land requirement for processing.[9] This concern is mitigated by low land prices in Western New York.

III. METHODOLOGY

The methodology section will be divided into separate components of the system with the last section for HOMER Pro™: load, feedstock, battery and converter, generators, emissions. The Load section will explore three load profiles with size as the main differentiating factor to determine what capacity the Western New York feedstock availability can meet. The Feedstock section will detail the three most promising biomass sources in the area. The Battery and Converter section will explain its necessity in the design and the selection and sizing process. The Generator section will detail the pricing and iterative sizing, as well as play the key component for CHP integration. The Emissions section will focus on the carbon capture potential of utilizing cow manure for power and, with CHP, heat production. Finally, the HOMER Pro™ section will explain how the software calculates the values presented in the results.

A. Load

To understand what is feasible with the feedstock available in the Western New York region, this thesis will be studying three different simulated load profiles: one, for Hornell, NY overall; two, for Hornell's residential power usage; three, for the Alfred, NY community. The loads for these various models were produced by using the HOMER Pro™ pre-generated loads and scaling them to a calculated average.

1. Hornell, NY Overall Load

Given a sample population of 8300 people, a national average of 2.58 people per household, and an average of 1 MW/900 households, we calculate a residential power usage of 3.630 MW.

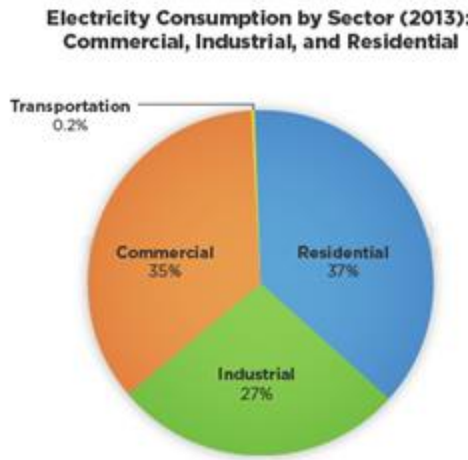

Figure 4: 2013 Electricity consumption by sector.[10]

National average electricity consumption as shown in Figure 4 above puts residential usage as 37%, with industrial usage accounting for 27% and commercial for 35%. For this thesis we will be taking the 0.2% for transportation as negligible. This makes for an overall usage of 9.7 MW. We will also be using January-peak models to reflect the generally higher winter energy usage.

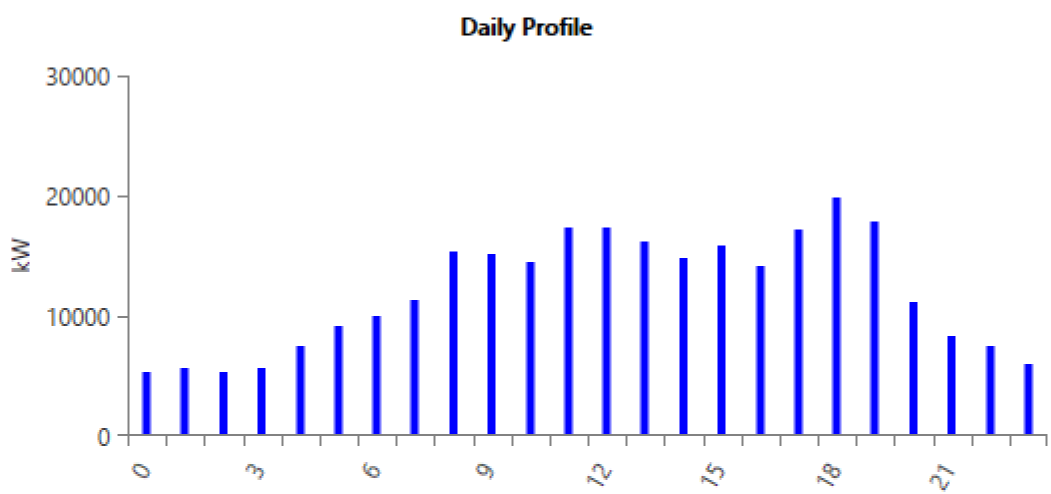

Figure 5: Hornell daily load.

As shown in Figure 5 above, the daily profile for energy usage has peaks corresponding to the standard beginning and end of people's work or school. This also reflects the higher electrical usage during business hours of the commercial sector as well as the more consistent load of the industrial sector.

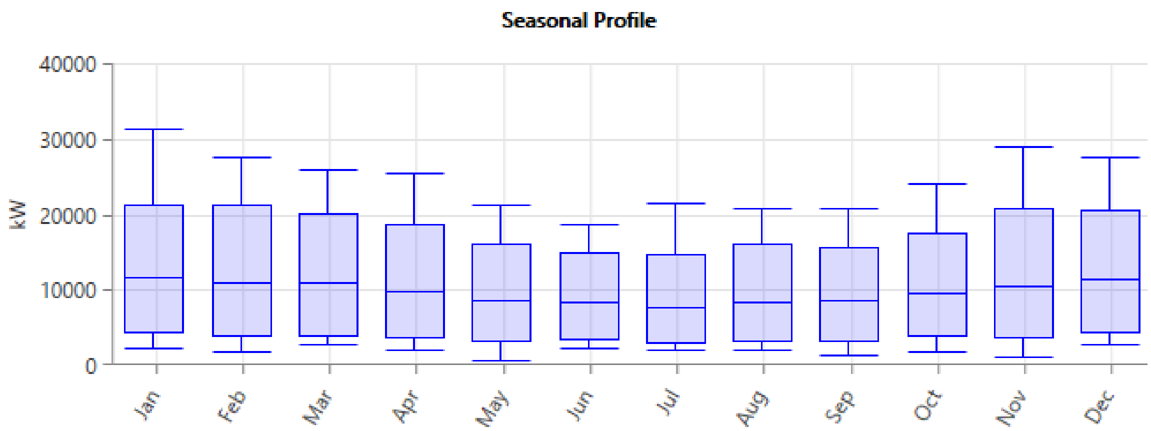

Figure 6: Hornell seasonal load.

Figure 6 above shows the seasonal profile and the typically higher winter loads. The seasonal profile indicates overall monthly minimum and maximum, the months' average daily minimums and maximums and the monthly overall average.

Table 1: Hornell Overall Load Data Summary

Metric	Baseline
Average (kWh/d)	233,155.99
Average (kW)	9,714.83
Peak (kW)	31,237.52
Load Factor	.31

Load Type: AC DC

The summary in Table 1 above provides more specific numbers for peak load and average load as well as providing the average daily energy needs and the load factor, which is the ratio of average load over peak load.

2. Hornell, NY Residential Load

Given a sample population of 8300 people, a national average of 2.58 people per household, and an average of 1 MW/900 households, we calculate a residential power usage of 3.630 MW. The second load set will test feedstock availability against this residential component alone.

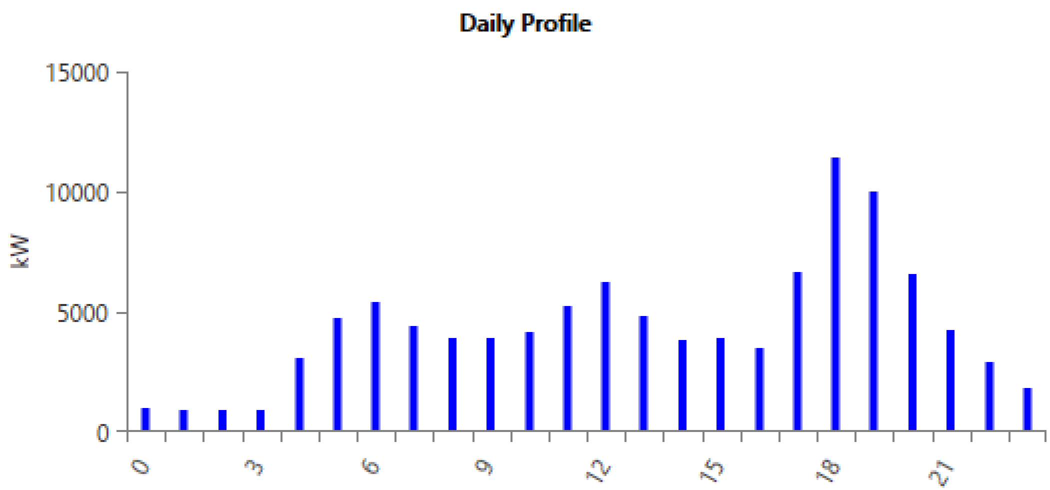

Figure 7: Hornell residential daily load.

The residential only profile for Hornell, NY in Figure 7 presents a higher disparity between peaks and valleys as the less erratic industrial and commercial loads are factored out. As with Figure 5, peaks can be seen occurring at the beginning and end of business day. A similar peak can be seen at noon.

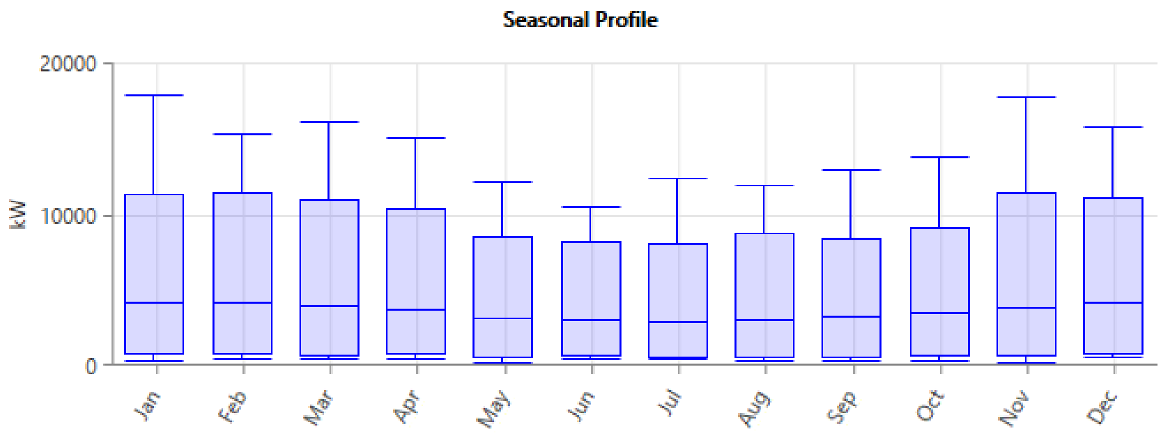

Figure 8: Hornell residential seasonal load.

The seasonal profile in Figure 8 differs from Figure 6 in terms of overall value and that the overall monthly minimums for Figure 8 are much closer to its average daily minimum, as can be seen with the whiskers almost touching the boxes.

Table 2: Hornell Residential Load Data Summary

Metric	Baseline
Average (kWh/d)	87,139.1
Average (kW)	3,630.8
Peak (kW)	17,937.84
Load Factor	.2

Load Type: AC DC

The summary in Table 2 above provides more specific numbers for peak load and average load as well as providing the average daily energy needs and the load factor, which is the ratio of average load over peak load. Comparing the load factors between Tables 1 and 2, we can see the effect of the difference seen between Hornell's overall and residential daily power demand.

3. Alfred, NY Community Load

Given an estimated population of 4000 people for Alfred, NY, using the same national average of 2.58 people per household, and an average of 1 MW/900 households, we calculate a residential power usage of 1.75 MW. Classifying Alfred, NY as a community reflects the greater integration between its residential, commercial, and industrial components.

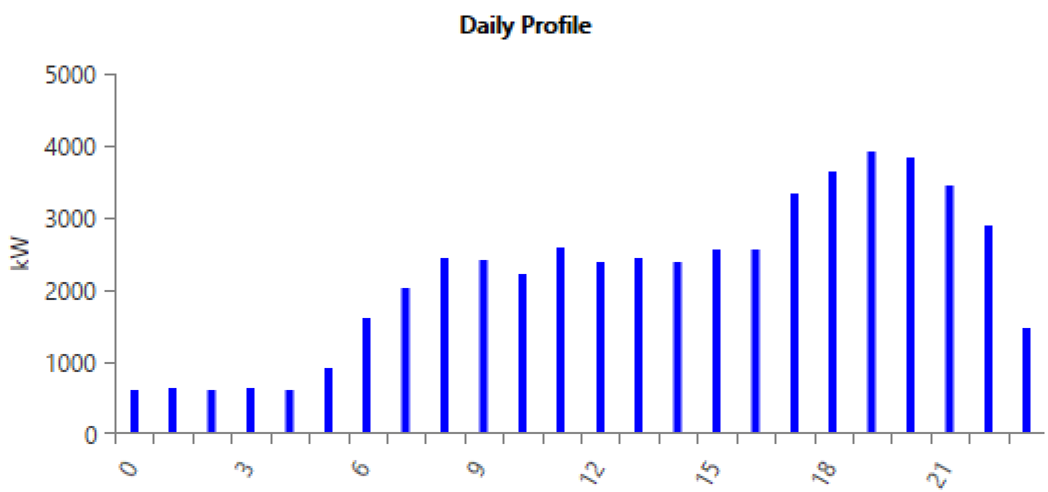

Figure 9: Alfred community daily load.

The daily community load for Alfred in Figure 9 presents a less pronounced peak load, as the built-in industrial and commercial components soften the previously seen residential extremes.

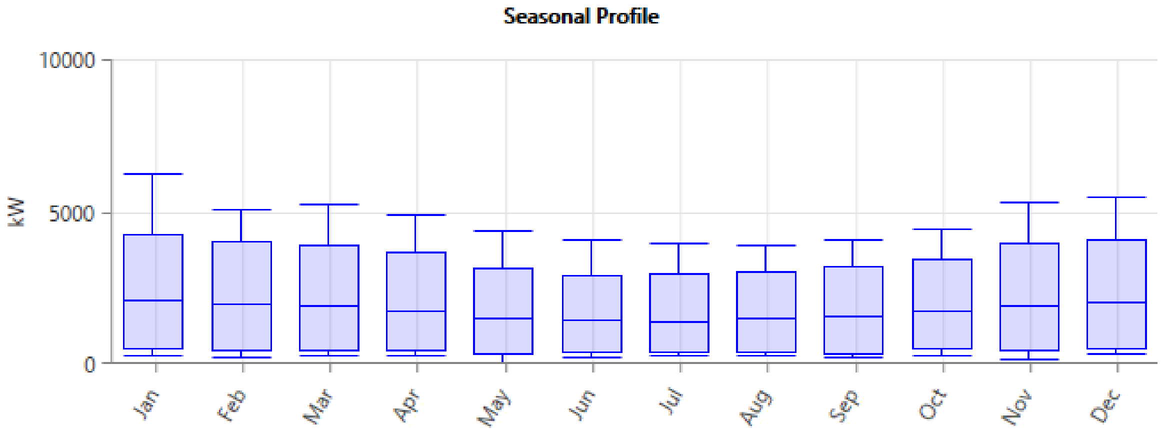

Figure 10: Alfred community seasonal load.

Figure 10 above shows the seasonal profile and the typically higher winter loads. The seasonal profile indicates overall monthly minimum and maximum power demand, the months' average daily minimums and maximums, and the monthly overall average.

Table 3: Alfred Community Load Data Summary

Metric	Baseline
Average (kWh/d)	41,994.74
Average (kW)	1,749.78
Peak (kW)	6,243.07
Load Factor	.28

Load Type: ◉ AC ○ DC

The summary in Table 3 above provides more specific numbers for peak load and average load, as well as providing the average daily energy needs and the load factor, which is the ratio of average over peak. As mentioned, this load factor is higher than that of the Hornell residential load.

B. Feedstock

A significant factor in biomass power feasibility is biomass type and feedstock availability. For the region being considered, rural Western New York, the types available are cow manure, wood, and municipal solid waste (MSW). Cow manure is sourced from the various dairy farms in Steuben County. Wood biomass, approximated as all oak for fuel data purposes, is sourced from forest residue in the area. MSW is calculated from national average human trash production. Table 4 below shows the fuel data for each feedstock type.

Table 4: Biomass Fuel Data[11]

Cow Manure		Wood (Oak)		Municipal Solid Waste	
Lower Heating Value (MJ/kg):	18.6	Lower Heating Value (MJ/kg):	27.32	Lower Heating Value (MJ/kg):	18.56
Density (kg/m3):	1009	Density (kg/m3):	750	Density (kg/m3):	500
Carbon Content (%):	49	Carbon Content (%):	78.11	Carbon Content (%):	47.00
Sulfur Content (%):	0.34	Sulfur Content (%):	0.12	Sulfur Content (%):	0.30

Despite HOMER Pro™ having a module for integrating a biomass resource into the model, each biomass feedstock is modeled in HOMER Pro™ as a conventional fuel. The advantage of the biomass resource module allowing for gasification ratio information and monthly availability limits is outweighed by this capability only applying to one feedstock type, which is inconsistent with the feedstock selection aspect of this thesis. Any capacity shortage will be addressed by first modeling the generators to work with CHP, and second uncapping the feedstock availability. This will indicate how far from feasible a particular load profile is and whether that distance can be sensibly achieved through importing feedstock.

It is important to note that the values presented in Table 4 and used for the systems modeled in this thesis are based on values from a European database. Different livestock feeding and care procedures, different climate and soil for oak, different consumptions and waste disposal patterns are just a few of the factors that may make the available feedstock in Western New York have fuel values different from the ones used.

Any implementation of biomass power must include physical testing of the feedstock available.

1. Dried Cow Manure

In terms of cow manure, we expand the local parameter to include all of Steuben County. This gives us 21,000 cows, each producing an average of 45 kg/day. For feedstock usage, this will require drying, which applies a 0.52% conversion rate resulting in 1,800 dry tonnes of cow manure/year at $56/ton.[12]

The low conversion rate is due in large part to the high water content of raw manure. Reducing this water content increases the amount of manure and other putrescible feedstock that can be put into an anaerobic digester, as shown in Figure 11 below, used to produce biogas.

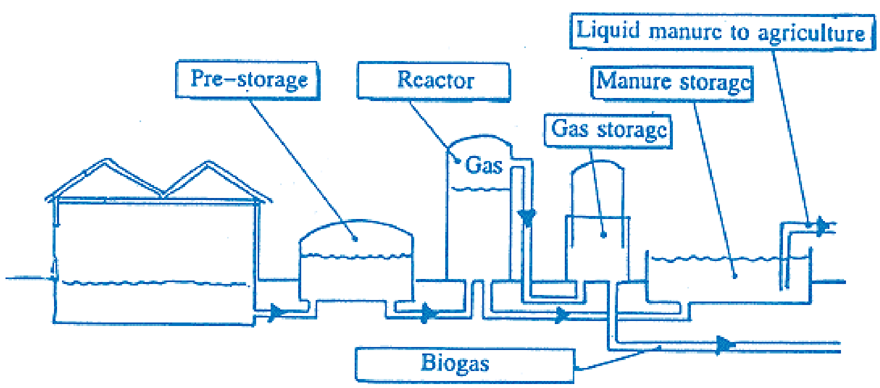

Figure 11: Cow manure gas production.[13]

This process can be further improved by the inclusion of a mixing mechanism to facilitate digestion, as well as by studying the bacterial ecosystem that has grown in the digester over time and optimizing that environment for methane quality production. As an anaerobic process this production can be hampered by a high enough presence of oxygen in the system, which can be inadvertently introduced by insufficient sealing of the digester or the loading of feedstock without safeguards. An additional value stream of this process is the fertilizer provided as a byproduct.

Due to the highly variable temperatures experienced in Western New York, anaerobic digesters would benefit from primarily summer usage or being built with insulation and/or heating elements. Insulation can be provided by building underground; however, this will reduce summer yields. Dependent on how the livestock is managed, there is also the potential for building close to the cows themselves to take advantage of body heat as well as any winter heating provided to the cows. This method, however, may be an unacceptable risk given the possibility of contamination and infection that arises from any potential leaks.

2. Wood (Oak)

For simplification, this wood in general will be assumed to be all oak. According to the National Renewable Energy Laboratory (NREL)'s Biopower Atlas[14], the region has 8,000 dry tonnes/year of wood available. Each ton is priced at approximately $63.[12] Converting this wood to char increases its efficiency and reduces the weight, making the feedstock easier to transport. This, with a 32% conversion rate, makes for 2,700 tonnes of char for $200/ton of raw material plus processing costs.

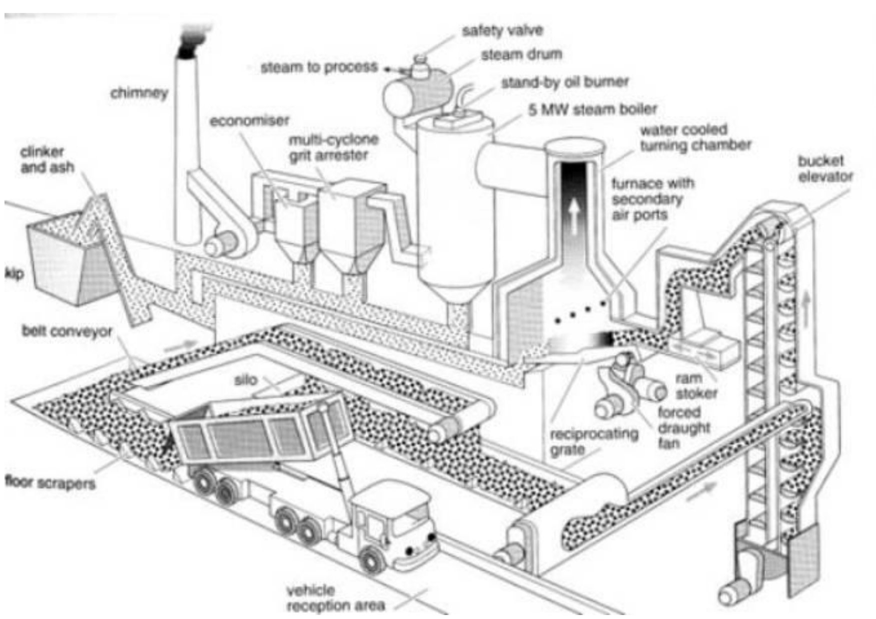

Figure 12: Wood biomass plant.[15]

As shown in Figure 12 above, the process of harvesting electricity from wood benefits from the addition of belt conveyors and a bucket elevator. This provides a continuous stream of feedstock to the combustor and allows for any final sorting prior to combustion. The three components of combustion can be broken down into the feedstock as fuel, the furnace providing heat, and finally air from a force draft fan. With this balanced, steam can be produced efficiently. This steam will then be used to run a generator, thereby creating the electricity. The grit arrester cleans the supply of flue gas and the economizer captures the waste heat and transfers it into the boiler feedwater. This effectively recycles the waste heat, reducing the energy input needed.

Wood biomass comes in many forms from unprocessed forest residue, saw mill and paper mill waste, to discarded Christmas trees. This diversity in form presents a challenge for modeling in that fuel data values may vary greatly between forms. To reduce this variability we used a common form of wood biomass in the area, namely oak, and modeled the system using the fuel data of it after char production at 565℃.[11]

In addition to the increased efficiency and reduced shipping, using char has a potential benefit of easier processing in the combustion stage. A common problem with wood biomass is its fibrous nature creating flow issues such as arching. The drier nature of char could lessen the likelihood of such disruptions in operation. A particular cause for concern in the oak forest residue biomass that this system is using is the potential ecological consequences of harvesting. For this reason, NREL’s Biopower Atlas notes that the stated available biomass in truth is 65% of logging residues and 50% of other removals. This means that any feedstock harvest operation must be done with at most a 50% collection rate in mind so as to preserve the forest ecology.

3. Municipal Solid Waste (MSW)

MSW availability was calculated using an average of 2 kg/person/day[16] with the 8,300 population of Hornell producing 6,000 tonnes/year. MSW is the least expensive of the feedstocks considered at $12/ton.[16]

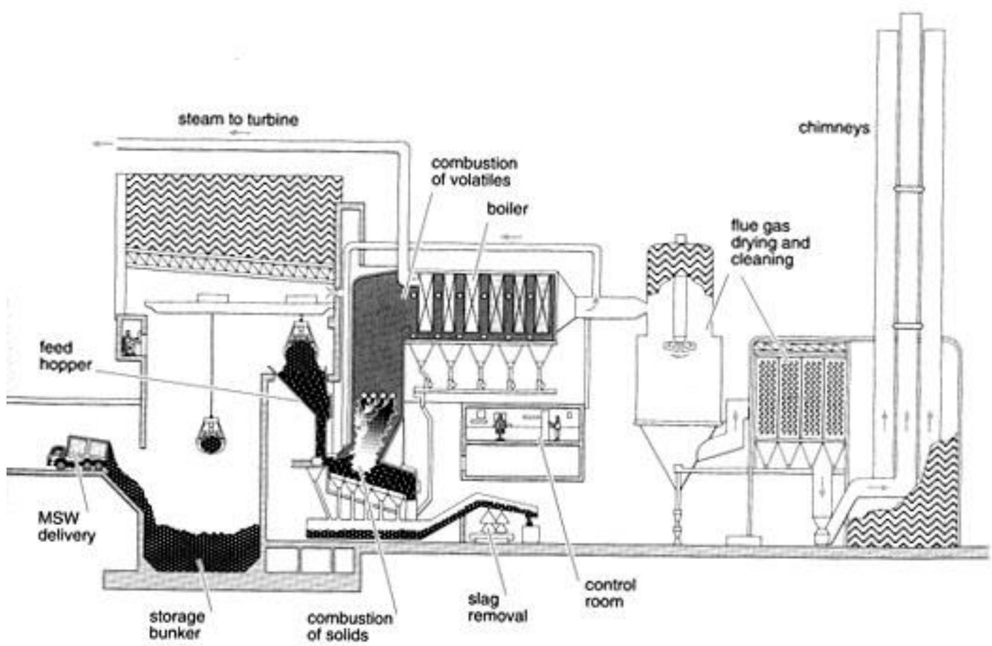

Figure 13: MSW power plant.[15]

Figure 13 shows the path MSW takes to become steam starting with a storage bunker which provides the same buffer capacity that the belt conveyor for wood biomass does. This system in particular uses a claw mechanism to transport the feedstock from the storage bunker to the combustion stage. This stage produces a slag byproduct to be removed as well as the desired heat which is run through boilers, thereby producing the desired steam. After this the flue gas must be cleaned before being exhausted via chimneys.

MSW feedstock availability is inversely proportional to recycling efforts. Therefore, despite the positive aspect of providing more feedstock for power production, it should be noted that recycling and recyclability should take precedence before biomass waste-to-energy in terms of waste processing. This means that any form of MSW power plant like the one shown in Figure 13 above should ensure that its MSW delivery contains only that which cannot be recycled.

C. Battery and Converter

Microgrid frequency regulation is dependent on having reserve power ready to deploy to match load peaks. The alternative would be to rely on the various generators to ramp up and down to meet demand in time and maintain a stable frequency. This process leads to generators running above optimal efficiency, meaning higher feedstock usage. This in turn leads to additional feedstock transport costs. In addition, generator ramping leads to wear and tear in the system, reducing its lifetime and increasing maintenance cost. Energy storage capable of real and reactive power enables generators to run at nearer to optimal capacity by storing energy from times when generators would ramp down due to low demand and using that energy for times when generators would ramp up due to high demand.

A significant barrier in microgrid implementation is the cost involved. A primary contributor to this prohibitive cost is the chemical battery/energy storage system. Alternative storage methods were considered such as pumped hydro. However, this did not have the scalability that chemical storage provides. This means any microgrid design must have optimal battery size included, namely, the minimum battery size that allows the system to perform reliably. The cost for the battery for the HOMER Pro™ model will be based on a Lazard Financial Advisory Study which found an average capital cost of $652/kWh for a Li-ion battery storage system. This will be increased to $700,000/MWh to account for converter costs.[17]

Table 5: HOMER Pro™ 1 MWh Li-ion Battery Properties

Properties
Idealized Battery Model
Nominal Voltage (V): 600
Nominal Capacity (kWh): 1E+03
Nominal Capacity (Ah): 1.67E+03
Roundtrip efficiency (%): 90
Maximum Charge Current (A): 1.67E+03
Maximum Discharge Current (A): 5E+03

This battery is set to have a lifetime of 15 years with a throughput of 3,000,000 kWh and a minimum state of charge of 20%. Battery cost will also include the Generic large, free converter which HOMER Pro™ provides as an option for battery sizing without having to size the converter.[18] The idealized battery unit is a 1 MWh Li-ion. Its properties are shown in Table 5 above.

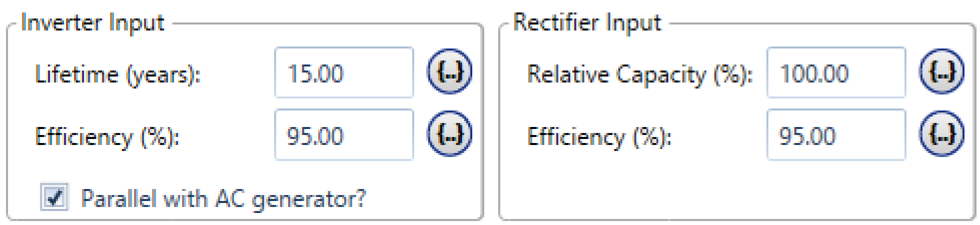

Figure 14: Converter details.

The battery model also must accommodate the 9999999 kW converter capacity. Battery system sizing is given priority and the converter is, according to the note in HOMER Pro™ component properties, “intended to be as large as necessary to avoid bottlenecks converting between AC & DC bus.” This method also accounts for losses from inverter and rectifier efficiency shown as 95% in Figure 14 above. This relationship with the battery system does mean, however, that all converter costs must be taken into account on the battery side. Allowing the converter to work parallel with AC generators prevents excess electricity and capacity shortage from occurring on the same bus on the same time step. This and the high efficiency indicate that the converter modeled in the system is of high quality.

D. Generator

The generator costs for all three feedstock types were set between \$3,000/kW and \$5,000/kW.[19] Where the chosen generator's price falls within these ranges is determined by the size of the generator chosen as price per kW trends downwards as capacity goes up as shown in Table 6 below. The replacement costs occur after the generators' lifetimes of 20,000 hours.

Table 6: Generator Cost Curve Reference Points

Capacity (kW)	Capital (\$)	Replacement (\$)
5000	\$25,000,000.00	\$12,500,000.00
25000	\$75,000,000.00	\$37,500,000.00

HOMER Pro™ uses the size versus price data to form a price curve with a dynamic \$/kW dependent on the generator size. The sizes considered by HOMER Pro™ are user inputted through the search space shown in Table 7 below.

Table 7: Load-Dependent Generator Search Space Matrix

Hornell Overall			Hornell Residential			Alfred Community		
CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)
0	0	0	0	0	0	0	0	0
5000	5000	5000	3000	3000	3000	1000	1000	1000
10000	10000	10000	6000	6000	6000	2000	2000	2000
15000	15000	15000	9000	9000	9000	3000	3000	3000
20000	20000	20000	12000	12000	12000	4000	4000	4000
25000	25000	25000	15000	15000	15000	5000	5000	5000
30000	30000	30000	18000	18000	18000	6000	6000	6000

As shown in Table 7 above, the search spaces are varied to fit each load profile. The resulting model can be further iteratively optimized to more and more specific generator capacities to a theoretical optimal combination of generator sizes; however, there is a real-world limit of standard generator sizing and additional cost for specificity.

The generators will be running in two different modes dependent on the scenario being modeled, with CHP or without. Without CHP, the generators will be running at 20% efficiency to reflect the power production capability of biomass. With CHP, the generators will be running at 80% efficiency to reflect the higher general biomass utilization with a combined heat and power system.

E. Emissions

As CO_2 and CO_2 equivalents are the primary focus when discussing greenhouse gas emissions, so too will this study focus on it. Cow manure is an especially ideal feedstock as its use prevents excessive and environmentally harmful levels of manure spreading, the process of spreading and disposing of cow manure on fields as fertilizer. While good for the nitrogen content of the soil, this process leads to a significant amount of methane being released. The Cow Power Program by Central Vermont Public Service Corporation produced 12 million kWh of electricity / year and prevented an estimated 45,000 tonnes of methane[8], which has the GHG effect of 944,000 tonnes of CO_2. In addition, they calculated a net reduction of 414 g CO_2 / kWh produced using cow manure as opposed to fossil fuel. With this we calculate a GHG saving of approximately 78 kg CO_2 equivalent / kWh of electricity produced using cow manure or 81 kg CO_2 equivalent / kg of cow manure used.

F. Hybrid Optimization Model for Multiple Energy Resources [HOMER Pro™]

HOMER Pro™ is employed in this thesis for its modeling, simulation, and optimization capabilities. The program works first with the user establishing the components of the desired system. Figure 15 below shows the system this thesis is modeling with four types of generators, a converter, load and storage system. The schematic further specifies load values by showing daily energy and peak power.

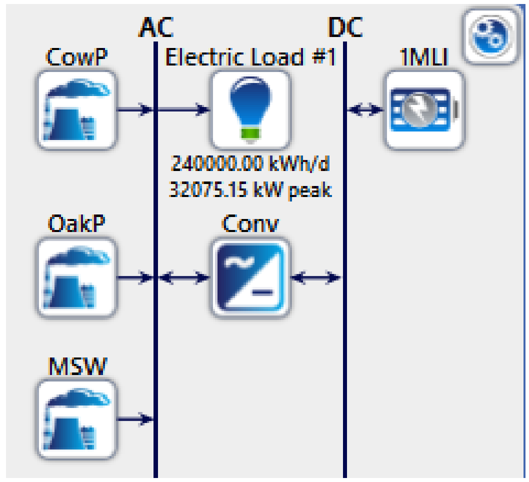

Figure 15: HOMER Pro™ schematic.

The final cost of energy in $/kWh is calculated with HOMER Pro™ using Equation 1 below.

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}} \tag{1}$$

where:

$C_{ann,tot}$ = total annualized cost of the system [$/yr]

c_{boiler} = boiler marginal cost [$/kWh]

H_{served} = total thermal load served [kWh/yr]

E_{served} = total electrical load served [kWh/yr]

As thermal load is beyond the scope of this thesis, it will be treated as zero.

The total electrical load served in kWh/year is the sum of AC primary load, DC primary load, deferrable load, and energy sold to the grid. This system modeled will only consist of an AC primary load.

The total annualized cost of the system is the annualized value of the total net present cost calculated using Equation 2:

$$C_{ann,tot} = \mathrm{CRF}\left(i, R_{proj}\right) \cdot C_{NPC,tot} \tag{2}$$

where:

$C_{NPC,tot}$ = the total net present cost [$]

I = the annual real discount rate [%] =

R_{proj} = the project lifetime [yr] = 25 years

CRF() = a function returning the capital recovery factor

The total net present cost (NPC) is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. This functions as the primary optimization point for HOMER Pro™ as it considers more parameters such as revenue through salvage rather than solely prioritizing initial capital.

The project lifetime for all systems modeled in this thesis is set at 25 years.

The real discount rate is used to convert between one-time costs and annualized costs and is calculated using Equation 3:

$$i = \frac{i' - f}{1 + f} \tag{3}$$

where:

i = real discount rate = 5.88% for initial modeled scenarios

i' = nominal discount rate = 8% for initial modeled scenarios

f = expected inflation rate = 2% for all modeled scenarios

HOMER Pro™ uses the real discount rate to factor out inflation, assumed to be 2% for all scenarios, in economic analysis of the project. This method, therefore, presents all costs in equal, present dollar terms. This approach, however, does assume that rate of inflation is consistent and similar for all costs. The nominal discount rate is the rate at which money can be borrowed.

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is calculated using Equation 4 where *i* = the real discount rate and N = the project lifetime.

$$\mathrm{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{4}$$

Example: For *i* = 5.88% and N = 25 years, the capital recovery factor is equal to 0.0773. A $1,000,000 loan at 5.88% interest would therefore be paid back with twenty-five annual payments of $77,300. The present value of the twenty-five annual payments of $77,300 is $1,000,000.

IV. RESULTS AND DISCUSSION

The results section will be addressed in different sections with each load profile being addressed separately. Table 8 below provides a summary of the key load data values.

Table 8: Load Data Summaries

Hornell Overall Load

Metric	Baseline
Average (kWh/d)	233,155.99
Average (kW)	9,714.83
Peak (kW)	31,237.52
Load Factor	.31

Hornell Residential Load

Metric	Baseline
Average (kWh/d)	87,139.1
Average (kW)	3,630.8
Peak (kW)	17,937.84
Load Factor	.2

Alfred Community Load

Metric	Baseline
Average (kWh/d)	41,994.74
Average (kW)	1,749.78
Peak (kW)	6,243.07
Load Factor	.28

Table 9 below provides a binary summary of the results, given current levels of feedstock and comparing the effect of CHP integration. As shown in the table, the use of biomass in electricity production, at 20-25% efficiency, is not feasible in even the lowest of the three loads, the Alfred community.

Table 9: Feasibility Chart

Load	No CHP	With CHP
Hornell Total	No	No
Hornell Residential	No	Yes
Alfred Community	No	Yes

A. Hornell, NY Overall Load

As shown in Table 8 above, Hornell overall load has the highest demand of the three loads. The intent is to test the possibility of a city solely reliant on locally available biomass as fuel sources. However, as can be seen in Table 9, even with the integration of CHP, the locally available feedstock is not enough to address this load. The feedstock necessary to meet the load, with CHP integration, consists of 9,200 tonnes of dried cow manure and 17,700 tonnes of MSW. This compared to the 1,800 and 6,000 tonnes available respectively, puts current feedstock levels at 20% and 33% respectively.

B. Hornell, NY Residential Load

As mentioned in Table 9, the level of feedstock available is insufficient for power only generation. For CHP generation, the optimal system, using the initial search space consists of 6 MW Cow Manure, 3.3 MW Wood (Oak), and 6 MW Municipal Solid Waste generators with 2 1MWh Li-ion batteries for storage. This optimal system, however, only considers the generator sizes from Table 7.

Table 10: Hornell Residential Search Space Iteration

Baseline			Iteration 1			Iteration 2			Iteration 3		
CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)
0	0	0	0	0	0	0	0	0	6000	2500	4500
3000	3000	3000	3000	1500	3000	5000	3500	3500	6250	2750	4750
6000	6000	6000	4500	3000	4500	5500	4000	4000	6500	3000	5000
9000	9000	9000	6000	4500	6000	6000	4500	4500	6750	3250	5250
12000	12000	12000	7500	6000	7500	6500	5000	5000	7000	3500	5500
15000	15000	15000	9000	7500	9000	7000	5500	5500	7250	3750	5750
18000	18000	18000							7500	4000	6000

Table 10 above shows the iterative process conducted with each iteration providing the search space with smaller intervals between available sizes.

Table 11: Hornell Residential Iteration Cost Data

Hornell Residential	Base	ITER 1	ITER 2	ITER 3
1 MWh Li-ion Battery	2	3	2	2
Cow Manure (kW)	6,000	6,000	6,500	6500
Wood Oak (kW)	3,000	4,500	3,500	3250
Municipal Solid Waste (kW)	6,000	4,500	5,000	5000
Net Present Cost	$137,000,000	$133,000,000	$132,000,000	$132,000,000
Initial Capital	$76,000,000	$77,100,000	$76,400,000	$75,800,000
Cost of Energy ($/kWh)	$0.334	$0.323	$0.322	$0.320

Through generator sizing iteration, NPC, the initial capital, and the cost of energy can be lowered as more appropriate generator sizes are chosen. As seen in Table 11, the latter iterations exhibit less change from earlier iterations as is expected.

Table 12: Hornell Residential Converter Sizing

Quantity	Inverter	Rectifier	Units
Capacity	9,999,999	9,999,999	kW
Mean Output	63.7	74.5	kW
Minimum Output	0	0	kW
Maximum Output	1,199	1,273	kW
Capacity Factor	0.000637	0.000745	%

Converter and battery sizing is essential to smooth operations of the system. With the generator size iteration, we see the number of batteries the system needs fluctuate between 2 and 3, this automated battery sizing is made possible in large part by the converter included being as large as necessary. Table 12 above shows an ideal converter size of 1.4 MW to accommodate the maximum output with a 10% buffer for unexpected surges.

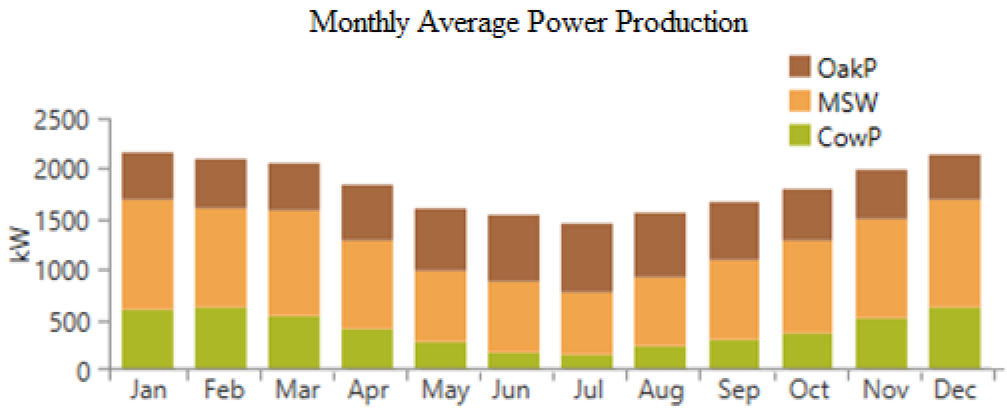

Figure 16: Hornell residential monthly power production.

Figure 16 above shows the amount of power produced for a month in a sample year with the power broken down by feedstock type. We can see that cow manure usage peaks in the winter while oak usage has its peak in the summer with MSW being fairly consistent throughout. Given that varying seasonal availability and cost was not in the input data, one can assume that seasonal feedstock pattern is due to generator balancing.

Table 13: Hornell Residential Feedstock Usage and Energy Production

Feedstock	kg used/yr	kg available/yr	usage by %	kWh/yr	% of kWh
Processed Cow Biomass	1,689,512	1,800,000	94	6,982,417	21.9
Processed Oak Biomass	1,600,456	2,500,000	64	9,715,407	30.4
Municipal Solid Waste Biomass	3,695,070	6,000,000	62	15,238,467	47.7
				31,936,291	100

As shown in Table 13 above, this system would have a high utilization of cow manure, which is ideal in terms of emissions as its use prevents its disposal in ways that release methane into the atmosphere. With 47.7% of the energy production, MSW on Table 13 is shown to be the primary fuel, which explains its notable contribution in every month of Figure 16.

Table 14: Hornell Residential Emissions

Hornell Residential	kg/yr
System CO2 Emissions	13,987,086
Cow Manure Used	1,689,512
CO2 equivalent caputred	136,850,472
Overall net CO2 eq emissions	-122,863,386

This sytem, by making use of cow manure at such a high percentage, leads to a significant reduction in CO_2 in the atmosphere as shown in Table 14. This savings value, however, is based on comparison to a scenario where the cow manure is disposed of irresponsibly, spread out on fields allowing methane to release into the atmosphere.

1. Hornell Residential Load Subsidized

The GHG capture comes at a great cost to the end consumer at $0.32/kWh, when current electricity prices are approximately $0.11/kWh. A potential avenue for lowering this premium is to provide subsidized loans to capital investment. This was modeled by lowering the nominal discount rate from 8% to 0%. This change in the initial condition necessitates reassesing reiterating of generator sizes as well as number of batteries. Table 15 below shows the iterative sizes for the generators given a system with a nominal discount rate of 0%.

Table 15: Hornell Residential 0% Loan Search Space Iteration

Baseline			Iteration 1			Iteration 2			Iteration 3		
CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)
0	0	0	0	0	0	0	0	0	0	0	0
3000	3000	3000	6000	6000	3000	5000	6500	3500	6500	7500	4500
6000	6000	6000	7500	7500	4500	5500	7000	4000	6750	7750	4750
9000	9000	9000	9000	9000	6000	6000	7500	4500	7000	8000	5000
12000	12000	12000	10500	10500	7500	6500	8000	5000	7250	8250	5250
15000	15000	15000	12000	12000	9000	7000	8500	5500	7500	8500	5500
18000	18000	18000							7750	8750	5750

Table 15 above follows a similar procedure as that done prior to the loan subsidy modeling. Each iteration is centered around the previous iteration's choice and provided with smaller generator size steps.

Table 16: Hornell Residential Subsidized Iteration Cost Data

Hornell Residential 0% Loans	Base	ITER 1	ITER 2	ITER 3
1 MWh Li-ion Battery	4	3	3	4
Cow Manure (kW)	9,000	6,000	7,000	7500
Wood Oak (kW)	9,000	7,500	8,000	8250
Municipal Solid Waste (kW)	6,000	4,500	5,000	5000
Net Present Cost	$216,000,000	$210,000,000	$209,000,000	$208,000,000
Initial Capital	$100,000,000	$84,600,000	$89,600,000	$92,200,000
Cost of Energy ($/kWh)	$0.208	$0.202	$0.201	$0.200

Table 16 shows a primary aspect of introducing 0% loan to the system, increased capital cost and NPC; both in general and between iterations. The drawback of higher costs is mitigated by the government assuming a major portion of that risk. A possible explanation for the increase in NPC and initial capital is the salvage potential of higher capacity generators. The removal of the interest more importantly leads to higher capacity generators and lower cost of energy for end users. However, the decreases in cost of energy (COE) and NPC between iteration 1 and 3 of $0.002/kWh or $2 savings per month for an average home and $2,000,000 over 25 years respectively, is outweighed by the $7,000,000 increase in capital costs. Given this, all following results and data will be based on the iteration 1 system.

Table 17: Hornell Residential Subsidized Converter Sizing

Quantity	Inverter	Rectifier	Units
Capacity	9,999,999	9,999,999	kW
Mean Output	107	126	kW
Minimum Output	0	0	kW
Maximum Output	1,768	1,933	kW
Capacity Factor	0.00107	0.00126	%

The iteration process shows the need for three to four 1 MWh Li-Ion batteries, the integration for which requires a converter larger than 2.2 MW to safely buffer the 1.9 MW rectifier output. Providing a margin for overflow, 10% as before, in the converter is a key component to system reliability as unexpected surges remains a primary cause of failure.

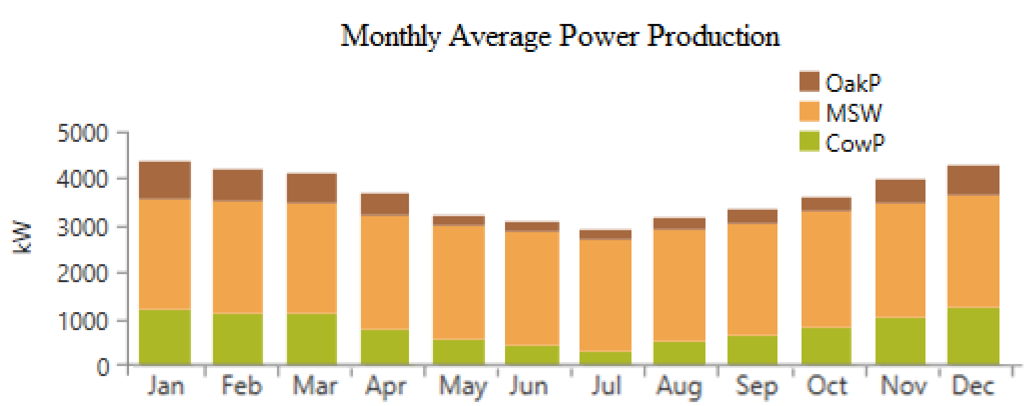

Figure 17: Hornell residential subsidized monthly power production.

Figure 17 shows less wood biomass is being used in the subsidized system. This may be an effect of the wood fuel’s high cost per kg, seventeen times the cost of MSW and four times that of cow manure. With this cost structure we see that oak power production proceeds to join cow manure in heavier winter rather than summer usage.

Table 18: Hornell Residential Subsidized Feedstock Usage and Energy Production

Feedstock	kg used/yr	kg available/yr	usage by %	kWh/yr	% of kWh
Processed Cow Biomass	1,706,524	1,800,000	95	7,052,722	22.0
Processed Oak Biomass	654,193	2,500,000	26	3,971,215	12.4
Municipal Solid Waste Biomass	5,092,673	6,000,000	85	21,002,184	65.6
				32,026,121	100

Comparing Table 18 with the unsubsidized usage and energy production in Table 13, we see the oak biomass usage as the one most heavily affected. The total energy produced however does exhibit a 3% increase. This indicates that the decrease in oak energy production is possibly overcompensated for by the cow and MSW energy production.

Table 19: Hornell Residential Subsidized Emissions

Hornell Residential Subsidized	kg/yr
System CO2 Emissions	13,716,059
Cow Manure Used	1,706,524
CO2 equivalent caputred	138,228,444
Overall net CO2 eq emissions	-124,512,385

As shown in Table 19, the carbon capture value remains above 120,000 tonnes, similar to the unsubsidized system. This indicates that subsidizing the Hornell Residential system by providing 0% loans does not provide an economic, net present cost based incentive to move away from cow manure power generation which provides a major source of carbon savings.

C. Alfred, NY Community Load

Similar to Hornell Residential, an Alfred Community microgrid requires the integration of CHP to meet the load. Given the smaller load, the initial search space, as shown in Table 20 below, has a size variance of 1 MW, rather than the 3 MW used for Hornell Residential. Table 20 also shows that an Alfred Community biomass microgrid would be better economically with only cow manure and MSW.

Table 20: Alfred Community Search Space Iteration

Baseline			Iteration 1			Iteration 2			Iteration 3		
CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)
0	0	0	0	0	0	0	0	0	0	0	0
1000	1000	1000	1000	1000	3000	1500	1000	3500	1950	1000	3700
2000	2000	2000	1500	2000	3500	1750	2000	3750	2100	2000	3850
3000	3000	3000	2000	3000	4000	2000	3000	4000	2250	3000	4000
4000	4000	4000	2500	4000	4500	2250	4000	4250	2400	4000	4150
5000	5000	5000	3000	5000	5000	2500	5000	4500	2550	5000	4300
6000	6000	6000	3500	6000	5500						

As a smaller system, the initial capital needed is expectedly lower as well as the net present cost. However, economies of scale mean that to be viable the cost of energy for consumers served would be approximately $0.43/kWh.

Table 21: Alfred Community Iteration Cost Data

Alfred Community	Base	ITER 1	ITER 2	ITER 3
1 MWh Li-ion Battery	1	1	2	2
Cow Manure (kW)	2,000	2,000	2,250	2100
Wood Oak (kW)	0	0	0	0
Municipal Solid Waste (kW)	4,000	4,000	4,000	4000
Net Present Cost	$84,900,000	$84,900,000	$84,800,000	$84,700,000
Initial Capital	$40,700,000	$40,700,000	$42,000,000	$41,700,000
Cost of Energy ($/kWh)	$0.429	$0.429	$0.428	$0.428

As shown in Table 21 the first iteration did not provide a small enough variance to produce any change. Given the minimal cost improvements through further iterative sizing process, coupled with the $1,000,000 increase in initial capital, all following data will be based on the base system.

Table 22: Alfred Community Converter Sizing

Quantity	Inverter	Rectifier	Units
Capacity	9,999,999	9,999,999	kW
Mean Output	49.0	57.4	kW
Minimum Output	0	0	kW
Maximum Output	721	766	kW
Capacity Factor	0.000490	0.000574	%

As with the other scenarios, converter sizing was done by creating an intentionally larger converter than is necessary and assessing the results. In Table 22 above we see that for the Alfred Community load with CHP integration, a converter capable of outputting 850 kW is necessary to accommodate the maximum rectifier output with a 10% buffer.

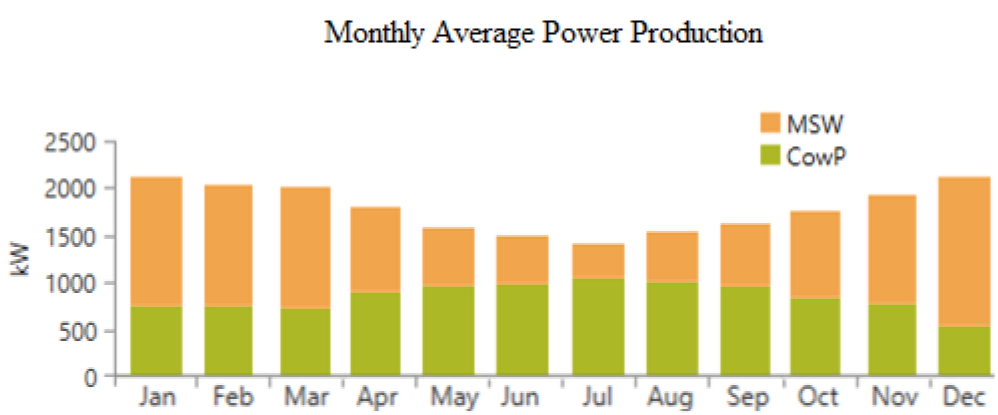

Figure 18: Alfred community monthly power production.

The removal of wood as a feedstock is reflected in the monthly average electric production by feedstock in Figure 18. This of course is expected. What is not is the increase in power produced by cow manure. This usage pattern runs counter to those of systems shown before and, given the higher summer gas yields that can be expected from an above ground digester, may be more ideal. MSW summer production reduction could be the cause for this increase, though it is also possible that the causation is the reverse.

Table 23: Alfred Community Feedstock Usage and Energy Production

Feedstock	kg used/yr	kg available/yr	usage by %	kWh/yr	% of kWh
Processed Cow Biomass	1,799,966	1,800,000	100	7,438,898	47.8
Processed Oak Biomass	0	2,500,000	0	0	0.0
Municipal Solid Waste Biomass	1,971,532	6,000,000	33	8,130,598	52.2
				15,569,496	100

As with the Hornell models, Table 23 shows that a majority of the energy produced comes from MSW. However, for this scenario, this majority is a narrower one. The lower load combined with the removal of wood biomass brings up the cow manure usage close to that of MSW. This occurs due to the relative availabilities of the feedstocks; while Alfred load exhausts 100% of the available cow manure biomass it uses a mere 33% of the MSW. This means that any increase in demand will increase MSW usage or introduce wood usage, which we can see is what occurs with the Hornell loads.

Table 24: Alfred Community Emissions

Alfred Community	kg/yr
System CO2 Emissions	6,631,545
Cow Manure Used	1,799,966
CO2 equivalent caputred	145,797,246
Overall net CO2 eq emissions	-139,165,701

The Alfred Community model emission, seen in Table 24 above, shows a higher amount of overall CO_2 eq reduction. This is due to the greater usage of cow manure leading to higher carbon capture values as well as the lower system demand meaning less CO_2 system emissions as a baseline.

1. Alfred Community Load Subsidized

As with Hornell Residential, the cost of energy for the system is too high in comparison to market rates. The same consumer cost reduction strategy is applied by modeling the system with the ability to take on subsidized loans, 0% interest down from the original 8%. Given the new cost structure, the iteration process must be repeated.

Table 25: Alfred Community 0% Loan Search Space Iteration

Baseline			Iteration 1			Iteration 2			Iteration 3		
CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)	CowP Capacity (kW)	OakP Capacity (kW)	MSW Capacity (kW)
0	0	0	0	0	0	0	0	0	0	0	9000
1000	1000	1000	1000	1000	4500	1000	1000	6500	1000	1000	10000
2000	2000	2000	2000	2000	5000	2000	2000	7000	2000	2000	11000
3000	3000	3000	3000	3000	5500	3000	3000	7500	3000	3000	11250
4000	4000	4000	4000	4000	6000	4000	4000	8000	4000	4000	11500
5000	5000	5000	5000	5000	6500	5000	5000	8500	5000	5000	11750
6000	6000	6000	6000	6000	7000	6000	6000	9000	6000	6000	12000

As displayed in Table 25, a subsidized Alfred Community system would, economically, only use MSW generators. Given the 6.3 MW peak of the Alfred load, the baseline search space used was the same used for the unsubsidized model. This, however, led to three iterations in which the model opted for the highest possible generator size. In an effort to address this, the final iteration's search space was purposefully oversized. This oversizing is most likely due to the combined effects of generator pricing per kW decreasing with size as well as the subsidy applied in the form of 0% interest loans. This leads to a system wherein the salvage revenue from the larger generator is worth the additional baseline capital costs.

Table 26: Alfred Community 0% Loan Iteration Cost Data

Alfred Community 0% Loans	Base	ITER 1	ITER 2	ITER 3
1 MWh Li-ion Battery	4	5	6	7
Cow Manure (kW)	0	0	0	0
Wood Oak (kW)	0	0	0	0
Municipal Solid Waste (kW)	6,000	7,000	9,000	11,500
Net Present Cost	$137,000,000	$134,000,000	$131,000,000	$130,000,000
Initial Capital	$30,300,000	$33,500,000	$39,200,000	$46,200,000
Cost of Energy ($/kWh)	$0.273	$0.267	$0.261	$0.260

Table 26 provides more insight into the economic aspect of generator oversizing. As mentioned before, the net present cost of investment decreases as the initial capital and generator size increase. Given the $7,000,000 increase in initial capital between iterations 2 and 3 for the minimal reduction of net present cost of $1,000,000, all following data will be based on the second iteration.

Table 27: Alfred Community Subsidized Converter Sizing

Quantity	Inverter	Rectifier	Units
Capacity	9,999,999	9,999,999	kW
Mean Output	777	909	kW
Minimum Output	0	0	kW
Maximum Output	3,899	4,000	kW
Capacity Factor	0.00777	0.00909	%

The converter size based on Table 27 should be 4.4 MW to facilitate smooth operations. This number is based on the maximum rectifier output with a 10% buffer in case of power surges.

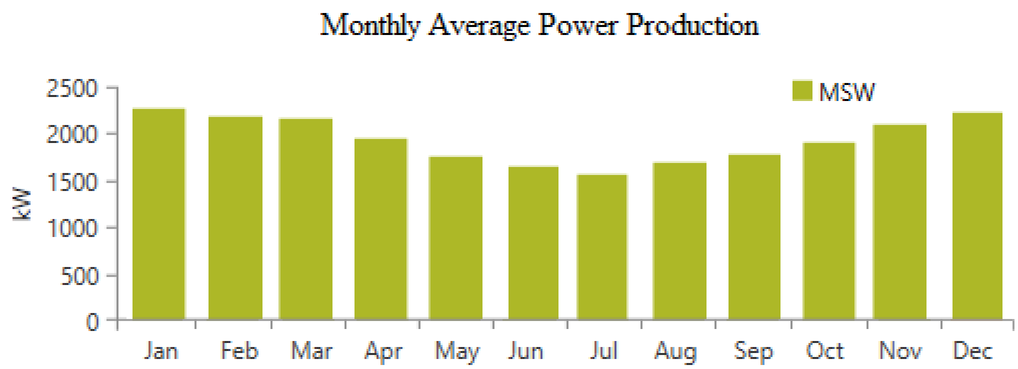

Figure 19: Alfred community subsidized monthly power production.

The higher winter values reflect the higher power demand caused by heating needs. These models assume some homes as having electric based heating and others gas, which is substituted for by the CHP efficiency modeling done with the generators.

Table 28: Alfred Community Subsidized Feedstock Usage and Energy Production

Feedstock	kg used/yr	kg available/yr	usage by %	kWh/yr	% of kWh
Processed Cow Biomass	0	1,800,000	0	0	0.0
Processed Oak Biomass	0	2,500,000	0	0	0.0
Municipal Solid Waste Biomass	4,103,145	6,000,000	68	16,921,370	100.0
				16,921,370	100

Table 28 above shows that an MSW only plant for Alfred Community will be able to produce enough energy. It must be noted that this result is founded on database MSW fuel data. Direct measurement of local MSW is necessary to ensure positive results. As an MSW only system, this method of power and heat production has the greatest potential for reducing landfilling rates.

Table 29: Alfred Community Subsidized Emissions

Alfred Community Subsidized	kg/yr
System CO2 Emissions	10,080,059
Cow Manure Used	0
CO2 equivalent caputred	0
Overall net CO2 eq emissions	10,080,059

Due to the removal of the carbon capture provided by cow manure power generation, the Subsidized Alfred Community model's reduced COE comes at a cost to the environment as the system's CO_2 emission is not cancelled out by anything, as shown in Table 29 above.

D. Overall Comparison

Table 30: Data Summary

Model	Load Profile	Hornell Residential		Alfred Community	
	State of Subsidy	Unsubsidized	Subsidized	Unsubsidized	Subsidized
	Iteration Chosen	Iteration 3	Iteration 1	Base	Iteration 2
Architecture	1 MWh Li-ion Battery	2 units	3 units	1 unit	6 units
	Converter (kW)	1,400	2,200	850	4,400
	Cow Manure (kW)	6,500	6,000	2,000	0
	Wood Oak (kW)	3,250	7,500	0	0
	Municipal Solid Waste (kW)	5,000	4,500	4,000	9,000
Costs	Net Present Cost	$132,000,000	$210,000,000	$84,900,000	$131,000,000
	Initial Capital	$75,800,000	$84,600,000	$40,700,000	$39,200,000
	Fuel Cost ($/yr)	$459,045	$287,516	$124,456	$49,238
	Cost of Energy ($/kWh)	$0.320	$0.202	$0.429	$0.261
Emissions	System CO2 Emissions (kg/yr)	13,987,086	13,716,059	6,631,545	7,071,086
	Cow Manure Used (kg/yr)	1,689,512	1,706,524	1,799,966	0
	CO2 equivalent caputred	136,850,472	138,228,444	145,797,246	0
	Overall net CO2 eq emissions	-122,863,386	-124,512,385	-139,165,701	7,071,086
System	Capacity Shortage (kWh/yr)	30,880	2,295	5,706	0
	Capacity Shortage (%)	0.09710	0.00722	0.03720	0.00000
	Excess Power (kWh/yr)	11,084	1,391	143,490	18,986
	Excess Power (%)	0.03470	0.00434	0.92200	0.11200
	Power Produced (kWh/yr)	31,936,290	32,026,120	15,569,497	16,921,370
	Power Consumed (kWh/yr)	31,795,914	31,805,772	15,325,980	15,328,082

Beginning with the modelling portion, Table 30 shows that the iteration process would be more impactful with more specificity applied to each generator's cost structures. Without this, the increase in initial capital for three of the four models was deemed too high in comparison to the returns from reduced net present cost.

With regards to the architecture aspect, we can see that converter sizing is heavily dependent on the number of batteries the system contains. This is most evident with the comparison of the converter sizes of the subsidized and unsubsidized Alfred Community load.

There appears to be an inverse relationship between what systems would cost less for investors and what would cost less for consumers; net present cost decreases as cost of energy increases. This highlights the need for government subsidy, which in both cases reduced the cost of energy by about 40%. Table 30 also shows that a subsidy in the form of 0% loans may in fact increase the cost of the system, thereby requiring an additional or different form of assistance.

The emissions data on Table 30 shows the importance of methane capture in reducing system emissions and even producing a net negative carbon effect. With the best emission result and the lowest net present cost, the unsubsidized Alfred Community system seems to be the best environmentally. This however comes at a steep cost to the consumers at $0.43/kWh.

Finally, Table 30's systems data shows the relative stability of the various microgrids. Due to the integration of properly sized energy storage systems, we are able to minimize capacity shortage and excess power production. The disparity between the power produced and power consumed is likely due to the model accounting for transmission losses.

Table 31: Economic Comparison to Current Electricity Market

	Power Consumed (kWh/yr)	Cost of Energy ($/kWh)	Revenue from Consumers	Revenue at $0.11/kWh	Financial Support Needed
Hornell Residential Unsubsidized	31,795,914	$0.320	$10,174,692	$3,497,551	$6,677,142
Hornell Residential Subsidized	31,805,772	$0.202	$6,424,766	$3,498,635	$2,926,131
Alfred Community Unsubsidized	15,325,980	$0.429	$6,574,845	$1,685,858	$4,888,988
Alfred Community Subsidized	15,328,082	$0.261	$4,000,629	$1,686,089	$2,314,540

The high unit cost of energy in comparison reflects the investment in infrastructure that is a CHP integrated biomass microgrid. The CHP integration also means that this new system would alleviate or completely eliminate heating costs. Table 31 above calculates and shows how much added yearly revenue each system requires to be able to offer energy at $0.11/kWh. Due to the prior subsidization with 0% loans, Hornell Residential Subsidized and Alfred Community Subsidized require less financial support. This financial support need can be lowered by the exploration of alternative revenue streams, primarily the sale of byproducts.

V. SUMMARY AND CONCLUSIONS

A Western New York biomass microgrid requires CHP integration and the higher efficiency it allows to meet the power needs of Hornell Residential and the Alfred Community. The investment in new infrastructure will increase costs to end consumers by, at best, doubling, and, at worst, quadrupling electricity cost. However, it is possible that the inclusion of heating may help mitigate this burden. Government subsidy in the form of 0% interest loans lowers the price for consumers while increasing the system's investment costs. This indicates the need for additional revenue streams or other forms of assistance instead of or in addition to discounted loans.

The high average MSW production rate combined with its low cost makes it an ideal fuel. Methane capture from the use of cow manure is a significant factor in GHG reduction. Wood biomass and cow manure energy production is for many cases treated as secondary to MSW. This may be due to the relative fuel costs of the three feedstocks.

The largest initiative for renewable energy in NYS is Governor Cuomo's 50 by '30, which will require 50% of the state's electricity to be from renewable sources. This focus on electricity production curtails the potential for biomass with its need for CHP integration. Biomass' similarity to traditional fuels, with its need for processing, transport, and combustion makes it subject to conversion losses as well as the additional costs and emissions that accompany transport and processing. This manifests itself as a perception problem, putting biomass in stark contrast to its renewable peers despite the calculated GHG reduction potential.

VI. FUTURE WORK

The importance and feasibility of a biomass microgrid has been stated but these serve as merely a starting point. The next step requires the consideration of the following:

- Generator inefficiencies due to ramping on and off

The current generator models use an idealized mode of operation. This mode does not take into account losses from the less efficient operations during startup and shutoff.

- Additional costs in the form of
    - Feedstock processing

    Dependent on the form of drying, charring, or sorting for cow manure, wood, and MSW respectively, costs will vary. This processing cost is likely to require further investment into infrastructure and machinery.

    - Feedstock transportation

    The cost of transporting biomass from its source to the generators, with a potential detour to a processing facility if neither has the capability, needs to be addressed. This cost must also account for the environmental cost of the fuel used transporting the biofuels.

    - Generator operation and maintenance

    The costs of day to day operations and routine maintenance will vary based on system size and uptime.

- Direct measurement of feedstock lower heating value and other fuel data

The current biomass fuel data used may be close but inexact to actual values of the available feedstocks. This necessity for localization aspect of biomass power potential is a natural byproduct of using such an inherently variable form of energy.

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