Feasibility Study for Developing a Microgrid to Serve the Ithaca South Energy District

Final Report

Fractal Energy Consulting
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Advisor Project Introduction

The following document reports on the feasibility of a proposed Ithaca "South Energy District", or SED, electricity microgrid for Ithaca's South Hill and surrounding area. It is the second of two microgrid studies, the first being for the Ithaca "North Energy District" in the area surrounding the Ithaca Area Waste Water Treatment Facility (IAWWTF) and Fourth Street substation, which was studied in the Fall 2015 semester. The report on the Ithaca NED study as well as several other reports of local interest from past semesters can be found at www.lightlink.com/francis/.

The role of the team of engineering students and my role as advisor resembles that of other Master of Engineering in Engineering Management team projects (course code CEE 5910) that have been conducted in the past in the School of Civil & Environmental Engineering at Cornell University. Working with partners in Ithaca Community Energy, a local nonprofit dedicated to developing sustainable energy resources in the Ithaca area, I framed the broad goals of the Ithaca SED project and presented them to the 12-member student team. Thereafter, the team defined a specific scope of work and progressed toward project deliverables, culminating in the final report that you are about to read.

The elements of the project reflect the different levels of scope for installing a microgrid (by which we mean a generation-distribution system that functions in parallel with the regional transmission-distribution grid during normal operations, but that can also function in standalone "island mode" in the event of a region-wide outage). The narrowest scope is a microgrid that supports only key "priority loads" (schools, first responders, city hall, retirement communities) in island mode. Beyond that, a larger microgrid with access to greater capital investment might have sufficient capacity to support the entire SED in island mode. This objective is ambitious, but reflects the goal of New York State and the administration of Governor Andrew Cuomo to install and operate a microgrid capable of supporting "a population of up to 40,000 people." A further increment of the microgrid discussed in the report cover the proposed Chain Works District (CWD) development of the former Emerson Transmission plant on South Hill, a residential-commercial property that might eventually incorporate approximately 900 living units. Another increment is the possibility of incorporating the electricity load of the Ithaca College campus, which is adjacent to the geographic boundaries of the microgrid district.

The report identifies several ongoing issues that will arise if the Ithaca community continues to pursue microgrids. One issue is the relationship with the existing energy delivery utility (NYSEG). Although there is little experience with microgrids to date, the opportunity to design, build, and operate the microgrid may interest NYSEG in becoming a partner rather than a competitor to the microgrid. Another issue is the additional generation that would be required to go beyond using natural gas as a microgrid energy source to becoming 100% carbon free, as many of the required technologies and systems are still being developed. A related issue is the possibility of eventually using centralized ground-source geothermal, since this source could eliminate the burning of natural gas for space heating purposes. Lastly, the implied fugitive methane emissions from extraction and delivery of natural gas (using hydraulic fracturing, especially in the Marcellus Shale formation) to the microgrid for the duration of time when gas is used as a fuel are not covered in the report, but would provide a further motivation to move toward a 100% carbon-free energy supply for the microgrid, including heating/cooling as well as electricity loads.

In closing, I wish to thank the other members of Ithaca Community Energy, as well as representatives of Cornell University, Ithaca College, and the City of Ithaca who provided input to this project. While this assistance is gratefully acknowledged, the findings in this report do not represent the official positions of any of these four organizations, and responsibility for all errors and omissions rests with the team and with myself as advisor.

Francis M Vanek, PhD, Senior Lecturer and Research Associate

Executive Summary

The creation of this project resulted from the combined efforts of the Ithaca Community Energy Group and Cornell University. A microgrid for the South Energy District of Ithaca, New York is being considered, and is the over-arching topic in the following report. The project scope and the model iterations to be produced were the primary focus for the first half of this project. The market survey was the primary way in which to help familiarize all members on the project team with the major concepts as well as the intricate details behind the design of a microgrid.
The market survey allowed for members of the project team to specialize in one of three general sub-categories. Demand, financial considerations, and technology were the three sub-categories created. Further breakdown was then carried out with respect to every individual on the project team, to the point where everyone was assigned a niche/specific aspect of the microgrid. Not all portions of the market survey were directly relevant in the completion of the final microgrid model. In many cases the market survey highlighted limitations, such as the high cost of biomass integration, limited potential grant opportunities or subsidies, or the lack of viability for wind technologies in the Ithaca area. However, the market survey also made many direct contributions to the model such as what underlying discount rate should be used and would be most reasonable. The market survey also highlights many important points that do not in any way shape or form correlate to direct monetary gain. Understanding the infrastructure and architecture behind the microgrid brings to light benefits such as added security in case of an attack on the macrogrid, added health and safety benefits in case of a blackout due to extreme weather, and sustainability benefits that help adapt and move modern society towards a more carbon neutral lifestyle.

After generating the comprehensive market survey, a model was developed that allowed for the project team to easily assess multiple different scenarios based off of findings from the market survey. The project team agreed upon five overarching scenarios to focus upon. A minimum sized microgrid, a priority load and Chainworks district focused microgrid, a microgrid that included all loads except Ithaca College, an all-inclusive microgrid that includes Ithaca College, and lastly a carbon neutral microgrid were the five scenarios agreed upon and assessed. These scenarios stemmed from potential considerations that could arise if the project were to actually begin being built in present time. Many of the scenarios were based around potential customers, however, the final scenario is an attempt at trying to make the microgrid as sustainable as possible via the most realistic means.

After creating all of the scenarios further analysis needed to be conducted. Thus, a conservative baseline case was created that every scenario should assess and slowly deviate from if needed. This conservative baseline case includes a peak to average ratio of 2, no combined heat and power (CHP), no biomass, a retail price of electricity of $.07 per kWh, no storage technology, no solar integration, and consideration of which of the three non-renewable technologies between fuel cells, microturbines, and reciprocating engines should be used based on economics alone. After evaluating this baseline case and approximating a payback period deviations were made for every scenario to see what kind of economic situation would be needed to make the scenarios more reasonable. However, of course any deviations made from the conservative baseline case mean that there is inherent risk due to the fact that these conditions are not necessarily controllable nor necessarily realistic the farther the deviation becomes.

After assessing all of the scenarios some general observations were brought to attention such as the fact that microturbines generally seemed to perform economically the best of any of the three non-renewable technologies considered. Finally, discussion regarding what recommendations the project team would make based on the findings of the report and model was conducted. In summary, the recommendation largely "depends" on the situation at hand because different policies and environmental initiatives could swing the findings of this report drastically (such as if a carbon tax were implemented). However, proof of concept of the microgrid has definitively been shown. This stems from the fact that for the minimal sized microgrid the payback periods had the realistic potential of being extremely short. At worst, the payback period of 14 years for the baseline case, and also associated with 100% solar integration, was still reasonable and an enticing investment from an economic, sustainability, and time based perspective. The sustainability perspective can be vouched for considering that net carbon emissions were substantially lower than that of the macrogrid with only 10% solar integration (.54 kg per kWh of electricity for the microgrid versus .75 kg per kWh of electricity for the macrogrid). Then, further discussion was done in regard to the fact that as the scenarios progress and further demand is added that more risk is being taken upon the investors. This is because as more demand is added to the model there is more need to deviate from the baseline scenario. Which, in turn means that the conservative economic scenario of the present would not necessarily be good enough to justify certain aspects of the project, such as reasonable time frame for payoff/payback. Relying on a higher retail price of electricity accepts more risk, thus the investors and owners of the microgrid project would need to assess for themselves how much risk is allowable. Another limitation is the difficulty in quantifying this risk.

It is very fitting that an environmentally conscious town like Ithaca, NY shows so much potential for spearheading a viable microgrid project in its South Energy District. A microgrid project that, within this report, has been shown to have social, economic, and environmental benefits locally.

Introduction

Fractal Energy Consulting's Mission

In the Fall of 2016, a group of graduate engineering students came together under the supervision of Prof. Francis Vanek in the Civil and Environmental Engineering School at Cornell to form the Fractal Energy Consulting Team.

All partners, i.e. team members, share the belief that one of the greatest challenges of the present time is addressing effectively the planet's climate change. As future leaders in engineering management, we propose to focus our involvement in this project on a study and evaluation of the application of existing technologies aimed to mitigation of environmental impacts associated with energy (i.e. heat and electricity) generation, supply, and consumption.

The initiative to create a microgrid in Ithaca, NY to serve the South Hill Community (South Energy District, a.k.a. SED) has been brought to us by Prof. Vanek as a perfect opportunity for the exploration of a solution that has the potential of breaking ground into more sustainable development in respect to the traditional energy infrastructure. Moreover, the necessity of discussing this proposal from a multi-objective perspective with several stakeholders, developing a technical feasibility study and creating an evaluation model will serve to all partners as the ideal means to achieve the personal and professional growth.

Fractal Energy Consulting's mission is to produce insightful and actionable analysis of energy infrastructure systems, while ensuring a fruitful work environment for all partners such that the skill and likelihood of each member's success in future engineering projects is maximized. In accordance to the team values, the team will not endorse any recommendation that possess negative environmental impacts in terms of an increased carbon footprint. The carbon footprint of the microgrid will be assessed by comparing its net carbon emissions to the baseline, average, net carbon emissions of the macrogrid.

Project objectives and scope definition specific to the creation of the SED microgrid will be discussed and determined in the following section.

Motivation for the Project

Globally, the energy market has experienced a massive boost in the last decade. This is due to the availability of microgrid technology and capital for multiple energy transition projects. The reduction of CO_2 emissions and the expansion of renewable energies as an alternative to fossil power plants are the central premises behind this concept. The use of greener technology has increased in our communities drastically, due to the increased concern of global warming. Energy companies have been moving to greener energy generating technology. In addition to serving green energy source, microgrids also protect critical infrastructure, such as hospital, school, and police station, from losing power in the case of unexpected extreme weather conditions.

The U.S. Department of Energy's Microgrid initiative mainly focuses on the development of commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply [UPS] plus diesel Gensets), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020. In par with this, New York Energy Research and Development (NYSERDA) helps communities reduce costs, promote clean energy, and build reliability and resiliency into the electric grid. NY Prize is a part of a statewide endeavor to modernize New York State's electric grid, spurring innovation and community partnerships with utilities, local governments, and private sector. Their mission is to enable the technological, operational, and business models that will help communities reduce costs, promote clean energy, and build reliability and resiliency into the grid.

In common with communities throughout the state, the City of Ithaca is vulnerable to grid-wide power outages caused by increasingly common extreme weather and other emergencies. In addition, Ithaca is highlighted in the New York Prize's Finger Lakes "Opportunity Zone" as an area where microgrids may reduce utility system constraints and defer expensive infrastructure investment costs. This project aims to study the economic feasibility for an Ithaca Community Microgrid for power generation to serve the Ithaca South Energy District (SED), preferably via existing NYSEG distribution. The feasibility assessment of Combined Heat and Power (CHP) as well as extensive biogas, solar PV and micro turbines is analyzed in this report. The value of energy production is emphasized by the extensive planned developments in the local areas and the significant increase in electricity demand with it. Thus, the microgrid configuration as proposed would provide electricity that is island able from the commercial grid to power vital community services during emergencies. Collaboration with NYSEG to improve electric system reliability, efficiency, expansion, emissions reduction, and cost will also interest leading microgrid developers and other third party investors.

Objectives

The goal of this project is to study the economic and technical feasibility of creating a microgrid that would serve Ithaca's South Hill community. The team will develop an efficient and effective plan that would increase the sustainability of this region. A holistic approach will be used to frame the problem in order to both quantitatively and qualitatively engineer the best solution.

The team studied the proposal's economic feasibility by evaluating its financial and systematic logistics. They explored various types of alternative energy sources and sources of funding. The technical feasibility of this project is evaluated by exploring the various options of designing a microgrid system architecture within the constraints of its geographic location and related demand. The 5910 team utilizes different optimization and modeling tools to study and estimate the required capacity of the system and its financial costs and constraints. They integrate technical, economic, regulatory, and mathematical knowledge to reach well informed conclusions and design the best microgrid for the South Hill community.

Team Member Background

The team is comprised of 1 Bachelor of Engineering and 11 Masters of Engineering students:

Justyna Bujno is from Forest Hills, NY. She graduated from Cornell University in 2016 with a Bachelor of Science in Civil Engineering. After completing her Master of Engineering in Engineering Management, she plans to pursue a career in Construction Management. Her hobbies include traveling, cooking, and kayaking.

Allen Chien is originally from Taiwan. He graduated from Purdue University in 2015 with a Bachelor of Science in Computer Engineering. He is currently in the Master of Engineering in Engineering Management program and will be graduating this December. He hopes to move to the West Coast upon graduation to work either in the Silicon Valley or Seattle in the tech industry.

Mark Flamme is a Cornell University Master of Engineering student majoring in Engineering Management. He hopes to combine this degree with his Mechanical Engineering bachelors from Cornell in an engineering and business role where he helps create products and solutions for people's daily problems. Professionally, Mark has interned at two New York based consumer product startups and is interested in eventually creating his own company. Mark is from Ann Arbor, MI and in his free time can be found running on a trail or watching college football.

Victoria Hu is from Washington Township, NJ. She graduated from Cornell University in 2016 in Biological Engineering with a minor in Business. She is currently finishing her Master's in Engineering Management.

Jeevan Kadam is originally from Pune, India. He graduated from University of Pune in May 2014 with bachelor’s degree in Mechanical Engineering. After finishing his Master of Engineering in Engineering Management, he plans to work for a global management consulting firm either as a practice consultant in Strategy & Operations or as a generalist consultant. His hobbies include travelling, reading, boating, flying, and having a barbeque party in park when it’s a beautiful sunny day outside.

Mauricio Medaets has graduated from University of Sao Paulo in 2009 in Mechanical Engineering with emphasis on Aviation. After college, he worked for 5 years with railroad infrastructural development in Southeastern Brazil. During this period he participated in a project of renovation of the rail connection between Santos and Sao Paulo, the biggest port and largest city in South America, respectively. As an engineer and assistant project manager, he led the technology transfer activities for the Swiss high-tech rack-and-pinion locomotive fleet, supervised the commissioning of the equipment and start-up of the operation. Mauricio’s interest in utilizing technology to bridge gaps in human development translated to his passion in clean-tech, efficient transportation, renewable energy and waste management. With his dual degree program at Cornell University, MBA in Sustainability and M.Eng in Renewable Energy and Water Resources Systems, he hopes to gain insight into ground-breaking technologies and business models to revolutionize the way mankind utilizes the world’s limited resources.

Louis Monteagudo is from Cranford, New Jersey. He is currently pursuing a Bachelor of Science in Operations Research and Information Engineering at Cornell University’s College of Engineering. In his free time, he enjoys playing soccer, discovering new music, and spending time outdoors. After graduating, he aspires to work in Strategy or Operations Consulting.

Krishnamurthy Narayanan is from Coimbatore, India. Krishna graduated from PSG College of Technology in Electrical and Electronics Engineering and has worked with Caterpillar Engineering Design Centre for about 4 years as a Test Engineer for Embedded Software of multiple engines and its applications. He is looking forward to have a career as a technical manager after completing his Master in Engineering Management from Cornell University. He is a bass and an acoustic guitarist and is very interested in music.

Adam Schecter is from Ridgefield, CT. He graduated Cornell University in 2016 with a Bachelor's Degree in Environmental Engineering. He is pursuing a graduate degree in Water Resources. In undergrad, he was a member of the fraternity, AEPi, and now after graduating he is interested in potentially getting an MBA and spends some of his spare time studying for the GMAT.

Shankar Suresh Kartha is originally from Kerala, India. He, however, did his schooling in Qatar and completed his Bachelor's in Electrical and Electronics Engineering from NITK, India. His academic interests mainly lie in areas of renewable energy, grid technology, and its integration with generation and load side. He wishes to pursue a career in the energy industry. He is a violinist and also plays percussion and has a very varied interest in music.

Felicia Violitta is originally from Indonesia. She graduated from the University of Southern California in 2015 with a Bachelor's Degree in Chemical Engineering. She is pursuing a graduate degree in Engineering Management. She will be moving back to Indonesia after she graduates and working for a family business in manufacturing.

Hanqing XiaoXiao Yang was born in Shenyang China, but currently lives in Ithaca, NY. He graduated from Cornell University in May 2016 with a Bachelor of Science in Chemical Engineering and a minor in business. During his time as an undergrad, he did a co-op at Mondelez International as a process development engineer and an internship at Capital One as a Business Analyst. He is currently pursuing a Master of Engineering degree in Engineering Management and will be graduating in December 2016. Upon graduation, he will most likely return to Capital One full-time in Washington, DC. In his free time, he enjoys working out, playing sports like basketball and tennis, or doing research for his fantasy football team.

Team Structure

The team operates under the leadership of Justyna Bujno and Mauricio Medaets. They serve as the liaisons between the project's advisor, Francis Vanek, and the rest of the team. Justyna's role is primarily administrative and organizational. Mauricio's role is more technical in nature, as he has experience related to microgrids and energy.

The remainder of the team does not have a predefined position in a rigid structure. Instead, the project team assigns tasks to individuals and small groups and the team meets on a weekly basis to go over the progress of the project. The team decided to tackle the project by assigning tasks based on each team member's skill, experience, and preferences. Appropriate measures were taken to ensure equal distribution of workload via general team consensus. For example, work for our first major deliverable, the Market Survey, was split as seen in the following table:

Market Survey Groups

Energy Demand

Team Member	Research Topics
Mark Flamme	Demand, End Users
Louis Monteagudo	Boundary Conditions and Stakeholders
Krishnamurthy Narayanan	Microgrid and Macrogrid Technology

System/Techonology

Team Member	Research Topics
Justyna Bujno	Infrastructure
Allen Chien	Solar
Wilson Raposo	Heat and Power
Mauricio Medaets	Fuel Cells, Microturbines and Reciprocating Engines
Adam Schecter	Biomass
Shankar Kartha	Infrastructure/Architecture

Pitch Strategy

Team Member	Research Topics
Jeevan Kadam	Investment, Operating Cost, Financing Sources, Tax Credits, and Regulations
Victoria Hu	
Felicia Violitta	
Hanqing XiaoXiao Yang	

Matrix of skills each team member possesses:

	Matlab	**MS Office**	**Python**	**“R”**	**Energy Related Course-work**	**Economics**	**Modeling**
Justyna Bujno	**X**	**X**		**X**		**X**	**X**
Allen Chien	**X**	**X**	**X**				**X**
Mark Flamme	**X**	**X**	**X**			**X**	**X**
Victoria Hu		**X**	**X**	**X**		**X**	**X**
Jeevan Kadam		**X**			**X**	**X**	**X**
Mauricio Medaets		**X**			**X**	**X**	**X**
Louis Monteagudo	**X**	**X**		**X**		**X**	**X**
Krishnamurthy Narayanan	**X**	**X**	**X**	**X**	**X**		**X**
Adam Schecter	**X**	**X**		**X**	**X**		**X**
Shankar Suresh Kartha	**X**	**X**			**X**		
Felicia Violitta	**X**	**X**			**X**		**X**
Hanqing XiaoXiao Yang		**X**	**X**	**X**	**X**	**X**	**X**

Assumptions

To proceed with this feasibility study for Ithaca's South Energy District several assumptions must be made. The largest being this project will face no social or political barriers, or else if such barriers do arise, they may be identified as part of the project, but it is outside the project's scope to solve them, due to the technical and economic focus. With such a large infrastructure project it will most likely not be the case that no bariers arise. Furthermore, it will be assumed that the microgrid has no negative effects to residents such as plant noise, biomass smell, or obstruction of landscape visibility. One major load assumption must also be made. While Ithaca College is adjacent to the SED, and could potentially be a part of the microgrid in the future, it will be assumed to not be a load in the base case scenario since it is load is so high it will greatly change the demand and financial scope of the project. However, we will conduct an alternative scenario analysis where Ithaca College will be in the microgrid.

This microgrid is built around the assumption of creating a microgrid connection near the Chainworks facility. Thus we will assume the real estate developer successfully funds and completes all parts of renovation project. Specifically, spending the $4 million necessary to clean the site, the construction of 900 living units, and permission to have our microgrid base there.

Several assumptions must also must be made regarding electricity. Despite the fact that meter prices for electricity are constantly changing, a constant fixed price for electricity from the grid will be assumed. Additionally, it will be assumed that all energy produced from the microgrid will be able to be easily distributed to areas with load or sold back into the grid. The microgrid will simply be a feeder to the grid. This means that were not concerned with the transportation system of the electricity to the load. We will simply feed the energy to the grid for the load and assume it is transported to the load. For customer's electricity charge, we will assume they are just charged according to their kW usage rate instead of a combination charge of kW usage and peaked charge rate.

For financial analysis, we will assume a base case discount rate of 5.00% with a 20 year investment life.

Geographic Scope

The geographic scope of this project is the South Energy District (SED) of Ithaca New York. The distributor of electricity for Ithaca, New York State Electric and Gas (NYSEG), provides electricity through four substations. The SED is defined as all of the buildings and infrastructure that receive electricity through the SED generation facility located on South Hill. The proposed microgrid uses the NYSEG electricity substation adjacent to the Chainworks District to integrate and distribute loads.

Energy Scope

We classify two types of users, priority and non-priority. Our project evaluates the implementation of various technologies such as solar, combined heat and power, fuel cells, biomass production, microturbines, and reciprocating engines to determine whether an affordable system that meets energy demand for its users can be achieved. Additionally, we explore the prospects of selling surplus production to the main grid to realize a profit. This project primarily focuses on understanding and addressing the big picture implementation of a microgrid system and opportunity for carbon dioxide emission reduction in the South Energy District. We do not assess specific energy or fuel distribution, microgrid details (location of specific electricity feeders), plans to store energy, or carbon dioxide capture and storage.

Microgrid and Macrogrid Technology

Traditionally, the energy market has been divided into three separate constituents: energy generator, energy distributor and energy consumer. Using conventional sources like coal, oil, gas and nuclear, energy has been generated in bulk by power plants. The distributor buys energy from the specific plants, and transfers and sells it to consumers through grids. The consumers, including individual households and various enterprises, pay for it to be delivered by the utility companies. To safely and efficiently generate energy so that it can be consumed on demand in a secure and reliable way has always been a challenge and priority in the energy market.

In the past decade, however, the energy storage industry has constantly evolved to provide a wide array of technological approaches to manage the power supply, create a more resilient energy infrastructure, and reduce cost for utilities and consumers. To name a few, lithium ion batteries, solid state batteries, flow batteries, flywheels, compressed air energy storage, thermal, pumped hydro power, etc.

Though a number of countries are turning significant efforts towards the expansion of renewable energy, its market is facing multiple challenges. Unlike the conventional power sources, the generation is usually not matched with consumption in the renewable energy market, leading to either overproduction or underproduction of energy. For example, wind speed varies with time and season, and solar energy can only be generated during the day. On the other hand, the consumption also varies during day and night in different time of a year. Such uncertainty and imperfect foresight is the primary reason why the renewable energy is considered unreliable in many cases and experts are seeking more and conventional sources have not yet diminished.

Notably, the latest technologies mentioned above open up possibilities for individuals and enterprises to generate their own energy and store it for future use, for instance, solar for homeowners, heat for beer brewers and wind for farmers. This will remove the distinction between the generator and consumer, even remove the distributor completely in some cases. Additionally, self-generated energy system will reduce the burden on government to install more power plants or replace inefficient plants that run only in times of high demand. A good example would be Cornell University, which has its own power plant, but also buys energy from NYSEG during excess peak time. The concept of generating, buying, and selling energy has opened a market. The locally generating energy will allow real-time energy exchange to and from distributor. Enabling such complex technologies is made possible with the help of advanced distribution power grids. This technology is currently focusing on Microgrids which tap energy available locally to a community and make use of the already existing macrogrids for the distribution of power in a cost efficient and sustainable way.

Macrogrid

The U.S. power grid is the electrical system that connects electricity producers and consumers by transmission and distribution lines and related facilities. The U.S. power grid has evolved into three large interconnected systems that move electricity around the country. The electric power industry has developed mandatory reliability standards that have been approved by the Federal Energy Regulatory Commission (FERC) to ensure coordinated electric system operations.[i] FERC is an independent federal agency that regulates the interstate transmission of natural gas, oil, and electricity. To ensure the stability of the entire power grid, electricity must be produced at the same time it is used as large quantities of electrical power cannot be stored effectively.

High-voltage transmission lines, which are often seen hanging between tall metal towers, are used to carry electricity from power generating stations to the places where electricity is needed. When electricity flows through these transmission lines, some of it is lost. High-voltage transmission lines have a high carrying capacity, which makes them more efficient at transmitting electricity. This carrying capacity results in lower losses of electricity. Transformers at substations then reduce the strength of the high-voltage electricity coming from power plants through the stepped-down process, which lowers the voltage levels so the electricity can be used safely in homes and businesses.

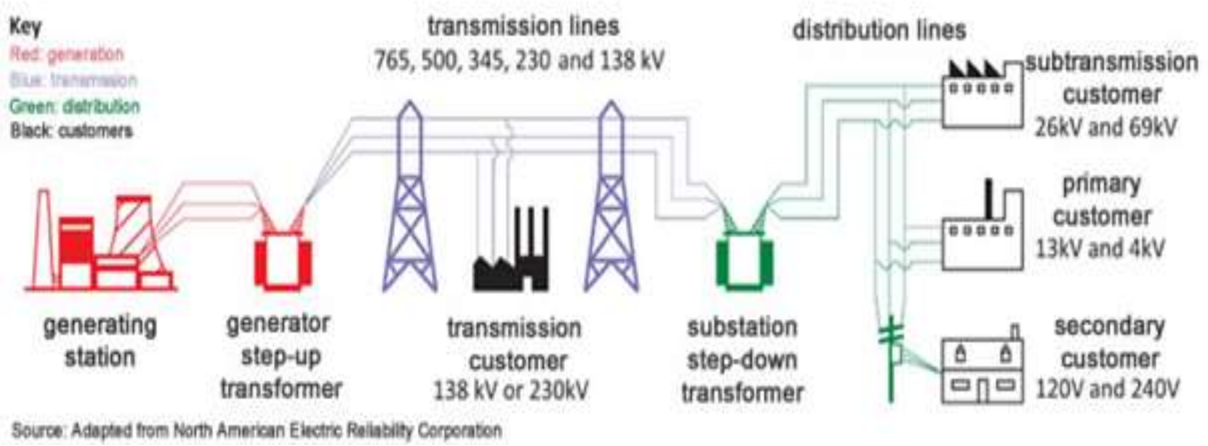


Figure 1: Schematic of Electricity Transmission and Distribution Grid from North American Electric Reliability Corporation[ii]

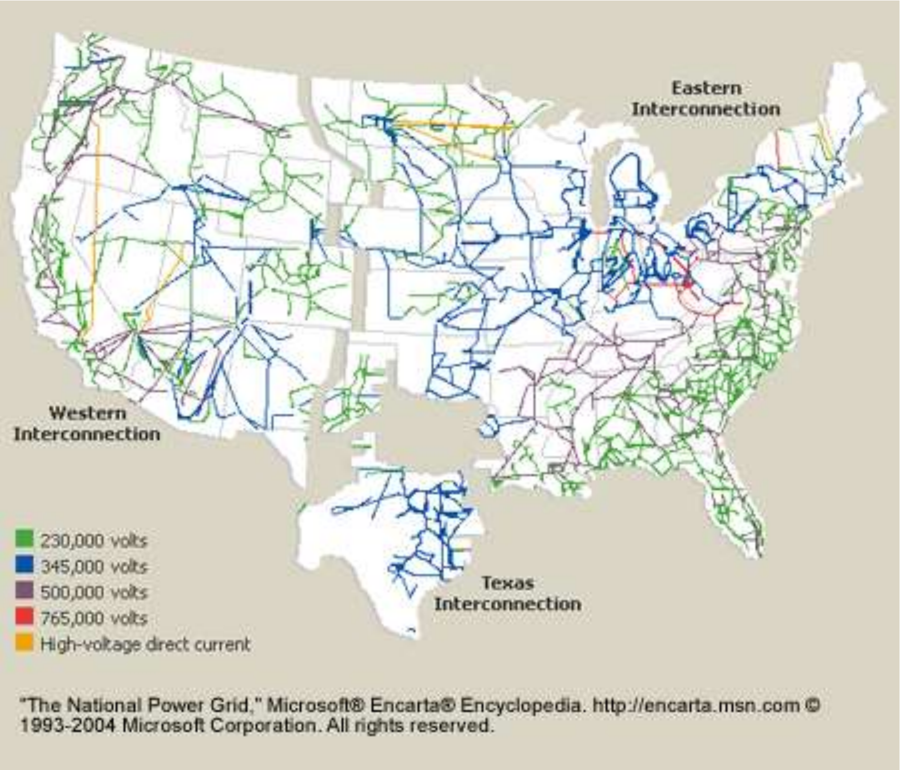
History of the Electric Power Grid

At the beginning of the 20th century, there were more than 4,000 individual electric utilities. Each utility operated in isolation from one another. Almost all of the electric utilities used low-voltage, direct current connections to transport electricity over distribution lines to their customers. This changed when the power industry adopted alternating current (AC) technology, which transmits electricity over longer distances than direct current. Widespread use of AC technology throughout the electric industry enabled utilities to build larger power plants located farther away from their customers.

As the demand for electricity grew, particularly in the post-World War II era, electric utilities found it more efficient to interconnect their transmission systems. This enabled utilities to share the benefits of building larger and often jointly-owned electric generating units to serve their combined electricity demand at the lowest possible cost. Interconnection also reduced the amount of extra capacity that each utility had to hold to ensure reliable service. Over time, three large interconnected systems evolved in the United States. Today, these three large interconnected systems separately serve Texas and the Eastern and Western halves of the United States.

Today, electric transmission and distribution lines owned by an individual utility are no longer used only by that utility. Electrical systems have been expanded and interconnected. Close coordination of operations among the three power grids is needed to keep the various components connected.[iii] The interconnected systems now include about 2,000 electric distribution utilities, more than 300,000 miles of transmission and distribution lines, millions of customers, and more than 7,200 power plants and generating facilities that each has at least 1 megawatt of generating capacity.

Electric utilities are responsible for maintaining the safety of their systems and planning the future power needs of their customers. Initially, voluntary standards were developed by the electric power industry to ensure coordination for linked interconnection operations. These voluntary standards were instituted after the historic power blackout in 1965 that left much of the northeastern United States (including New York City) and parts of Canada in the dark. Today, there are mandatory reliability standards for planning and operating power systems and for addressing security concerns at critical electrical infrastructure. These standards are developed and enforced by the country's designated electricity reliability organization, the North American Electric Reliability Corporation (NERC). NERC's activities are regulated and overseen by FERC.



"The National Power Grid," Microsoft® Encarta® Encyclopedia. http://encarta.msn.com © 1993-2004 Microsoft Corporation. All rights reserved.

Figure 2: National Power Grid Lines and Capacity[iv]

Challenges Facing the Power Grid

Investments in U.S. electricity infrastructure began in the early 1900s and were driven by the increased use of new transmission technology and central station generating plants. Given the age of the national electric grid, some existing transmission and distribution lines must be replaced or upgraded. New lines will also need to be constructed to maintain the electrical system's overall reliability.

There are several challenges to improving the infrastructure of the electric power grid:

- Siting new transmission lines (getting approval and obtaining rights to the necessary land)
- Determining an equitable approach for recovering the construction costs of a transmission line being built in one state when the new line provides benefits to out-of-state customers
- Ensuring that the network of long-distance transmission lines reaches renewable energy generation sites where high-quality wind and solar resources are located far from demand.
- Addressing the uncertainty in federal regulations regarding who is responsible for paying for new transmission lines; this uncertainty affects the private sector's ability to raise money to build transmission lines
- Protecting the grid from physical and cyber security attacks

Microgrid

A microgrid is a local energy grid with control capability, which means it can be disconnected from the traditional grid and operate autonomously. To understand how a microgrid works, we must understand how the grid works.

The grid connects homes, businesses and other buildings to central power sources, which allows us to use appliances, heating/cooling systems and other electronics. But this interconnectedness means that when part of the grid needs to be repaired, everyone is affected. This is where a microgrid can help. A microgrid generally operates while connected to the grid, but importantly, it can break off and operate on its own using local energy generation in times of crisis like storms or power outages, or for other reasons. It can be powered by distributed generators, batteries, and/or renewable energy sources. Depending on how it is fueled and how its requirements are managed, a microgrid might run indefinitely.

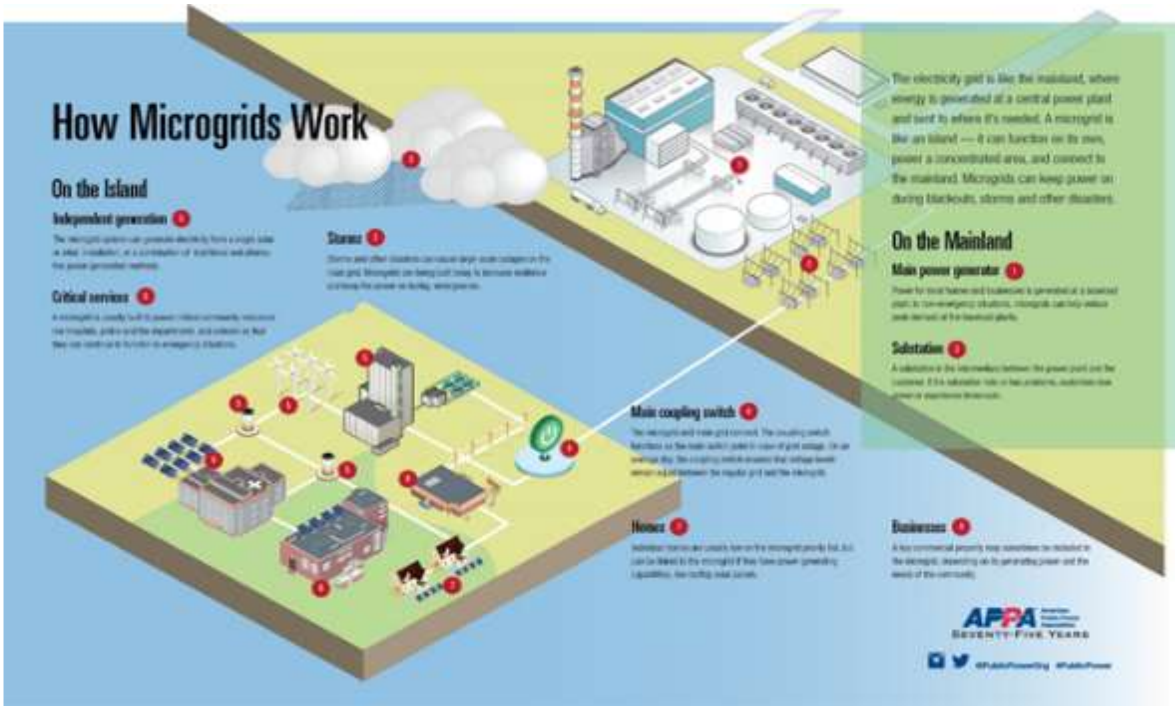


Figure 3: A typical Microgrid System[v]

Microgrid connects to the grid at a Point of Common Coupling (POCC) that maintains voltage at the same level as the main grid unless there is some sort of problem on the grid or other reason to disconnect. A switch can separate the microgrid from the main grid automatically or manually, and it then functions as an island. A microgrid not only provides backup for the grid in case of emergencies, but can also be used to cut costs, or connect to a local resource that is too small or unreliable for traditional grid use. It allows communities to be more energy independent and, in some cases, more environmentally friendly. A microgrid comes in a variety of designs and sizes.

It can power a single facility like the Santa Rita Jail microgrid in Dublin, California or a larger area such as Fort Collins, Colorado, a system designed to create enough energy for the entire district that equals to the amount of energy it consumes. Microgrids can be installed with technology that allows them to ride through a macrogrid failure without interruption. However, this technology is expensive, so many macrogrids instead power down briefly during a failure, and then power back up in island mode as quickly as possible.

Figure 4: Microgrids development and deployment in U.S[vi]

Microgrids are able to operate while the main grid is down. It can strengthen grid resilience and help mitigate grid disturbances as well as function as a resource for faster system response and recovery. Microgrids support a flexible and efficient electric grid by enabling the integration of growing deployments of distributed energy resources such as renewables like solar. In addition, the use of local sources of energy to serve local loads helps reduce energy losses in transmission and distribution, further increase the efficiency of the electric delivery system.

Microgrid Infrastructure and Architecture

Centralized generation, or conventional power generation, uses energy from fossil fuels (oil, gas, coal) or nuclear material to produce electricity. In this system, high voltage transmission lines from the central power station transport electricity through a long distance to the distribution network. The distribution network delivers power to the consumers (industrial, commercial and residential).

The recent, rapid growth of the Earth's population has increased the demand for electrical energy. This increases the levels of primary energy consumption (non-renewable energy), which consequently leads to the depletion of fossil fuels. South Africa's power blackout in 2007 serves as an example of what happens when available resources for supply, powered by the Eskom utility company, are temporarily unable to meet electricity demand (Grover & Pretorius, 2007).

The power generation industry also faces other challenges, including production losses, as well as the aging of infrastructure. The energy produced by a power plant is considerably reduced before reaching the end-users due to losses that occur in long transmissions lines during the transport of energy from the power plants to distribution points. It is also very difficult to incorporate new, automated systems into existing centralized control schemes that are 30 to 50 years old.

On top of that, the power industry is a major contributor to global warming and pollution. This increasing damage to the environment inflicted by the extraction of energy from conventional energy sources has led to serious thought in restructuring the current power industry. As such, many countries have engaged in the Kyoto Protocol to considerably reduce greenhouse gas emission by at least 34% by 2020 and 80% by 2050. Governments are now supporting the use of renewable energy sources (RES), in order to produce eco-friendly, clean power, having a minor impact on the environment.

Distributed generation (DG) is an approach that small energy sources (normally less than 50 MW) to generate electric power. These DG systems use non-traditional RES (i.e., other than large-scale hydropower) such as wind power, solar power, and biomass. Since these power plants are usually very close to the consumer, transmission line losses are considerably reduced.

Furthermore, the distributed power unit can be directly connected to the customer load or to the supporting distribution network. Besides providing cheaper electricity, DG has the advantage of clean energy because no fossil fuels are used. One of the most popular renewable energy sources is solar energy because it is abundant, accessible and easily converted into electricity. The demand for solar energy has on average increased by 20% to 25% per annum over the last two decades, and in 2015 the worldwide increase was 34% according to the European Photovoltaic Industry Association, or EPIA. More importantly the photovoltaic (PV) system is one of the most efficient renewable energy technologies, especially in remote areas where electricity from the central grid is not available and alternative sources of electricity are expensive.

A microgrid is a group of DG units, controllable loads, and interconnected and communicated storage devices, all operating together as a single system, using power electronic interfaces and controls for flexibility. It is essential to adopt a flexible control to a microgrid in order to be seen by a primary grid as a single controllable unit.

A connected microgrid is a grid that is connected to a utility grid at a static switch called the point of common coupling (PCC). It cooperates with the utility grid by adjusting the power balance of the utility grid in terms of intelligently facilitating the import/export of power. On the other hand, a stand-alone microgrid is referred to as a utility grid which is disconnected from the utility grid at the PCC, and operates autonomously.

In order to monitor the entire microgrid system, intelligent devices integrated into the DG system provides information to the individual microgrids. This information can be used by the energy management system to make better decisions with regard to the optimal amount of energy production and how to best use the generators for producing this electric power. The microgrid can do all of this without human intervention.

Different aspects of microgrid design include:

1. Sitting of microgrid within a distribution system
2. Optimal size of distribution generators in microgrid
3. Interaction between microgrid and distribution system during
    a. Normal supply condition
    b. Island operation

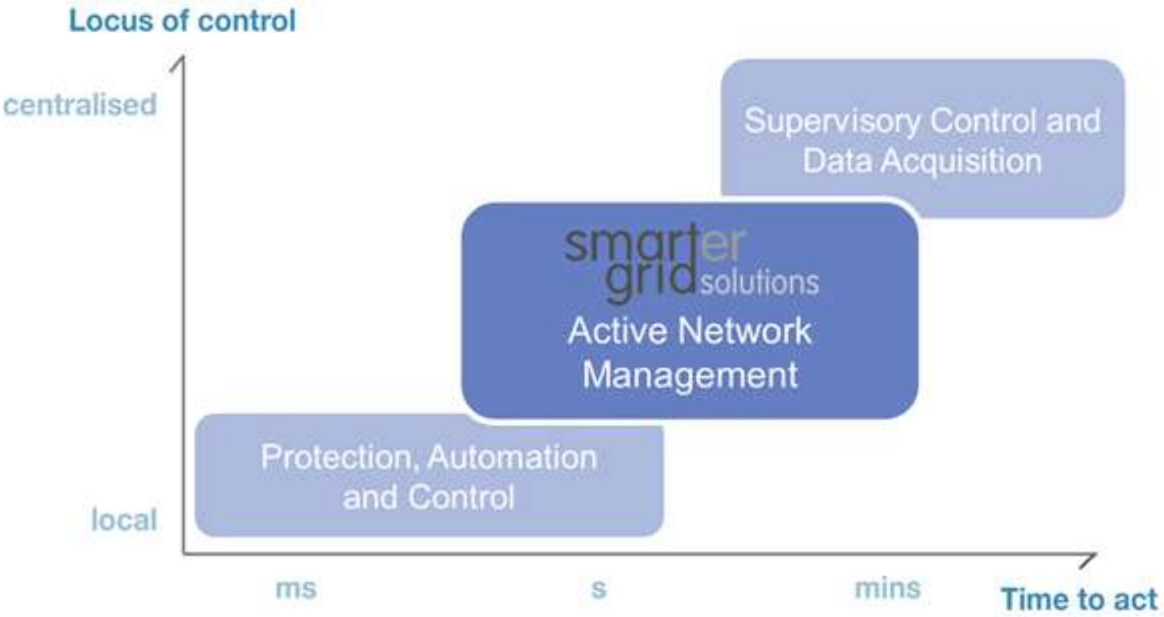


Figure 5: Active Network Management-End to End Autonomous Control Solutions [vii]

Primary Areas of Research to Improve System Architecture

- The research aims to determine the best implementation and design of smart control for microgrids utilizing solar PV, with the microgrid operating in isolation from the main electrical utility grid in the Ithaca area.

- A further aim is to determine how information can be efficiently used and intelligently exchanged between the different components of a microgrid.
- This research will also examine at how smart microgrid controllers can incorporate sensing and control algorithms to effectively stabilize the grid. Sensors will be analyzed in order to investigate how they can increase the information on load demand of the Ithaca community.

Current Microgrid Structure

An overview of the benefits of a microgrid system using DG based on PV, wind, and microturbines are discussed. Furthermore, the major problems associated with a microgrid system, frequency deviation and voltage drop, are also investigated. These problems are controlled by mechanisms such as droop control and master-slave methods. The control mechanism, voltage source inverter (VSI), is used to maintain the output voltage waveform and power sharing in a microgrid. There are also several other control methods for improving the power quality and load sharing of a microgrid connected to the main grid or operating in autonomous mode.

Most of the distributed energy sources interface with the utility grid and to the customer loads through a DC-to-AC VSI[viii]. The inverter is an important component of the microgrid, forming the main interface component. It integrates the DC voltage of the renewable energy source with the AC voltage requirements of the demand load and the grid utility. It is used to stabilize the grid by controlling the voltage, frequency, the active power[ix] and reactive power[x].

Fundamentals of a Microgrid

Low and medium DG infrastructure is in rapid development around the globe. They are powered by renewable, non-conventional generators which include fuel cells, wind turbines, and PV systems[xi]. Normally, they are used to augment the utility grid during peak hour load, when there is a shortage of supply. They can also provide support to the grid when the main grid system fails. In recent years, the structure of microgrids has gotten more complex. They are formed by a grouping of an arrangement of loads forms a cluster, coupled together with parallel DG units. Small generators can be incorporated into the power system. In the traditional method, a small generator unit was used to reduce the impact of grid operation in each interconnected microsource. When there is an outage in the grid network, it will systematically affect and shutdown the generator units. Conversely, in a microgrid, when the grid network is off and the power shuts off, the microgrid will systematically disconnect from the grid network and will operate independently.

Microgrid Structure

The structure of microgrid consists of five major components. These are microsources (power sources), loads, storage devices, control systems, and the point of common coupling (PCC).

These five components are connected to a low voltage distribution network. The low voltage distribution incorporates a variety of microsources and different types of loads that are supported by the power electronic interface. At the PPC, the microgrid is coupled with the main medium voltage utility grid. The PCC determines the mode of operation, providing synchronization and controlling grid operation.

The function of CB4 (shown in the figure below) is either to connect or disconnect the operation of the microgrid from, or to, the main grid. The operation and management of a microgrid are supported and coordinated using the microsource and central controller to ensure the overall stability of the system.

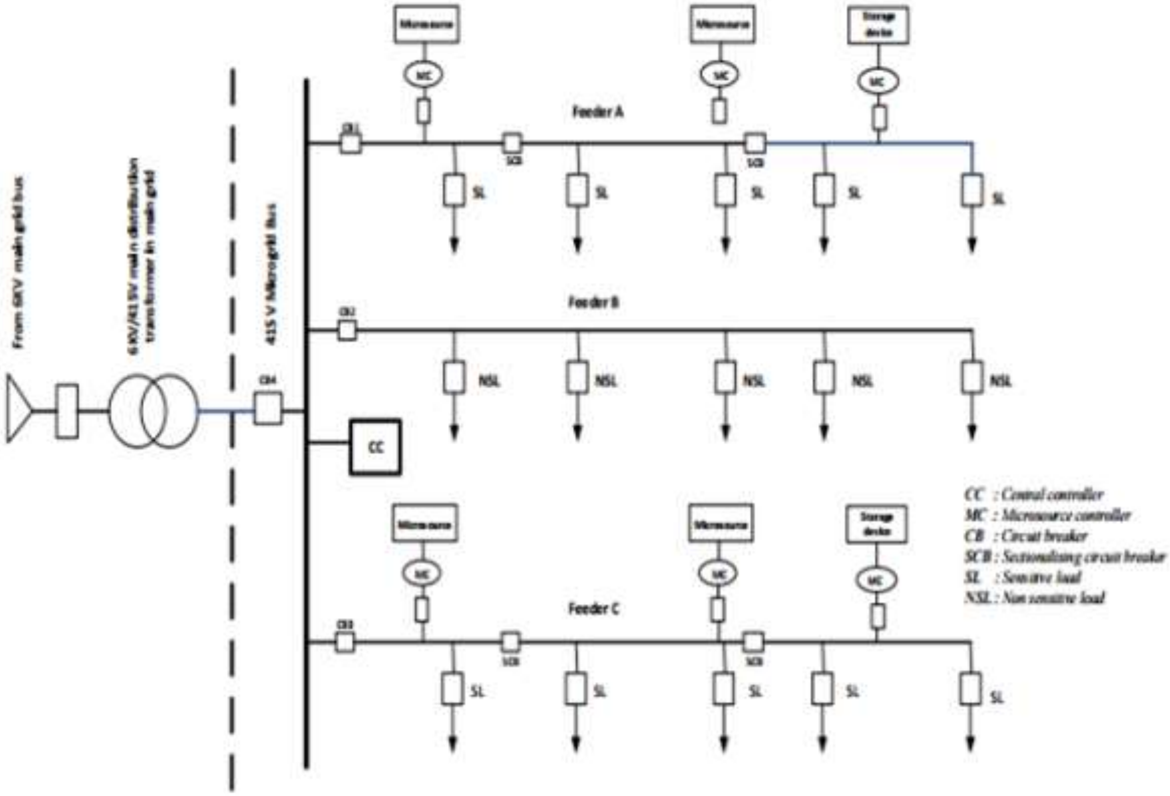


Figure 6: Typical microgrid configuration[xii]

<u>Microgrid Types</u>

DC Microgrid System

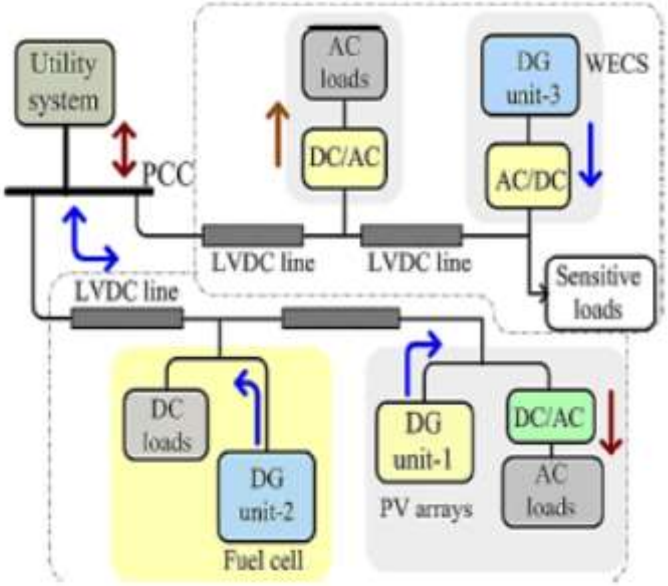


Figure 7: Concept of a DC microgrid system with DG units and mixed load types[xiii]

AC Microgrid System

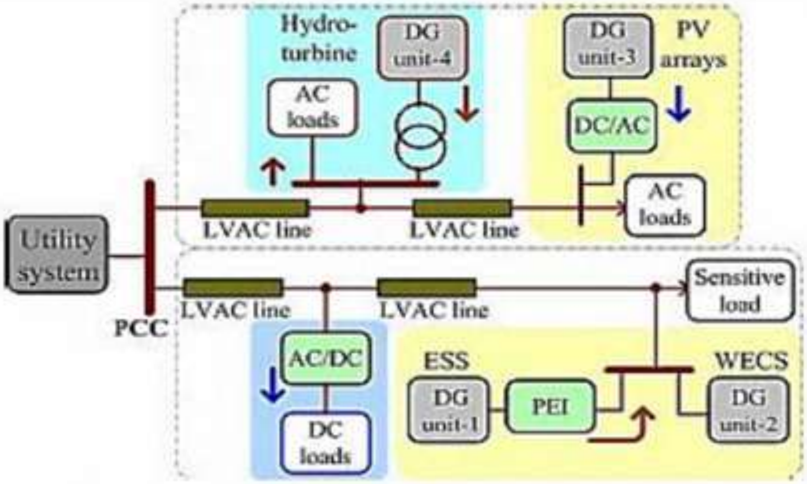


Figure 8: AC microgrid Structure with DG units and mixed types of loads[xiv]

Distributed Generation Types and Technologies

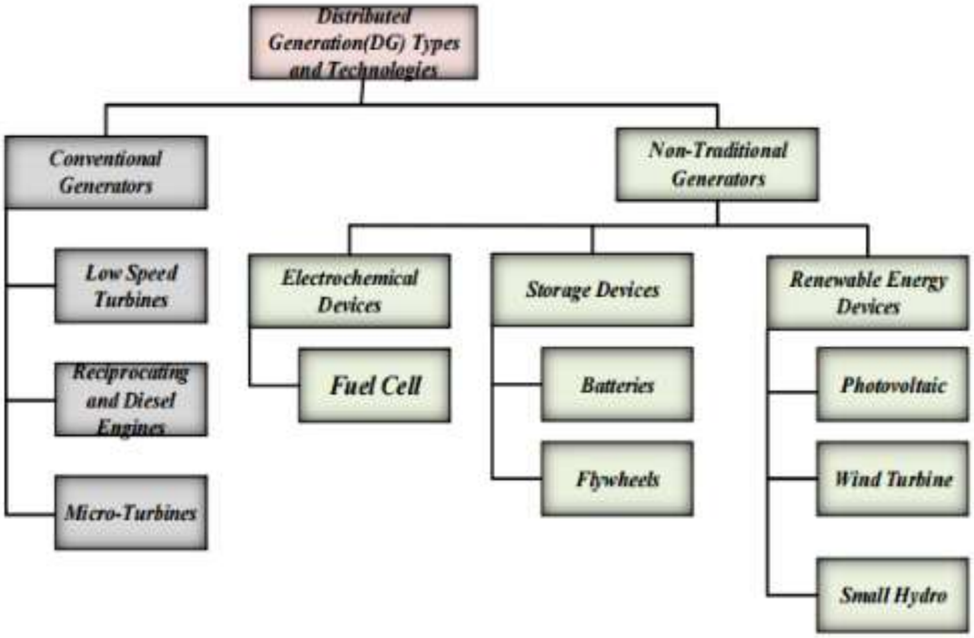


Figure 2.6: DG types and technologies

Figure 9: Algorithms for Maximum Power Point Tracking[xv]

Different algorithms have been developed to spontaneously track the peak power point of a solar PV module. The common method is maximum power point tracking (MPPT) of a PV system, where the maximum power possible is extracted. Popular controllers for PV systems developed using MPPT methods are:

- The perturbation and observation (P&O) algorithm
- Incremental conductance (INC)
- Parasitic capacitance
- Voltage-based peak power tracking
- Current-based peak power tracking

Microgrid Control Layer

The microgrid control system makes sure that the ensemble of control tasks is achieved. The entire control operation is located at three control layers in the microgrid as seen in the figure below.

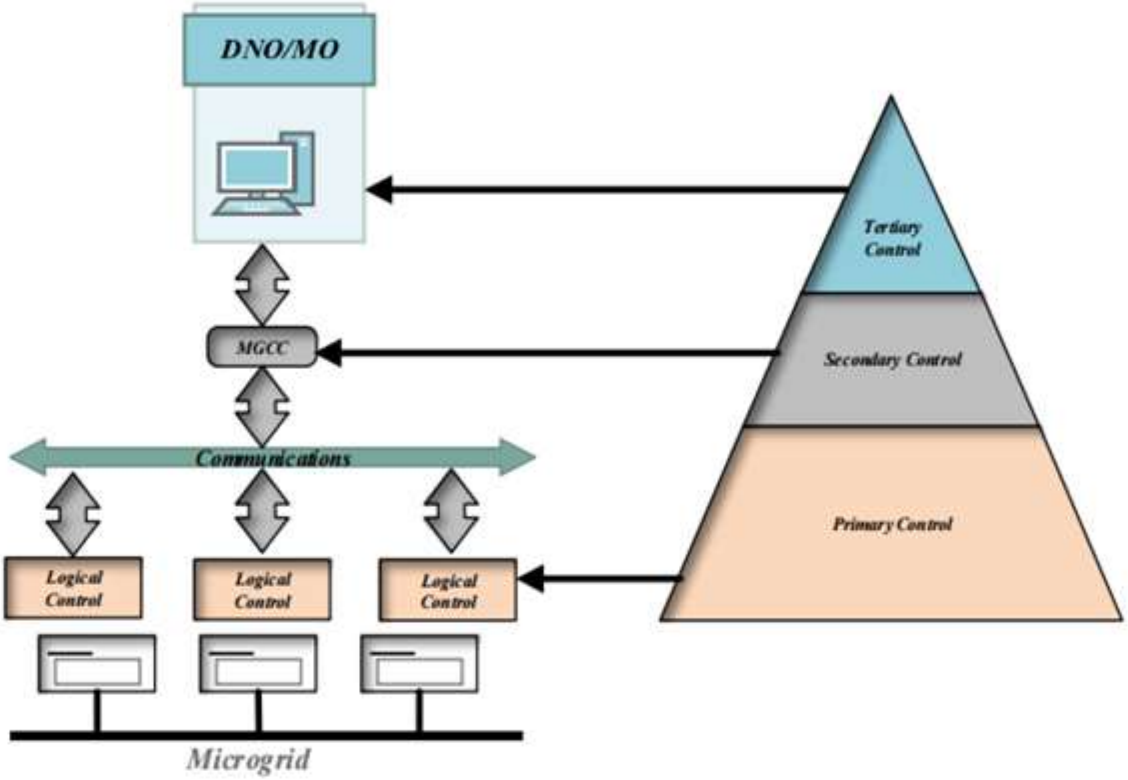


Figure 10: Microgrid Control Structure

- The primary level is the lower level. It contains the local control, which is responsible for the control of distributed energy resources (DERs), some local load, and the balance of the active and reactive power. At this level, some decisions can be made locally when a microgrid is operating in decentralized control. On the other hand, when it is operating in centralized control, it will receive a set point from the MGCC.
- The second level refers to the microgrid central controller (MGCC); it is the area where DER clusters are integrated into the microgrid. The MGCC is in charge of stabilizing the voltage and frequency within a specific, limited range at the PCC. It is also responsible for controlling the active and reactive powers dispatched from an individual DER.
- The third level is the distribution network operator (DNO) control, coupled with a market operator (MO). This is situated in the main grid. It is the upper management area and it facilitates the buying and selling of energy between consumers.

Control Involving Communication

The active load-sharing method is used in parallel, connected microgrid converters. Inverter control is based on communication that relies on sharing information among different microgrid generators. Varying information from inverters at different load conditions converge to a centralized microgrid controller[xvi]. The microgrid controller in turn gives specific control commands to each individual inverter unit. Communication between the microgrid controller and the inverters can involve the following control techniques:

- Master-slave control
- Current limitation control
- Circular chain control (3C)
- Average load sharing control

This approach of control, based on communication, represents a critical need for the intercommunication lines. However, the active load-sharing method decreases system reliability and expandability.

Control With No Communication Inverter

Inverter control without communication is mainly based on droop control. This scheme adjusts the output voltage and frequency in response to the active power (P) and reactive power (Q) delivered by the inverter. Each DG inverter has the ability to regulate the output voltage and frequency, while at the same time sharing the active and reactive power command. This method identifies power sharing and provides signal injection in a decentralization system. However, this signal produces some variation in the output power. Frequency and voltage droop techniques are used for power sharing in non-communication based systems. Drooping the frequency allows each microgrid generator to deliver real output power and share the reactive power.

The droop method does not require communication signals between units in parallel. Therefore, it enhances the reliability of the system and cost is reduced. Nowadays, the droop method is considered to be a standard control method in microgrid systems. However, this method is inadequate for the detection of voltage measurement errors. The errors that occur during current/voltage measurement of feedback signal will destabilize the operation of power sharing in the system.

Local Control of Distributed Generation Structure in the Microgrid

The distributed generation sources are normally connected to the main grid or to the load through the interface of power electronics, which manage the power and the output voltage. Therefore, the implementation of droop control, within the context of controlling distributed generation, is implemented to connect inverters to the energy source in the electrical system. Moreover, power electronic systems will interact with microsources and local controllers. In this process, they will be responsible for active and reactive power control, data storage for fast load tracking, and load sharing through power-frequency control. Multiple control strategies have been introduced to eliminate or lower the current flow among parallel distributed generation sources. Among the adapted controls is the master-slave control method which equalizes the load current shared between the inverters.

A modular control method has been proposed with the objective of eliminating signal communication between the inverters connected in parallel. Although this control method produces a high reactive power, it is insufficient for the requirements of the capacitors.

Moreover, Hanaoka et al. (2003) have analyzed the behavior of inverters in parallel operation when using a power protection technique compared to using the power deviation technique in the system. In their experiment, the power protection performs better unless the line resistance increases and influences the phase and amplitude difference.

Other authors (Yao et al., 2007) presented a frequency voltage droop method for a parallel inverter. In this method, four compensation loops are added to the conventional droop method. The results show improved execution of individual inverters. The response and power sharing accuracy were also improved. However, the traditional droop control is inadequate for the elimination of the circulation of current. This is due to the low efficiency of power sharing in a complex situation, where the system is characterized by the coupled, active and reactive power.

Moreover, Sao & Lehn, 2008 proposed that the voltage power droop/frequency reactive power, should be designed to control several voltage source converters (VSCs). The voltage power droop/frequency reactive power performs in a parallel microgrid in both autonomous and grid-connected modes. Energy management is improved using the droop controller. At a low voltage, traditional droop control, using frequency and voltage magnitude droop, introduces instability in a microgrid. This instability is detected in the inductive line impedance. The stability of the system is compromised by many factors, for example, a high R/X ratio (line resistance to reactance ratio) makes the autonomous system more vulnerable to voltage collapse.

However, another method called the virtual ω-E frame droop method overcomes the difficulties caused by the traditional droop and improves the stability. Like the traditional droop method, the ω-E frame droop method controls the power sharing between DG units in autonomous mode by decoupling real and reactive power control. Several authors (Guerrero et al., 2009) proposed a method for controlling the parallel connection of an uninterruptable power supply (UPS) by implementing the droop control scheme. The droop method utilizes the phase and amplitude adjustment of the inverter to control active and reactive power flow. The droop method was readily adapted for parallel connection to UPS systems in both autonomous and grid-connected modes. The droop control strategy resulted in good steady-state regulation and good transience in sharing linear and nonlinear loads.

Other authors (Majumder et al., 2010) offered a relevant control system that deals with the demands in DG units of a microgrid by simulation. These others used PSIM simulation software for controlling the demands of DG, and applied droop characteristics to active and reactive power (PQ) control, as adopted for parallel DG. This was done in order to establish a reference power when the microgrid is connected to the main grid. In addition, the frequency and voltage control are adopted to act on each DG output by adjusting them to share the load power once the microgrid is disconnected from the main grid. PQ control is used in renewable energy such as PV and wind generation systems, and VF control is used for fuel cells and gas turbines. The simulation result showed that the control strategy is effective and leads to better performance in satisfying the demand.

Some authors (Majumder et al., 2010) discussed the advantage of angle droop control over frequency droop control to avoid the limitation of a frequency. Hence, it is beneficial and convenient to use angle droop over frequency droop for load sharing.

Moreover, Majumder et al. (2010) investigated the load sharing with the microgrid in autonomous mode. For a weak system, a high gain angle droop control performs well in load sharing. However, it has a side effect on the system stability. Nevertheless, an additional loop is suggested for the traditional droop control of each individual DG unit in order to stabilize it while the system is still implementing the high angle droop gains. Renewable energy sources (RESs) in microgrids are faced with a problem of active power balancing, which has an impact on the frequency in autonomous operation (Serban & Marinescu, 2011). The RESs of microgrids are subject to frequency control, mainly at the energy storage units in which it compensates for the difference between parallel DG production and the load power demand. However, it is difficult to track an instantaneous frequency measurement like that of active power. Therefore, the phase-locked loop is used to measure the instantaneous frequency of the national electricity grid. The parallel inverters of microgrids supply power to the load by exploring active power versus voltage frequency and reactive power versus voltage magnitude of droop controls. The variance in frequency, phase angle, and voltage magnitude affect the multi-inverters of a microgrid by enabling unwanted currents to circulate. Even a small change in voltage magnitude will drive the circulation of current in the parallel AC system.

Trujillo Rodriguez et al., 2013 emphasized reconfiguration of the inverters, this would be achieved by adding some functionality by allowing micro-inverters to operate in both autonomous and grid-connected modes. It is used within PQ control strategies in the inverters, via sharing the power delivered to the loads. These inverters keep the same control algorithm throughout the transition. The retained control algorithm and the inverters overload when changing from a grid-connected to an autonomous mode. The operation of the wind and PV generators must be kept at the maximum power set point by using the PQ control method.

Due to the shortcomings of the master-slave control method, the peer-to-peer control method is limited in the demand to the better control inverters (Wei et al., 2012). However, based on the simulation result using MATLAB/SIMULINK, the combination photovoltaics, PQ and droop control substantially solve the problem of parallel inverters.

Problem and solution of microgrid control objective:
Some authors (Serban & Serban, 2010; Moreira et al., 2007) pointed out the problem related to in-line frequency deviation when batteries are overcharged. This problem causes an unbalanced supply and frequency regulation; also, it has an effect on the accuracy of the load sharing and the

accuracy of the voltage regulation. This trouble is resolved by manipulating the direction of the real power (P) with respect to battery voltage regulation.

Other authors (Piagi & Lasseter, 2006; Lasseter, 2011; Lasseter & Piagi, 2006) focused on the problem of the reactive current circulation that occurs with any change that takes place in load impedance (ZL), output impedance (ZO) or line impedance (ZLine). This causes a low ZL among the DERs in the microgrid system and affects the voltage regulation. One possible solution is to change the local set point in a way that increases the set point at the inductive reactive power (QL) and decreases the capacitive reactive power (QC) (Wang et al., 2012; Azmi et al., 2013; Kim et al., 2008).

A possible imbalance of reactive power can arise when there is a change in Z-Line. It may disturb the accuracy of load sharing and the accuracy of voltage regulation. As a solution, Mihalache (2013) suggested the injection of a high frequency signal through the power line, but the implementation of this method comes with the disadvantage of the limiting the power rating of the DERs.

The imbalance in reactive power when there is a change in Z-Line leads to a disturbance in the accuracy of load sharing, as well as in the accuracy of voltage regulation. As a potential solution some authors (Chandorkar et al., 1994) suggested adding external data communication signals, but the disadvantage of doing so, is low reliability and low expandability.

The difference in distances between the various DERs and the MGCC, results in an imbalance in the line impedances. The imbalance in Z-Line affects the control accuracy objective of load sharing of linear and non-linear loads. As part of the solution Guerrero et al. (2005; 2009) insisted that ZO should be properly designed. Several authors (Wang et al., 2012; Peas Lopes et al., 2006; Ito & Lyama, 1997; Wang et al., 2012) have attempted to improve the problem of imbalanced Z Line by modifying the distances between the various DERs and the MGCC. These changes had an immediate negative impact on Z-Line. As a consequence, modifying the distances induces some irregularity on the accuracy of the load sharing for linear and non-linear loads. The implementation of an adaptive and virtual ZO is proposed as a solution to the problem. The outcome of this proposed solution results in good reactive power sharing, regardless of ZL (Guerrero et al., 2009; Hatziargyriou et al., 2005). Other authors (Kamel et al., 2011; Peas Lopes et al., 2006; Mihalache, 2003) claimed that the droop method is not efficient when applied to the load sharing, including the sum of ZO and ZL when they are not balanced. It is caused by an imbalance in ZO because ZL is always affecting the active and reactive power. A solution to the problem is the use of the adaptive virtual ZO method, with emulating resistive, and reactive loads with less loss (Z. Zhang et al., 2010; Guerrero et al., 2009; Barklund et al., 2008; Dimeas & Hatziargyriou, 2005). Unequal, instantaneous supply and demand can cause a problem of frequency deviation. This badly affects the frequency regulation of the system. The method used to solve the problem of frequency deviation, is to change the no-load generator speed or the power dispatch (Guerrero et al., 2011; Yubing et al., 2008; Blaabjerg et al., 2004).

The other control objectives of load sharing include balancing the sum of ZO and Z-Line, which always affects the balance by influencing Z on PQ.

Chandorkar et al. (1993) proposed a solution to eradicate the problem by using an interface inductor between the inverter and the load; the drawback however, is that it is heavy and bulky. A deviating frequency and voltage occur when unintentional autonomous states occur due to the loss of the load or imported power. This causes disturbances in the on-going frequency regulation of the system.

One suggestion to solve the problem was to incorporate a load shedding controller module. This technique systematically disconnects a number of the important load feeders (Delghavi & Yazdani, 2012; De & Ramanarayanan, 2010). The control of voltage regulation and load sharing are difficult to implement due to the resistive nature of the distribution network. Thus, the control objective of voltage regulation and load sharing become a priority.

The proposed solution to the problem is to use the voltage power droop technique; this involves the direct relation between power and voltage (Delghavi & Yazdani, 2012; Sao & Lehn, 2006; Katiraei et al., 2005). Failure of any functions associated with a microgrid will result in failure of the microgrid itself. So the potential solution could be in the triple-layer control structure comprising DNO, MGCC and local control (LC) which are respectively the primary, secondary and tertiary control layers (Delghavi & Yazdani, 2012; Colet-Subirachs et al., 2012; Katiraei et al., 2008; Meiqin et al., 2008; Piagi & Lasseter, 2006). The problem connected to any failure related to load sharing criteria, is produced by the load and the changeable energy demand. This is due to the change in load, which affects the active and reactive power. The change in active and reactive power has a severely detrimental effect on instantaneous equal load sharing, as well as on voltage regulation.

Some solutions to the problem have been suggested by different authors, such as (Sun et al., 2003; Martins et al., 1995) who used the centralized load technique, and Chen et al.(2001) and Chiang et al. (2004) who implemented the average load sharing technique. Several authors (Li et al., 2004: 3; TsaiFu Wu, 2000) proposed current limitation control as a solution.

Other authors (Guerrero et al., 2008; Tsai-Fu Wu, 2000) suggested the use of circular chain control (3C). Zhao et al. (2012) and Holtz & Werner (1990) solved the problem by using the master-slave method. These methods were used with communication interconnections which are based on active load sharing techniques. Others like Zhao et al. (2012), Ustun et al. (2011), Guerrero et al. (2011), Serban & Serban (2010), Katiraei et al. (2008), Peas Lopes et al. (2006), and Chandorkar et al.(1994), used the droop method without communication interconnections, which provides high reliability and flexibility. The accuracy of the load sharing is affected by the harmonics. Unbalanced power is poorly compensated for, due to nonlinear and unbalanced loads when there is a low ratio of distribution ZLine. Some scholars (El Khateb et al., 2013; Rahim et al., 2010; Cheng et al., 2009; Guerrero et al., 2005; Mihalache, 2003; Ito & Iyama, 1997) suggested the use of frequency components, active power, reactive power and distortion power as a solution to the unbalanced power.

Another solution to the problem is the implementation of an adaptive virtual ZO. Thus, the virtual impedance has no power losses and can provide "plug & play operation" (Silva et al., 2012; Kamel et al., 2011; Peas Lopes et al., 2006; Mihalache, 2003; Ito & Iyama, 1997). The frequency deviation problem occurs when there is intentional autonomous with no synchronous machine to balance the demand and supply during the unbalanced demand and supply. As a solution to the problem, some authors preferred a single master and multi-master operation (Kamel et al., 2011; Georgakis et al., 2004; Guerrero et al., 2007).

Central Control of Distributed Generation in a Microgrid

An energy management system makes decisions by providing the active power and voltage set points for the micro-source controller (MC), while the basic micro-source control executes the order from the central control (CC). Several authors (Katiraei & Iravani, 2006) acknowledged that they used real and reactive power droop control for management strategy in electronically interfaced DG units. This is implemented 34 times in the context of multiple DG units by examining the parameter gains of real and reactive power control. This control method is based on investigating the dynamic behavior of a microgrid, and also selecting the control parameters utilizing eigenvalue analysis.

The study showed that electronically interfaced DG unit controls have an important effect on the behavior of a microgrid in autonomous mode.

Several authors (Khan & Iravani, 2007) worked on hybrid control techniques which involve an extension of the finite state machine. This has brought some improvement to different modes of operation of a microgrid. The structure of hybrid control as a supervisory controller is situated at the top level of the hierarchy and interacts with both the unit level regulators and the regulated plant. The simulation showed that the concept of hybrid control has been run to analyze the supervisory scheme. Smart grid development is the new research focus area in many countries. This focus has resulted in better security features, higher efficiency, and improved environmentally friendly operation of renewable energy sources, thus surmounting the difficulties normally encountered with distributed generation in power systems.

Several research angles, from the architecture to the control side, have been undertaken and tested in the laboratory. Some authors (Kim et al., 2011) examined the management of the power flow among microgrid inverters in the flexible-phase. In order to improve the power loop dynamics, this approach involves implementing the interaction of droop control and proportional derivative (PD) control in autonomous mode. The power factor is controlled at the PCC[xvii] by the combined operation, a droop controller and a PI controller, with the microgrid in grid-connected mode. Hence, the system can operate smoothly in both grid-connected mode and autonomous mode. Alternatively, several authors (Azevedo et al., 2011) suggested the master-slave configuration as an alternative and suitable option to droop control. In the master-slave configuration a master could be seen as a single inverter that alternates between two modes. Therefore, this master inverter will be controlling the voltage in grid-connected mode, and the current in autonomous mode, while other inverters are slaves and control the current. In order to synchronize with the system, the master inverter has the ability to connect smoothly in either mode by using a frequency locked loop as opposed to a phase-locked loop. This system also responds as a voltage reference oscillator in accordance with an input selector.

In addition, Cheng et al. (2012) stated that a master-slave control strategy can perform a seamless, smooth transient between grid connected and autonomous operations. This means that when the microgrid is connected to the 35 utility grid, the PQ control is applied to both the master unit and slave units. While in disconnected mode, VF[xviii] control is applied to the master unit and PQ control is applied to the slave unit. Another control method used for power management is: decentralized control Agent-based framework control is used in a decentralized system for microgrid system. Where each agent technology takes full control of its sector without knowing what is happening in the rest of the system. They are acting in the sense of organizing and making decisions without any intervention, even from the central controller. It runs on a software environmental platform.

Similarly, a multi-agent system (MAS) is used to control a set of small power producing units and to take action in case of autonomous mode, with respect to power quality, demand and supply, and also allowing communication between microgrids (Dou et al., 2009). Furthermore, several authors (Yunusov et al., 2011) stated that the multi-agent in energy management system controls the distributed generation and also the demand. For them, it is the ultimate solution to overcome loss in a transmission line, which is forcing the system to be at low efficiency. Therefore, decentralization controls are used to improve the efficiency by applying suitable control strategies and methods like agent base on DG. Instead, they presented an overall view of a multi-agent based model in the hierarchical and distributed energy control of microgrid.

The multi-agent is designed under C++ development for client and server. This concept of "agent based", can be applied to Energy management system of microgrid (EMS-MG) and is explained in detail with multiple functions applicable to the micro grid at three different levels of control (Meiqin et al., 2011). Several authors (Shah et al., 2011) mentioned how to enhance the power management achieved on smart micro-grid by acting on a power electronic transformer (PET) at the point of common coupling (PCC) using software simulation MATLAB/SIMULINK. This strategy has been employed within the decentralized controller on the microgrid. It utilizes the change in the grid frequency as a parameter in the presence of the active power control, without the necessity of implementing grid synchronization. Hence, the power management system of the microgrid is improved, while the grid is connected because of the bidirectional active power flow control at PCC. However, renewable energy integrates AC and DC in the microgrids, so (Guerrero et al., 2011) developed a hierarchical control derived from ISA-95 and the electrical dispatching standards.

The droop control is used to prevent current to flow among converters in the absence of commutation when the prime mover and the microgrid are interfacing. Most of the time, the power electronic converters behave like a voltage source. The hierarchical control has three- 36 level control, which can be applied on AC and DC on microgrids. It is enabling the MGs to operate in both autonomous and grid-connected modes, as well as, in transient between the two modes.

Firstly, the control of AC microgrid emulates a large-scale power system AC grid, showing the concordance between both systems. Secondly, the hierarchical control in DC microgrid exhibits novel characteristics, which may be helpful applications in distributed power systems, such as telecommunication DC-voltage networks and more. In contrast, (Vargas-Serrano et al., 2012) presented the master-slave control strategy to regulate the main energy storage VSI (Voltage Source Inverter) developed in the microgrid on account of reducing the communication between VSI and microgrid controller. In addition, this control strategy seems to achieve a seamless transfer between grid connected and autonomous modes with minimum communication.

The micro-source controller (MC) of the battery energy storage system (BESS) uses droop curves to follow the set points with a linear droop function and it has three levels of control, namely; high level, medium level, and low level. The high level controller acts according to the droop function parameters from the central control (CC) and also depending on micro-grid operating conditions. The mid-level controller generates simultaneous voltage amplitude and phase references for the VSI[xix] output. The low-level controller is based on hysteresis, SPWM[xx] or SVPWM[xxi].

Moreover, some authors (Wang et al., 2012) insisted on a design of an intelligent multilayer supervisor control and smart grid communications based on MATLAB simulation. The structure of the supervisory control brings more organization in the control balance to participate in optimizing energy cost and to exchange information with the smart grid by dealing with the end users demand. However, (Piacentini, 2012) developed a program in LabVIEW with a set of instruments, which are proposed to be used in the smart grid. This enables easy monitoring and supervising of the system by making decisions. The LabVIEW software is used to facilitate an easy management data. This comes to erase the use of FPGA or MATLAB. Besides, it uses multiple communication protocols to operate the entire system, which can be an advantage over other platform, because, one protocol cannot usually meet with the entire requirement of communication of the system.

A technique of double layer control is designed in microgrid energy management operation in the stand-alone and connected grid mode. This controller consists of two layers which are the schedule layer for an economic operation scheme based on forecasting data, and the dispatch layer which provides power for controllable units based on real-time data. Therefore, it improves microgrids to operate economically, safely, and stably (Jiang et al., 2013).

Other Control Methods Used for Power Management

Decentralized control Agent-based framework control is used in a decentralized system for microgrid systems. Each sector of the system is controlled by an agent, in full control of that sector, but oblivious to what is going on in the rest of the system. These agents act in the sense of organizing and making decisions without any intervention, even from the central controller. The framework runs on software environmental platform.

Similarly, a multi-agent system (MAS) is used to control a set of small power producing units. The MAS can take action on power quality in case of autonomous mode, control demand and supply, and also communicate between microgrids.

Furthermore, several authors (Yunusov et al., 2011) stated that in an energy management system, a MAS controls distributed generation, as well as the demand. For these authors, a MAS is the ultimate solution to overcoming transmission line losses; these losses cause the system to run at a low efficiency.

Therefore, decentralization controls are used to improve the efficiency by applying suitable control strategies and methods like agent-based DG. The authors presented an overall view of a multi-agent-based model in the hierarchy of distributed energy control in a microgrid. A MAS is designed using C++ development for both client and server.

This concept of MAS applied to an energy management system in a microgrid (EMS-MG) is explained in detail, outlining the multiple functions applicable to a microgrid at the three different levels of control (Meiqin et al., 2011).

Several authors (Shah et al., 2011) mentioned how to enhance the power management achieved on smart micro-grid, by using power electronic transformer (PET) at the point of common coupling (PCC). This strategy has been employed within the decentralized controller on a microgrid. It utilizes the change in the grid frequency as a parameter in the presence of the active power control, without the necessity of implementing grid synchronization.

Hence, the power management system of the microgrid is improved while the grid is connected, because of the bidirectional active power flow control at PCC. However, the microgrids renewable energy integrates AC and DC. Accordingly, Guerrero et al. (2011) developed a hierarchical control derived from the electrical dispatching standards. When the microsource and the microgrid are interfacing, droop control is used to prevent commutation between converters. Most of the time, power electronic converters behave like a voltage source. Hierarchical control has three levels, which can be applied to AC and DC in microgrids. Hierarchical control enables a MG to operate in both autonomous and grid connected modes, as well as, in the transient period between the two modes. There are two 38 advantages in using hierarchal control.

Firstly, the control of AC in a microgrid emulates a large scale power system AC grid, showing the concordance between the two systems. Secondly, the hierarchical control in a DC microgrid exhibits novel characteristics, which may provide helpful applications in distributed power systems, such as telecommunication DC-voltage networks. Vargas-Serrano et al. (2012) presented a master-slave control as a strategy to regulate the voltage source inverter developed in the microgrid, to reduce the communication between VSI and microgrid controller. In addition, this control strategy seems to achieve a seamless transfer between grid-connected and autonomous modes with minimum communication.

The microsource controller (MC) of the battery energy storage system uses droop curves to follow the set points with a linear droop function. It has three levels of control, namely; high level, medium level, and low level.

The high level controller acts in response to the droop function parameters from the central control (CC), and also depends on the micro-grid operating conditions. The mid-level controller generates simultaneous voltage amplitude and phase references for the VSI output. The low-level controller is based on hysteresis, SPWM, or SVPWM. Piacentini (2012) developed a set of instruments using a system design platform called LABVIEW.

He suggested that these instruments, used in a smart grid, would enable easy monitoring and supervising of the system, as well as decision-making. The LabVIEW software was used because it facilitated the easy management of data. The development of this set of instruments on the LabVIEW platform, could decrease the popularity of FPGA and MATLAB for this kind of application. Additionally, the instruments make use of multiple communication protocols to operate the entire system, which can be an advantage over other platforms, because, a single protocol cannot usually meet the communication requirements of the entire system.

Existing Control Methods within the Inverter

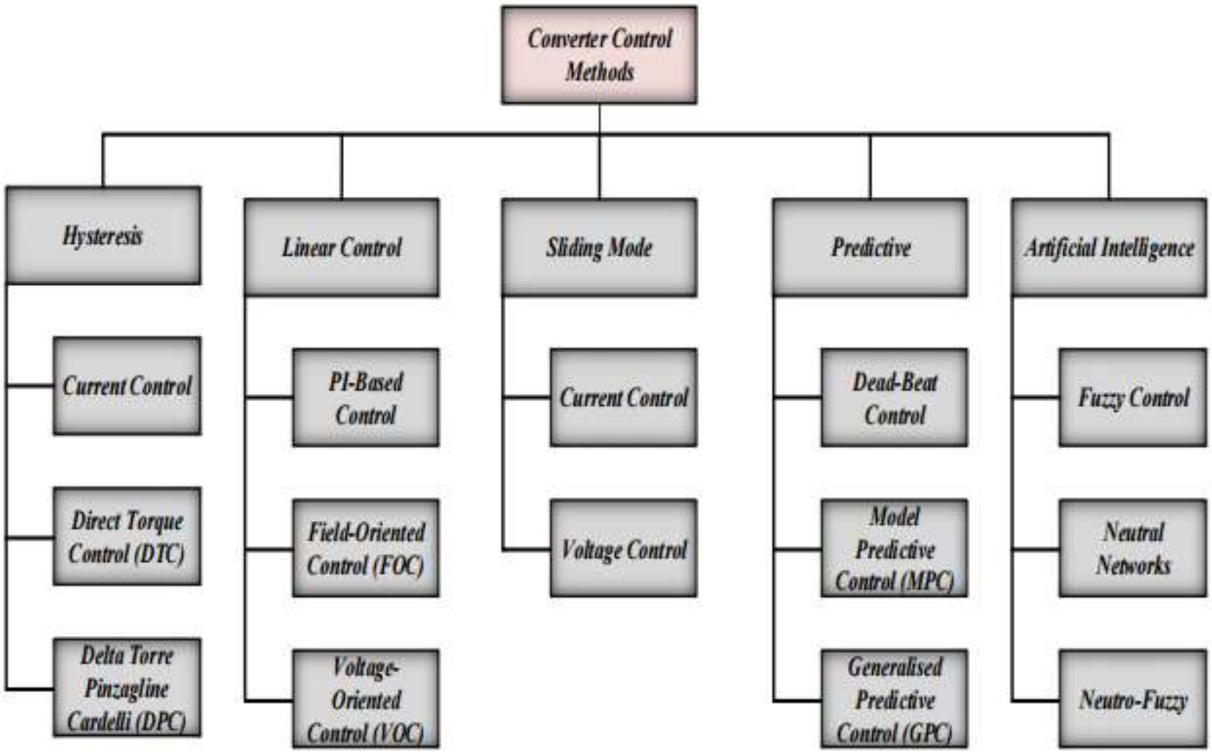


Figure 11: Control Schemes of Power Converters

Microgrid Smart Metering

AC microgrids may be associated with smart meters, communications, and remote controls; these elements will form the basis of future smart grids. The collection of data is an integral process in the operation of a smart meter within the microgrid. Smart meters can also be applied in the energy market of a smart grid.

The following examples illustrate development in the field: Luan et al. (2009) developed and implemented the design of a smart meter using Microchip dsPIC30F4011, embedded into the advanced metering infrastructure. The purpose of the smart meter they developed was to monitor consumption by the end-user and also to detect the occurrence of outage events.

By adopting the star topology, data is transferred wirelessly using ZigBee communication; this allows the ZigBee coordinator to initiate and maintain the ZigBee devices. The smart meter developed shows how much the smart meter can significantly integrate the advanced metering infrastructure (AMI).

The concept of a smart meter controller is an important component in the smart grid. It fulfils multi-functions between the utility control unit and the network interfacing with the information flow. Moreover, this smart meter can be involved in the marketing of energy, communicating with the smart appliances in the process, and regulate the frequency balance.

The communication between a smart meter, a smart server, and a smart regional 48 server, is based on a TCP protocol that deals with the congestion control and is secure from data losses (Jamian et al., 2011). Several authors (Chen & Klemm, 2011) developed statistical approaches for the malfunctioning of meter detection; data collected from different meters in real-time operation are statistically analyzed. The smart meter can optimize the decision-making process in order to manage those floods of data in an efficient way.

The smart meter can also detect anomalies and assist with forecasting load demand. Furthermore, some authors (Percec et al., 1995) have designed the smart meter to overcome the incapability of a traditional meter, which is unable to satisfy the demands of new generation of electricity supply devices. Smart meters display improved speeds of information collection in order to manage the electrical energy. These meters have the ability to make certain decisions and communicate with the central controller via wireless links.

The core of the controller is a TMS320C6474 DSP from Texas Instruments, which has multi-task capabilities. Similarly, other authors (Kulatunga et al., 2012) have developed a smart meter with ZigBee wireless communication, that works in conjunction with the micro controller TMS320C6474 in the HAN connected to the main grid. The design is built in an intelligent way so as to measure the instantaneous and accumulative consumption of the electricity value.

The demand side of the energy is managed by monitoring the daily energy demand as per the actual forecast, and availability of resources. This approach improves the security of the AMI and integration of key management schemes. However, other researchers (Sofla & King, 2012) proposed the optimization of the operation and guarantee the stability of a microgrid by using the hierarchical control strategy. This strategy incorporates advanced metering infrastructure and communication, supporting the higher decision-making which enables interconnection with a multi-microgrid (MMG).

Therefore, hierarchical control is an intelligent control scheme, composed of multi-microgrid features, and one that contributes a system which has commendable advantages. Additionally, other authors (Singh et al., 2013) proposed a smart meter architecture which, in case of power failure, sends data directly to the control center. The more efficient way of achieving this is to use two radios that permit the smart meter to cater for the needs of the smart grid on a large scale. The communication is established between the consumers and the production through the HAN/NAN concentrator, WAN aggregator and the control center.

Combined Heat and Power

The Ithaca South Hill (ISH) power system is a conventional power plant with independent production of power and heat. The ISH is complex system because it is consisted of hundreds of miles of high-voltage cables that serve thousands of residents. This power system utilizes combined heat and power (CHP) as an efficient method to produce both power and heat.

CHP, also known as cogeneration, represents the application of a series of reliable and cost-effective technology. It is a clean, efficient, and cost-effective choice to produce power because of its ability to generate two forms of energy, which are electrical and thermal, by using one type of fuel. Besides the contribution to meet heat and electricity demand, CHP also serves a function to reduce the greenhouse gases emitted during conventional power generation.[xxii] In the conventional power generation, the heat loss due to the efficiency of power generator is recovered by CHP. This heat is then converted into a useful form of energy for heating purposes.

CHP is a highly efficient system that is designed to power multiple large buildings, such as Cornell University. The efficiency of CHP could go as high as 80% compared to conventional power generator, which has an efficiency of around 45%.[1] As a result, consumers who use CHP have lower costs of electricity and heat. Another benefit of using CHP is its reliability under emergency conditions, such as natural disasters and failure caused by leakage in the major grid. This is because CHP is able to operate under "island mode" or isolation from the major grid. Therefore, CHP is a reliable back up for power outage.

CHP can be powered by a variety of fuels, including natural gas, coal, oil, and alternative fuels (biomass), which makes CHP is easy to be applied to small communities due to the availability of the fuels.[xxiii] In addition, biomass can be gotten from by-products from industrial, agricultural, or other commercial activities.

There are some limitations of using CHP system; it is better used only when there is constant demand of heat and power. Also, CHP is not ideal when there is another source of heat due to hot weather, like in tropical climate areas, Florida, and Arizona. In Ithaca, thermal energy demand lasts around 10 months per year. Therefore, CHP is a system that is feasible to be applied in Ithaca community.

CHP Process

There are two types of CHP systems, they are “topping cycle” (CHPT) and “bottoming cycle” (CHPB).[2] CHPT uses fuel to generate electricity or mechanical energy at the facility and recovers thermal energy from waste heat. CHPB, the least common one of the two, does a reverse process; first produces useful heat via fuel combustion or heat-generating chemical reaction and recovers exhaust heat which is then used to generate electricity.

CHP systems typically include heat engines, generators, heat recovery units, and interconnection components for electricity. The way this works is by the input of fuel into engines or turbines - such as coal, natural gas, biomass- to produce electricity by powering a generator. These engines/turbines dissipate heat as a result of powering the generator, which is then recovered in a heat recovery unit. The heat recovery unit then can take an input of water, which then combines with heat to produce either steam or hot water. This steam or hot water is then brought into cooling/heating systems that is delivered into buildings or facilities. The generator, produces electricity that then can either go to building and facilities and the rest of the grid.

There are 5 primary movers for CHP systems. These include gas turbines, steam turbines, reciprocating engines, microturbines and fuel cells. Below are the two main types of turbines to be considered, along with a typical breakdown of costs and facts.

Gas Turbines

One of the most efficient CHP system components is a Gas Turbine (GT), with a typical capacity range between 500 KW and 250 MW. A working gas such as ambient air enters the compressor, with then is fed with fuel in the combustor and ignited. The combustion products that result are then expanded through turbines to generate shaft power for the compressor and the electrical generator. The dissipated heat is then collected through a heat recovery unit, which is then distributed into different demanding units. This process is repeated and continuous. Typical efficiency for simple cycles range from 20% to 35%.[xxiv]

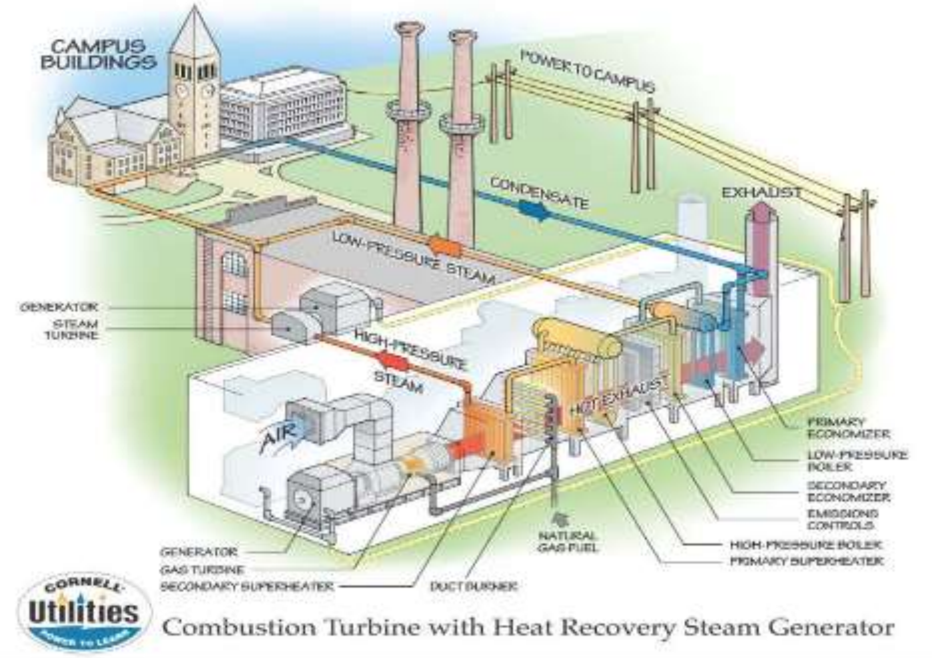


Figure 12: Cornell University's Ithaca Campus Combined Heat and Power System - Cornell Utilities.

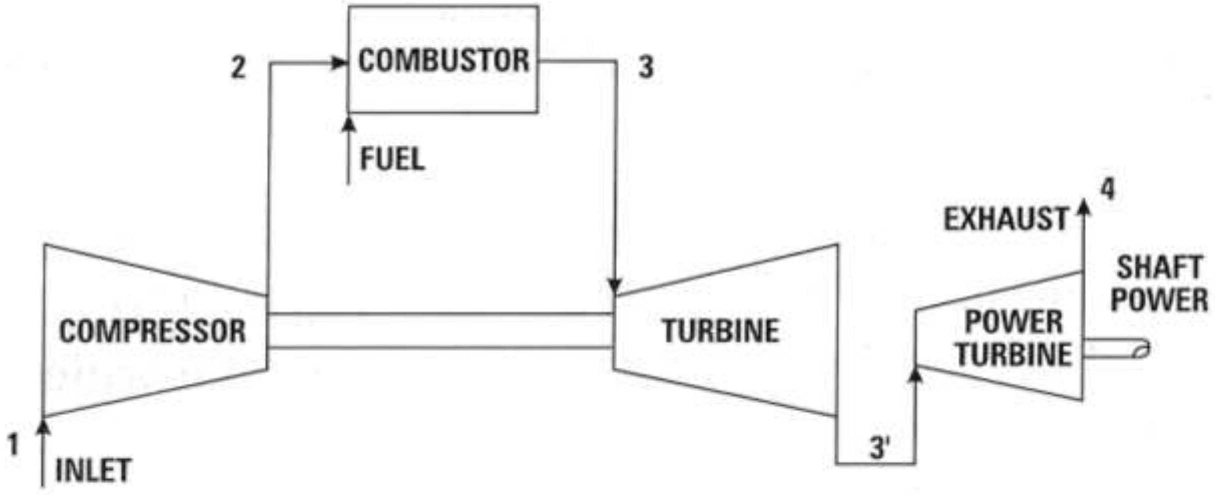


Figure 13: Gas Turbine Setup Diagram. U.S. EPA - Combined Heat and Power Partnership

<u>Steam Turbines</u>

Steam turbines (ST's) are similar to gas turbines in the overall set-up, but in this case fuel (includes natural gas, solid waste, coal - among others) is fed into a boiler where is combusted and produces high pressure steam. This high-pressure steam enters the steam turbine, which then produce mechanical power to generate electricity and the low-pressure steam or hot water leaves the turbine to be used throughout demanding units. Typical capacity for steam turbines can range from 50kW up to 250MW, and efficiency similar to those of a gas turbine. Figure 3 shows a set-up for a ST.

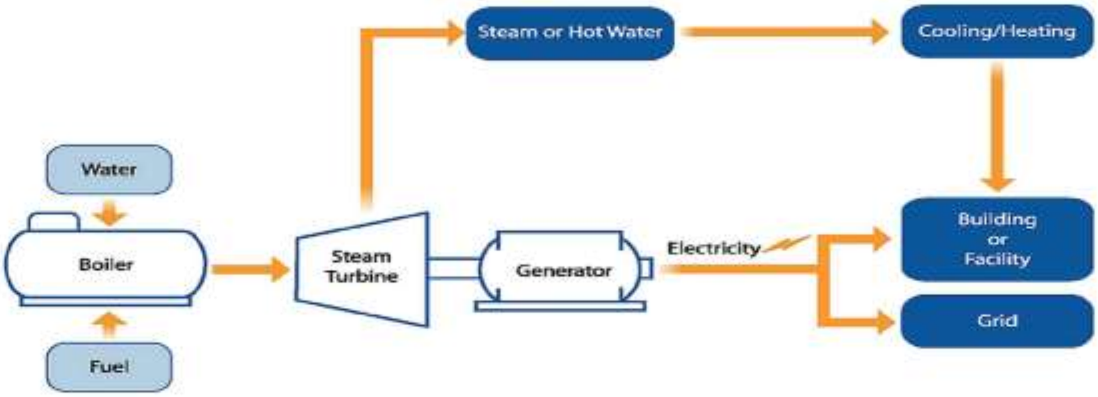
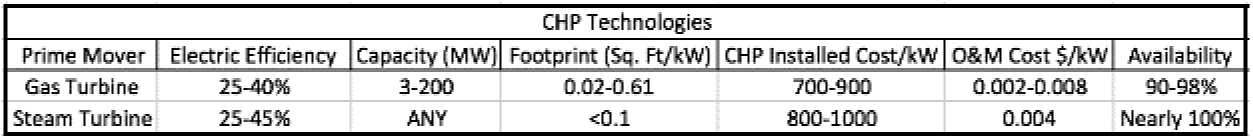


Figure 14. Steam Turbine Setup Diagram. U.S. EPA - Combined Heat and Power Partnership

Below are some useful facts regarding operating costs, efficiency, among other facts.[xxv]



CHP Technologies						
Prime Mover	Electric Efficiency	Capacity (MW)	Footprint (Sq. Ft/kW)	CHP Installed Cost/kW	O&M Cost $/kW	Availability
Gas Turbine	25-40%	3-200	0.02-0.61	700-900	0.002-0.008	90-98%
Steam Turbine	25-45%	ANY	<0.1	800-1000	0.004	Nearly 100%

Table 1: CHP Tech. Table

Natural-Gas-based Generation

In this section the technologies as well as possible suppliers related to natural-gas-based energy generation will be presented.

<u>Reciprocating Engines</u>

Reciprocating engines have been historically operated mostly with liquid fuels that are gasified right before or at the moment of injection into the piston chamber. Although conversion from older engines to gas-based engines is possible, several manufacturers have started in the past decades to offer an engine optimized (e.g. with adequate compression ratio) for gas use.

Because of the fact that the underlying technology is widely applied and known by the market (from bicycles to ships) and maintenance can be executed without the need for highly specialized labor, reciprocating engines have secured a significant share of the gas-based energy generation mix. The units tend to be smaller, more modular, than the utility scale gas turbines and therefore offer the possibility of more discrete ramping.

CAPEX [$/W]	**Operating Cost [$/kWh]**	**Typical Power Range per Unit**	**Typical Gas-Electricity Efficiency**	**Possible Manufactures**
~1$/W	~0.005$/kWh	20kW - 10MW	~35-40%	Caterpillar[xxvi]

Table 2: Reciprocating Engine Variables

Fuel Cells

There are only a few of commercial scale fuel cell systems available in the market. One example is BloomEnergy in Cafilornia. The technology BloomEnergy uses is based on a solid oxide fuel cell platform with roots in the NASA Mars Program. The BloomEnergy “server” converts fuel into electricity through a clean and efficient electrochemical process which emits significantly less greenhouse gases, NOx, SOx, and particulate matter than conventional combustion technologies. The system is fuel flexible and can run on natural gas for significant greenhouse gas reductions, or biogas for a carbon neutral solution.

BloomEnergy itself calls the product a “server” in accordance with their typical client, tech companies. Because these cells are not produced in scale, costs are still prohibitively high for the “usual” energy consumer, while tech companies can afford the premium for this cleaner technology.

CAPEX [$/W]	**Operating Cost [$/kWh]**	**Typical Power Range per Unit**	**Typical Gas-Electricity Efficiency**	**Possible Manufactures**
~10$/W[xxvii]	0.001 $/kwh	200kW	~52-60%	BloomEnergy

Table 3: Fuel Cell Variables

Microturbines

Microturbines[xxviii] are relatively small combustion turbines that can use gaseous or liquid fuels. They emerged as a CHP option in the 1990s. Individual microturbines range in size from 30 to 330 kilowatts (kW) and can be integrated to provide modular packages with capacities exceeding 1,000 kW. There are over 360 sites in the United States that currently use microturbines for CHP, accounting for over 8% of the total number of CHP sites and 92 MW of aggregate capacity. In CHP applications, thermal energy from microturbine exhaust is recovered to produce either hot water or low pressure steam.

Microturbines are a simple form of gas turbine, usually featuring a radial compressor and turbine rotors and often using just one stage of each. They typically recover exhaust energy to preheat compressed inlet air, thereby increasing electrical efficiency compared with a simple-cycle machine. The air-to-air heat exchanger is termed a “recuperator,” and the entire system is typically called a recuperated cycle.

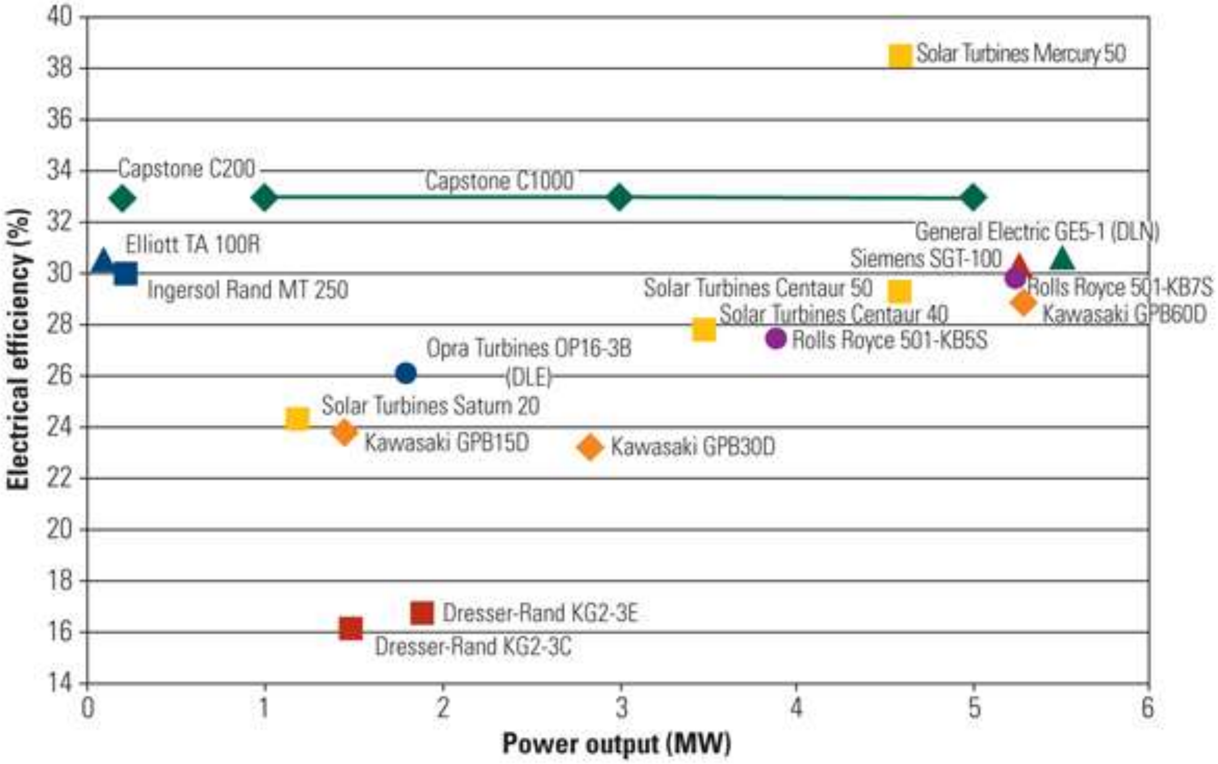
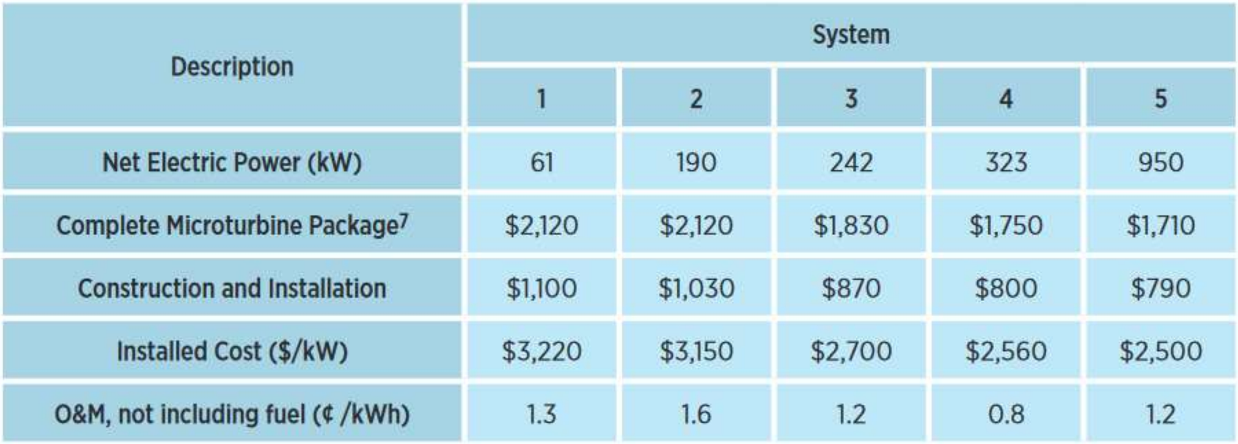


Figure 15: The electrical efficiency of the competitive offerings in the microturbine size range[xxix]

Microturbines are the ones on the upper left corner of the graph.

Following our methodology, the table[xxx] below presents the relevant information pertaining capital expenditure and operating and maintenance costs.



Description	System				
	1	2	3	4	5
Net Electric Power (kW)	61	190	242	323	950
Complete Microturbine Package[7]	$2,120	$2,120	$1,830	$1,750	$1,710
Construction and Installation	$1,100	$1,030	$870	$800	$790
Installed Cost ($/kW)	$3,220	$3,150	$2,700	$2,560	$2,500
O&M, not including fuel (¢ /kWh)	1.3	1.6	1.2	0.8	1.2

Table 4: Capital Expenditure and O&M Cost Table

Biomass

Overview

Biomass-derived energy is energy that comes from organic matter. Biomass acts as a storage unit for energy that originated from the sun. Unlike coal and other fossil fuels, biomass is live or recently dead organic matter. Biomass can come from a variety of sources. Typical biomass sources are wood, agricultural crops, food waste, industrial waste, public/community waste, and livestock waste [xxxi]. The chemical composition of biomass consists of primarily carbons, hydrogens, and oxygens (with some smaller amounts of nitrogen)[xxxi]. Thus, with less nitrogen and sulfur being part of biomass composition, biomass burns cleaner.

Biomass is a renewable energy source, as it is a quickly replenishable resource that does not take millions of years to replenish. Sustainable practices for harvesting biomass include continuous ag crop waste and tree pruning[xxxi]. Wastes are also constantly being produced, whether as food/drink wastes or as organic wastes from sawmills, paper plants, other industry, etc. All of these industrial wastes can be repurposed as either fuel to be combusted or as organic matter ready to be made into a gas/liquid fuel[xxxi].

Biomass is at an advantage compared to other renewable technologies in that it is readily available at any time to generate electricity, similar to fossil fuel-based energy generation systems. The major problem with biomass systems is procuring enough fuel, and then storing and delivering the fuel [xxxii]. Another issue with using biomass as fuel is the ability to dry the fuel. Drying out the biomass creates a more efficient burn, but is often not done for economic reasons[xxxii].

Carbon dioxide is released upon combustion or decomposition of biomass. However, biomass is considered carbon neutral due to the fact that the plants store carbon for photosynthetic purposes, which then is released back into the atmosphere. Thus, there is no net gain of carbon dioxide in the atmosphere with this method. Complications arise with biomass when humans use fossil fuels to acquire the biomass, such as using equipment or vehicles to harvest the biomass, create fertilizer for the soon-to-be biomass, or transport the biomass. When too much fossil fuels are burned to assist in the use of biomass energy systems, then the carbon neutrality of the process comes into question. However, in general, withdrawal and treatment of biomass to create energy is a great improvement over fossil fuels[xxxi]. Gathering woody biomass or agricultural waste for biomass energy systems is much easier when compared to extraction of oil from deep ocean-wells for fossil fuel-based systems. The amount of resources and the energy investments for gathering of biomass are significantly less.

Sources of Biomass

Sources of biomass can be classified as primary, secondary, and tertiary. Primary biomass is organic matter that directly resulted from photosynthetic processes such as wood, timber, and crop remains[xxxi]. Wood wastes are either burned to make heat or burned to make steam to generate electricity. Agricultural wastes can be fermented into ethanol for automobile fuels. Secondary biomass is matter that was processed in some form, whether it be physical, chemical, or biological processing[xxxi]. Public/Communal wastes can often be biologically decomposed into biogas (methane), which can then also be burned to generate electricity via steam or used as cooking gas. Tertiary biomass consists mostly of post-consumer byproducts and wastes such as fats and oils used in cooking[xxxi]. Fats and oils can be used to make biodiesel fuel for trucks and other large devices with diesel engines. Biodiesel also burns much cleaner than diesel fuels created by fossil fuels. Air pollutants like particulates, carbon monoxide, and sulfur compounds are less prevalent with biodiesel.

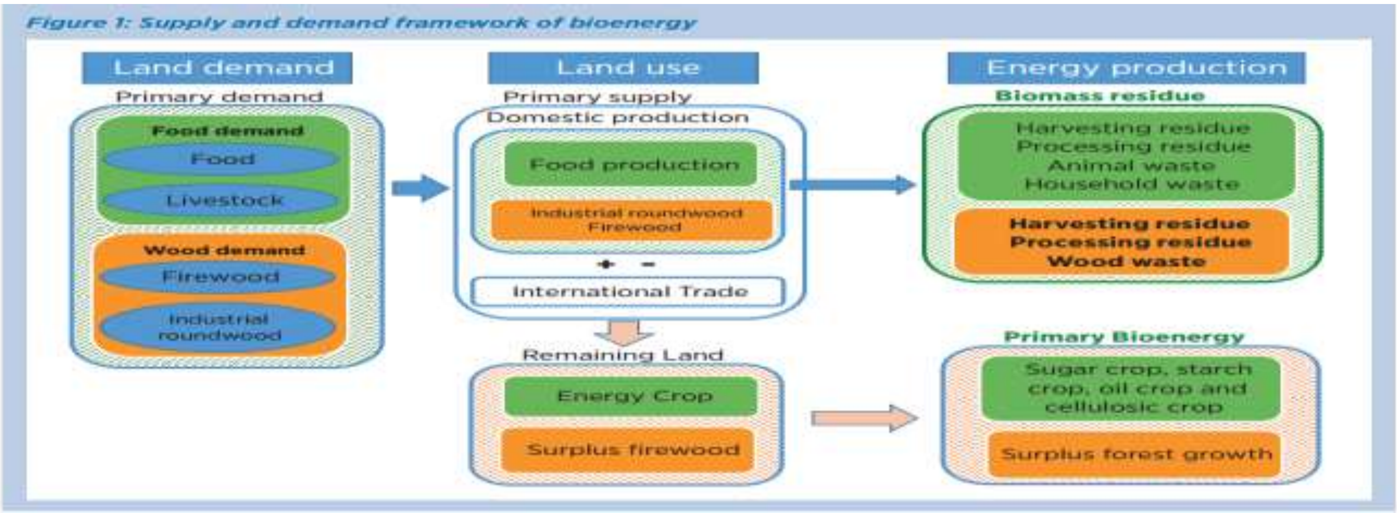


Figure 16: Supply/Demand for Bioenergy Visual

Conceptualizing supply and demand for biomass energy systems is shown in the visual above. It gives a visual representation of the general process by which biomass energy is cultivated (all the ways from the major sources of biomass fuels to energy production) [xxxiii].

Description of Types of Biomass Technology

There are three types of biomass energy systems: thermal (also known as combustion), chemical/gasification, and anaerobic digestion[xxxi]. Anaerobic digestion is best for wet biomass wastes, which in turn creates a biogas[xxxii]. Most biomass systems involve direct combustion that creates high pressure steam to run a turbine[xxxii].

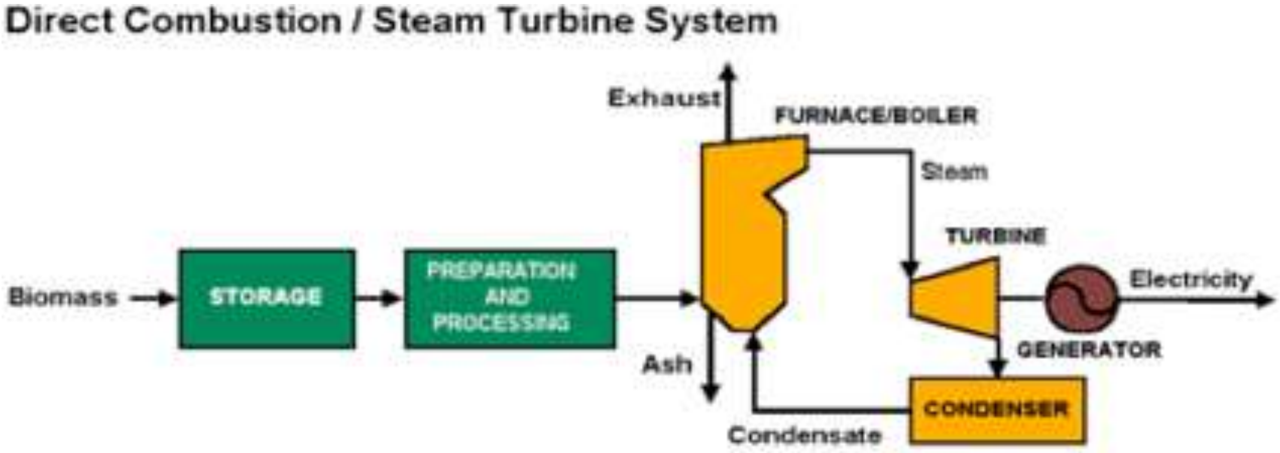


Figure 17: Direct Combustion Steam Turbine Biomass System

Harnessing the steam generated from these systems allows you to also heat homes and other structures or use it in a manufacturing process[xxxii]. This is much more efficient and is called a combined heat and power system. The ability to harness the energy of the biomass increases dramatically by four-fold, as combined heat and power plants are 80% efficient, compared to 20% for simple electricity generation systems[xxxii]. Similar air pollution controls that are used for fossil fuel power plants can be implemented for biomass power plants[xxxii]. A baghouse or electrostatic precipitator can be used to control particulate matter.

Biomass gasification systems are similar to combustion systems. The gasification system restricts the amount of air input, which in turn creates a clean biogas fuel, which can be used for a variety of purposes[xxxiii]. The efficiency of a biogas system can fluctuate due to dependence on more variables such as moisture, temperature/pressure, and exhaust temperature[32].

Assessing whether there are enough biomass resources available nearby the plant is important. One of the most common fuel types, wood chips, does not even have a distribution system in place throughout the majority of the U.S.[xxxii]. Typical local places to contact are businesses in the lumber industry, landscaping, landfilling, furniture, and papermaking[xxxii]. A generalized interactive map was created to help show people where a lot of biomass resources are located in the U.S. (shown below at top of next page)[xxxii]. Luckily for the Ithaca micro-grid, New York has some biomass reserves, but there are also lots of nearby locations with lots of biomass available such as Pennsylvania, New Hampshire, and especially Maine.

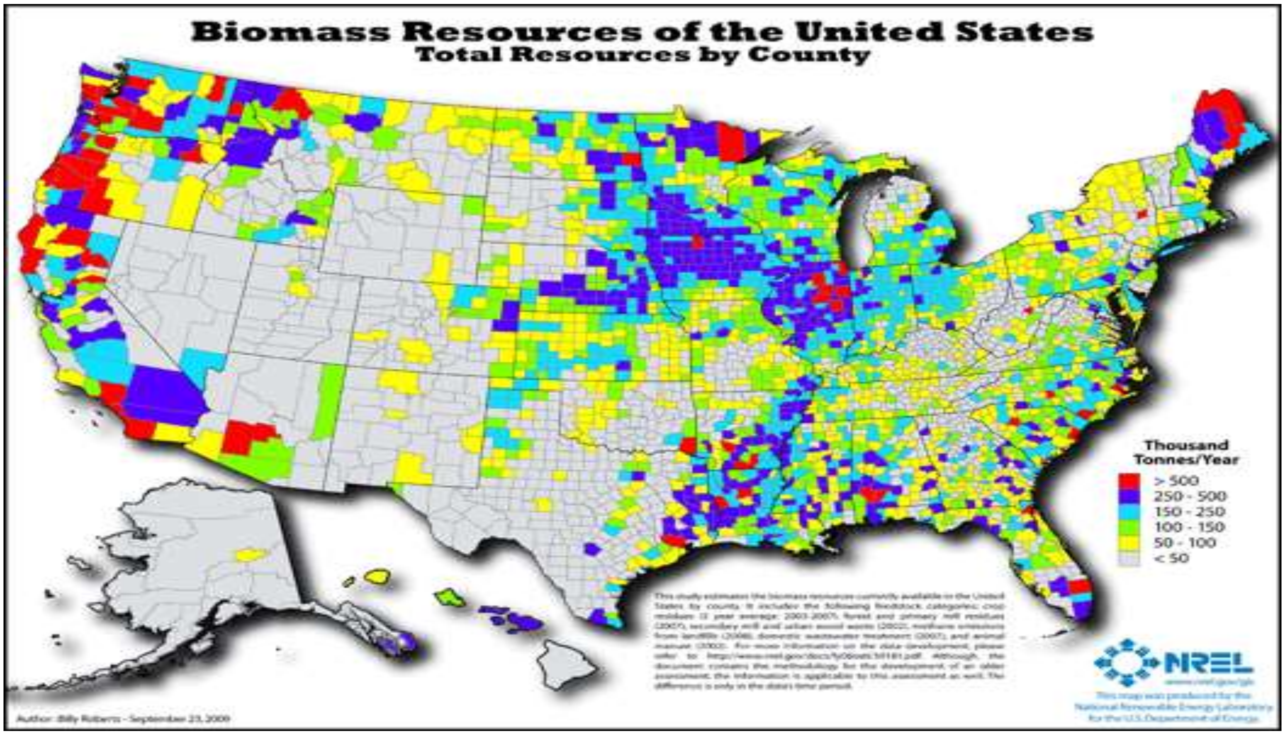


Figure 18: Biomass Availability in the U.S. Visual

<u>Environmental Regulations, Statistics, and Forecasting</u>

Environmental concerns in regard to storage of biomass fuel includes dust buildup and the uncommon case of spontaneous combustion of woodchips in large piles at the correct conditions (moisture, etc.)[xxxii]. Complying with the Clean Air Act's hazardous pollutant standards is something that should be assessed. Power plant size requirements should also be planned and assessed according to the Clean Air Act Permitting Greenhouse Gas Emissions Amendment because the government has restrictions in place for large power plants (smaller scale plants are exempt from these restrictions)[xxxii].

At a global scale, experts predict that only about 14% of the planet's energy consumption needs could be satisfied by biofuel systems at the moment[xxxi]. Bioenergy supplies about 10% of power throughout the world currently [xxxiv]. Biomass energy systems are especially useful in developing countries. However, modern biomass systems have become increasing prevalent and relevant. Biomass based energy systems are forecasted to increase in North America, but much more so in Europe and China[xxxiv].

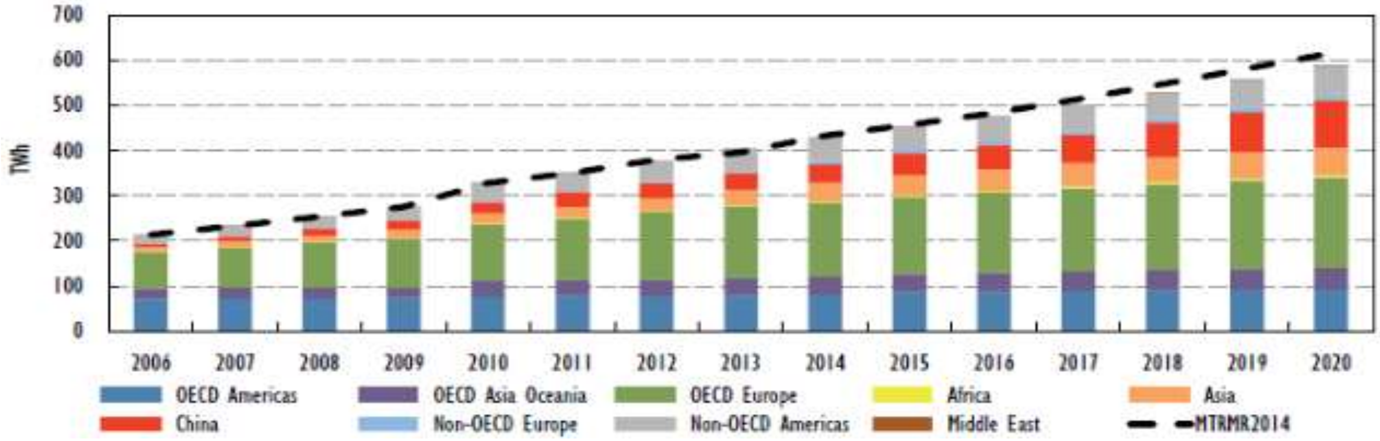


Figure 19: Biomass Usage Globally

Projections show that renewable energy is likely going to be a growing sector and account for up to 36% of the world's energy by 2030[xxxiii]. Cost of biomass in the U.S. is predicted to become as cheap as $3 per GJ of energy. However, it could conceivably be as high as $17 per GJ of energy, thus some skepticism is reasonable[xxxiii].

Another interesting question that should be asked about biomass energy systems is where the energy is being allocated. The visual below gives a breakdown of what biomass energy is being used for worldwide[xxiii].

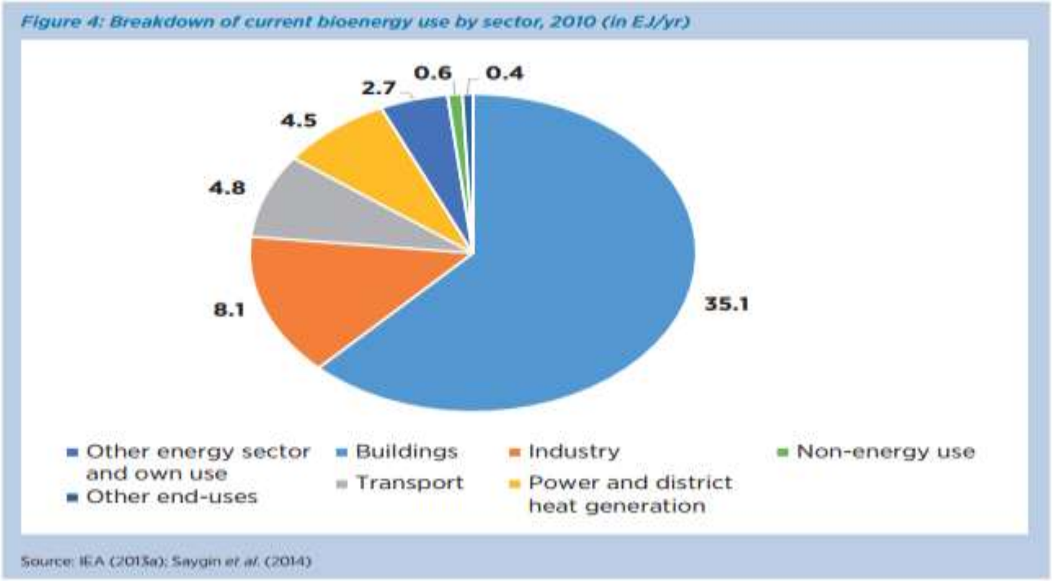


Figure 20: Bioenergy Usage Across Major Sectors

Local Incentive Programs, Case-studies, and Economics

The typical capital cost for a US biomass direct combustion plant is $3500/kW and the levelized energy costs are $0.11 to $0.12 per kWh[xxxii]. These values are for a 15 MW capacity plant.

Operation and maintenance costs of biomass power plants are mostly just the costs of fuel and labor.

Renewable Heat NY is a government agency that provides incentives for high efficiency biomass wood heating systems. These systems vary in cost depending on size and purpose. Residential, small commercial, and large commercial system types are available for heating purposes [xxxv]. There is also an option available for heating of stove tops in homes. The Renewable Heat NY program has funded 18 biomass projects. Projects all over New York ranging in cost from $49,000 to $300,000 have begun [xxxvi]. Money has been given to researchers as well as to areas wanting to install biomass powered boilers and heating systems[36].

The cost of removing the old boiler system is typically $5000. Depending on the size of the new cordwood or wood pellet boilers they can cost up to $5000 or $36,000 for residents or small businesses[xxxv]. At a larger scale they can cost between $200,000 and $270,000. For small systems 75% of the cost is covered, while for larger systems 55% of the cost is covered by the government incentives program[xxxv].

In the state of New York there are currently 121 renewable energy incentive programs. Three programs specifically target biomass systems [xxxvii]. One incentive is through property tax. For the next 15 years after you install your renewable energy system (including biomass systems), you are exempt from 100% of your property taxes. In order to help construct these facilities that use biomass to generate electricity and/or heat the government has a loan program that will cover 80% of the project's total cost or $250 million upon meeting certain requirements[xxxvii]. There is also a grant program that will cover up to 50% of the total project cost upon meeting certain requirements. Both the loan and grant program are through the U.S. Department of Agriculture.
One case study is the "Central New York Resource Conservation & Development Project." A sub-project named the "Willow Biomass Project" was created in an effort to try and teach farmers how to grow willow and use it to make a market out of renewable biomass material [xxxviii]. However, with no incentives on green energy and low prices of coal and methane, willow was simply not competitive. With rising fossil fuel costs or small incentives on biomass to make it cost competitive, willow biomass could be an alternative fuel source that competes with fossil fuels as a fuel source[xxxvii].

A second case study is an eco-grid created in Hudson, NY[xxxvii]. This grid included a combined heat and power system with a capacity of 5 MW. They used locally sourced wood and crops plus crop waste to fuel the biomass plant. It required 35,000 tons of wood chips a year[38]. The system created hot water and heated many homes. The grid covered all government/city buildings, industry, and high-priority areas.

Applying Biomass Energy Processes to Ithaca

Creating large scale opportunities for biomass energy generation is unlikely to be feasible. Combustion, chemical, and anaerobic-style power plants for biomass are all very expensive. The U.S. Department of Agriculture does have large amounts of money available to fund such a power-plant, but it is out of the scope of this project because it would involve designing an entire power plant facility, in addition to the micro-grid.

However, that does not mean that biomass will be completely ignored with respect to the micro-grid. Despite being very expensive, there are situations where some biomass fuels are cheap enough to be worth acquiring, especially when natural gas and other fossil fuels become more expensive. Thus, we can blend in roughly 10% biomass fuel sources for use in a combined heat and power systems. This will lead to a small carbon dioxide emissions reduction and make the process more environmentally friendly.

Local sources for this biomass include wood pellet industries in the area. Ehrhart Energy sells wood pellets and is located 15 miles from Ithaca. Another option is New England Wood Pellet LLC, which has locations about 80 miles and 120 miles from Ithaca. Local options are available too in the form of willow. If the micro-grid owners give incentives to some local farmers to grow willow for combined heat and power systems, then that could also be a method for acquiring adequate small scale biomass.

Neither company publicly lists its wood pellet prices. However, on average, wood pellets costs around $180 - $250 per ton, according to a study done by the US Department of Energy [xxxix]. Prices in New York and Pennsylvania tend to be slightly higher than the national average, so the Ithaca microgrid would most likely be subject to prices on the higher end of the scale.

Based on a gross heating value of 8500 BTU/lb, we calculated a net heating value of 6800 BTU/lb with an average system efficiency of 80% [xl]. The approximate cost to get 100 million BTU's is about $2016 [xl]. For context, 100 million BTU's is 105.5 million GJ or 29,300 kWh. A more conventional use for wood pellets is for them to be burned in specially designed wood pellet stoves. Between 7 and 8 tons of wood pellets are needed for each season (roughly 4 months)[xxxvii]. That is a large quantity of wood pellets. This gives some context as to why wood pellets and biomass fuel sources are not as economical on a large scale for energy and heat generation when compared to fossil fuels.

However, based on Department of Energy calculations and recommendations from the team's advisor we considered the cost of energy and other important information such as the operating costs as well as thermal efficiency[xli]. The cost per ton of wood pellets when bought in bulk for energy production was 44.35 in 2004, and when adjusted for inflation equates to 56.68 in 2016. The capital cost is $4000 per kW on average as was found from a previously cited source (wbdg.org). For an investment length of 20 years, discount rate of 5%, thermal efficiency of 20%, and capacity factor of 80% the levelized cost came out to be $0.112 per kWh.

In regard to the model, the value in dollars per watt of electricity produced was calculated through comparison. The smallest biomass gasification power plant costed 2500 euros per kW. By converting this to U.S. dollars and converting "kW" to "W" the calculation amounts to $2.65 per Watt (or $2650/kW). The International Renewable Energy Agency was helpful at finding the rest of the values used in the model, such as the Joules of energy harnessed per kilogram of biomass, the capacity factor, the gasification efficiency, etc[xlii].

Some final significant calculations that were used to justify values in our model pertaining to biomass were: [($57/ton)/2000lbs]*(2.2 lb/kg) = $0.063 per kg. This calculation was significant because it converted the cost of biomass fuel from $/ton to $/kg. The other significant calculation completed was: (17 MMbtu/ton) * (1.055 GJ/MMbtu) = 17.9 GJ/ton = 19.7 GJ/metric ton. This calculation validated some of the assumptions and equations used to integrate biomass into the model.

Generally speaking, 10% biomass integration versus 90% natural gas usage for the non-renewable technologies was the goal set. However, this is highly dependent on which scenario in the model is being discussed. Some scenarios can exceed this goal easily and some will have a very difficult time.

Solar Energy

Solar power is the conversion of sunlight into useful forms, such as electricity. It is an important source of renewable energy as it can generate electricity without any waste or pollution. Solar power systems derive clean and pure energy from the sun. The technologies currently available on the market are broadly characterized as either passive solar or active solar. The difference between passive and active solar depends on the way they capture and distribute solar energy. Passive solar refers to the use of the sun’s energy for heating and cooling of living spaces. For example, orienting a building to the sun or selecting materials with favorable thermal mass. Active solar refers to the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. In this project, we will be focusing on photovoltaic systems.

A photovoltaic system converts the sun’s radiation into usable electricity. However, the availability of the resource, the sun, is an important barrier to solar power. Solar radiation varies with changing atmospheric conditions and the position of the earth relative to the sun and is rarely consistent. That being said, it is necessary to incorporate solar energy with a back-up energy system in case of the varying weather conditions.

The rising demand for solar power has resulted in more advanced research and development in solar photovoltaic system technologies. However, the fundamentals of electricity generation are still very much the same except for the improvement in efficiency, quality, and versatility of the photovoltaic system.

There are three main types of solar panels on the market today: Monocrystalline Silicon Solar Cells, Polycrystalline Silicon Solar Cells, and Thin-Film Solar Cells. We will discuss the advantages and disadvantages of each types of solar panels and determine the best fit for the Emerson plant roof-top installation.

The first type of solar panel is Monocrystalline Silicon Solar Cellsxliii. Monocrystalline solar is the oldest and the most developed of the three technologies. The panel is made by growing a single crystal. Due to the shape of these crystals, the monocrystalline panel is very recognizable by its appearance of even coloring and uniform look. This particular solar panels have the highest efficiency rate as measured by wattage output related to the panel's size. Currently, the typical monocrystalline solar panels efficiency rate is around 15-20%. However, according to the National Renewable Energy Laboratory, Sun Power's newest solar panel has a record of 24.1% efficiency, the highest record for silicon module efficiency.[xliv] In addition, monocrystalline solar panels are space efficient. Since, the panels yield the highest power outputs, they required less space. It also has a long lifespan of up to 25 years.

On the other hand, monocrystalline solar panels tend to be more efficient in warm weather. But the degradation of output is less severe than polycrystalline solar panels. They are the most expensive compared to the other types of solar panels.

The second type of solar panel is Polycrystalline Silicon Solar Cells[xlv]. Polycrystalline and Monocrystalline both start as a silicon crystal placed in a vat of molten silicon. However, rather than draw the silicon crystal seed up as the Monocrystalline, the vat of silicon is simply allowed to cool, omitting the Czochralski process. Some of the advantages of polycrystalline solar panels include less costs than monocrystalline due to the simpler production method, lesser amount of silicon waste, lower heat tolerance, and higher temperature coefficient.

Some of the disadvantages of polycrystalline solar panels include less efficient, typically efficiency is around 14-16% due to the lower silicon purity and require more space in order to produce the same output as the monocrystalline solar panels.

Lastly, Thin-Film Solar Cells. Thin-film solar cells are made by depositing one or more layers of photovoltaic material onto a solid surface such as glass. The different types of thin-film solar cells can be categorized by which photovoltaic material is used. Thin-film cells are considered as the worst among the three types of solar cells. Depending on the substances used in manufacturing, the typical efficiency rate is around 7-13%. Thin-film solar panels can be mass produced more simply than crystalline-based solar cells, making it cheaper to manufacture. It can be made flexible, increasing the potential applications. In addition, a high temperatures tend to have less impact on the performance

There are two main disadvantage of thin-film solar panels. First, it requires more space. This is because thin-film solar panels generally have a lower efficiency. The second disadvantage is because thin-film solar panels have a shorter life span, due to the fact that they degrade faster.

Cost of Solar Power

According to the Solar Energy Industries Association[xliii], the cost to install solar panels has dropped by more than 70% over the last 10 years. From $7.50 per watt in 2009 to $2.00 per watt in the first half of 2016. We also see a steady increase in solar panel installations since 2009 as shown in Figure 1. The decreasing costs of solar photovoltaic panels, increasing competition, installation incentives and environmental awareness have resulted in an increasing growth in residential installation of photovoltaic systems. However, for commercial markets, the challenges remain in providing competitive financing for smaller companies without credit ratings.

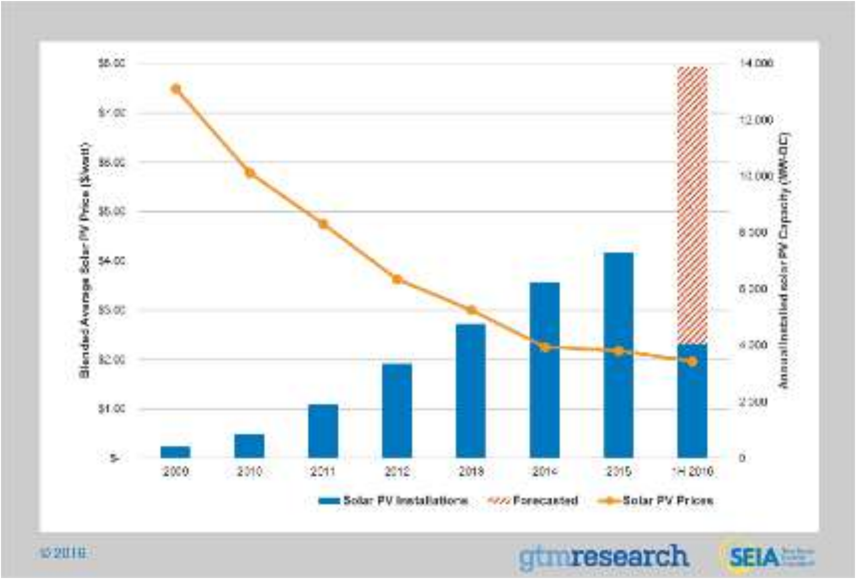


Figure 21: Average Solar PV Price and Annual Installation Capacity since 2009

Hardware remains an important driver of photovoltaic system cost structures. In addition to equipment costs, other costs include direct and indirect labor costs, developer overhead, and sales tax. Based on the benchmark cash purchase price in 2015 published by the National Renewable Energy Laboratory[xliv], the national weighted average cost for commercial-scale system is modeled at $2.16/W. The model provided by the NREL is a 200-kW, 1,000-Vdc commercial-scale flat-roof system using 72-cell, polycrystalline modules. The cost breakdown is illustrated in Figure 2.

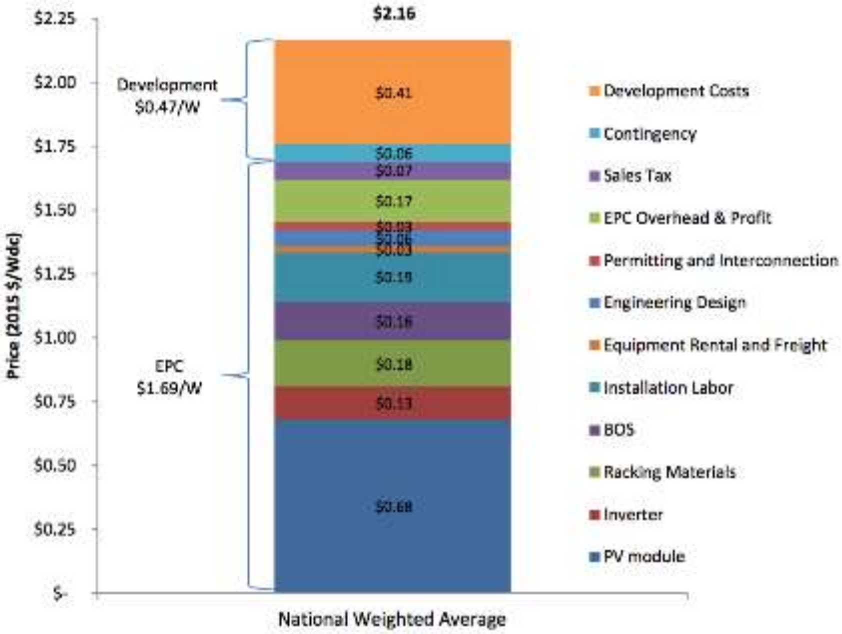


Figure 22: Modeled Commercial PV System Price

Solar Power at the Emerson Plant

According to Google Maps and its measuring tool, the rooftop of the Emerson plant is approximately 8.26 acres or 33,427.03 square meters as illustrated in Figure 3. However, the area approximation does not take into account of the space already in use or the height differences in the buildings. The actual area that can be converted into space for solar panel could be smaller.

Figure 23: Aerial View of the Emerson Plant

In order to model the potential solar system installation at the Emerson plant, we need to consider numerous parameters. First, is the module type. The module type describes the photovoltaic modules in the array with its approximate efficiency and temperature coefficient of power. For our analysis, we will be using the standard, crystalline silicon solar cells as it is the most commonly used module type. The table below shows the three module types we see on the market today.

Type	Approx. Efficiency	Module Cover	Temp. Coefficient of Power
Standard (Crystalline Silicon)	15%	Glass	-0.47 %/°C
Premium (Crystalline Silicon)	19%	Anti-reflective	-0.35 %/°C
Thin Film	10%	Glass	-0.20 %/°C

Table 5: Module Types

One of the important parameters in installing solar systems in a region with a lot of snow is the snow losses percentage. Based on the data from Southern Ontario, Canada[xlv], the annual average snow losses ranged from 1-3.5 percent. In addition, the snow losses percentage also depends on the tilt angle of the solar arrays. For this project, we will be using 3.5 percent as the annual average snow losses with a tilt angle of 30-degree for estimating the worst case scenario.

Using the System Advisor Model (SAM) provided by the National Renewable Energy Laboratory[xlvi], we can estimate the system output per year on a monthly basis. The parameters used in the calculations are listed below.

Parameter	**Value**
DC System Size (kW)	5014.05 (Based on 8.26 acre area size)
Module Type	Standard (Crystalline Silicon, 15% approx. efficiency)
Array Type	Fixed (Roof Mount)
System Losses (%)	17.08
Tilt (Degree)	30
System Type	Commercial

Table 6: Significant Parameter Values

Metric
Annual energy (year 1)
Capacity factor (year 1)
Energy yield (year 1)
Levelized COE (nominal)
Levelized COE (real)
Electricity bill without system (ye
Electricity bill with system (year
Net savings with system (year 1)
Net present value
Payback period
Net capital cost
Equity
Debt

Figure 24: System Advisor Model Output

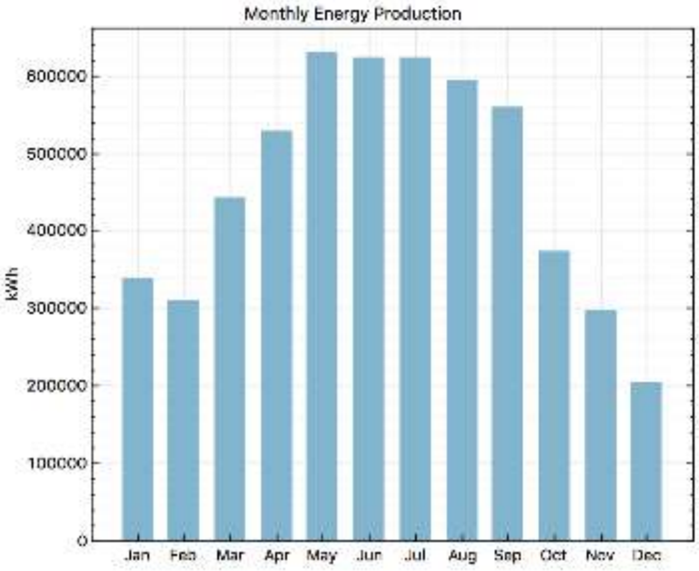


Figure 25: System Advisor Model Estimated Monthly Energy Production

Based on the calculations, the estimated annual system output from the solar arrays is 5.52 MWh/year with a capacity factor of 12.6%. The System Advisor Model also estimated the system costs related to installing the solar arrays at around 12.28 million dollars with 100% exemption from New York state sales tax[xlvii]. These costs include module, inverter, indirect and direct labor costs, and permit cost.

Demand and End Users

This feasibility study is for The Ithaca South Energy District (SED). For this proposed microgrid, it is assumed that the electricity substation adjacent to the former Emerson plant on Ithaca's South Hills will serve as a station for various electrical load integrations into the microgrid. With this assumed position, the predicted loads were determined and sorted into priority loads and non-priority loads.

The determined priority loads were South Hill Elementary School, Ithaca City Hall, Ithaca Police Department, South Hill fire station, Tompkins County Library, City Water Treatment Plant, Town of Ithaca Offices, Longview Retirement Home, Titus Towers Public Housing, and public lighting. The non-priority loads consist of 3,885 households, which house 11,822 people, and the renovated Chain Works District[xlviii].

Figure 26: Power Generation Facilities: The City of Ithaca

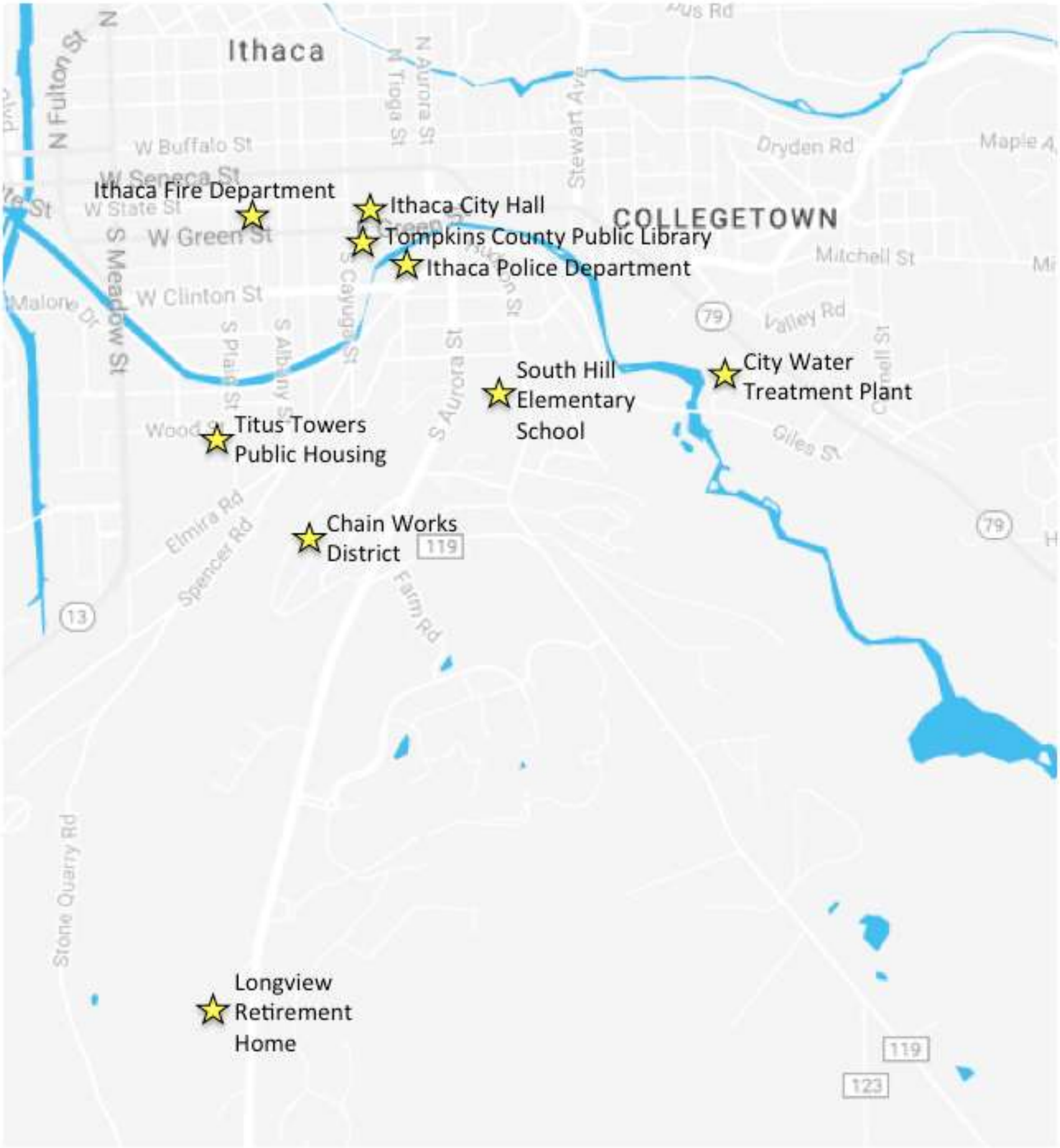


Figure 27: Priority Load: Ithaca South Energy District

Priority Load Analysis

For the South Energy District, loads that were determined to affect public safety, a large number of people, and high risk people were characterizes as priority loads. These loads were researched and the determined loads for each can be observed in Table 1.

Priority Load	**Average Demand (kWh/y)**	**Average Peak Demand (kW)**
South Hill Elementary School	294,600	68
Ithaca City Hall	299,000	70
Ithaca Police Department	496,000	114
Ithaca Fire Department (Central Office)	237,880	56
Tompkins County Library	852,432	196
City Water Treatment Plant	707,458	162
Longview Retirement Home	132,660	32
Titus Towers Public Housing	566,820	130
Public Lighting	720,000	166
Ithaca College Maintenance Building	122,160	28
Total	4,402,010	1022

Table 7: Energy Demand Data for South Energy District Priority Loads

Several demands in this table were estimated. South Hill Elementary School provided electricity usage for 11 months, so the electricity usage for the 12th month was forecasted, and the annual average of the electricity usage was used for this table. For the Tompkins County Library, the kWh/sq.ft of Ithaca City Hall, which is directly across the street, was used with the square footage of the library to estimate its potential load[xlix] [l] The Titus Towers public housing contain 235 single dwelling units[li]. A single dwelling unit will be defined as a third of a household, so using the household monthly electricity rate the Titus Towers load was estimated. This method was also used for the Longview Retirement home, which has 55 single units.[lii] Public lighting demand data was found for all of Ithaca[liii]. Using the percentage of Ithaca land in the NED and the SED, from visual inspection, the distribution of public lighting was assumed to follow these percentages, which were 60% and 40% in this case. Thus 40% of the Ithaca public lighting electricity is assumed to be used in the SED. The Ithaca College Maintenance Building demand was given directly by a source[liv].

Non-Priority Load Analysis

The Non-Priority loads are divided into two sectors: Residential and Commercial loads. The residential load contains 3885 households. From Ithaca electricity data, the average monthly household load is 603 kWh/month[lv]. Using this monthly load and the number of households, the residential load was determined. The Commercial loads consisted of the restaurants and companies in the area. The loads experienced from the restaurants Rogan's Corner and Sunset Grill were modeled by determining a building of matching size and using the load from it, for this case the demand data from the Southside community center was used[lvi]. Using the energy per sq. foot assumption made for some of the priority loads, the demand was simulated for the South Hill Business Campus based off of their square footage[lvii]. Table 2 illustrates all of these loads.

Non-Priority Loads	**Average Demand (kWh/y)**	**Average Peak Demand (kW)**
3885 Households	28,111,860	3,418
Rogan's Corner and Sunset Grill	83,000	18
South Hill Business Campus	3,050,000	696
Total	31,244,860	7,132

Table 8: Energy Demand Data for South Energy District Non-Priority Loads

Chainworks Load Analysis

According to the City of Ithaca, the Chainworks project will consist of 4 phases that will take between 10 to 15 years[lviii] [lix]. Phase 1 is the redevelopment of buildings 21, 21, 33, and 34. Phase 2 is the repurposing/demolition of the remaining buildings. Phase 3 is potential future developments within the areas of site adjacent to the existing buildings and parking acres. Phase 4 is potential future developments within areas on the remainder of the site.

The Chain Works District Draft Generic Environmental Impact Statement had the expected electric and head demands for all of the Chainworks buildings. By assigning each building to its corresponding phase, the electric demand for every phase was determined. Table 3 shows these demands.

Chainworks Demands	Electric Demand (kWh/y)	Heat Demand (kBTu)
Phase 1	6,748,362	23,025,411
Phase 2	4,228,914	14,429,056
Phase 3	7,546,893	25,750,000
Phase 4	7,546,893	25,750,000
Full Chainworks	26,071,063	88,954,467

Table 9: Expected Electric and Heat Demands for Chainworks

Capacity Analysis

The capacity factor used for determining the average peak demand in tables 1 and 2 was determined by analyzing the historic peak to average ratio in New England[lx]. The data is shown Figure 2.

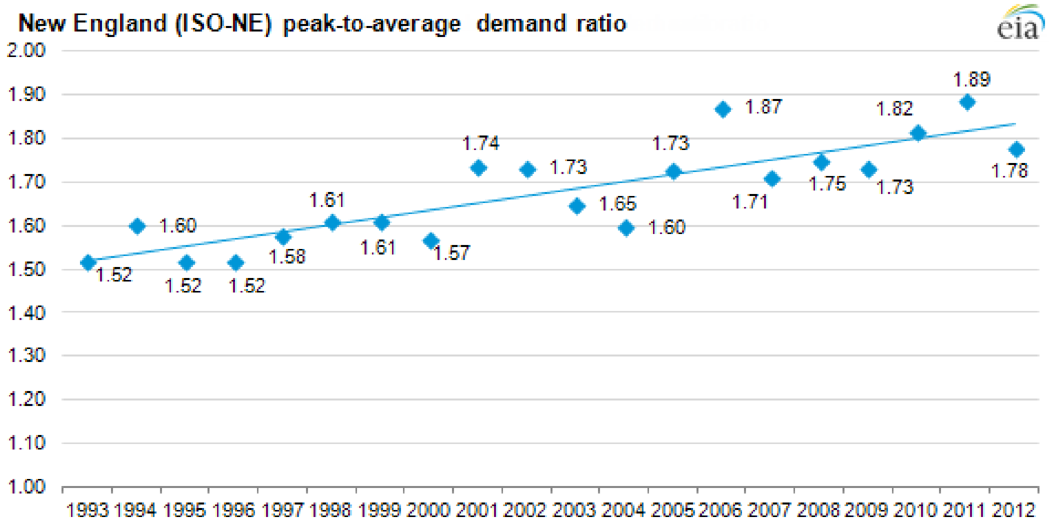


Figure 28: New England Peak-to-Average Demand Ratio

This data indicates that the demand ratio has steadily increased for the past 20 years and that it is currently at approximately 1.83. Assuming this trend continues, a Peak-to-Average demand ratio of 2 was used for the microgrid as it will compensate for this expected increase.

Additionally, to find the maximum capacity of the microgrid, a seasonality factor must be applied to the average peak demand. To determine the seasonal changes in demand, the energy for the state of New York was analyzed for the past 15 years. The average ratio between the monthly demand and the average demand for that year, for the past 15 years was analyzed in Figure 3. [lxi]

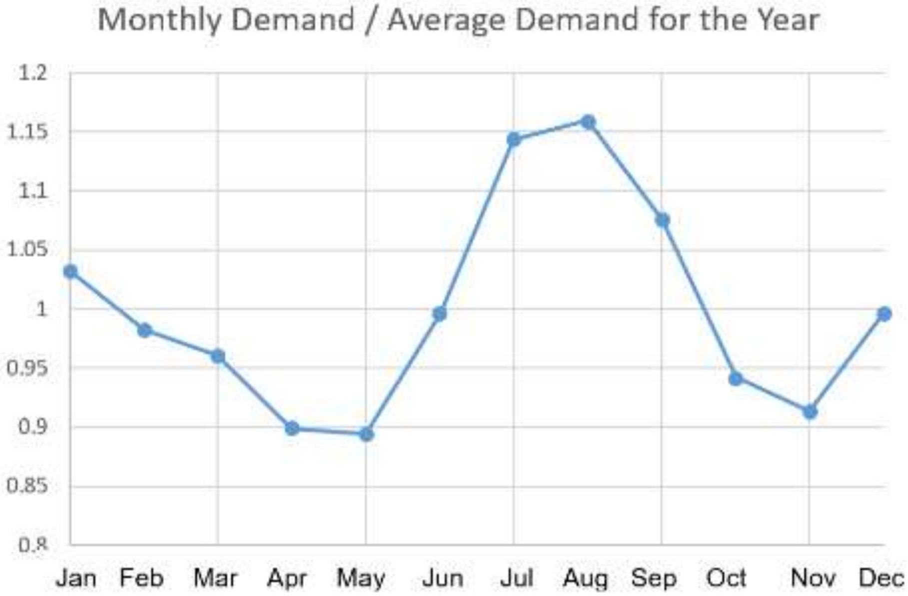


Figure29: Ratio of Monthly Demand to Average Demand of Year

The highest variation in monthly energy demand is seen in July where there is approximately a 16% increase because of air conditioning. To compensate for this, a seasonality factor of 20% was used in this model.

Using the demand load data from Tables 1, 2, and 3, the total energy demand of the microgrid was calculated as shown in Table 4.

Capacity Calculation	
Priority Load	1,022 kW
Non-Priority Load	7132 kW
Chainworks Load	5,952 kW
Combined	14,106 kW
Seasonal Buffer	20%
Required Power	16,928 kW

Table 10: Total Microgrid Capacity Calculation

With the current assumptions, the demand for power for the South Energy District microgrid is estimated to be 16,896 kW.

Pitch Strategy

Chain Works District

[lxii]

Figure 30: Chainworks District Overhead Photo

Unchained Properties, LLC (UP) has recently purchased the former Emerson Power Transmission Plant. The plant spans a surface area of 800,000 square feet and includes 95 acres of land. Unchained Properties plans on repurposing the buildings as a sustainability measure in order to create a community they call “Chain Works District”. Unchained Properties has already begun the cleanup process to remediate the contamination of the area.[lxiii]

Unchained Properties’ places value on sustainability and they are a promising potential partner. Since they have begun cleaning the area of contamination, environmental regulation would not be an issue. In addition, their plan to develop the neighborhood into an urban community presents an additional customer base to our target market.

ASI Energy

ASI Energy developed the Energize Ithaca initiative in 2010 in the hopes of replacing Ithaca’s energy system with a more sustainable, efficient energy district. They currently have a CHP system running. It serves the entire South Hill Business Campus, including their own office. They hope to have a microgrid running by 2018, with the CHP plant as the center of the microgrid.[lxiv] Due to ASI’s Energize Ithaca initiative and their desire to operate a microgrid, ASI is a good potential owner of this microgrid.

Carbon Tax

Microgrids use cleaner energy sources but still produce carbon as a byproduct. The New York State requires taxation on carbon dioxide emission. By 2017, the carbon tax rate will be $50/ton of CO_2 where $20/ton of CO_2 will benefit the Tompkins county.[lxv]

Financing

To finance the microgrid, the two options currently available are grants from the government or from third party lenders. The government usually provides several clean energy fund programs such as Property Assessed Clean Energy (PACE) and Energize NY. PACE offers low cost and long term financing for renewable energy projects owned by commercial or non-profit entities. Through PACE, we can choose to use their licensed contractors for the whole project. The repayment is through a charge on tax bills over the course of up to a 20 year period.[lxvi] Another government funding program is the Energize NY program, which is funded by the New York State Energy Research and Development Authority (NYSERDA). It leverages PACE to provide access to capital, extended loan term, transferability, and any other benefits.[lxvii] Third party lenders that could potentially be funding the microgrid are Hannon Armstrong. They have funded projects ranging from $1 to $200 million.[lxviii]

Tax Credit Regulations

According to the tax credit regulations for the use of renewable energy, there is a rebate of 30% for using solar, fuel cells, and small wind. For geothermal, microturbines, and combined heat and power (CHP), the rebate amount is 10%. The credit amount for each system is presented in the table below.

Technology	12/31/16	12/31/17	12/31/18	12/31/19	12/31/20	12/31/21	12/31/22	Future Years
PV, Solar Water Heating, Solar Space Heating/Cooling, Solar Process Heat	30%	30%	30%	30%	26%	22%	10%	10%
Hybrid Solar Lighting, Fuel Cells, Small Wind	30%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Geothermal Heat Pumps, Microtubines, Combine Heat and Power Systems	10%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Geothermal Electric	10%	10%	10%	10%	10%	10%	10%	10%
Large Wind	30%	24%	18%	12%	N/A	N/A	N/A	N/A

Table 11: Tax Credit Table by Technology

For solar, the rebate is not eligible for passive solar system. For fuel cells, the credit is capped at $1,500/0.5 kW of capacity and eligible for systems with a minimum capacity of 0.5 kW with electricity-only generation efficiency of higher than 30%. For microturbines, their credit is capped at $200/ kW of capacity and eligible for systems up to 2 MW in capacity with electricity-only generation efficiency of higher than 26%. For CHP, there is no limit to the credit.

The rebate is eligible for systems up to 50 MW in capacity with a minimum efficiency of 60%. However, the efficiency does not apply to CHP systems that use biomass; the efficiency must be higher than 90% of the system's energy source. There are credit reductions for systems that do not meet the minimum efficiency requirement. Another criterion for the CHP system to be able to receive full credit is the electrical capacity must be less than 15 MW and mechanical energy capacity of less than 20,000 horsepower. Larger CHP systems up to 50MW and 67,000 horsepower are eligible for reduced tax credit. [lxix]

Finance

A discount rate is an interest rate used to compare cash flows that occur at different points in time. In capital budgeting, a discount rate is used to adjust future cash flows to their present value in order to compute the net present value (NPV) of the project. This method is used to analyze the economic value of a project and to compare different projects. Projects with a negative NPV should not be pursued (from a purely economic standpoint) while projects with a positive NPV should be pursued. If there are multiple potential projects with positive NPVs, the project with the highest NPV should be pursued. Thus, the choice of an appropriate discount rate is of vital importance.

Government Investments

There has been a debate among economists as to appropriate discount rate for government projects. Some argue that it should reflect the social rate of time preference which is the rate that individuals are willing to make trade-offs between present and future consumption. Others argue that it should reflect the opportunity cost of capital, which is the expected return that is given up by investing in a particular project as opposed to another project of similar risk[lxx].

In practice, there is little consensus among government organizations as to what discount rate is used. The Department of Energy publishes an annual report titled “Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis” which includes a suggestion for the discount rate, which was 3.0% in 2015[lxxi]. On the other hand, the Office of Management and Budget, which produces the budget of the executive office uses a discount rate of 7.0%, which is based on the average rate of return for private investments[lxxii]. A 2002 study based on a random sample of 72 cities with populations over 100,000 observed that over half (54%) of municipalities did not even use discount rates when analyzing potential projects. Of those that did, rates varied from 2.0 – 5.0%[lxxiii].

Private Investments

For most companies, it is appropriate to use the company's weighted average cost of capital (WACC) to discount cash flows for projects that are of similar risk to the company's overall business. The WACC represents the company's overall cost of financing and is calculated using the following formula:

$$WACC = \frac{E}{V} * R_E + \frac{D}{V} * R_D * (1 - T_C)$$

$$\begin{gathered} R_E = cost\ of\ equity \\ R_E = cost\ of\ debt \\ T_C = corporate\ tax\ rate \\ E = market\ value\ of\ equity \\ D = market\ value\ of\ debt \\ V = E + D \end{gathered}$$

In this case, a microgrid represents a slightly riskier than average investment for an electric utility company so an appropriate discount rate would be slightly higher than the WACC. Based on data from January 2016, the average WACC for companies in the general utilities sector is 4.14%[lxxiv]. Iberdrola, the parent company of NYSEG, has a current WACC of 3.92%[lxxv].

Recommendation

The funding for the Ithaca SED microgrid project will likely be a mix of state/municipal funds and investment from utilities companies such as NYSEG or its parent company, Iberdrola. Based on the rates used by various government entities and the WACC of utilities companies, we suggest using a base-case of 5.0% for the discount rate but also analyzing the project with a discount rate of 3.0% and 7.0%.

Considerations and Decisions

System Architecture

After the analysis from the stakeholders and the assessment of their needs, different concepts for the power production side of the microgrid were generated and one final concept was selected.

After the generation sources that seemed most feasible to implement were decided, the formulation of system configurations started.

1. Solar, Microturbine, Reciprocating Engine, Fuel Cell and Biomass being our sources of energy generation, one case was focused on distributing the generation solely between Solar and Microturbine.
    - Specific to Ithaca, this could be done by choosing a specific location as generation site for the microgrid.
    - This way, the system architecture would be straightforward and allow the robust functioning of a microgrid.
2. With the integration of other major sources of generation, it was decided that the best path to going about designing the system is by distributing the sources of generation all over the microgrid system map rather than focusing on isolated generation sites.
    - The microgrid consumer map will be split into separate blocks and will be prioritized through ranking in terms of load type.
    - The microgrid load map will then be prioritized in terms of availability of energy resource type for throughout the year to decide which areas will be selected and within those areas which rooftops will be installed with solar panels, for instance.
    - This distributed system will also contain a distributed storage system as well. This improves accessibility to the energy produced, transmission (for sell-to-Utility state) and makes storage more modular which reduces the cost even while maintaining, if not increasing, storage capacity.

Both the above scenarios are tempting as each of them has their own benefits. Although for the scope of this project, the team concluded that the first scenario would be better for installation, maintenance and upgradation in terms of reducing the payback period to a realistic and reasonable number.

In either case, the microgrid system will have a Central Energy Management and Control System (EMCS) to co-ordinate data between generation, transmission, control structure, storage and load subsystems that form the microgrid.

The system architecture of the EMCS could be another topic by itself as the system intelligence to manage demand response and shave peak loads or shed them if necessary in a smart way is only one of the features that a Central EMCS will be required to do.

Areas of Focus

Originating Requirements

Based on this, an exhaustive list of Originating Requirements were made to look into how the microgrid would need to function and how the Central EMCS will respond to those needs.

INDEX	**ORINGINATING REQUIREMENTS**	**ABSTRACT FUNCTION NAME**
OR1.	The Energy Management and Control System (EMCS) shall compare generation and consumption dynamically.	Analysis
OR2.	The EMCS shall monitor macrogrid operational status.	Monitor
OR3.	The EMCS shall detect rise in energy demand.	Detect
OR4.	The EMCS shall optimize transmission losses.	Optimize
OR5.	The EMCS shall detect rise in energy demand.	Detect
OR6.	The EMCS shall monitor storage capacity	Monitor
OR7.	The EMCS shall check for need of stored energy delivery	Monitor
OR8.	The EMCS shall check for storage operational status	Monitor
OR9.	The EMCS monitor individual Load consumption	Monitor
OR10.	The EMCS shall check for voltage drop in the system	Warn
OR11.	The EMCS shall analyze the data acquired	Analysis
OR12.	The EMCS shall forecast daily energy demand	Predict
OR13.	The EMCS shall forecast hourly energy demand	Predict
OR14.	The EMCS shall monitor Renewable Energy Sources	Monitor

	(RES) operational status	
OR15.	The EMCS shall accommodate climatic conditions into the analysis of RES generation capacity	Plan
OR16.	The EMCS shall monitor Data communication operational status	Monitor
OR17.	The EMCS shall be able to detect faults in the grid network	Detect
OR18.	The EMCS shall island the microgrid in case of macrogrid outage	Island grid
OR19.	The EMCS shall regulate voltage level in the microgrid	Regulate
OR20.	The EMCS shall monitor switch gear operational status	Monitor
OR21.	The EMCS shall operate switch gear to re-route power	Route
OR22.	The EMCS shall look for energy spikes	Monitor
OR23.	The EMCS shall decide between storing and routing of excess energy back into the macrogrid	Decision making
OR24.	The EMCS shall monitor the amount of energy routed back into the macrogrid	Calculate
OR25.	The EMCS shall check for tinkering with the smart meters	Tampering check
OR26.	The EMCS shall control re-distribution of energy on the load side within consumers	Control
OR27.	The EMCS shall look Monitor and control storage facility temperature	Monitor and control
OR28.	The EMCS shall monitor power quality and power factor of the energy supplied to the load	Regulate
OR29.	The EMCS shall send a message to the maintenance crew in case of physical system failure	Communicate/warn

OR30.	The EMCS shall study the priority load chart in case of load shedding and proceed accordingly	Analyze and Decide

Table 12: Originating Requirements Table

Use Case Diagram – explaining inter-connected functionalities

On deciding that the system needs to accomplish and lead the microgrid functioning smoothly, a use case diagram of how the system would behave and be connected was made.

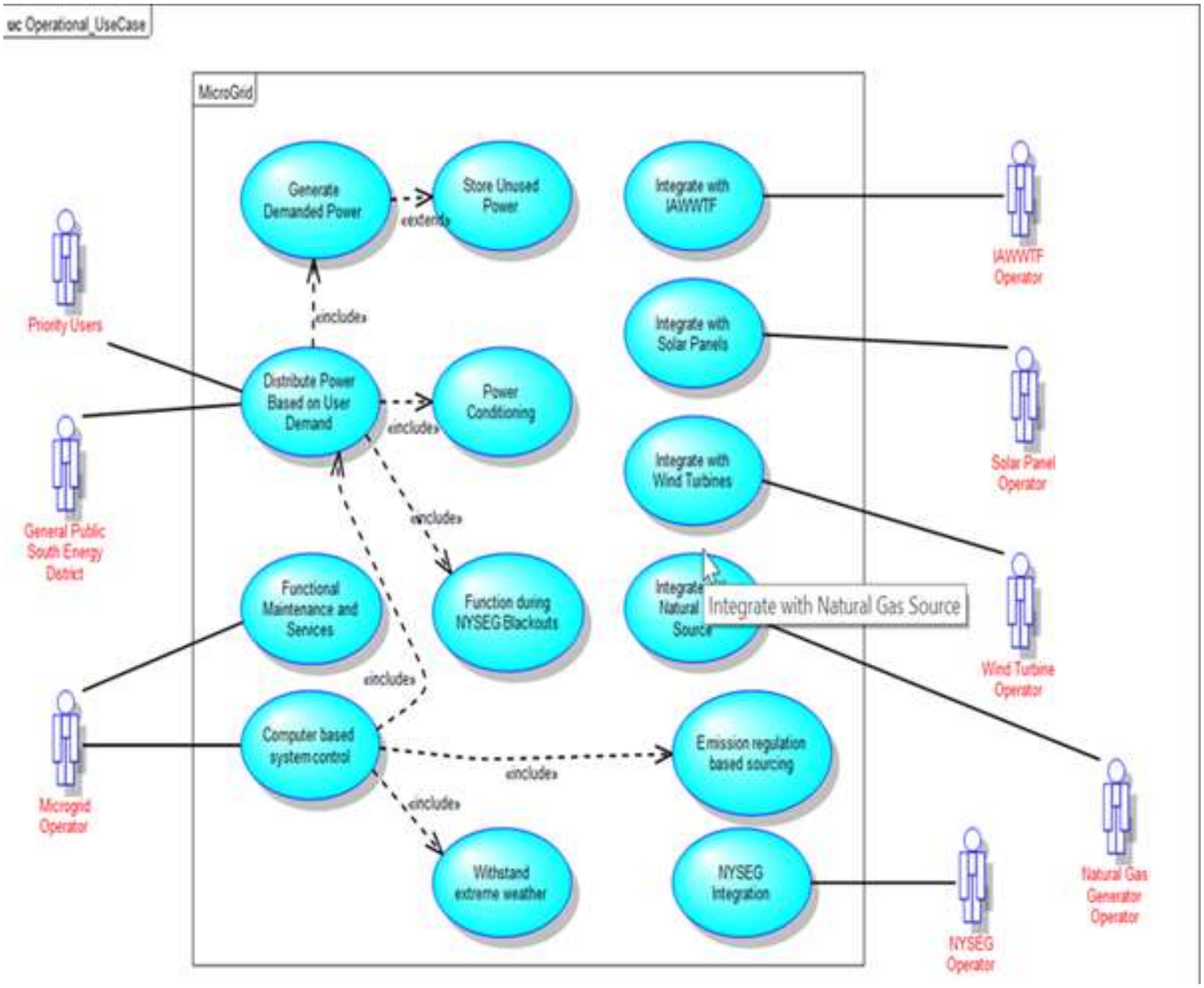


Figure 31: IDEF0 – The IDEF0 gives a layer by layer view of the microgrid components' functionality

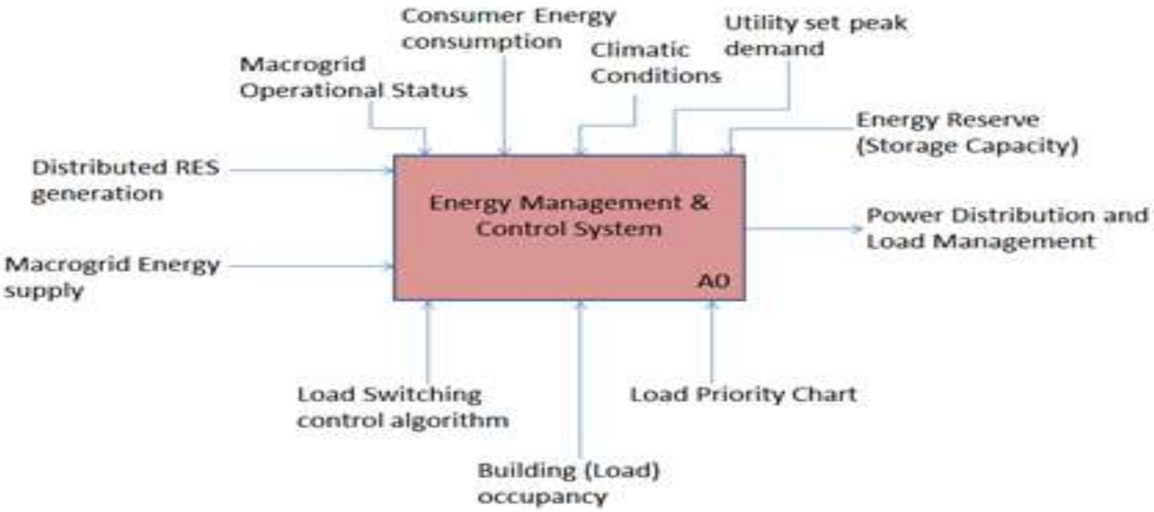


Figure 32: A0 - Level 0 is the outermost layer that shows a rough input/output situation for the microgrid

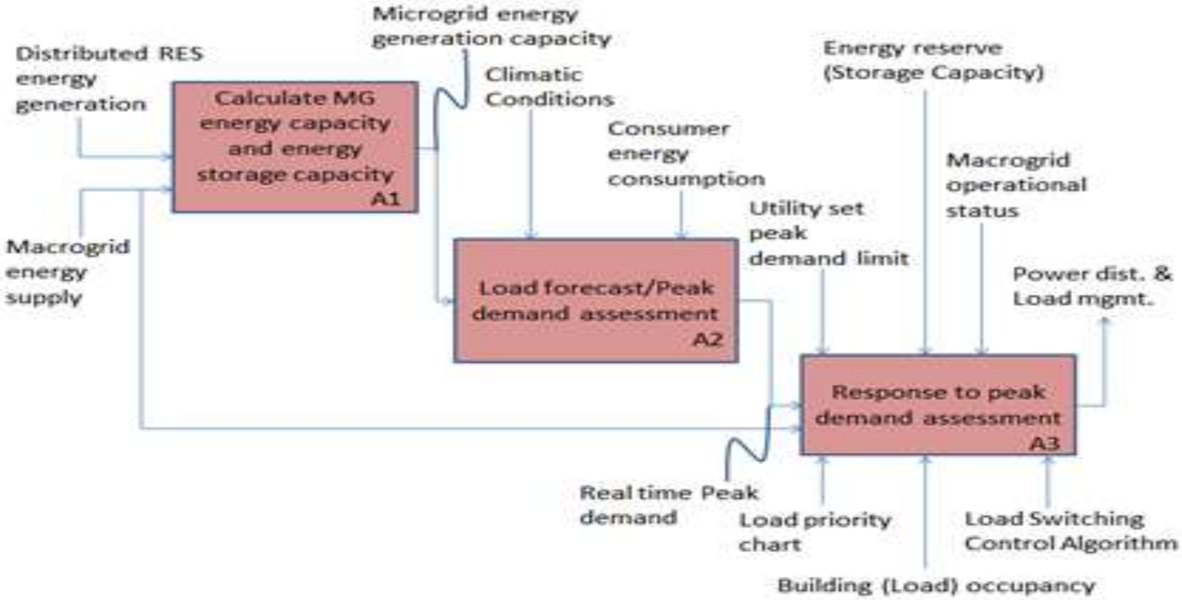


Figure 33: A1, A2 and A3 show the second layer which is within Layer 1

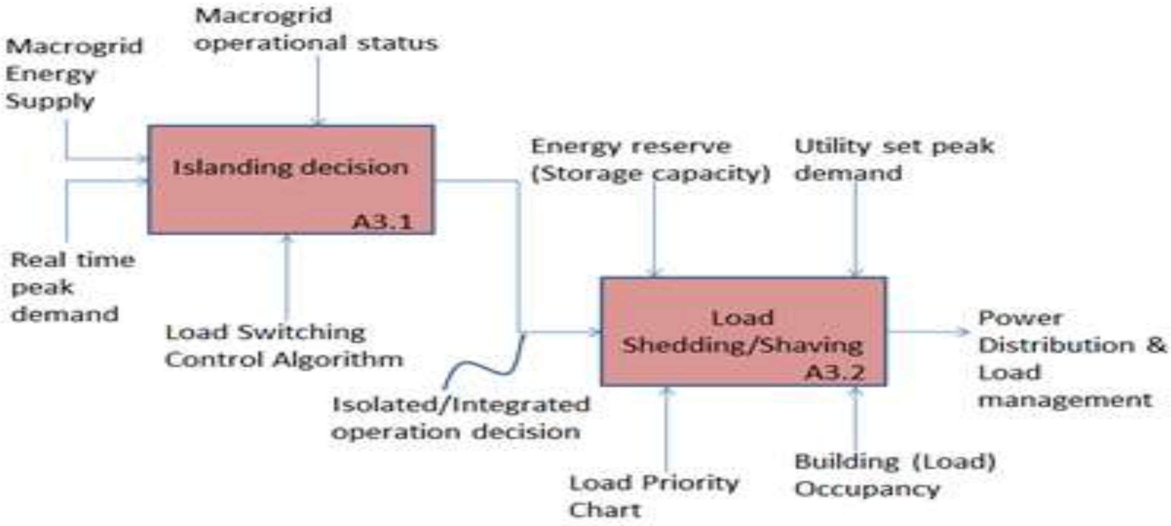


Figure 34: A3.1 and A3.2 (Layer 3) show the two functional blocks which form layer 2

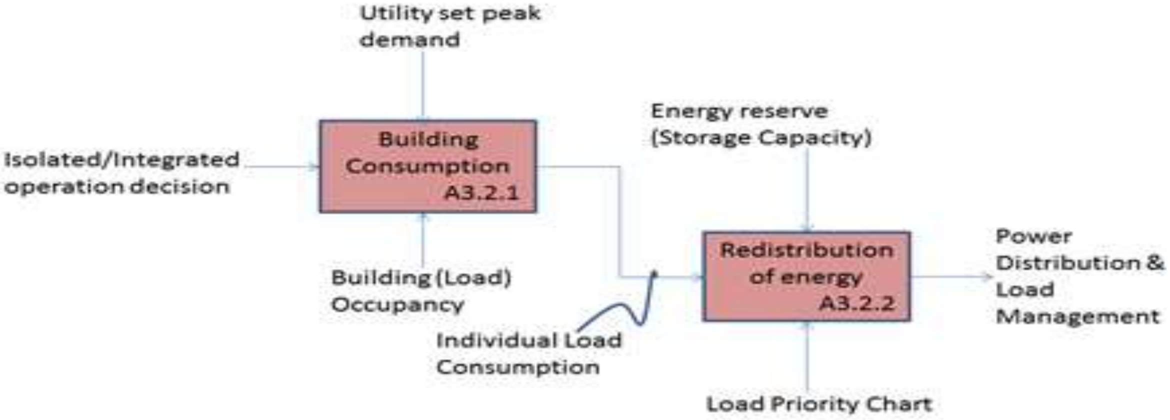


Figure 35: A3.2.1 and A3.2.2 constitute Layer 4 that's underneath A3 (Layer 3)

An overall structure layout context diagram is shown below on the next page.

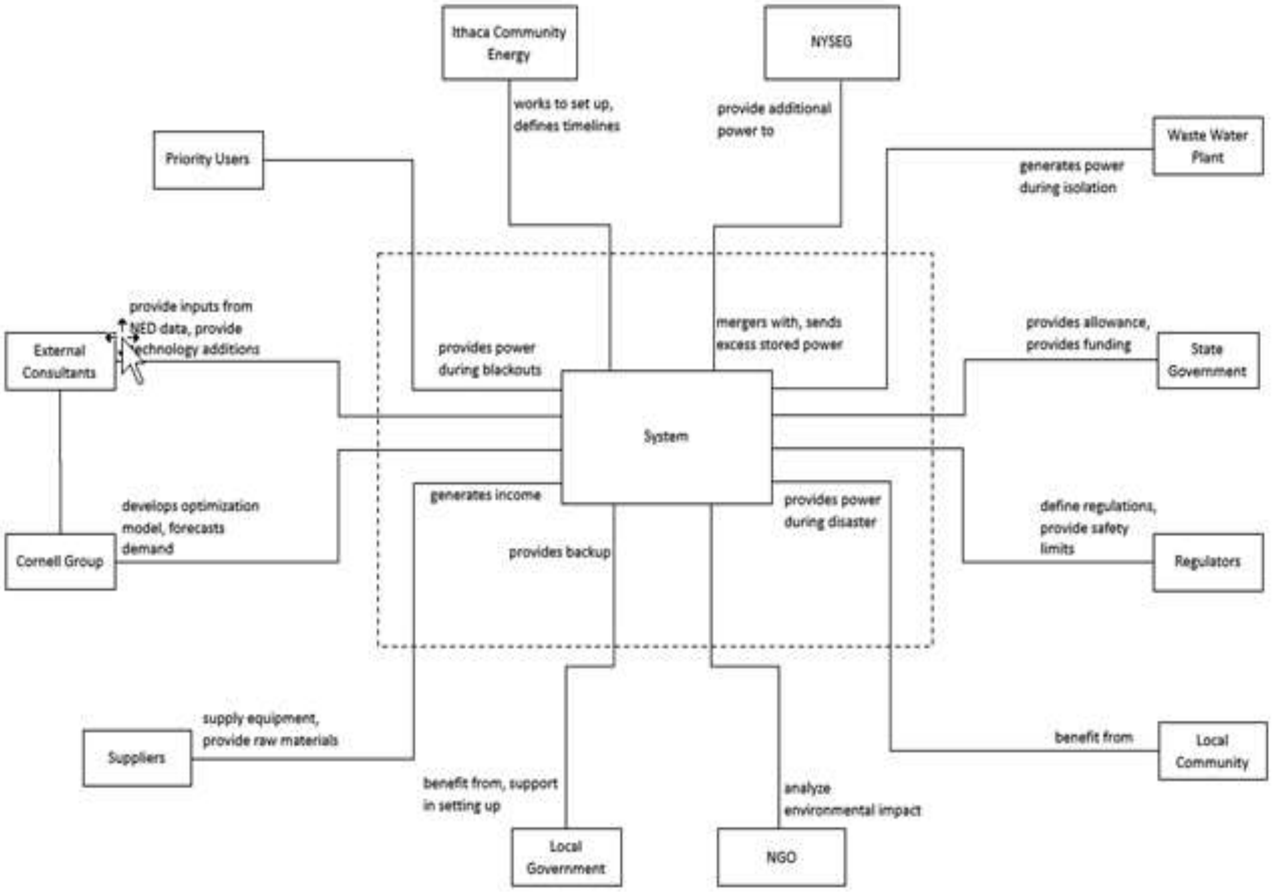


Figure 36: Structure Layout Diagram

Considering the above structure, the team decided on generating a feasibility structure that gave an end comparison between NPV Schedule and Project Lifetime.

Different scenarios in terms of demand variation were made to give the team an insight into what needs to improve from the technology side to make system implementation more feasible.

The evaluation technique for this and the different scenarios have been discussed in the following sections.

On a completely alternative note, there are two considerations that are worth discussion that were brought to attention during the presentation to the client, the Ithaca Community Energy Group and the advisor. The first consideration that was brought up was in regard to carbon dioxide coming from the construction and development of solar panels. Thus, looking into the "life cycle energy" of solar PV panels would be useful. From a textbook that this classes' advisor wrote, it cites that this is indeed a common question and comments about this specific topic[lxxvi]. Whether or not any sort of pollution or emissions from manufacturing these solar panels outweigh the benefits of their use. The text cites that there is no one formal process for the production of solar panel technology, thus it is hard to make a statement with 100% certainty; for example, one study cited found that the energy required in manufacturing and installing PV might be 3.4 years in a sunny location like Phoenix (AZ), and 5.1 years in a less sunny location like Detroit (MI). However, the text does say that the productive capacity of solar technology is very miniscule when compared to global electricity use/demand. Then the text goes on to say that future emissions are the real topic of concern and that due to the constant development of solar technology that it is hard to know what the future will hold. It is also worth noting expert opinion. The advisor to this project did also say that based on findings from the Department of Energy that solar panels on average pay for the carbon emissions used to manufacture them in roughly five years or so.

The second consideration from the presentation that is worth noting in this section is that there will be property costs associated with the model. In particular, Chainworks District can definitely accommodate some of this project's property needs. Thus, it would not be difficult to approximate the property costs for this project and include those within the model for a more holistic and accurate model. This was discussed after the presentation somewhat and it was agreed upon that this could be easily added into the model, but considering that there is a limited amount of time left that it would be left out of the model and out of the scope of this report. It would be part of the future considerations for this project when or if the South Energy District microgrid gets invested in and officially planned.

Evaluation Techniques and Methodologies

An “Integrated Capital Budgeting Model” was developed in order to understand the trade-offs between achievable carbon emissions targets and the desired financial targets, i.e, the levelized cost of electricity (LCOE) and payback period for the total investments.

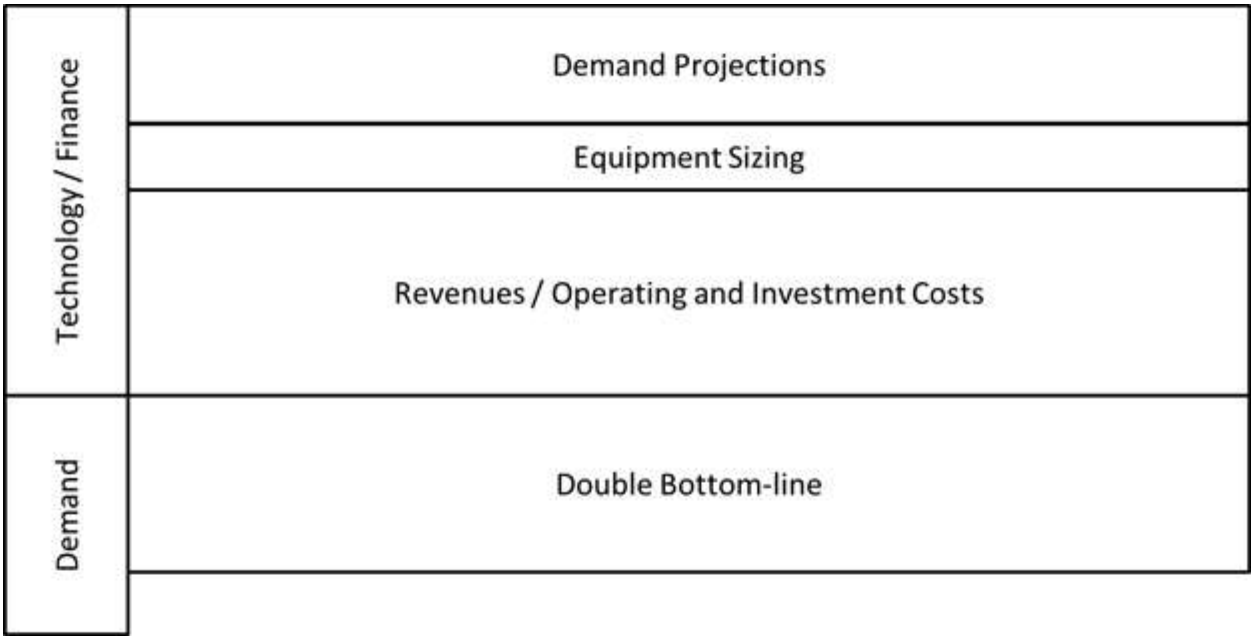


Figure 37: General Layout: Integrated Capital Budgeting Model

The diagram provides a general layout of the whole model, which can help us understand the various parameters we considered and the way the model is designed, as follows:

<u>Technology / Finance Parameters</u>:

- We considered various feasible technology options for energy generation in microgrid such as Reciprocating Engine, Microturbine, Fuel Cells, CHP, Solar etc. along with the supporting technologies such as storage systems, boiler, and biomass gasifier.
- After thorough research, we determined various costs and performance parameters associated with the above-mentioned technologies, e.g., the capital costs ($ per kW) including construction and installation costs, non-fuel operations and maintenance costs ($ per kWh), capacity factor, and efficiency ratios etc.
- The effective tax rate and incentive rates were determined after researching federal and New York state tax incentives for microgrid and renewable energy source based power plants.

<u>Demand parameters and projections:</u>

Based on our demand analysis for priority and non-priority load, we created a four-phase modular investment strategy and projected the electricity and heat demand for next 30 years accordingly. The four phases of construction are as follows:

Phase 1 - Repurpose Buildings 21, 24, 33, 34
Phase 2 - Repurpose Remaining Buildings
Phase 3 - New Development

Phase 3 - New Development

Equipment Sizing:

We estimated the required capacity that needs to be installed for specific energy generation technology based on the desired combination of energy generation resources, the total electricity and heat demand, and the peak/average ratio.

Solar integration and biomass substitution definitions:

The inherent intermittency of renewables, even when extenuated by storage, represents a critical challenge in the integration of such resources into the energy generation mix. At high levels of solar integration, it cannot be avoided that some energy resource that can be utilized on-demand, e.g. gas turbines, hydro, etcetera, is made idly available in case of a prolonged absence of insolation. Therefore, even a generation mix that is designed to nominally supply enough solar energy to meet the demand and considering the help of storage to the limit of economic feasibility, it is to be expected that some more traditional resource will have to be used occasionally. If that resource is a gas turbine, then a design that is nominally carbon neutral becomes effectively not so. For this reason, in the lack of other on-demand renewable resources such as hydro, considering bio mass substitution of the fuel that such a turbine would require can serve a solution to ensuring carbon neutrality. Hence, when considering solar and gas turbines as the base technology for a low-carbon design, then the more solar is integrated, the more it is to be expected that some idle on-demand gas turbine capacity needs to be made available, and the more would the substitution of natural gas by gasified bio mass be of interest to furthering carbon emission reductions.

Revenues / Operating and Investment Costs:

We calculated the revenue generated by considering the total demand for electricity and heat, and relative microgrid tariff in comparison with price charged by utilities for the same. Furthermore, we estimated the net present value of total future cash flows by considering the revenues, operating costs, fuel costs, depreciation, required modular CAPEX investments, government tax incentives and external grants. The annualised total cost was calculated based on present value of net operating costs and present value of all the investments.

Double Bottom-Line:

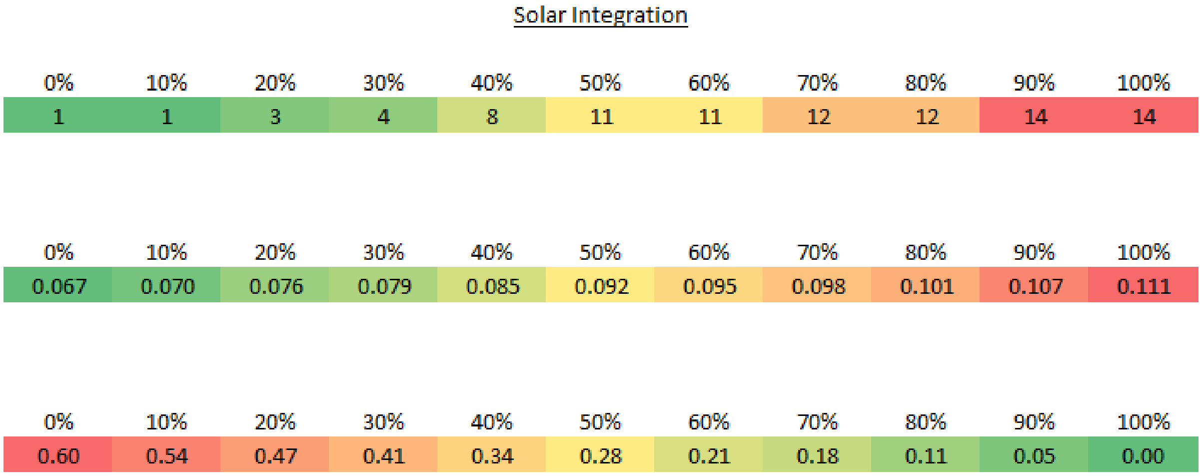
We created the double bottom line by taking stakeholder expectations into consideration. The financial bottom line consists of LCOE and payback period and environmental bottom line consists of carbon emissions.

Based on the type of loads, type of energy generation sources, the associated costs and desired level of net carbon emissions, we created five scenarios to consider for the feasibility study of the microgrid, and analysed the various trade-offs between financial and environmental targets in order to select the optimum case scenario.

Model Discussion/Summary of Results

Scenario 1: Minimal Size Microgrid

This first scenario being evaluated will first look at a baseline case as well as a more in-depth case that fluctuates multiple variables to help visualize the feasibility of the minimum size microgrid. The assumptions used in the baseline evaluation are that there will be no CHP with 100% microturbine use (compared to using fuel cell or reciprocating engine technology), a peak/average ratio of 2, a grant of $1.5 million, no biomass, and no storage. It is also worth noting that only the priority loads like the South Hill Elementary School, Ithaca City Hall, Ithaca Police Department, etc.,are being considered in this scenario. The below figure provides a good summary of this baseline scenario. The three lines in the figure, from top to bottom, represent the minimal sized microgrid model's payback period, levelized cost of energy, and net carbon dioxide emissions in kg of CO2 per kWh. For all three of these variables the amount of solar integration is varied.



Solar Integration

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	1	3	4	8	11	11	12	12	14	14

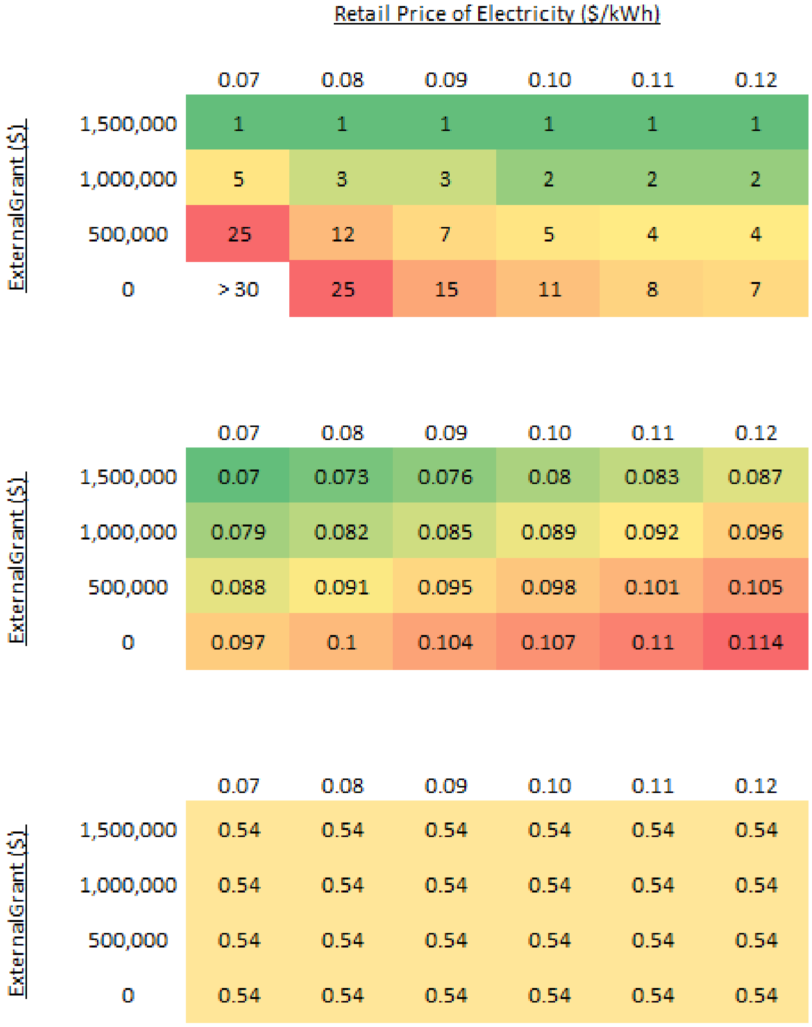
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0.067	0.070	0.076	0.079	0.085	0.092	0.095	0.098	0.101	0.107	0.111

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0.60	0.54	0.47	0.41	0.34	0.28	0.21	0.18	0.11	0.05	0.00

Figure 38: Baseline Case Minimum Sized Microgrid, Solar Variation

From the above figure, it is clear that the payback period for the minimum sized microgrid would be well within a reasonable time frame with the $1.5 million grant, since it will be paying for itself before even the 20-year mark even with 100% solar integration. It is also worth mentioning how short the payback period is for use 0%-30% solar integration. At 30% solar integration the microgrid is still paying for itself within 4 years and is reducing carbon emissions to .41 kg/kWh of energy, which is significantly beneath the .75 kg/kWh of energy baseline of the macrogrid. There is some clear monetary potential for this minimal sized model.

The more in-depth analysis of this scenario stems from varying from the baseline variables, via changing the amount of grant money received and changing the retail price of electricity with respect to the payback period, levelized cost of energy, and net carbon dioxide emissions. By seeing how the market could change, via adjusting the retail price of electricity, the viability of this scenario can be fully assessed. The below figures from top to bottom show the payback period, levelized cost of energy, and net carbon emissions respectively. The figures below still assume no CHP with only microturbine usage, a peak/average ratio of 2, no biomass, no storage, and 10% solar integration.



Retail Price of Electricity ($/kWh)

ExternalGrant ($)

	0.07	0.08	0.09	0.10	0.11	0.12
1,500,000	1	1	1	1	1	1
1,000,000	5	3	3	2	2	2
500,000	25	12	7	5	4	4
0	> 30	25	15	11	8	7

ExternalGrant ($)

	0.07	0.08	0.09	0.10	0.11	0.12
1,500,000	0.07	0.073	0.076	0.08	0.083	0.087
1,000,000	0.079	0.082	0.085	0.089	0.092	0.096
500,000	0.088	0.091	0.095	0.098	0.101	0.105
0	0.097	0.1	0.104	0.107	0.11	0.114

ExternalGrant ($)

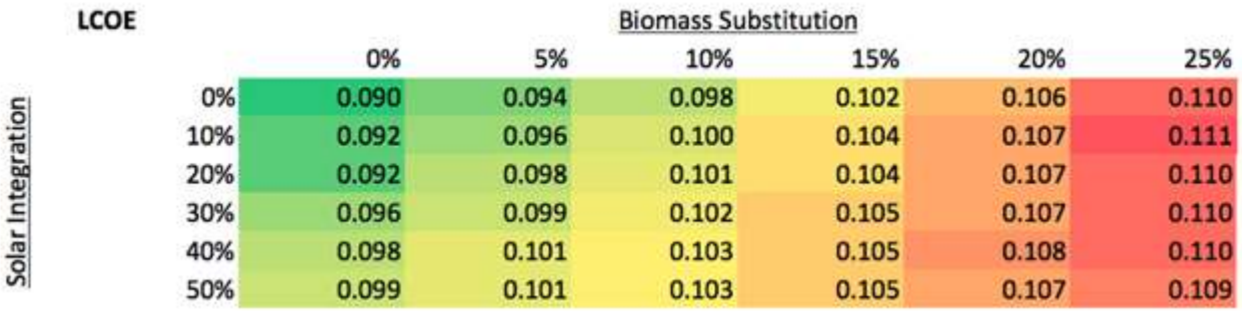
	0.07	0.08	0.09	0.10	0.11	0.12
1,500,000	0.54	0.54	0.54	0.54	0.54	0.54
1,000,000	0.54	0.54	0.54	0.54	0.54	0.54
500,000	0.54	0.54	0.54	0.54	0.54	0.54
0	0.54	0.54	0.54	0.54	0.54	0.54

Figures 39-42: Retail Price vs. External Grant Money for Payback Period, LCOE, and Net CO2

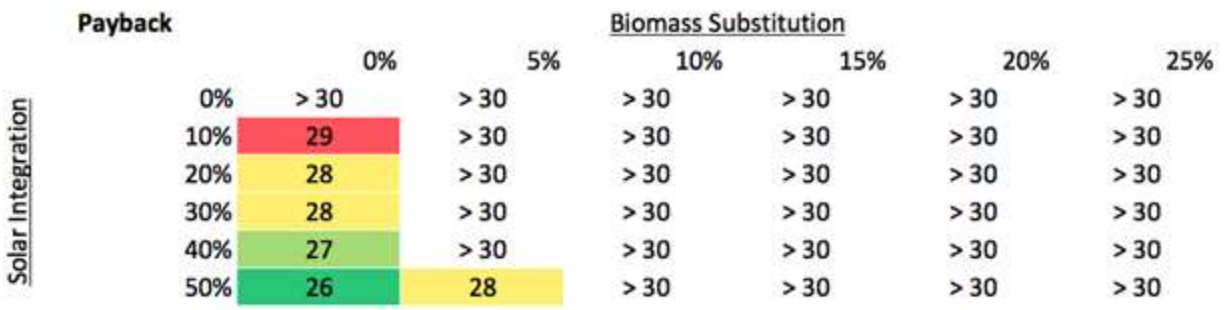
The above figures bring to attention the fact that the grant money is very important with respect to making this project economical. With no grant money at the most conservative retail electricity price of $.07/kWh the payback period becomes greater than 30 years, which is sub-optimal economically as well as sub-optimal with respect to keeping a reasonable time frame. However, under all other combinations of retail price and grant funding amounts the project does stay at or below a 25-year payback period. It is also worth noting that the levelized cost of energy is relatively competitive and under $0.10 for most combinations. Lastly, the net carbon emissions are down to .54 compared to the macrogrid baseline of .75 making this specific situation optimal environmentally when compared to the macrogrid. As a result, if choosing to create the microgrid for the minimalistic scenario, then a great amount of solar could be integrated into the system with a modest amount of grant money. It is worth keeping in mind that there would be no storage paired with this solar integration in this scenario, but it is still economically impressive.

Scenario 2: Chainworks and Priority Load

This scenario only includes the electric loads from Chainworks and the Priority Loads. It assumes that the heat from the combined heat and power can be sold to the Chainworks buildings. Additionally, it assumes the current four phase, 12-year construction plan of Chainworks. In the baseline case, there will be a grant of $1.5 million, energy is sold at a retail price of $0.07/kWh, byproduct heat is sold at $0.011/kWh, and there is a peak to average ratio of 2. The two figures below depict the way that levelized cost and payback period change with incremental changes in biomass substitution and solar integration. Biomass substitution was ranged from 0% to 25% in increments of 5% and solar integration was ranged from 0% to 50% in increments of 10%.



LCOE		Biomass Substitution					
		0%	5%	10%	15%	20%	25%
Solar Integration	0%	0.090	0.094	0.098	0.102	0.106	0.110
	10%	0.092	0.096	0.100	0.104	0.107	0.111
	20%	0.092	0.098	0.101	0.104	0.107	0.110
	30%	0.096	0.099	0.102	0.105	0.107	0.110
	40%	0.098	0.101	0.103	0.105	0.108	0.110
	50%	0.099	0.101	0.103	0.105	0.107	0.109



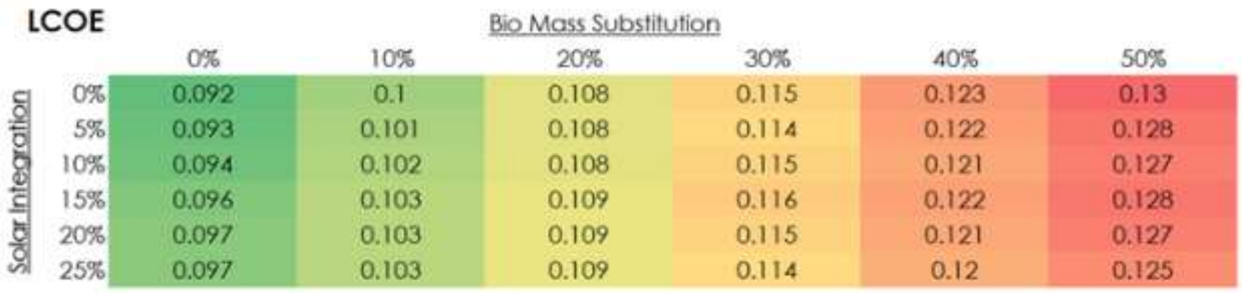
Payback

Solar Integration	Biomass Substitution 0%	5%	10%	15%	20%	25%
0%	> 30	> 30	> 30	> 30	> 30	> 30
10%	29	> 30	> 30	> 30	> 30	> 30
20%	28	> 30	> 30	> 30	> 30	> 30
30%	28	> 30	> 30	> 30	> 30	> 30
40%	27	> 30	> 30	> 30	> 30	> 30
50%	26	28	> 30	> 30	> 30	> 30

Figures 43-44: Biomass Substitution vs. Solar Integration for LCOE and Payback Period

The figures above indicate the difficulty of reaching a reasonable payback period with this baseline scenario. As expected, levelized costs increase as solar integration and biomass substitution increases. Payback periods are less than 30 years in only six out of the 36 scenarios. Payback period increases as biomass substitution increases. But it decreases as solar integration increases. This is due to the tax incentives that the grid would receive with increased solar integration.

Given the baseline results, another iteration of this Chainworks and Priority Loads scenario was completed. This time it was assumed the grant would be $2 million. This is reasonable since the scope of the project is getting so much bigger that more and larger grants will now be applicable. The peak to average ratio was lowered to 1.8. This is because with integration of the microgrid into the Chainworks facility, effective demand management can be used to the loads there to do peak demand shaving. The retail electricity price rose to $0.09 from $0.07, because in this model carbon emission are reduced by 50% so it is expected this electricity can be sold for a premium of $0.09. With these new inputs, the model tradeoff tables were created and are shown in Figures A, B, and C.



LCOE

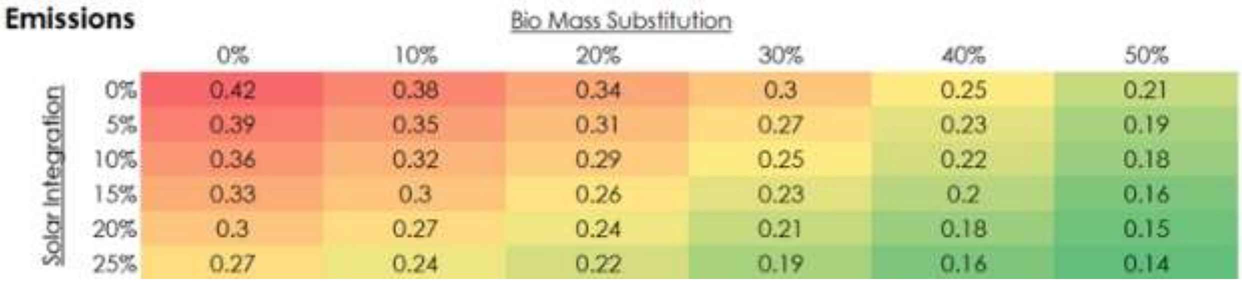
Solar Integration	Bio Mass Substitution 0%	10%	20%	30%	40%	50%
0%	0.092	0.1	0.108	0.115	0.123	0.13
5%	0.093	0.101	0.108	0.114	0.122	0.128
10%	0.094	0.102	0.108	0.115	0.121	0.127
15%	0.096	0.103	0.109	0.116	0.122	0.128
20%	0.097	0.103	0.109	0.115	0.121	0.127
25%	0.097	0.103	0.109	0.114	0.12	0.125

Figure 45: Levelized Cost of Electricity Visual for Modified Scenario 2

Payback

		Bio Mass Substitution					
		0%	10%	20%	30%	40%	50%
Solar Integration	0%	13	17	24	>30	>30	>30
	5%	14	18	22	29	>30	>30
	10%	14	18	22	28	>30	>30
	15%	15	18	22	28	>30	>30
	20%	15	18	22	26	>30	>30
	25%	16	18	21	25	>30	>30

Figure 46: Payback Period Visual for Modified Scenario 2



Emissions

		Bio Mass Substitution					
		0%	10%	20%	30%	40%	50%
Solar Integration	0%	0.42	0.38	0.34	0.3	0.25	0.21
	5%	0.39	0.35	0.31	0.27	0.23	0.19
	10%	0.36	0.32	0.29	0.25	0.22	0.18
	15%	0.33	0.3	0.26	0.23	0.2	0.16
	20%	0.3	0.27	0.24	0.21	0.18	0.15
	25%	0.27	0.24	0.22	0.19	0.16	0.14

Figure 47: Carbon Emissions Visual for Modified Scenario 2

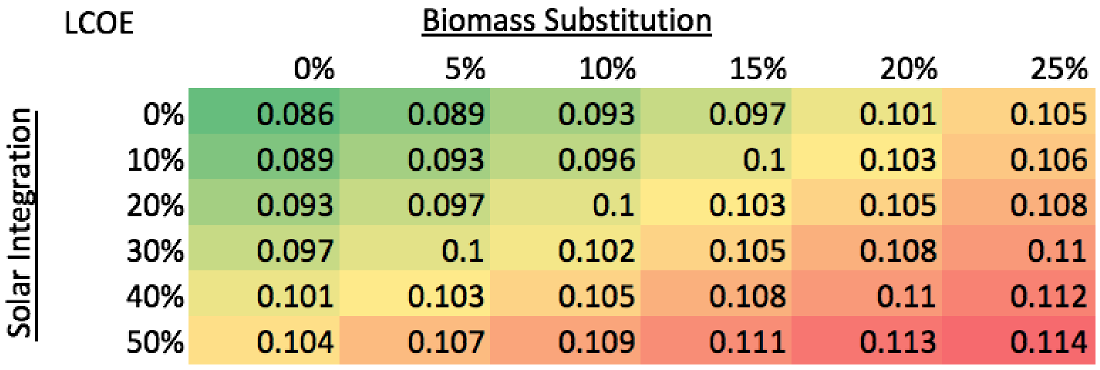
From these tables, it is concluded that a microgrid, given the assumptions made, is feasible. The microgrid is made up of 100% microtubines, approximately 10% biomass, and approximately 15% solar integration. This solution set satisfies the double bottom line of the microgrid of providing an economic return and reducing emissions. The financing party of the microgrid will recoup their initial investment in approximately 18 years. Concurrently, there is expected to be a 60% decrease in carbon emissions. Physically, this solution also makes sense. Given the surrounding Ithaca area, both a solar integration of 15%, which could be incorporated to the top of the Chainworks buildings, and 10% biomass seem reasonable. An example of the cost per ton of CO2 reduction is provided in the appendix.

Scenario 3: All Demand Except Ithaca College

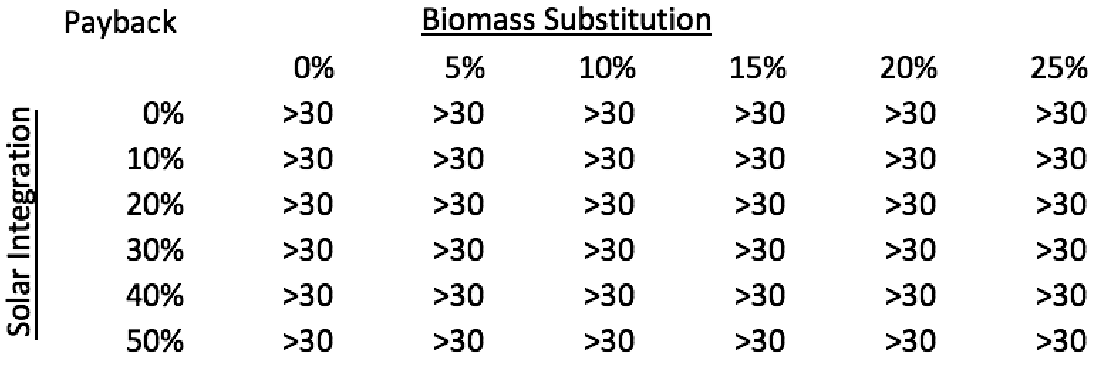
In this Scenario, our model includes all of the demand, priority, non-priority, and Chainworks, except Ithaca College. Excluding Ithaca College, the total electricity demand per year is roughly 36 GWh. As we include Ithaca College demand into our model, it becomes more difficult and challenging to find a feasible solution. Non-priority users include all the resident in the Ithaca South Energy District.

In this model, we are assuming that no heat will be sold. Therefore, no additional revenue will be generated. In the case where if we were going to bring and sell heat to the residents would require additional infrastructure, raising the costs drastically. The return will become not feasible and poses a big risk to the operator.

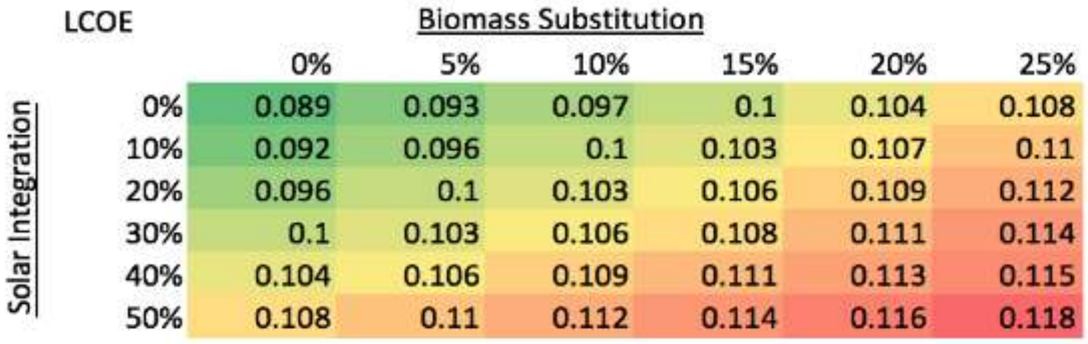
The baseline of this scenario, like others, has a baseline of $1.5 million grant, $0.07 power tariff, and a peak to average ratio of 2. The baseline model produces a return period of over 30 years in all cases when we varied the solar integration and biomass substitution percentage as shown in the figure below. If we relax our assumption, keeping the grant and power tariff the same, and increases the selling price to $0.08 per kWh, we began to see a potential feasibility to implement our model with some return periods of less than 28 years. Due to the high cost of biomass initial installation and equipment required to operate biomass, it is still difficult to find a feasible solution. However, we can see that just by raising the selling price by $0.01, there is still a potential for implementation.



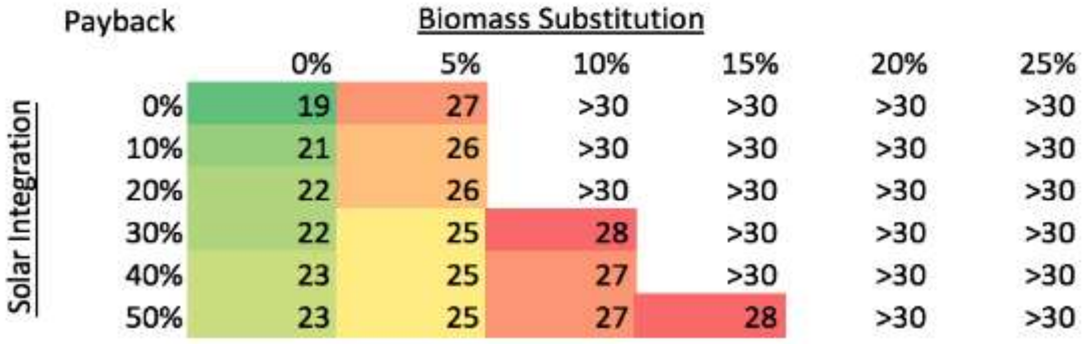
LCOE		Biomass Substitution					
		0%	5%	10%	15%	20%	25%
Solar Integration	0%	0.086	0.089	0.093	0.097	0.101	0.105
	10%	0.089	0.093	0.096	0.1	0.103	0.106
	20%	0.093	0.097	0.1	0.103	0.105	0.108
	30%	0.097	0.1	0.102	0.105	0.108	0.11
	40%	0.101	0.103	0.105	0.108	0.11	0.112
	50%	0.104	0.107	0.109	0.111	0.113	0.114



Payback		Biomass Substitution					
		0%	5%	10%	15%	20%	25%
Solar Integration	0%	>30	>30	>30	>30	>30	>30
	10%	>30	>30	>30	>30	>30	>30
	20%	>30	>30	>30	>30	>30	>30
	30%	>30	>30	>30	>30	>30	>30
	40%	>30	>30	>30	>30	>30	>30
	50%	>30	>30	>30	>30	>30	>30



LCOE		Biomass Substitution					
		0%	5%	10%	15%	20%	25%
Solar Integration	0%	0.089	0.093	0.097	0.1	0.104	0.108
	10%	0.092	0.096	0.1	0.103	0.107	0.11
	20%	0.096	0.1	0.103	0.106	0.109	0.112
	30%	0.1	0.103	0.106	0.108	0.111	0.114
	40%	0.104	0.106	0.109	0.111	0.113	0.115
	50%	0.108	0.11	0.112	0.114	0.116	0.118



Payback		Biomass Substitution					
		0%	5%	10%	15%	20%	25%
Solar Integration	0%	19	27	>30	>30	>30	>30
	10%	21	26	>30	>30	>30	>30
	20%	22	26	>30	>30	>30	>30
	30%	22	25	28	>30	>30	>30
	40%	23	25	27	>30	>30	>30
	50%	23	25	27	28	>30	>30

Figures 48-51: Biomass Substitution vs. Solar Integration for LCOE and Payback Period for both $.07 and $.08 Retail Prices

Scenario 4: All Demand Including Ithaca College

In this scenario, our model includes all of the demand: priority, non-priority, Chainworks, and Ithaca College. The total electricity demand per year is roughly 68 GWh in the early stages of Chainworks development, increasing to roughly 93 GWh once Chainworks is fully built out. When we include the Ithaca College demand into our model, the total demand approximately doubles to that of scenario 3 and it becomes more difficult and challenging to find a feasible solution. Non-priority users include all the residents and businesses in the Ithaca South Energy District.

Since the infrastructure of heating systems tend to be high, we are assuming that no heat will be sold. Therefore, no additional revenue from heat, will be generated. If the microgrid were able to sell heat to Ithaca College as well as the other residents and businesses in the South Energy District, it would be good to install a combined heat and power system to be integrated into the microgrid. In order to accomplish this, additional infrastructure for distribution would need to be installed, raising the costs drastically. The return on this investment would become infeasible and poses a large risk to the operator of the microgrid.

Since the demand is very high, this scenario represents the case of microgrid operation with the highest demand. With such high demand from the customer side, the feasible and most economical source would be to use a 100% microturbine to satisfy the demand, based on the available technology and the accompanying installation and operation costs. For the same reason, investing in strict demand management is required. Compared to other scenarios, the decision variables of this scenario differ because of the fixed economical source. The better way to evaluate the model is to increment the grants, electricity selling cost and a better peak to average ratio.

The first criterion evaluates the payback period and leveled cost by changing the peak to average ratio and grants. From Figure A, it can be inferred that the payback period is not very attractive and remains to be higher than 30 years for the maximum grant of $4,000,000 and a strict peak to average ratio of 1.7. However, the second criterion assumes an incremental electricity selling cost with a fixed grant of $1,500,000. With this relaxation of a slightly higher selling cost, we observe that the payback period reduces drastically. The sweet spot would be a tradeoff between the investment in demand management, which could be around 1.8 peak to average ratio and a selling cost of around $0.085. This gives us a reduced and a potentially feasible payback period in the range of 14-20 years.

If biomass is integrated into this scenario, power would need to be sold at a tariff of $0.09 per kWh. As you can see in Figure C, when holding the power tariff at this rate, the microgrid would need a strict demand management system in order to have an attractive payback period. In order to have 10% biomass integration, the peak to average ratio would need to be lowered from 2.0 to

1.8 or less for the payback period to be under 20 years. In order to have 15% biomass integration, the peak to average ratio would need to be lowered from 2.0 to 1.5 for the payback period to be under 20 years. In order to have 20% biomass integration, a peak to average ratio of 1.5 corresponds to a payback period of 22 years, which is rather high. Therefore, biomass integration is not economically attractive over 10-15%.

100% Microturbine, No CHP

LCOE — Peak/Average Ratio

Grant ($)	2.00	1.90	1.80	1.70	1.60	1.50
$1,500,000.00	$ 0.095	$ 0.095	$ 0.094	$ 0.094	$ 0.093	$ 0.093
$2,000,000.00	$ 0.095	$ 0.094	$ 0.094	$ 0.093	$ 0.093	$ 0.092
$2,500,000.00	$ 0.095	$ 0.094	$ 0.093	$ 0.093	$ 0.092	$ 0.092
$3,000,000.00	$ 0.094	$ 0.094	$ 0.093	$ 0.092	$ 0.092	$ 0.091
$3,500,000.00	$ 0.094	$ 0.093	$ 0.092	$ 0.092	$ 0.091	$ 0.091
$4,000,000.00	$ 0.093	$ 0.093	$ 0.092	$ 0.091	$ 0.091	$ 0.090

Payback Period — Peak/Average Ratio

Grant ($)	2.00	1.90	1.80	1.70	1.60	1.50
$1,500,000.00	> 30	> 30	> 30	> 30	> 30	> 30
$2,000,000.00	> 30	> 30	> 30	> 30	> 30	> 30
$2,500,000.00	> 30	> 30	> 30	> 30	> 30	> 30
$3,000,000.00	> 30	> 30	> 30	> 30	> 30	> 30
$3,500,000.00	> 30	> 30	> 30	> 30	> 30	29
$4,000,000.00	> 30	> 30	> 30	> 30	29	28

Figure 52-53: Payback Period Visual for Criteria 1

100% Microturbine, No CHP, $1.5M grant

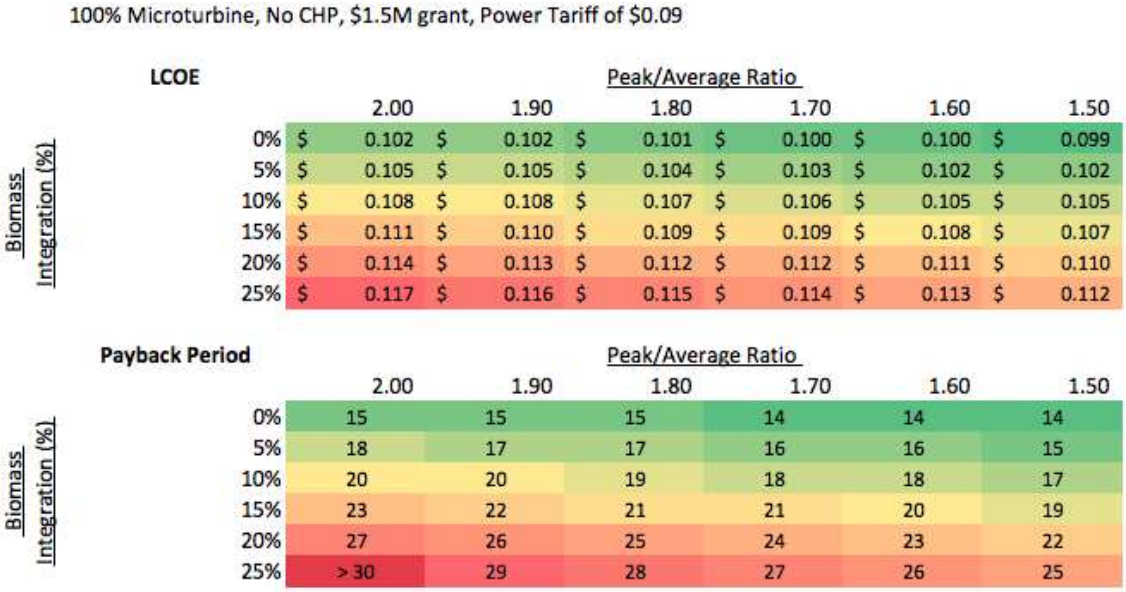
LCOE — Peak/Average Ratio

Power Tariff ($/kWh)	2.00	1.90	1.80	1.70	1.60	1.50
$0.070	$ 0.095	$ 0.095	$ 0.094	$ 0.094	$ 0.093	$ 0.093
$0.075	$ 0.097	$ 0.097	$ 0.096	$ 0.095	$ 0.095	$ 0.094
$0.080	$ 0.099	$ 0.098	$ 0.098	$ 0.097	$ 0.096	$ 0.096
$0.085	$ 0.100	$ 0.100	$ 0.099	$ 0.099	$ 0.098	$ 0.097
$0.090	$ 0.102	$ 0.102	$ 0.101	$ 0.100	$ 0.100	$ 0.099

Payback Period — Peak/Average Ratio

Power Tariff ($/kWh)	2.00	1.90	1.80	1.70	1.60	1.50
$0.070	> 30	> 30	> 30	> 30	> 30	> 30
$0.075	28	27	26	26	25	24
$0.080	22	21	21	20	20	19
$0.085	18	18	17	17	16	16
$0.090	15	15	15	14	14	14

Figure 54-55: Payback Period Visual for Criteria 2



100% Microturbine, No CHP, $1.5M grant, Power Tariff of $0.09

LCOE

Biomass Integration (%)	Peak/Average Ratio					
	2.00	1.90	1.80	1.70	1.60	1.50
0%	$ 0.102	$ 0.102	$ 0.101	$ 0.100	$ 0.100	$ 0.099
5%	$ 0.105	$ 0.105	$ 0.104	$ 0.103	$ 0.102	$ 0.102
10%	$ 0.108	$ 0.108	$ 0.107	$ 0.106	$ 0.105	$ 0.105
15%	$ 0.111	$ 0.110	$ 0.109	$ 0.109	$ 0.108	$ 0.107
20%	$ 0.114	$ 0.113	$ 0.112	$ 0.112	$ 0.111	$ 0.110
25%	$ 0.117	$ 0.116	$ 0.115	$ 0.114	$ 0.113	$ 0.112

Payback Period

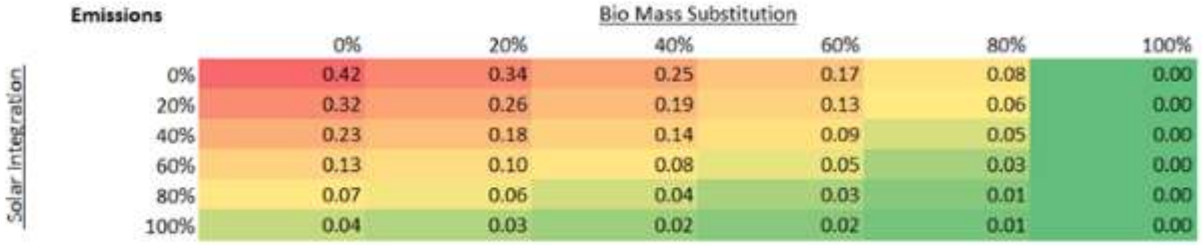
Biomass Integration (%)	Peak/Average Ratio					
	2.00	1.90	1.80	1.70	1.60	1.50
0%	15	15	15	14	14	14
5%	18	17	17	16	16	15
10%	20	20	19	18	18	17
15%	23	22	21	21	20	19
20%	27	26	25	24	23	22
25%	> 30	29	28	27	26	25

Figure 56-57: Payback Period Visual for Criteria 3

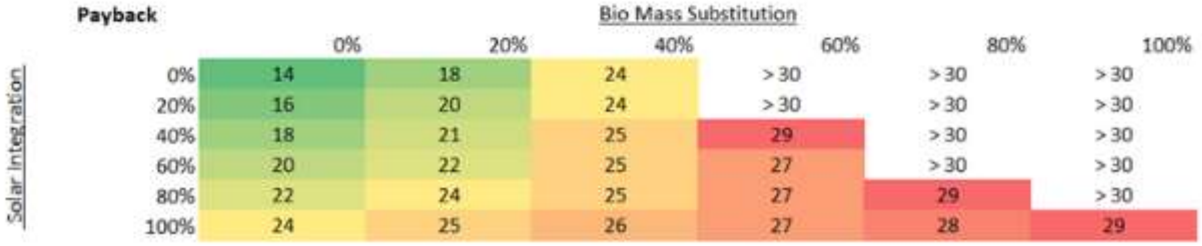
Scenario 5: Carbon Neutrality

An extremely important scenario from an environmental standpoint is the consideration of having the microgrid go carbon neutral. This scenario like many of the others will assume a $1.5 million grant. However, unlike the previous scenario it will only be accounting for the Chainworks district and the priority loads, which equates to a total of 30 GWh per year. Another assumption in this scenario is that the retail price of electricity will double from our original conservative estimate of $.07 per kWh to $.14 per kWh. This drastic increase in retail price was assumed because a price premium should be paid for carbon neutral electricity. The microgrid will also be selling very cheap heat at only $.011 per kWh equivalent to these users for some additional revenue. It can also be assumed that there will be a stricter demand management and storage resiliency in this scenario when compared to other scenarios. The figures below show the feasibility of such a system.

LCOE		Bio Mass Substitution					
		0%	20%	40%	60%	80%	100%
Solar Integration	0%	$ 0.139	$ 0.153	$ 0.167	$ 0.180	$ 0.194	$ 0.208
	20%	$ 0.148	$ 0.159	$ 0.171	$ 0.182	$ 0.194	$ 0.205
	40%	$ 0.157	$ 0.167	$ 0.176	$ 0.186	$ 0.195	$ 0.204
	60%	$ 0.165	$ 0.173	$ 0.180	$ 0.187	$ 0.194	$ 0.201
	80%	$ 0.173	$ 0.179	$ 0.184	$ 0.188	$ 0.193	$ 0.199
	100%	$ 0.180	$ 0.184	$ 0.187	$ 0.190	$ 0.193	$ 0.196



Emissions		Bio Mass Substitution					
		0%	20%	40%	60%	80%	100%
Solar Integration	0%	0.42	0.34	0.25	0.17	0.08	0.00
	20%	0.32	0.26	0.19	0.13	0.06	0.00
	40%	0.23	0.18	0.14	0.09	0.05	0.00
	60%	0.13	0.10	0.08	0.05	0.03	0.00
	80%	0.07	0.06	0.04	0.03	0.01	0.00
	100%	0.04	0.03	0.02	0.02	0.01	0.00



Payback		Bio Mass Substitution					
		0%	20%	40%	60%	80%	100%
Solar Integration	0%	14	18	24	> 30	> 30	> 30
	20%	16	20	24	> 30	> 30	> 30
	40%	18	21	25	29	> 30	> 30
	60%	20	22	25	27	> 30	> 30
	80%	22	24	25	27	29	> 30
	100%	24	25	26	27	28	29

Figures 58-60: Biomass Substitution vs. Solar Integration for LCOE, Emissions, and Payback Period

It is clear from the levelized cost analysis that biomass substitution is the more expensive route to take when compared to integration of solar technologies. Optimally, both technologies would likely be used in a careful balance. From the emissions figure 80 to 100 percent solar integration can be enacted, while also implementing 60 to 80 percent biomass substitution for the microturbines through a wood pellet gasification system instead of purely using natural gas. Financially it is clear that this type of configuration does have potential. With 80% solar and 80% biomass substitution there is nearly no carbon emissions and the payback period is 29 years. This is still below a 30 year timeframe, which is the standard generally being used to assess whether the project will be paying for itself in a reasonable amount of time. However, to be able to get people to agree to this premium retail price of electricity for carbon neutral electricity is the real difficulty associated with this scenario, yet the value of $.14 per kWh was the more realistic estimate considered.

Alternatively, a more optimistic and idealistic carbon neutral scenario was considered. All assumptions from the previous figures and discussion for this scenario will be held constant. The only modification made was in regard to the retail price of electricity. In a truly ideal and environmentally conscious world a value of $.20 per kWh could be used as the retail price. Which, in turn would drastically improve the economic feasibility and payback period. The viability of this scenario under this new assumption can be seen in the figures below.

LCOE

	Bio Mass Substitution					
Solar Integration	0%	20%	40%	60%	80%	100%
0%	$ 0.157	$ 0.172	$ 0.185	$ 0.199	$ 0.213	$ 0.226
20%	$ 0.166	$ 0.178	$ 0.189	$ 0.201	$ 0.212	$ 0.224
40%	$ 0.175	$ 0.186	$ 0.195	$ 0.204	$ 0.214	$ 0.223
60%	$ 0.183	$ 0.192	$ 0.199	$ 0.206	$ 0.213	$ 0.220
80%	$ 0.191	$ 0.197	$ 0.202	$ 0.207	$ 0.212	$ 0.218
100%	$ 0.199	$ 0.203	$ 0.206	$ 0.209	$ 0.212	$ 0.214

Emissions

	Bio Mass Substitution					
Solar Integration	0%	20%	40%	60%	80%	100%
0%	0.42	0.34	0.25	0.17	0.08	0.00
20%	0.32	0.26	0.19	0.13	0.06	0.00
40%	0.23	0.18	0.14	0.09	0.05	0.00
60%	0.13	0.10	0.08	0.05	0.03	0.00
80%	0.07	0.06	0.04	0.03	0.01	0.00
100%	0.04	0.03	0.02	0.02	0.01	0.00

Payback

	Bio Mass Substitution					
Solar Integration	0%	20%	40%	60%	80%	100%
0%	9	11	13	15	18	22
20%	11	12	14	16	18	20
40%	13	14	15	16	18	19
60%	14	15	15	16	17	18
80%	15	16	16	17	17	18
100%	16	16	17	17	18	18

Figures 61-63: Biomass Substitution vs. Solar Integration for LCOE, Emissions, and Payback Period

The major takeaway trying to be shown from the figures above is that the same carbon neutral scenario assessed above with a retail price of electricity at $.14 per kWh can be even more economical with the retail price of electricity being $.20 per kWh. The payback period drops from 29 years to 17 years. While, 29 years is still within a reasonable time frame it is still a very long time before net positive monetary gains. However, under this idealistic scenario there is only a payback period of 17 years for a microgrid with 80% solar and 80% biomass substitution. A payback period of 17 years is much more enticing from an investment standpoint and would probably spur much more excitement around the project. However, drastic policy change like a carbon tax or some other major environmental initiative would need to take place for such an idealistic and optimal situation to present itself.

Recommendations

The major takeaways from the five previously discussed scenarios will be the focus of this section. All of the five scenarios previously mentioned are all important potential situations that could arise if construction and planning for the South Energy District microgrid were approved and started. It is also worth noting that one scenario could be the starting point for the microgrid and then as time passes the microgrid could evolve and grow toward becoming one of the other scenarios. An example of this would be if the minimal microgrid model was initially being considered and then a few years after its completion extra loads such as Ithaca College were to be added to it. This would create a transition between two of the scenarios discussed above.

The major takeaways from the first scenario involving the minimal sized microgrid was mainly that for just the priority loads assessed in this report that even 100% solar integration was possible for this smaller scale baseline scenario with just a payback period of 14 years. Also, varying the retail price of electricity and grant money showed that the minimal sized microgrid was viable under all scenarios, except for the one scenario with the most conservative retail price of electricity and no grant money. Lastly, the net carbon in this scenario was also substantially lower than the macrogrid baseline under a variety of solar integration levels. Thus, it is economical and environmentally substantial.

The significant takeaways from the second scenario, which involved adding the Chainworks to the model, was that for the baseline case no biomass substitution was viable for a payback period of less than 30 years, and for a small amount of solar integration the payback period was still quite high hovering between 26 and 29 years. By altering the retail price of electricity by mimicking a more favorable economic state for the microgrid the payback period was reduced to around the teens of years for no biomass. With 30% biomass the payback period was still long, yet still below 30 years. Thus, adding Chainworks district to the model does create a significant burden on the economic viability of the microgrid to the point where conservative approximations become quite risky and lengthy in terms of payback period.

For the third scenario, involving all demand except Ithaca College, the major takeaway is that the microgrid becomes even more difficult to make viable for baseline conditions. For all levels of biomass and solar integration the payback period is above 30 years for baseline conditions. Assuming slightly more favorable economic conditions via a 1 cent increase in the retail price of electricity a small level of biomass and solar integration can be achieved. However, having a 30 year or more payback period for the most conservative situation for this scenario means that there is an even greater amount of risk associated, without any sort of economic or policy changes internally within our government.

In the fourth scenario, where all potential foreseeable demand is accounted for (including Ithaca College), the major takeaway is that even with an adjusted baseline scenario involving a lower peak to average ratio that almost all payback periods are still above 30 years. For this scenario it takes an even greater increase in the baseline scenario involving a lower peak to average ratio and an increase in the conservative retail price of electricity by 2 cents to generate reasonable or enticing payback periods.

Finally, in the fifth scenario, pertaining to carbon neutrality, the major takeaway is that carbon neutrality will only come with significant adjustments. This comes as no surprise, however, considering that this is the most far reaching case for the microgrid considered. Yet, since this scenario is so extreme, it also means that there is more justification for large deviations from the baseline conditions specified earlier. Thus, by establishing price premiums, which nobody would be surprised by for a carbon neutral system, the scenario does actually become relatively feasible. Doubling and tripling the retail price of electricity lead to payback periods of 29 and 17 years respectively, which in the grand scheme of this project actually seems like quite good news because even greater increases in the retail price were expected to be required to achieve such returns, despite the specified increases in retail price still being quite significant.

Overall, it is hard to predict the economic state of the future. Assuming that the microgrid can sell for any price over 7 cents per kWh comes with some risk. Generally, for most scenarios CHP systems were generally more expensive up front than they were worth in the long run. Microturbines were generally the least expensive option amongst the three options of reciprocating engines, fuels cells, and microturbines. A conservative peak to average ratio of two was achieved in most scenarios, except for the fourth scenario containing all foreseeable demand.

As a result, generating a "final recommendation" is quite difficult to produce from a project of this scale, scope, and magnitude. To a large extent, the recommendation will change depending on a variety of factors both externally and internally. Thus, it really depends. However, just through consideration of the analysis of the minimal sized microgrid it is clear that this project has a lot of potential and definitely could be a wise economic investment, at least at a smaller scale. The minimal sized microgrid model gives merit and proof of concept to the idea that the microgrid can be designed and planned in such a way that it can be economically self-sufficient, while also being environmentally more sustainable than the macrogrid. However, as one deviates from this minimal sized microgrid model the complexities and uncertainties begin to become more apparent and more risk is taken on with each subsequent iteration.

Areas for Future Research

Much of the focus in the project so far, was to discuss the economic, social, and environmental benefits over the possible scenarios for the operation of a functional SED microgrid. The following areas of future research are foreseen:

1. The primary focus of the future research should be more inclined towards the efficacy of renewable power plans to displace conventional fuel sources. Though current market research and statistics seem promising for renewable energy to play a major role in the

future of generation capacity, it is unclear if fossil fuels will ever be completely replaced in the foreseeable future. This also emphasizes on the robustness of the microgrids design to be effective enough to add future renewable systems like the wind power and geothermal energy sources which are beyond the scope of the discussed scenarios. The dip in solar generation during winters, can be potentially matched by utilizing wind power. Also, advancement in geothermal research within the Cornell community also promises the availability and possibility of integrating geothermal sources for district heating purposes to the microgrid. Another future consideration that was referenced earlier in the considerations section would be in regard to improving the accuracy of the model by accounting for property costs associated with the Chainworks District.

2. Moving to the topic of demand prediction and management for the microgrid, extensive research work on community based distributed energy systems management provides an excellent opportunity to integrate and monitor SED's loads efficiently. Many key business giants and energy focused companies are constantly trying to make ground breaking technologies to accurately manage an entire electrical system. Such technologies not only save cost and energy but also contribute to sustainability by reducing carbon emissions. Managing demand will enhance the concept of energy arbitrage by selling the unused and excess power back to the macrogrid and provide a financial advantage to the microgrid community.
3. Lastly, the research on this project could be extended to identify efficient energy storage systems. Increase in energy storage enables the wastage of excess power generated. New technology batteries are more focused on storing higher energy in lesser area of the battery. This technology should be well researched to identify the suitable energy storage system for SED's microgrid based on the demand, cost of installation and other practical aspects like safety, involved in the operation of the storage system. With such broad areas on which to focus, the microgrid will transform the utilization of energy resources from being an emerging technology to an epochal pillar of sustainability. Though there are economic, regulatory and technological risks involved, current forecasts are more positive towards microgrids to be the critical solution for the next generation efficient energy management system.

Appendix

Spreadsheet Model

For space efficiency purposes copying and pasting the entire model into this section will not be done. However, to give the reader a general idea of the model without actually going into excel to look at it, the below figure should help give an idea as to the magnitude and comprehensiveness of the model.

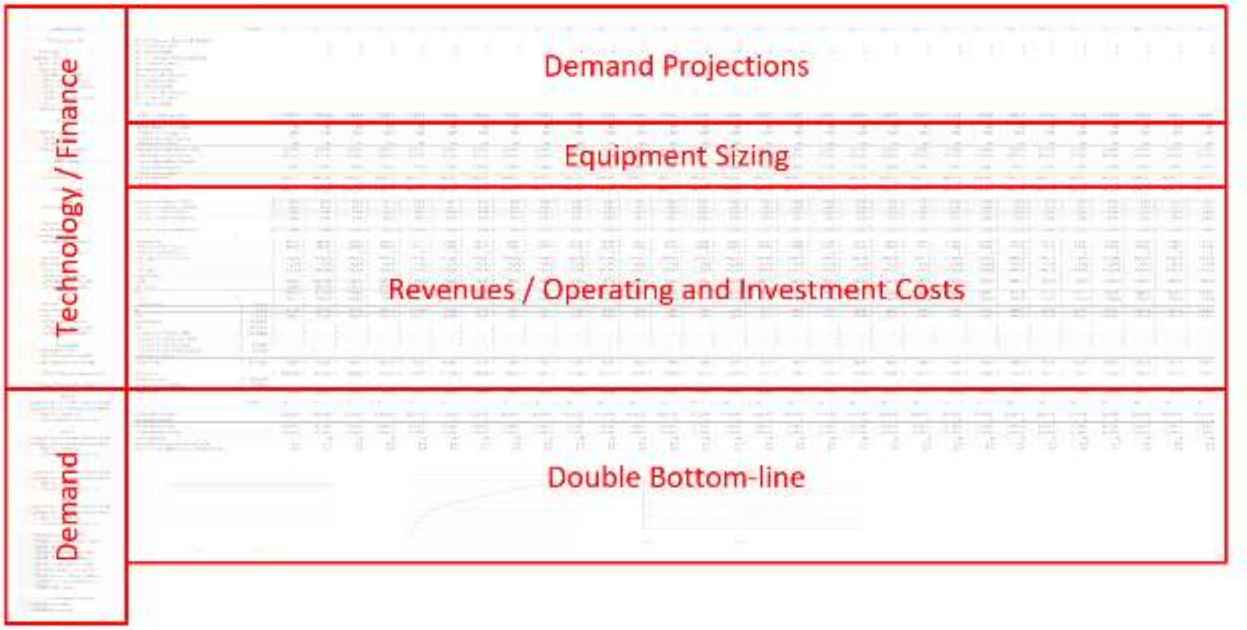
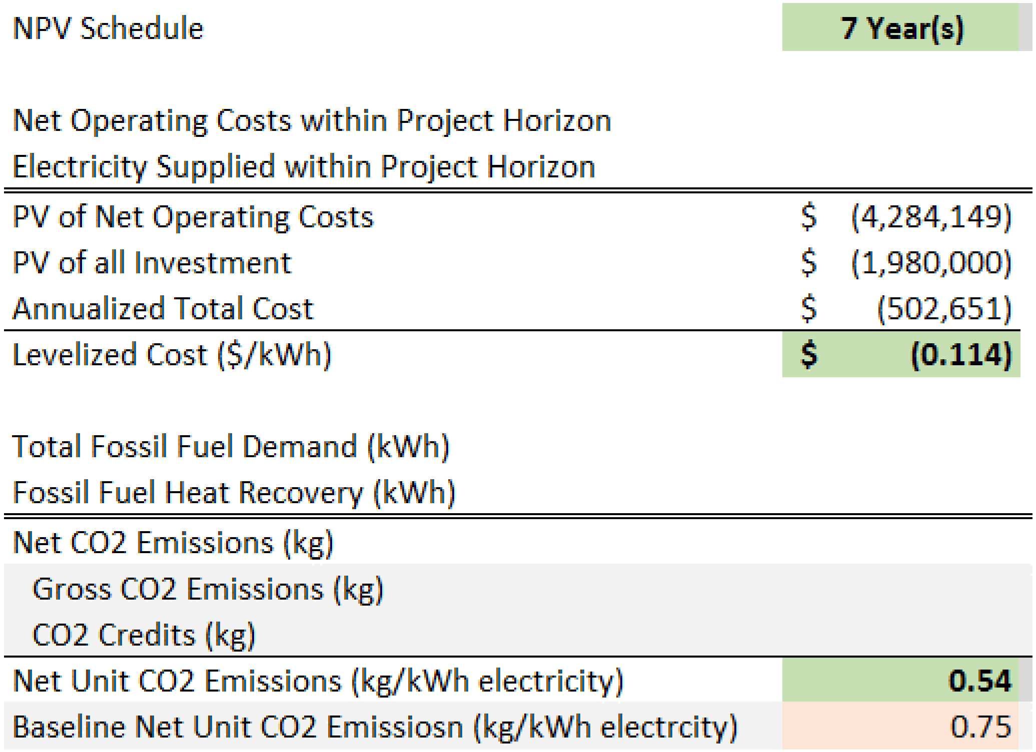


Figure 64: Model Overview Snapshot

Significant Outputs

The NPV schedule, the levelized cost of energy, and the net unit CO_2 emissions are the three significant outputs that act as indicators for the model. Some snapshots from the minimal microgrid model were used to show examples of where these indicators are located in the model and how to interpret them.



NPV Schedule		**7 Year(s)**
Net Operating Costs within Project Horizon		
Electricity Supplied within Project Horizon		
PV of Net Operating Costs	$	(4,284,149)
PV of all Investment	$	(1,980,000)
Annualized Total Cost	$	(502,651)
Levelized Cost ($/kWh)	**$**	**(0.114)**
Total Fossil Fuel Demand (kWh)		
Fossil Fuel Heat Recovery (kWh)		
Net CO2 Emissions (kg)		
Gross CO2 Emissions (kg)		
CO2 Credits (kg)		
Net Unit CO2 Emissions (kg/kWh electricity)		**0.54**
Baseline Net Unit CO2 Emissiosn (kg/kWh electrcity)		0.75

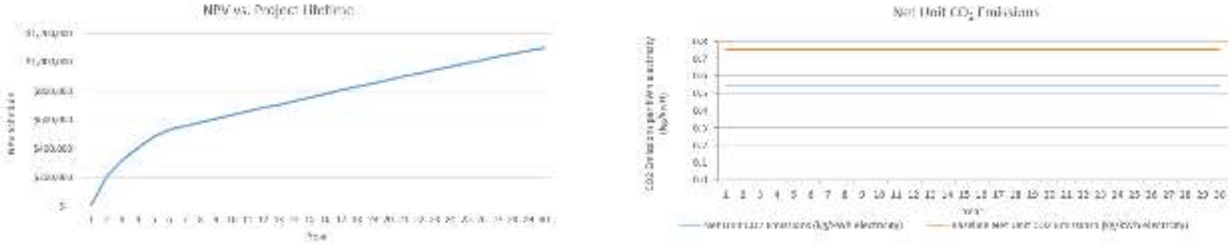
Figure 65: Significant Outputs

The NPV schedule estimates the amount of time that it will take for the project to pay for itself. This is essentially just an indicator for the payback period. The total levelized cost is also calculated, and thus this gives a good approximation of the amount of money per unit of electricity given all of the conditions specified. Both the net unit carbon dioxide emissions for the microgrid and the net unit carbon dioxide emissions baseline of the macrogrid are shown so that they can easily compared. Having a net unit carbon emission that is lower for the microgrid than for the macrogrid obviously means that the microgrid is more sustainable.

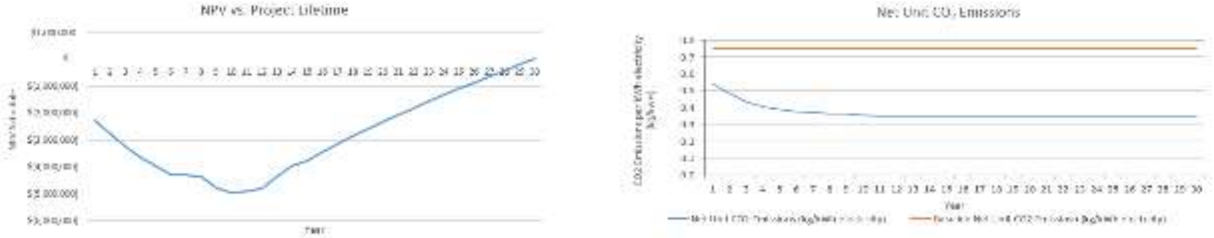
Significant Figures

The following figures are the baseline case (peak to average = 2, 0% storage, 100% microturbines, $1.5 million from grants, no CHP, no biomass substitution, 10% solar integration, and $.07/kWh retail price of electricity) for every scenario. The figures below are: NPV vs. Project Lifetime and the Net United CO_2 Emissions Comparison graphs for every scenario. These two graphs have been hardcoded into the model so that the user can quickly see changes to the model when they change (a) variable(s). Thus, displaying these graphs in the appendix seemed logical. Some exceptions to the baseline case for each scenario were made and they are listed in the title.

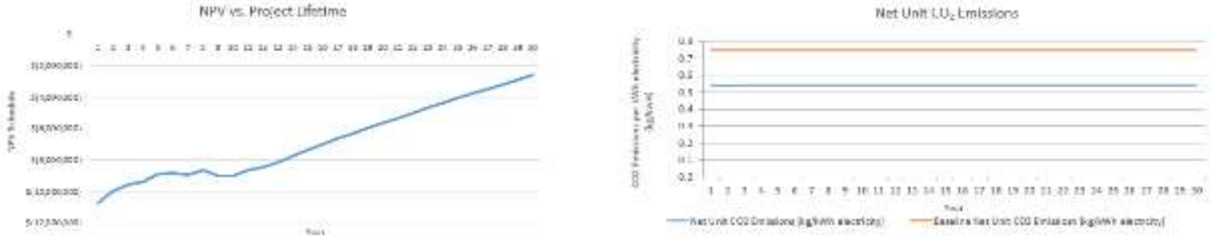
Scenario 1 (Minimal Microgrid):



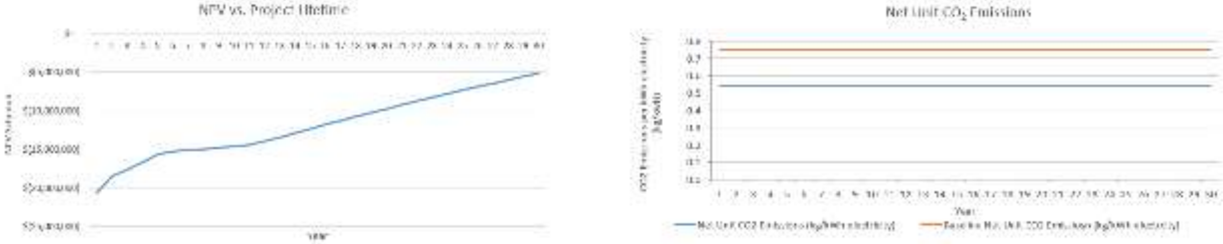
Scenario 2 (Priority loads and Chainworks District) [Exception: CHP = True]:



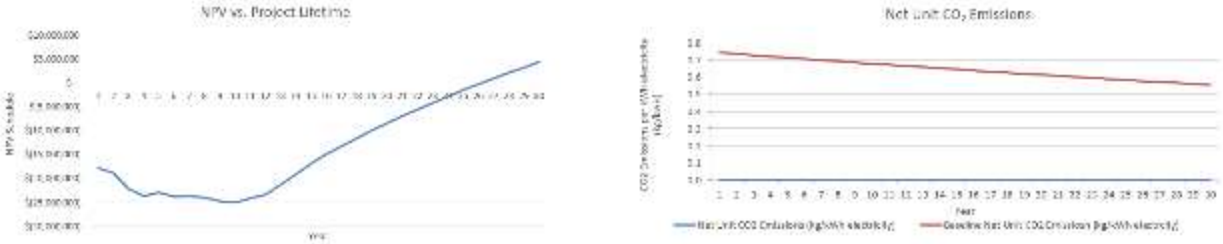
Scenario 3 (All loads Except Ithaca College):



Scenario 4 (All loads, with Ithaca College) [Exception: CHP = True]:



Scenario 5 (Carbon Neutral Microgrid) [Exception: solar and biomass = 100%, storage = 35%, CHP = True, peak/avg = 1.5, retail price of elect. = $.20]:



Figures 66-70: All Scenario NPV vs Project Lifetime and Net CO2 Graphs

Role of energy service companies in emerging distributed energy market:

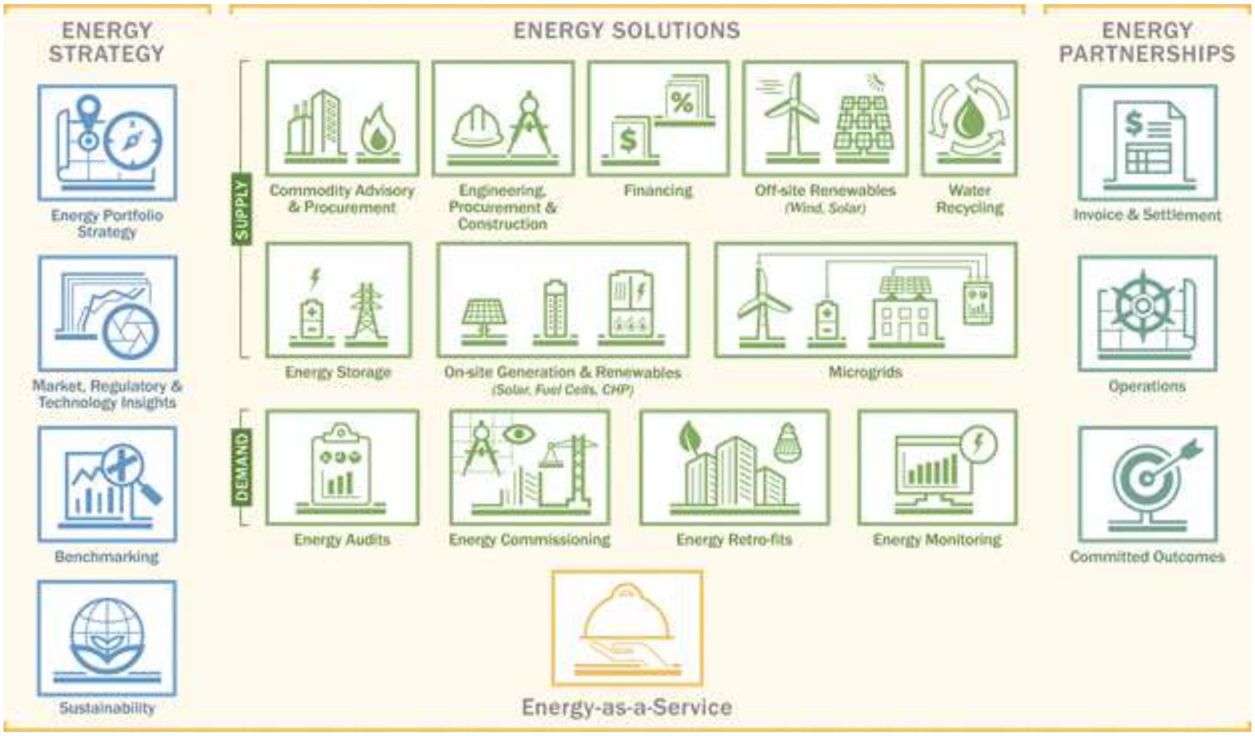


Figure 71: Energy as a Service - Emerging Business Model in Energy Industry

People are seeking new ways to more actively manage their energy consumption. Customers are demanding energy providers to deliver new services more nimbly Communication systems are changing from one-way to two-way. Helping customers increase their energy efficiency is also part of the energy provider's evolving business model. In the past, the energy providers made money on how much power they sold. The new business model is a combination of selling electricity and helping save it for customers.

Energy providers are trying to find new ways to grow their business by continuing exploration of clean – distributed energy solutions, energy storage solutions and their potential for broad adoption, by serving previously underserved small and medium-sized businesses. They see that the industry is being reshaped by evolving customer expectations, rapidly changing technologies and new public policies. As a result of which, there is potential for significant growth in Clean – Distributed energy solutions, Energy Saving and Performance Contracting Market.
They aim to be the *one-stop shop* for clean – distributed energy solution and provide *end-to-end energy solutions* to businesses, governments and educational institutions across the United States.

As a result, large energy providers are aggressively focusing on 'energy as a service' model to capture the growing demand for distributed energy, clean energy, and the services to manage the energy efficiently and position themselves as the integrator of energy solutions.

The following three energy providers are currently offering "energy as a service" model through their subsidiaries / partners/ private placements:

1) **Duke Energy**
2) **Edison International**
3) **Engie**

These large energy providers are ***using their financial strength and lower cost of capital to offer easy customer financing, including leases and power purchase agreements***.

The following section gives brief description of subsidiaries of aforementioned energy providers and their service portfolio:

Subsidiary Name	Service Portfolio
Duke Energy Subsidiaries	
REC Solar	REC designs and develops a customized-fully integrated rooftop and ground-mounted solar systems for customers in commercial sector. So unlike many solar firms, they finance, design, build and manage their projects from start to finish.
Phoenix Energy Technologies	Phoenix ET delivers a skilled analytics team and an advanced software system that enables customers to reduce their energy usage without upfront capital costs.
	PhoenixET's software is capable of integrating an entire customer's portfolio of buildings without the deployment of additional hardware.
	The system provides savings to its customers in real time through remote diagnostic and repair tools
Edison International Subsidiaries	
Eneractive Solutions	Enervative designs, develops, and installs commercial and industrial solar energy solutions.
Delta Energy, LLC	Delta provides customized energy management consulting services to large C&I consumers. Their service portfolio consists of energy procurement, energy data management, and renewable energy/energy efficiency consulting and regulatory services.
SoCore Energy	SoCore provides energy consulting, engineering, and project development services
Altenex LLC	Altenex provides renewable energy advisory and procurement services
Enbala Power Networks	Enbala is an energy management company which provides solutions to make the world's power grids more sustainable by harnessing the power of distributed energy, with their real-time energy balancing and distributed control systems.
Spruce Finance	Spruce provides financing solutions to US residential market to support the rapidly growing demand by homeowners for solar power, water conservation and energy efficiency tools
Optimum Energy	Optimum Energy provides optimization solutions for heating, ventilation and air conditioning (HVAC) systems to large, multi-site corporations.
Flywheel – SCIenergy	SCIenergy integrates technology and service providers, and

	capital markets to transform how building owners and occupants interact with energy. SCIenergy has developed the first Energy-Infrastructure-as-a-Service integrated platform, combining cloud-based software and project capital, to drive the mass deployment of comprehensive energy solutions in large buildings.
Proterra	Proterra is the leading manufacturer of electric-drive buses and zero-emission commercial vehicles. Proterra's products help transit agencies deliver clean, quiet, rider- and 99eighbourhood-friendly vehicles that also meet government regulations and local mandates, and establish it as the first company to deliver a full-size transit vehicle.
Engie Subsidiaries	
OpTerra Energy Services	OpTerra builds facility-customized technical scopes that enable customers to reduce energy consumption and energy cost
Ecova	Ecova leverages data collected from millions of households, utilities and business sites to help commercial, industrial & utility customers save energy costs and resources.
Green Charge Networks	Green Charge Networks is the country's largest provider of commercial energy storage for retail, industrial and government customers. The integrated solar and energy storage system improves energy savings by 20 – 50%

Table 13: Subsidiaries and Definitions

Example calculation of cost per ton of CO2 reduced

Per my note, I recommend adding this calculation here

Cost per Ton of CO_2 Reduced:

In this section of the appendix, an evaluation of how much money it costs to reduce carbon dioxide emissions of the microgrid. This evaluation is carried out via comparing the base case of a scenario (with no solar integration and no biomass substitution) against a separate case that involves some level of carbon reduction. The scenarios evaluated in this manner were scenario 2 and scenario 5. However, scenario 5 was modeled two different ways, containing both realistic and idealistic cases. The levelized cost of energy and the corresponding net emissions are recorded for the base case, and then compared to the reduced carbon dioxide case for scenario 2, scenario 5 (realistic), and scenario 5 (idealistic). The numbers used in the examples below came from figures 46 and 48, 59 and 60, and 62 and 63.

Cost per Ton for Scenario 2:

Base case: 0% solar integration and 0% biomass substitution
“Base case” Levelized cost of energy = .092 \$/kWh
“Base case” Net Emissions = .42 kgCO_2 / kWh
Reduced CO_2 case: 25% solar integration and 50% biomass substitution
“Reduced case” Levelized cost of energy = .125 \$/kWh
“Reduced case” Net Emissions = .14 kgCO_2 / kWh

Cost increase = .125 - .092 = .033 \$/kWh
Emission decrease = .42 - .14 = .28 kgCO_2 / kWh
Cost/kg = .033/.28 = .11786 → Cost/ton = .11786*1000 = \$117.86

<u>Cost per Ton for Scenario 5 (realistic):</u>
Base case: 0% solar integration and 0% biomass substitution
“Base case” Levelized cost of energy = .139 \$/kWh
“Base case” Net Emissions = .42 kgCO_2 / kWh
Reduced CO_2 case: 80% solar integration and 80% biomass substitution
“Reduced case” Levelized cost of energy = .193 \$/kWh
“Reduced case” Net Emissions = .01 kgCO_2 / kWh

Cost increase = .193 - .139 = .054 \$/kWh
Emission decrease = .42 - .01 = .41 kgCO_2 / kWh
Cost/kg = .054/.41 = .13171 → Cost/ton = .13171*1000 = \$131.71

<u>Cost per Ton for Scenario 5 (idealistic):</u>
Base case: 0% solar integration and 0% biomass substitution
“Base case” Levelized cost of energy = .157 \$/kWh
“Base case” Net Emissions = .42 kgCO_2 / kWh
Reduced CO_2 case: 80% solar integration and 80% biomass substitution
“Reduced case” Levelized cost of energy = .212 \$/kWh
“Reduced case” Net Emissions = .01 kgCO_2 / kWh

Cost increase = .193 - .139 = .055 \$/kWh
Emission decrease = .42 - .01 = .41 kgCO_2 / kWh
Cost/kg = .055/.41 = .13415 → Cost/ton = .113415*1000 = \$134.15

The above calculations give three examples of how to approximate the cost per ton of reducing carbon dioxide emissions for scenario’s 2 and 5. Although, the retail price of electricity was changed drastically for the two versions of scenario 5 (thus creating large differences in the levelized cost of energy for both the realistic and idealistic versions) both the realistic and idealistic calculations of cost per ton of carbon dioxide for scenario 5 were very similar. This is likely due to the fact that, although the levelized cost of energy went up in the idealistic case when compared to the realistic case, the overall net cost increase between the base case and the reduced carbon dioxide case were still similar. The upper and lower bounds changed, but the net difference between the levelized costs did not. Thus, for scenario 2 of the model, the cost of reducing carbon dioxide was roughly $118, while for scenario 5 of the model the cost of reducing carbon dioxide only increased a marginal amount up to around $132-$134. These were the two easiest scenarios to evaluate the cost per ton of reducing carbon dioxide given the figures the project team created. Doing such a calculation for all scenarios of the model would be an interesting endeavor that could be done for all scenarios. Comparing this calculation across all scenarios would show which scenarios are most effective at reducing carbon for the cheapest amount of money. This would an interesting area for further research.

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[viii] Voltage Inverter - Inverts DC to AC voltage mainly for transmission purposes.

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[x] Reactive Power - The power not used to do work on the load. Measured in Volt-Amperes Reactive (VAR).

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[xvii] Point of Common Coupling

[xviii] Voltage Frequency

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[xx] Synchronised Pulse Width Modulation

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