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A Technical and Economic Feasibility Study of Implementing a Microgrid at Georgia Southern University

Matthew S. Purser

A TECHNICAL AND ECONOMIC FEASIBILITY STUDY OF IMPLEMENTING A MICROGRID AT GEORGIA SOUTHERN UNIVERSITY

by

MATTHEW SCOTT PURSER

(Under the Direction of Youakim Kalaani)

ABSTRACT

The performance and benefits of microgrids were considered, and the feasibility of implementing a microgrid for a portion of the Georgia Southern University campus assessed. The existing power delivery system was described and characterized to ascertain whether conversion to a microgrid would be both feasible and beneficial. Different types of distributed generation were considered for their appropriateness for use on campus. A detailed economic analysis of potential microgrid configurations was then performed using HOMER, and the results were presented in the form of recommended action and alternatives.

INDEX WORDS: Microgrid, distributed generation, renewable energy, feasibility study, Georgia Southern University

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CHAPTER 1

INTRODUCTION

Microgrids- localized, small-scale groupings of generating sources, storage systems, and loads- are currently a hot topic in the world of electrical engineering. Some authors even claim that microgrids are “the biggest driving change in the electric power infrastructure on the horizon” (Masiello 2013). A major contributor to their rising popularity is their ability to easily integrate distributed generation sources such as solar or wind. They also offer increased energy reliability and security, and carry a large economic opportunity in terms of cost saving. Microgrids have been installed at various universities, medical campuses, and military facilities.

This thesis serves as a general investigation of how Georgia Southern University could potentially benefit from implementing a microgrid. Chapters 1, 2, and 3 provide background information on the state of microgrid research and adoption. Chapters 4 and 5 describe various attributes of Georgia Southern University that may affect or be affected by the implementation of a microgrid. Chapter 6 explains the rationale used to determine which distributed energy resources are appropriate for use at the GSU campus. Chapter 7 describes the steps used to perform economic analysis via HOMER. Chapters 8 and 9 present the results of this research and recommended actions.

CHAPTER 2

CONCEPTUAL FRAMEWORK OF A MICROGRID

Definition

Various researchers and organizations have defined microgrids in different ways. Siemens defines a microgrid as “a discrete energy system consisting of distributed energy sources (e.g. renewables, conventional, storage) and loads capable of operating in parallel with, or independently from, the main grid” (Dohl, 2011). The EPRI defines it as “a power system with distributed resources serving one or more customers that can operate as an independent electrical island from the bulk power system” (Herman, 2001). The Consortium for Electric Reliability Technology Solutions (CERTS) states that their microgrid concept “assumes an aggregation of loads and microsources operating as a single system providing both power and heat” (Lasseter, 2002). The Galvin Electricity Initiative defines microgrids simply as “modern, small-scale versions of the centralized electricity system” (Galvin Power 2014).

The State of Connecticut defines a microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or island mode” (Public Act 12-148§7). Similarly, the California Energy Commission (CEC) defines a microgrid as “an integrated energy system consisting of interconnected loads and distributed energy resources, which as an integrated system can operate in parallel with the grid or in an intentional island mode.” This definition was formulated after Navigant Consulting International (NCI) was commissioned to interview industry participants on the relative importance of various microgrid characteristics (Hyams, 2011). Each participant was asked to rank each characteristic as necessary or not required for the system to be considered a microgrid. Table 1 summarizes these findings.

Table 1: Percentages of Response for Different Physical Microgrid Characteristics

Microgrid Characteristic	Necessity or Preferred	Not Required	No Comment
Capable of Island Operation	100.0%	0.0%	0.0%
Capable of Operating in Parallel with the Grid	100.0%	0.0%	0.0%
Autonomous Control of System	64.3%	0.0%	35.7%
Single Point of Interconnection to Grid	50.0%	21.4%	28.6%
Non-interconnected systems can be micro-grids	35.7%	50.0%	14.3%
Ability to Meet Participant Customer's Full Load	35.7%	14.3%	50.0%
Capable of Two-Way Power Flow with Macro-Grid	35.7%	14.3%	50.0%
More than 1 Generation Source	78.6%	7.1%	14.3%
More than 1 Participating Customer or Facility	57.1%	14.3%	28.6%
Employs CHP	64.3%	14.3%	21.4%
Employs Storage Technology	35.7%	21.4%	42.9%

Adapted from US DOE/CEC Microgrids Research Assessment, Navigant Consulting Inc., May 2006

From these definitions we can see that microgrids can generally be described as a self-contained power system of interconnected loads and resources which interfaces with the external grid. They employ on-site, controllable generation sources to intelligently meet load requirements throughout the day. This contrasts with the traditional centralized power distribution approach, in which large amounts of power are generated at individual power plants and then transmitted large distances via transmission and distribution lines. A microgrid may operate completely independent of the bulk power system, or it may interact dynamically. The ability to “island”, or intentionally separate itself from the external grid without disrupting internal service, is considered the most important quality of a microgrid.

Benefits

Microgrids can offer many benefits over traditional grid-tied power delivery. *The Business Case for Microgrids* claims that microgrids offer increased efficiency, reliability, security, quality, and sustainability (Dohn, 2013). A study commissioned by IEEE and conducted by Zpryme Research and Consulting surveyed 460 global smart grid executives for their opinions on energy storage, distributed generation, and microgrids. The results of the survey revealed that the top three benefits were the ability to meet local demand, enhance grid reliability, and ensure local control of supply (Zpryme Research and Consulting 2012). These findings are shown in Figure 1.

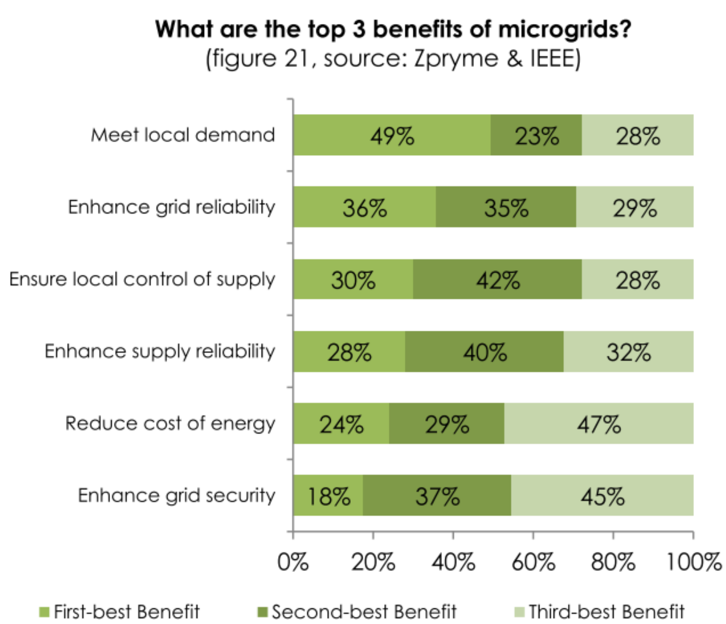


Figure 1: Surveyed Benefits of Microgrids

A study conducted by Burns & McDonnell identifies several effects and opportunities microgrids represent to utilities. In terms of electrical performance, the report states that the traditional distribution grid would benefit from reduced overall demand, increased reactive power generation capacity, and frequency and voltage regulation improvements to load balancing and power quality (Barr, Carr, and Putnam 2013). It also argues that utilities would benefit from the additional flexibility microgrids bring in terms of capital projects, and that microgrids would remove the burden of "negative public perception and increased regulatory pressure" that result from prolonged power outages (Barr, Carr, and Putnam 2013). Other researchers state that a microgrid could be considered a "model citizen" of the grid, reducing congestion and improving power quality by acting as a controlled impedance load, modulated load, or a dispatchable load (Robert Lasseter 2002).

The EPRI provides a detailed benefit identification framework in *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects* (EPRI, 2010). These are organized by economic, reliability and power quality, environmental, and energy security benefits, and are summarized in Table 2.

Table 2: Summary of Benefits Project-Funding Recipients can Expect to Report

Benefit Category	Benefit	Source of Benefit
Economic	Electricity cost savings	• Flatter load curve • Dynamic pricing and/or lower electricity rates • Lower total electricity consumption
	Reduced generation costs from improved asset utilization	• Flatter load curve • Dynamic pricing and/or lower electricity rates • Lower total electricity consumption
	T&D capital savings	• Deferred transmission and distribution capacity investments • Reduced equipment failures

	T&D O&M savings	• Reduced O&M operations costs • Reduced meter reading cost
	Reduced transmission congestion costs	• Increased transmission transfer capability without building additional transmission capacity
	Reduced T&D losses	• Optimized T&D network efficiency • Generation closer to load
	Theft Reduction	• Reduced electricity theft
Reliability and Power Quality	Reduced cost of power interruptions	• Fewer sustained outages • Shorter outages • Fewer major outages
	Reduced costs from better power quality	• Fewer momentary outages • Fewer severe sags and swells • Lower harmonic distortion
Environmental	Reduced damages as a result of lower GHG/carbon, SOx, NOx, and PM emissions	• Lower electricity consumption • Lower T&D losses • Lower emissions from renewable generation and combined heat and power
Energy Security	Greater energy security from reduced oil consumption	• Electricity substituting for oil by "smart-grid enabled" electric vehicles
	Reduced widespread damage from wide-scale blackouts	• Reduced wide-scale blackouts

Adapted from *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*, EPRI, Table 2-2

Adoption

Dohn identifies various situations that might make an organization consider a microgrid , including continuous power requirements, security requirements, planned transformation, regional drivers, and altruistic consumers (Dohn). Microgrid deployments are projected to increase significantly this decade: global capacity is estimated to increase as much as 5GW (Zpryme Research and Consulting 2012). The most likely industries to deploy microgrids during this time are healthcare, military, and government, as shown in Figure 2.

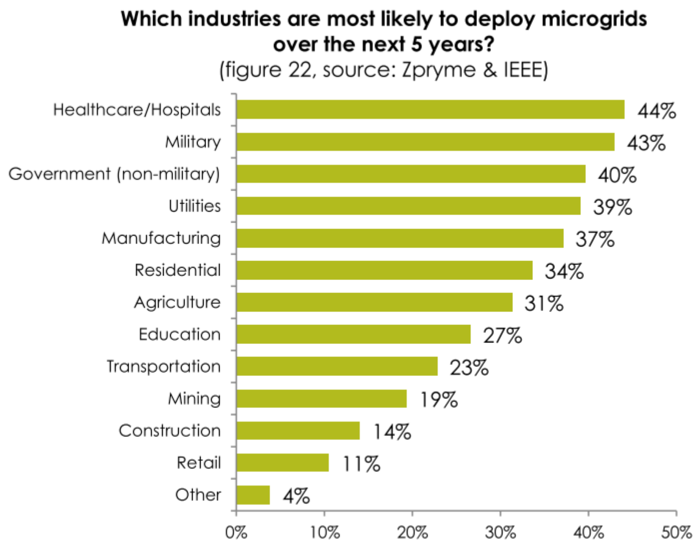


Figure 2: Industries Most Likely to Deploy Microgrids

The current landscape of microgrid adoption in the United States is dominated primarily by R&D test beds and governmental projects, with some activity by various industries, utilities, and universities (Marnay 2012). Figure 3 displays a map of current projects in the U.S.

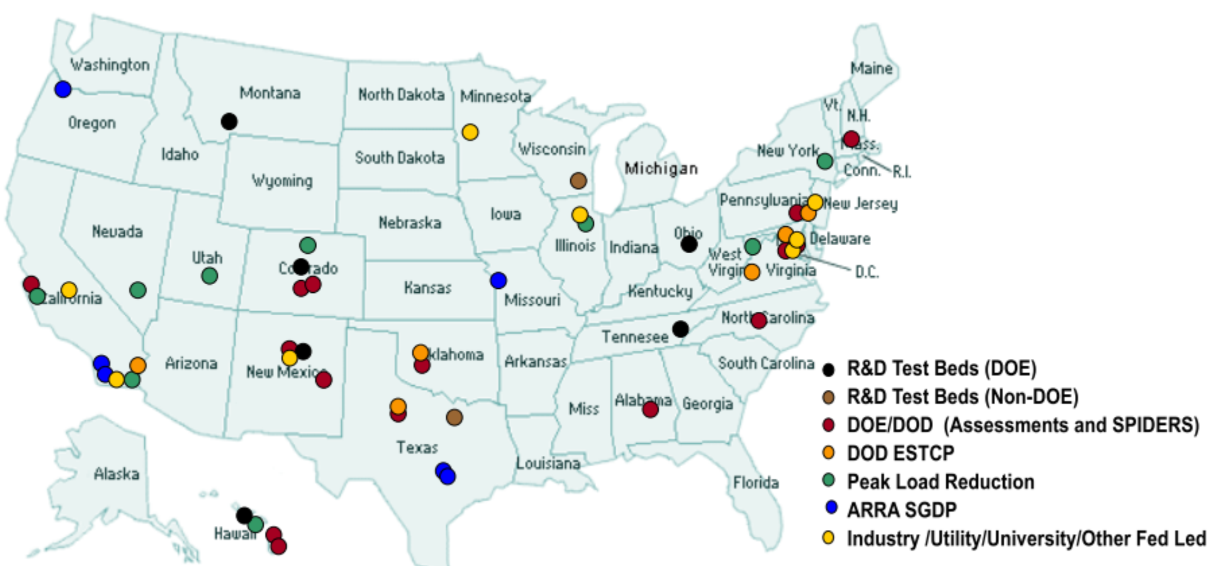


Figure 3: Map of Current Microgrid Deployments

As suggested by this map, there is substantial interest in microgrids shown by various state, federal, and foreign governments. The State of California funded the development of the CERTS Microgrid Concept through its California Energy Commission (Lasseter 2003). The State of New York commissioned an assessment of the values, opportunities and barriers to deploying microgrids (Hyams 2011). On the federal level, the Department of Defense, the Department of Energy, and other agencies have expressed considerable interest in microgrids, funding such projects as SPIDERS, or Smart Power Infrastructure Demonstration for Energy Reliability and Security. It is hoped that this technology could be used to equip military bases with reliable, secure electrical power (Saifur Rahman and Pipattanasomporn 2012).

Internationally, the European Commission has formed a consortium of various research universities, corporations, and agencies to expedite the implementation of microgrids within the European Union. This project, titled “More Microgrids”, has generated extensive research, such as the “Microgrid Evolution Roadmap in EU” (Strbac, et al 2009). Many other governmental programs exist or are in development: Table 3 lists all relevant policies, drivers, agencies, and demonstrations involving microgrids.

Table 3: International Review of Policy Drivers and Microgrid Projects

Table 1 International review of policy drivers and microgrid projects

Region	Country	Renewable energy/ microgrid policies	Other policies, drivers, and interests	Agencies involved	Demonstrations and research facilities
Asia	Japan	RPS (2002), feed in tariff (2012) Interconnection guidelines (1995); electric law amendments allowing IPPs and partial liberalization (1995, 1999, 2003); New Energy Basic Plan (2010)	Highly dependent on fossil fuel imports, partially liberalized electricity market, unofficial nuclear phase out (Fukushima), 25% reduction in greenhouse gas emissions by 2020	NEDO; METI	Hachinohe, Sendai, Aichi, Kyotango, Yokohama (Tokyo Gas), Tokyo (Shimizu) lab/demonstration, Aperture Project (U.S.)
	China	15% non-fossil target for 2020 (2009) Renewable energy law (2006) 100 New Energy cities, 30 microgrid pilots (2011) Draft management methods for distributed energy (2011)	50 GW CHP target, natural gas targets, feed in tariffs for renewable energy, 40-45% carbon intensity reduction target for 2020 (below 2005 levels)	NEA; Chinese Academy of Sciences: Inst. of Electrical Engineering	Hangzhou Dianzi Univ., Hefei Univ. of Technology, Xiamen Univ.
	South Korea	RPS – 2% by 2012, 4% by 2015, 10% by 2022	Focus on smart grid, Green Growth law, 30% below BAU greenhouse gas target for 2020	KERI	KERI microgrid; Jeju Island Smart Grid test bed
	Singapore	Singapore Initiative in New Energy Technology (SINERGY) (2007)	Nearly entirely dependent on fossil fuel imports, 16% below BAU greenhouse gas target for 2020	Energy Market Authority, A*STAR Inst. of Chemical and Engineering Sciences	Pulau Ubin, Experimental Power Grid Center (EPGC) Laboratory
Europe	EU	20% renewable energy by 2020; Framework Programmes 5 (large scale integration of micro-generation), 6 (More Microgrids), and 7 (smart grid), EU Emissions Trading Scheme	20% reduction in greenhouse gas emissions by 2020, feed in tariff programs in Spain, Germany, Italy, etc., unbundling of distribution system operators	European Commission, Director General for Energy and Transport	Kythnos, National Tech. Univ. of Athens, Mannheim Wallstadt, Bornholm Island, Eigg Island, Fraunhofer Inst.
Americas	U.S.	30 states with RPS, 44 states with interconnection policy, 44 states with a net metering policy	Development of CERTS technology, DER-CAM and µGrid software, IEEE 1547 standard development, proposed 80% clean energy goal by 2035, 17% reduction in greenhouse gas emissions by 2020 off 2005 levels	DOE, CEC, DOD, NREL	SPIDERS (Hickham AFB, Fort Carson, Camp Smith); RDSI grants (Santa Rita Jail, Borrego Springs, Univ of Hawaii, Univ of Nevada Las Vegas, ATK Space Systems, City of Fort Collins, Illinois Institute of Tech, Allegheny Power, ConEd NY); UCSD); CERTS (Univ of Wisconsin, AEP)
	Canada	Green Energy and Green Economy Act of Ontario, Ontario feed in tariff, British Columbia clean energy act (2010), Renewable Energy Standard Offer Program (2006)	Western Climate Initiative, 17% reduction in greenhouse gas emissions by 2020 off 2005 levels for participating provinces; notional clean energy standard – 90% from hydro, nuclear, wind, solar, or CCS by 2020 (from current 77%)	Natural Resources Canada, NSERC Smart Microgrid Network	Hartley Bay, BCIT microgrid, Boston Bar
	Chile	RPS of 20% by 2020	Strong renewable resources (solar, geothermal, wind), 20% below BAU greenhouse gas target for 2020		Huatacondo

Adapted from Strbac 2009, Table 1

Although much of this governmental interested has resulted from the perceived economic and environmental benefits microgrids could bring, a major driver is also the current regulatory framework involving the grid. This regulatory environment is said to be extremely complex, while the market mechanisms are not mature enough to accommodate microgrids (Marnay and Asano 2008). *Curbing Energy Sprawl with Microgrids* argues that some federal and state laws promote energy sprawl, a potential danger to the environment, while other laws inhibit the growth of renewable and distributed resources (Bronin 2010).

Standards

Because the modern conception of a microgrid is relatively new and rather esoteric, it is unlikely that they will become commonplace without the development of standard practices. Indeed, the Zpryme study found that the development of standards is considered by industry professionals to be the single most important factor towards the deployment or development of microgrids (Zpryme Research and Consulting 2012). This is being actively pursued by members of the IEEE Standards Association through IEEE 1547, which deals with interconnection issues, and IEEE 2030, which deals with interoperability issues (Basso and DeBlasio 2012).

IEEE 1547 provides interconnection technical specifications and requirements. These are universal requirements that apply to both distributed generators and energy storage systems. Originally created for the “smart grid”, the standard now has seven complementary standards that expand its application for related technologies and techniques. In particular, IEEE Std 1547.4-11 covers the intentional islanding of a power system containing distributed resources, which is a defining feature of a microgrid. The IEEE 1547 standard and its complementary standards are as follows:

- IEEE Std 1547–2003 (reaffirmed 2008), IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE Std 1547.1–2005, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
- IEEE Std 1547.2–2008, IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

- IEEE Std 1547.3–2007, IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems
- IEEE Std 1547.4–2011, Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- IEEE Std 1547.6–2011, Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Network
- IEEE P1547.7, Guide to Conducting Distribution Impact studies for Distributed Resource Interconnection (*under development)*
- IEEE P1547.8, Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547 (*under development)*

The IEEE Std 2030 series focuses on achieving interoperability between energy technologies with information technology within a smart grid. It aims to provide a roadmap in developing an international body of standards that would define alternative approaches and best practices in controlling and monitoring power applications via communications (Basso and DeBlasio 2012). There are currently three complementary standards that expand upon the base standard. The IEEE 2030 standard and its complements are as follows:

- IEEE Std 2030–2011, Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation With the Electric Power System (EPS), and End-Use Applications and Loads

- IEEE P2030.1, Guide for Electric-Sourced Transportation Infrastructure
- IEEE P2030.2, Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure
- IEEE P2030.3, Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications.

Barriers

Microgrids and Active Distribution Networks lists several challenges and disadvantages of microgrid development. These include the high costs of distributed energy resources, lack of technical experience, absence of standards, administrative and legal barriers, and market monopoly issues (Chowdhury, Chowdhury, and Crossley 2009).

Among those legal barriers are regulatory, political, and economic barriers (Bronin 2010). Very few states have laws that address microgrids, and current law can be contradictory or vague. Groups such as utility and neighbors may object to microgrid projects and lobby against them. Additionally, the large amount of capital required can deter investment. Possible solutions include may include selective pricing and public subsidization (Bronin 2010).

CHAPTER 3

DESIGN AND OPERATION OF A MICROGRID

Components and Topology

A microgrid, at its core, is a self-contained power system. It therefore contains all the components of a typical power distribution system, plus generation resources and a switch that allows it to disconnect from the utility grid. A typical microgrid system would also include intelligent management that interfaces with the equipment via wired or wireless communication protocols.

Microgrids can be implemented as radial or networked systems. Their topology is generally dictated by the current design practices for secondary distribution systems (Davis 2003). Various loads and resources may be interconnected to each other and to the utility system as 3, 2, or single-phase connections. Figure 4 displays possible interconnection methods to an overhead three-phase system.

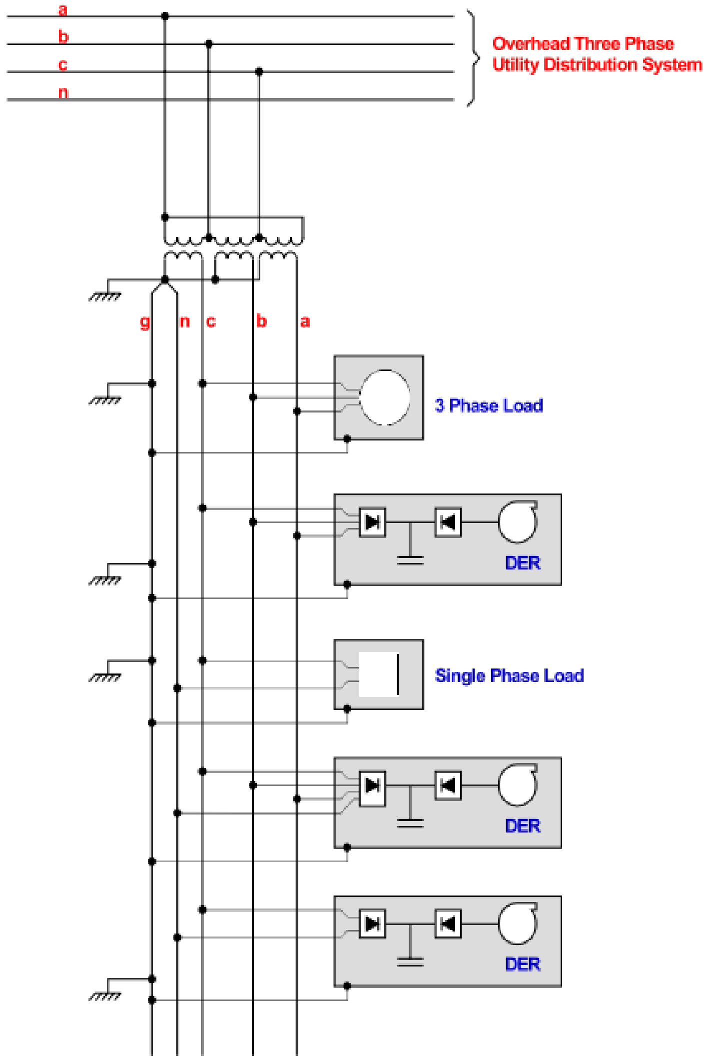


Figure 4: Methods of Integration of Loads and Resources

Management and Control

Central to the concept of a microgrid is its ability to control all aspects of its operation. It employs demand-side management strategies to control generation and load to meet the requirements of the customer as economically as possible (Robert Lasseter 2002). This is achieved through a central controller, which executes the overall control over microgrid operations, and dedicated microsource controllers, whose main function is to maintain power quality and reliability (Chowdhury, Chowdhury, and Crossley 2009).

Energy Manager Module (EMM)

The Energy Manager Module (EMM) exists as a subset of the Central Controller. Its acts as a master controller for the individual Microsource Controllers, providing active power and voltage set points, power factor control, prime mover speed control, and frequency regulation (Chowdhury, Chowdhury, and Crossley 2009). The EMM can supervise not only electrical microsources, but also diverse devices such as end-use equipment, energy storage devices, heat recovery equipment, and HVAC components (Firestone and Marnay 2005).

Sophisticated Energy Manager Modules can employ data logging and advanced algorithms to optimize the system with respect to load conditions, generation schedule, fuel availability, and pattern of consumption. External information such as weather conditions and energy price forecasting can be used to identify energy or cost saving opportunities (Chowdhury, Chowdhury, and Crossley 2009). In this way an intelligent EMM can optimize the entire system in terms of efficiency or economic performance.

Control Strategies

There are a variety of methods a microgrid might use to make decisions. Three possible control strategies are real-time optimization, expert system control, and decentralized control (Firestone and Marnay 2005).

An EMM would perform real-time optimization by considering past and current microgrid operation states, loads, weather, tariffs, and equipment, then consider the respective stochastic descriptions of these items to predict future microgrid operation states (Firestone and Marnay 2005). This strategy is limited by the system's processing power and the amount of data it can handle.

Power Quality and Reliability

A microgrid has the ability to increase overall power quality and system reliability due to the decentralization of supply (Lasseter 2006). If the external grid experiences a blackout or other disturbances the microgrid can go into island mode, ensuring continuous operation while protecting critical loads. System reliability can be increased via the redundancy of multiple generators. A Microsource Controller handles power quality issues at the local level.

Microsource Controller

The microsource controller (MC) has a large influence on power quality in a microgrid. MCs ensure that microsources can be added to the system with little modification, and can independently control their active and reactive power flow, allowing the microgrid to meet load requirements. They can also correct voltage sag, system imbalances, and fault conditions without loss of stability (Chowdhury, Chowdhury, and Crossley 2009).

Active and reactive power control

Figure 5 shows the fundamental relationship of a microsource and the power electronic converter. The voltage source inverter supplies output voltage, $V\angle\delta_1$, at the converter terminal, while controlled power is supplied to the microgrid bus at a voltage of $E\angle\delta_2$ (Chowdhury, Chowdhury, and Crossley 2009).

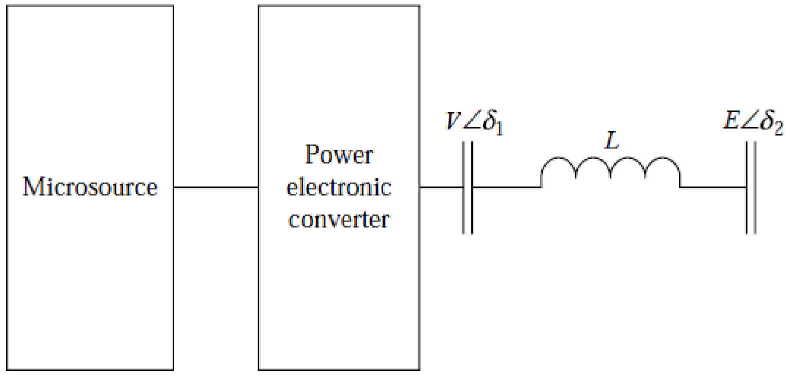


Figure 5: Active and Reactive Power Control of a Microsource

The control of active power flow is achieved by controlling the power angle (δ), as described by Equation 1. Reactive power (Q) is controlled by controlling voltage magnitude (V), as shown in Equation 2 (Chowdhury, Chowdhury, and Crossley 2009).

$$Equation\ 1: \quad P = \frac{3VE}{2X} sin\delta$$

$$Equation\ 2: \quad Q = \frac{3VE}{2X}(V - Ecos\delta)$$

where P = Reactive power

V = Voltage magnitude

E = Bus voltage magnitude

X = Reactance

δ = Phase angle

Voltage control

Microgrid systems with a large number of microsources may suffer from reactive power oscillations without proper voltage control; while this current is usually limited by the large impedance between generators in utility situations, microgrids typically demonstrate much smaller impedance between sources (Chowdhury, Chowdhury, and Crossley 2009). This problem can be controlled using voltage-reactive power (V-Q) droop controllers, which attempt to increase the local voltage set point when reactive currents are inductive and decrease the set point when the current becomes capacitive. Figure 6 demonstrates this relationship.

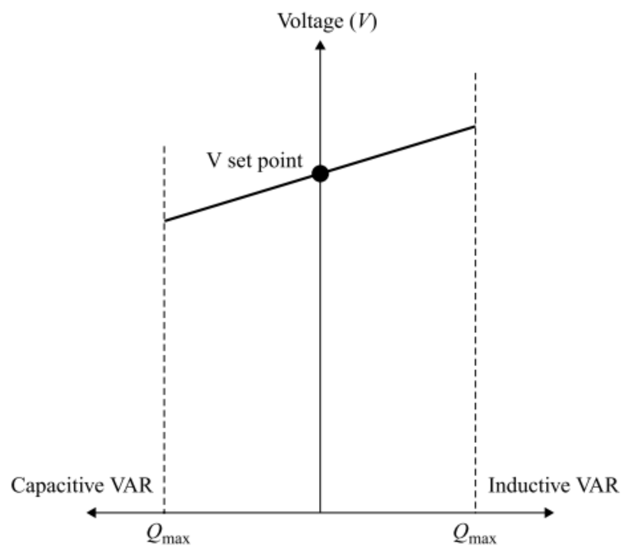


Figure 6: Droop Characteristics for V-Q Droop Controllers

Load sharing through P-f control

Microsource controllers adapt from grid-connected mode to island mode via load sharing through power-frequency (P-f) control. Because microgrid loads are generally supplied by both the main utility and distributed sources, switching to and from island mode results in changes to local power balance and loading. The controller can reinstate balance quickly using the drooping P-f characteristic shown in Figure 7. During the mode change, the voltage phase angles change, leading to a decrease in power output. This forces a change in load frequency, allowing the microsource to ramp up to meet its load without any external control or input.

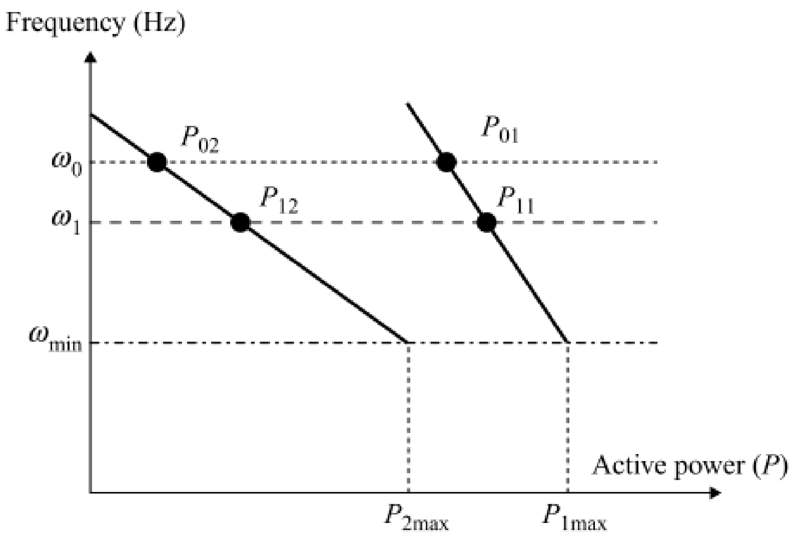


Figure 7: Active Power vs. Frequency Droop Characteristics

Redundant Generation

In general, the reliability of the microgrid in terms of ability to serve a load increases with the number of generators, as less surplus generation capacity is needed to survive the loss of any one unit (Herman 2001). This concept is illustrated in Figure 8. However, while redundant generation can increase the overall reliability of the microgrid, it comes with cost and performance penalties, as there is always some underused capacity.

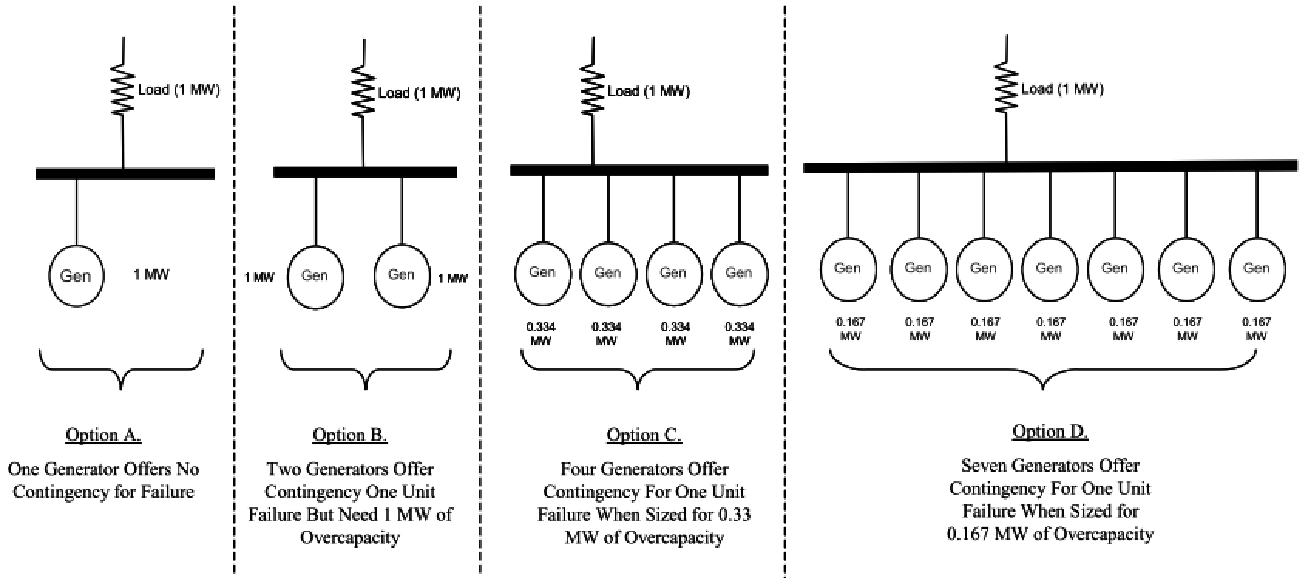


Figure 8: Redundant Generation and Effects on Reliability

Protection and Stability

The protection philosophy for a microgrid differs from conventional distribution networks for the following reasons: microgrids contain both generators and loads, resulting in bidirectional power flow; microsources require an active distribution network; and the changing from grid-connected mode to island mode can create large changes in short-circuit capacity (Chowdhury, Chowdhury, and Crossley 2009). Furthermore, unlike conventional distributed resource installations, a microgrid must satisfy two sets of protection criteria: the interconnection requirements of the utility, state, and IEEE standards, and the ability to separate from utility-side disturbances and transition into island mode if necessary (Feero et al. 2002). The Protection Coordination Module (PCM), a subset of the Central Controller, is responsible for managing the overall protection for the microgrid. An example of how a microgrid might coordinate its protection using centralized control is shown in Figure 9 (Dimitrovski et al. 2012). Breakers are found at each source and load, each bus, and at the point of contact with the utility. This allows the controller to provide protection from both internal and external disturbances. Note that this design relies largely on "smart inverters" using power quality and reliability methods described in the preceding section.

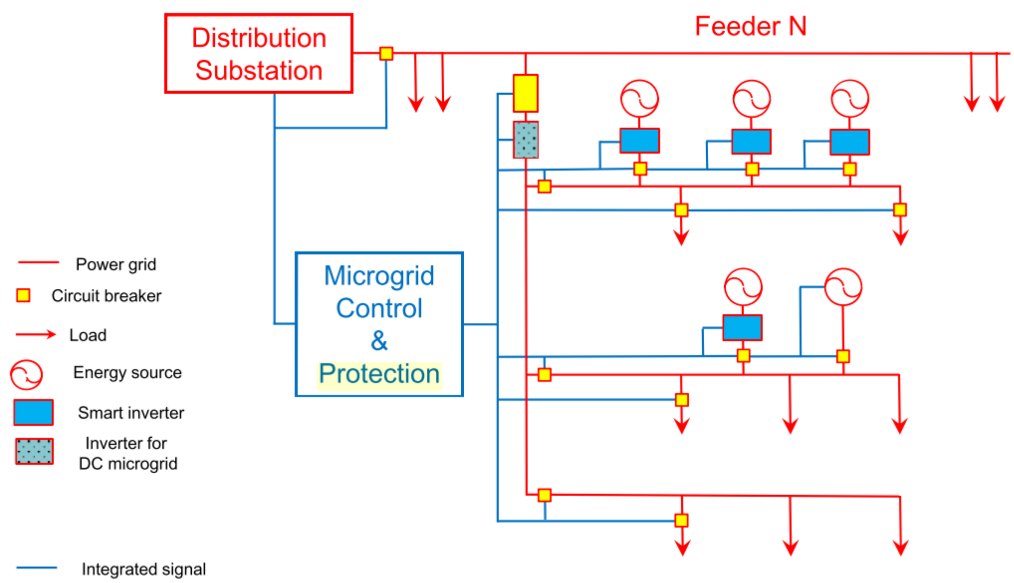


Figure 9: Microgrid Protection via Centralized Control

The major protection problem observed in microgrids is related to the large difference between fault current in main grid connected and islanded mode (Islam 2012). This is generally solved by using different relay settings for grid-connected mode and island mode.

CHAPTER 4

CHARACTERIZATION OF CAMPUS REQUIREMENTS

To determine whether a microgrid would be beneficial for Georgia Southern, we first must determine what exactly would qualify as a benefit. Microgrids offer diverse advantages for various end-users; this section attempts to match the goals of the University with the general benefits of a microgrid.

Strategic Themes

As of 2009, Georgia Southern University's stated goal is to "be recognized as one of the best public comprehensive universities in the country within the next ten years" (Georgia Southern University 2009). This is to be achieved through the strategic themes of Academic Distinction, Student-Centered University, Technological Advancement, Transcultural Opportunities, Private and Public Partnerships, and Physical Environment.

Table 4 displays a matrix of how a microgrid might contribute towards fulfilling certain strategic themes and their action steps.

Table 4: Microgrid Contributions to GSU Strategic Themes

Strategic Theme	Action Steps	Microgrid Contribution
Academic Distinction	Forge a stronger academic profile	
	Extend the culture of engagement to all campus units by increasing collaboration among campus divisions	
	Support and strengthen the excellent faculty	

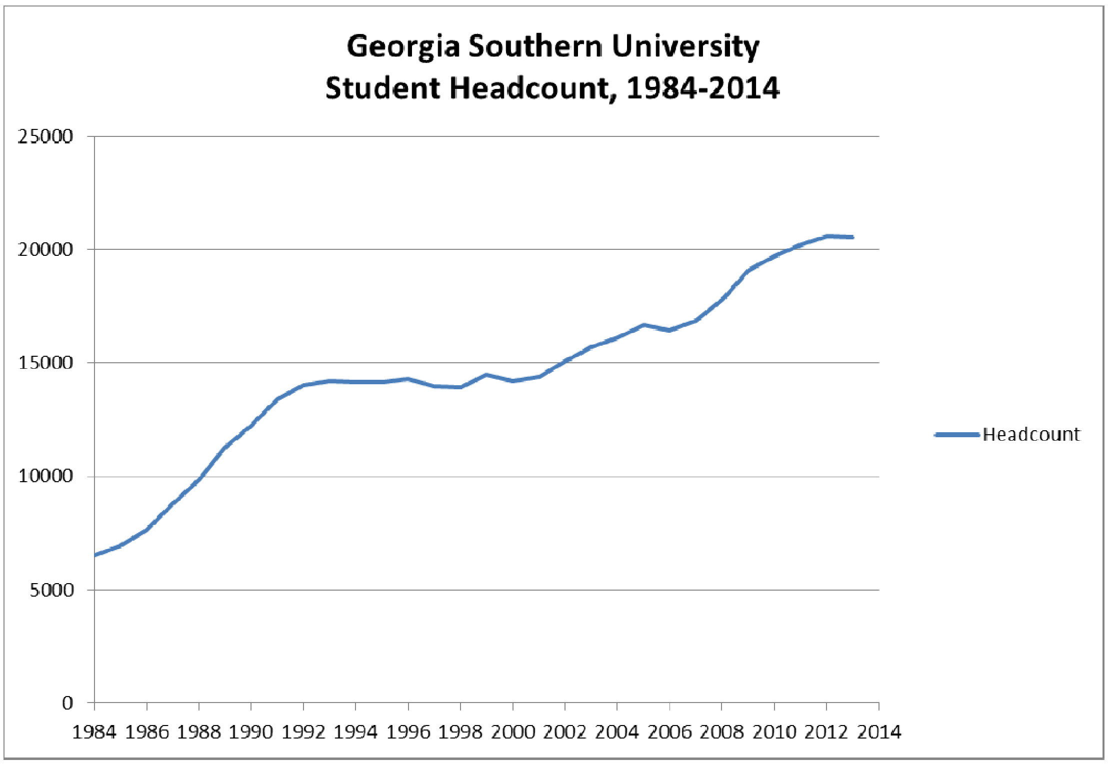
	Assertively market Georgia Southern University academics	
	Cultivate an academic environment exemplified by high expectations, engagement, self-directed academically-motivated students, scholarly faculty, cutting-edge technology, a physical campus that symbolizes the pursuit of academic excellence, and a commitment to wellness	Microgrids are cutting-edge, and the adoption of the technology is considered to be in its infancy; its implementation would undoubtedly symbolize the pursuit of academic excellent
	Make available the University's intellectual resources to all of its stakeholders	
Student-Centered University	Provide a rich, on-campus residential experience for all students who desire it	
	Convey high expectations for academic achievement, appropriate behaviors, and time spent on task	
	Promote engagement of students, faculty, staff, and administrators in events, activities, and scholarship	A microgrid can create new research and learning opportunities for faculty and students by functioning as a “hands-on” laboratory in diverse disciplines, such as electrical engineering, information systems, and finance/economics
	Consistently assess the quality of student interactions with all on-campus service units	
	Facilitate students' progression through a seamless transition from campus life	
Technological Advancement	Plan and budget for continuous funding of equipment, software, technology infrastructure, and technical staff to train and support students and employees in the effective and ethical use	A microgrid represents a technological infrastructure which requires advanced equipment, software, and staff members

	of technology	
	Provide the technological infrastructure needed to support the scholarly, administrative, and service activities of the University	A microgrid supports and increases the total efficacy of all university activities by increasing reliability, thereby decreasing loss of productivity from outages
	Increase electronic access to administrative services	
	Maintain the Technology Fee	
	Design new facilities and renovate existing facilities to accommodate multiple teaching and learning methodologies, technologies, and access to campus network resources	
Transcultural Opportunities	Increase diversity among faculty, staff, students, and administrators	
	Provide more diversity and transcultural experiences	
	Expand transcultural opportunities	
	Seek to increase the number of out-of-state students and of international students and the countries they represent. Georgia	
Private and Public Partnerships	Acquire the financial resources that will be Georgia Southern University's foundation for success.	A microgrid has the potential to decrease operating expenses by reducing the cost of energy
	Create a culture of service on campus	
	Empower every unit to explore partnership opportunities internally, among campus units,	The realization of a microgrid would require internal collaboration between administration,

	and externally through constituent relationships and collaborative alliances.	knowledgeable faculty, and Physical Plant employees; it would require external collaboration with Georgia Power/Southern Company and consulting firms
Physical Environment	Ensure that new construction and renovation projects meet present needs, accommodate future growth, are adaptable for multiple teaching and learning methodologies and technologies, and observe University guidelines for architecture and environment.	Microgrids provide a way for the campus to accommodate future growth by allowing its energy requirements to be met incrementally; this is achieved via the modular nature of distributed generation
	Enhance the beauty and utility of the campus through thoughtful landscaping	
	Enhance the residential nature of the University	
	Acquire adjacent properties for campus expansion	
	Provide primary on-campus points of first contact that facilitate both physical and electronic access to campus resources and events for students, parents, visitors, alumni, and community	
	Plan and budget for regular maintenance of facilities and for reducing deferred maintenance	A microgrid could reduce the need for planned maintenance via intelligent controllers and communication; it could reduce deferred maintenance time and costs by preventing or significantly reducing electrical power outages

Growth and Expansion

Georgia Southern University has experienced substantial growth in terms of student body headcount in the past thirty years. Figure 10 displays the student body headcount trend for 1984-2014.



Adapted from "Ten-Year Enrollment Report", Board of Regents University System of Georgia 2011, 2001, 1993 *and* "Fall Semesters Enrollment Summary", GSU Strategic Research and Analysis 2014

Figure 10: GSU Student Headcount, 1984-2014

This growth is expected to continue in the future, with a 4.0% increase per year projected through 2020, as noted by Section II of the 2008 Master Plan (Georgia Southern University 2008). To meet this growth, the campus has undergone extensive expansion in the past decade, and more is planned in the coming years. Figures 11 and 12 display projected short-term and long-term development as of the 2008 Master Plan.

Figure 11: GSU Short Term Development

Figure 12: GSU Long Term Development

As the student body population increases and new buildings and facilities are created to meet this need, the existing power system must expand to meet the increased load. More power must be bought from the utility, leading to steadily increasing operation expenses. The conversion of the existing power system to a microgrid would allow Georgia Southern to prepare for this growth, adding generation capacity as needed via distributed energy resources. In this way, increased load demand could be met without the need for additional feeders, thereby reducing the campus's dependence on the external grid.

Summary

Georgia Southern University demonstrates an ambition to become a leading university, both on the regional and national scale. It has experienced dramatic growth in recent years and expects to do the same in the future. The implementation of a microgrid would satisfy multiple actionable items proposed to achieve various goals. This research into the feasibility of a microgrid could be considered as applying to the Facilities Plan, a Level II item in GSU's official Strategic Plan. A flowchart of the Strategic Plan is presented in Figure 13.

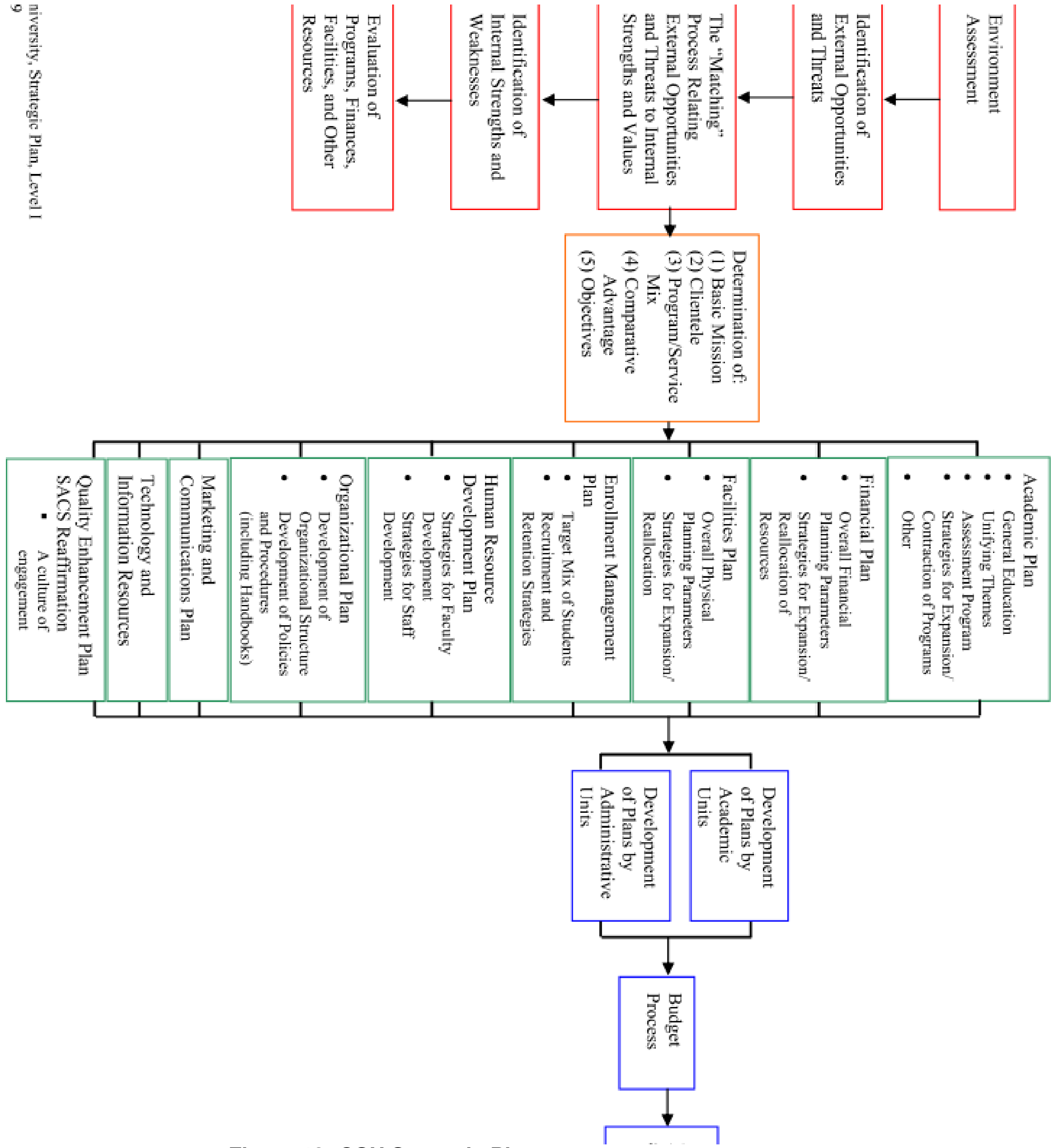


Figure 13: GSU Strategic Plan

CHAPTER 5

CHARACTERIZATION OF EXISTING POWER DELIVERY SYSTEM

Multiple interviews were conducted with Steve Watkins, the Design Engineer and Energy Manager at GSU. These were performed through email correspondences and several in-person meetings, and yielded invaluable insight into the design and requirements of the power delivery system. The GIS information was provided by Dustin Sharber, GIS Supervisor. This allowed the system to be visualized, and helped identify and characterize the existing backup generators. All additional documentation was obtained via Open Records requests or online public documents.

Architecture

The Academic Corridor is served by the GSU Underground Electric System, a 12,470 GY/7200 Volt, three phase, four wire, 60 Hz, grounded neutral, wye connected loop system. This is comprised of six circuits having A and B sides. The system is supplied by one primary and one back-up feeder which connect via 12 KV Georgia Power service lines to the South – City of Statesboro and Old Register Road substations, respectively. Additionally, the campus switchyard can select a 12 KV feed known as Circuit 7 A and B, itself fed from either of the Fair Road or Old Register Road substations. The underground electrical system includes over 78 manholes and 74 transformers, which are either 480/277V or 208/120V. The cable type is 4/0 15KV XLPE. The original underground system was created in the late 1970's, but underwent various upgrades starting in 1998 (Georgia Southern University 2008). Figure 14 displays the entire power distribution system as viewed by ArcGIS.

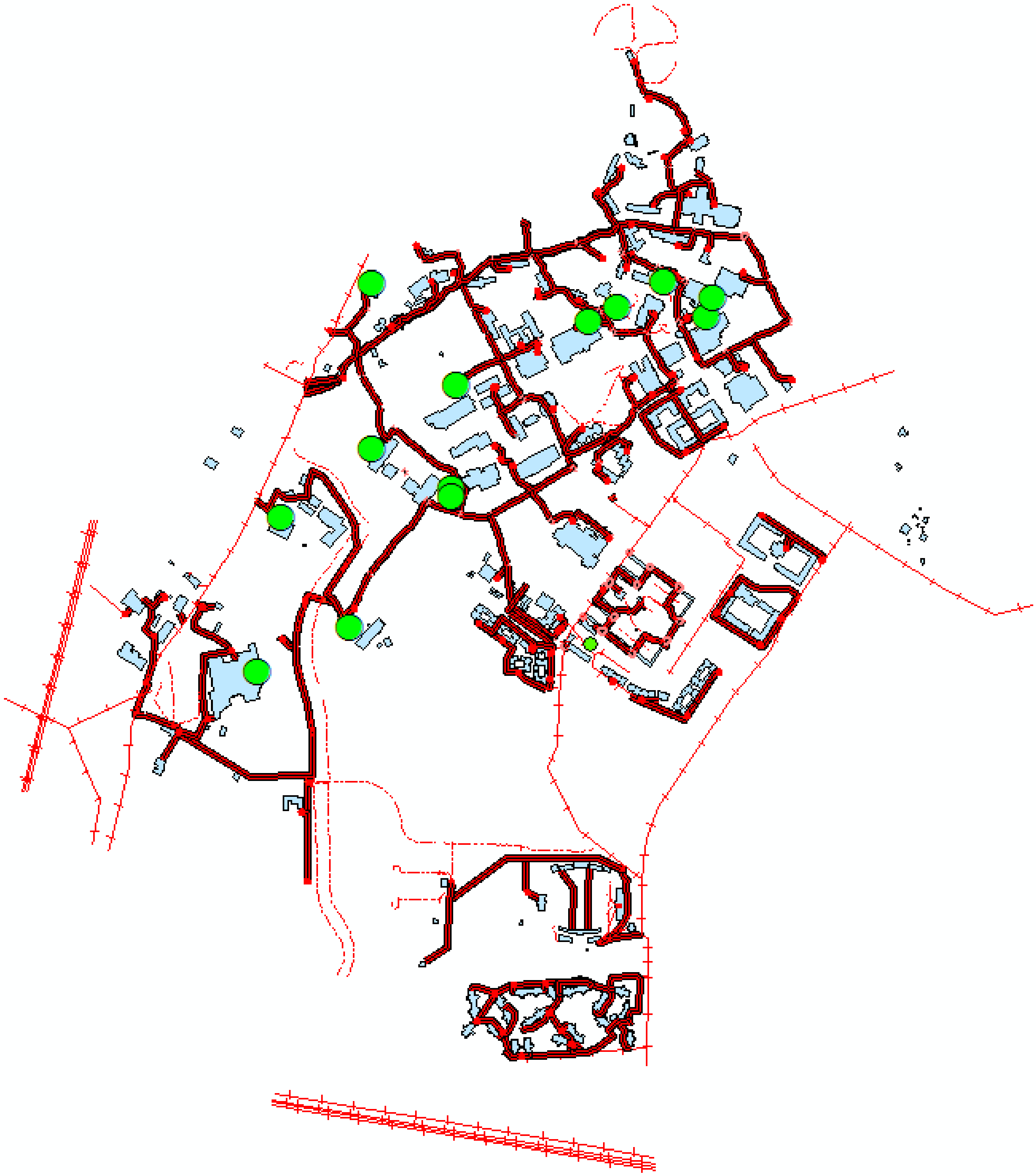


Figure 14: GSU Power Distribution System

We see from Figure 14 that the current system includes certain backup generators, identified in the GIS map by a green circle. Figure 15 displays a table created in ArcGIS of these generators. These generators were identified in interviews conducted with Mr. Watkins as being possible candidates for integration into a future microgrid as distributed energy resources, as it would be relatively simple to direct their flow towards the internal grid instead of to a single building. Additionally, their use as generation sources would allow their contribution to the capital costs of a microgrid to be discounted, as they are already purchased and installed.

GISADMIN.Emmisions_Generators

FUEL	OBJECTI	EQUIP_NAME	OID_1	EMERGENCY_	EQUIP__	KW	DATE_OF_I
DIESEL							
	5	GEN-232	0	ET	GEN-232	200	1995
	4	GEN-237	0	COLLEGE OF ED	GEN-237	175	2001
	1	GEN-401	0	RUSSELL UNION	GEN-401	100	1990
	2	GEN-110	0	PUBLIC SAFETY	GEN-110	50	2007
NAT GAS							
	7	GEN-202	0	BIOLOGY	GEN-202	350	2001
	6	GEN-251	0	NURSING CHEMISTRY	GEN-251	250	2003
	8	GEN-254	0	IT	GEN-254	250	2003
	12	GEN-208	0	HENDERSON LIBRARY	GEN-208	100	2008
	10	GEN-201	0	HERTY	GEN-201	0	2007
	321	GEN	0	Admin Building	GEN	<null>	2010

Figure 15: Existing Generators

Note that 525kW is supplied by diesel generators, while 950kW is shown for natural gas generators, although two generators seem to be missing their capacity values. As such, the real generation capacity of the natural gas generators is likely more than what can be used for our simulation.

Land Zones

The campus is divided into five separate zones: Administration, Academic, Residential/Mixed Use, Physical Ed./Recreation/Athletics, and Physical Plant/Support. Each zone is overseen by a distinct administrative body which handles planning and billing affairs internal to the zone. This affects any proposed change in infrastructure, as any increased or decreased costs associated with power or energy will be incurred by the body responsible for the zone. Figure 16 displays these zones.

Figure 16: GSU Land Use Zones

At the recommendation of Steve Watkins, the Academic Zone, or “Academic Corridor”, was selected as most appropriate for the implementation of a microgrid. This area hosts by far the highest density of students, faculty, and staff, and already contains what could be considered onsite distributed generation in the form of diesel and natural gas backup generators. The power system serving this area is a networked system of loops, with switches already in place to divert power in case of failure from one source. The power system section serving the Academic Corridor and its buildings is shown in Figure 17.

Figure 17: "Academic Corridor" Section

Interval Load

Interval load data (kW) for the Academic Corridor was provided by Steve Watkins. This data was obtained via Southern Company's EnergyDirect.com, which works in conjunction with the on-campus smart meter system. Specifically, data reported by the "Chandler Road", "Main Campus 1", and "Main Campus 2" meters were downloaded as .csv files. Each dataset contained the average load read by a single meter in 30 minute increments from 1/1/13 to 12/31/13. The total interval load for the Academic Corridor was determined by summing the reported data across the three files. The resulting data was plotted according to load by time and date, as shown in Figure 18. The raw data was then used for the HOMER portion of the analysis. This data can be considered to be very high resolution, having approximately 17,470 data points.

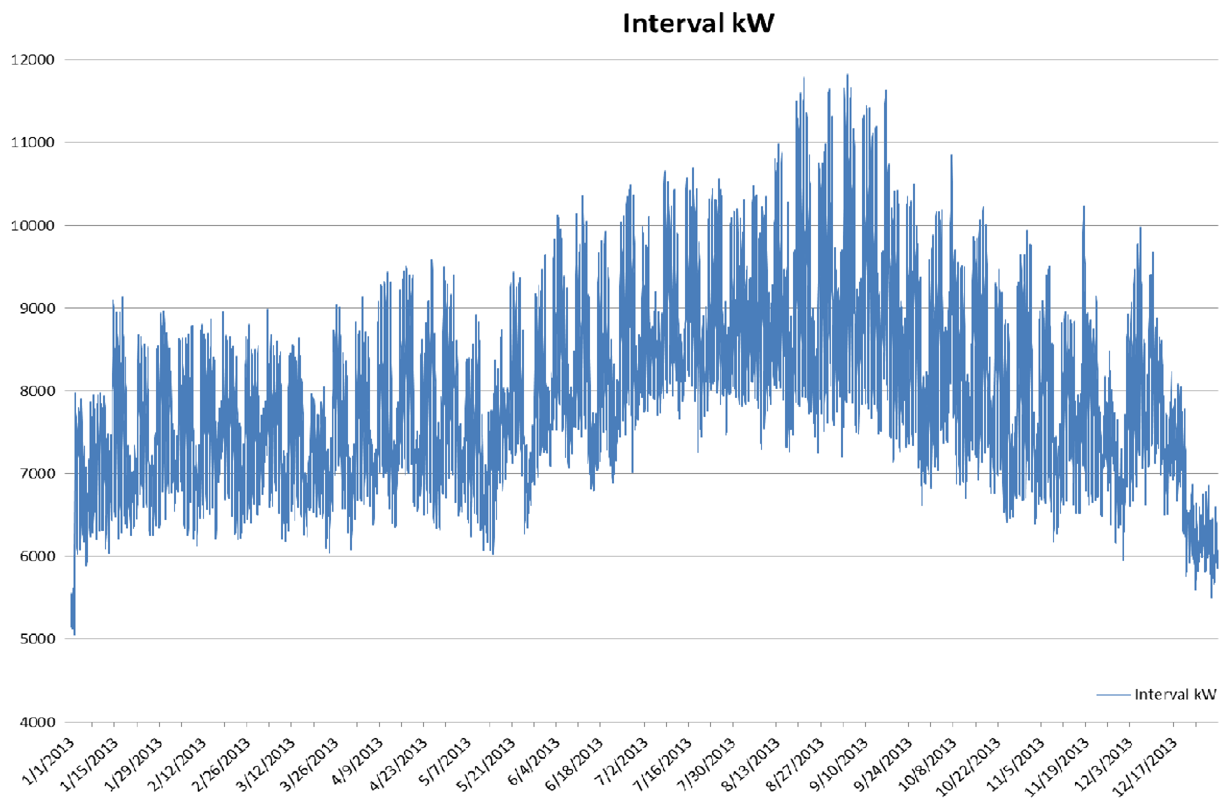


Figure 18: Academic Corridor Interval Load (2013)

We can also view this data in HOMER in various ways. Figure 19 displays the yearlong interval load data as a "DMap", or Data Map. This is essentially a heat map in which the magnitude of the interval load is colored with respect to the hour of the day (y-axis) and the day of the year (x-axis). When presented this way, it is easy to identify when the system experiences the highest loads.

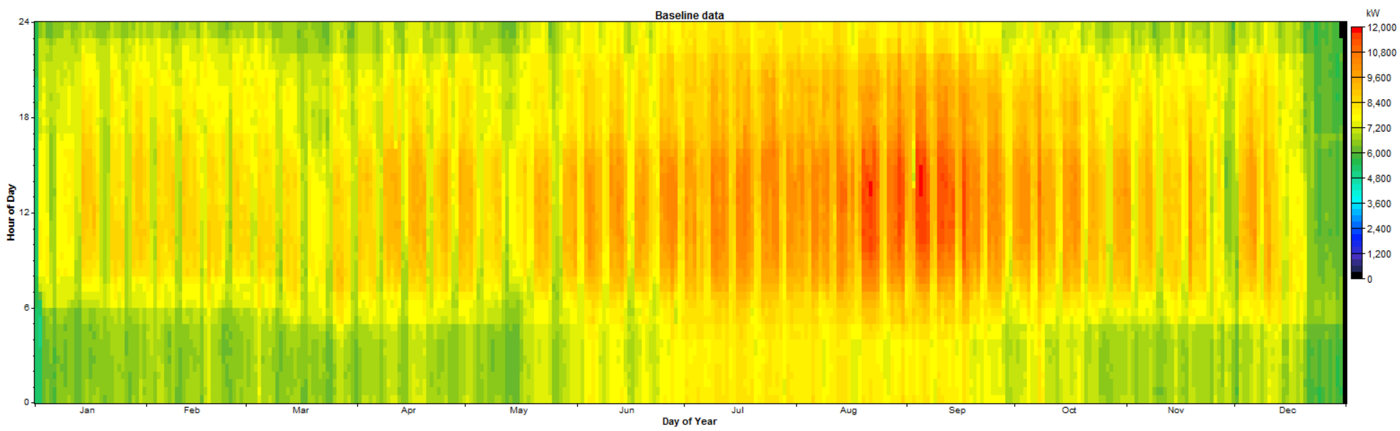


Figure 19: Load DMap

The "Seasonal Profile" option displays the data as a box plot, as shown in Figure 20. The y-axis is the average KW value, while the x-axis is the month. This allows us to observe the statistical distribution of the load for each month.

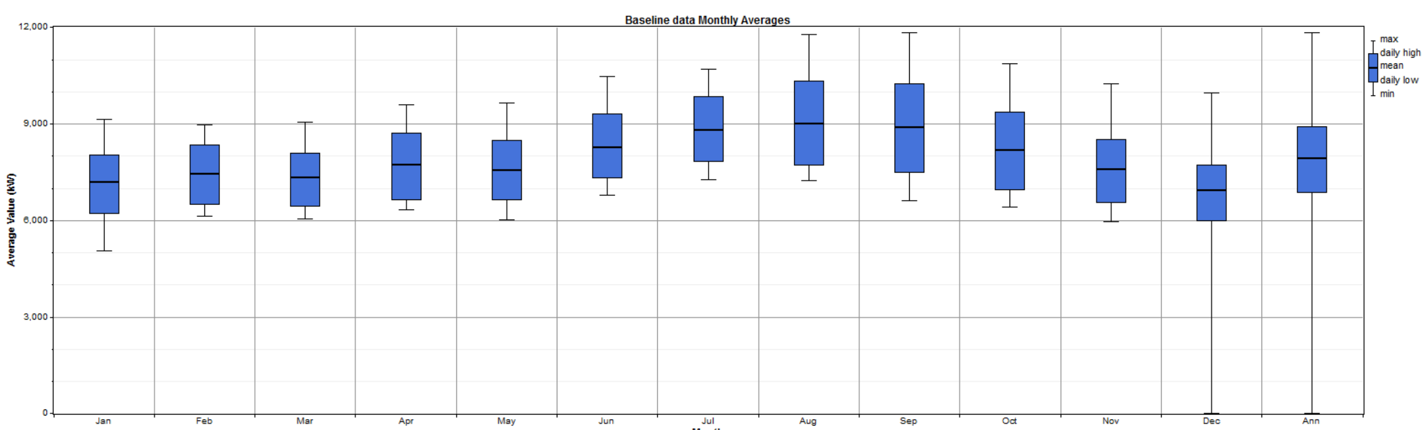


Figure 20: Load Seasonal Profile

Finally, the “Daily Profile” can be viewed, which shows the average interval load for days within a specified time period. We can view the average daily loads for each month, as shown in Figure 21. The y-axis for each chart represents the interval load, while the x-axis is the time of day.

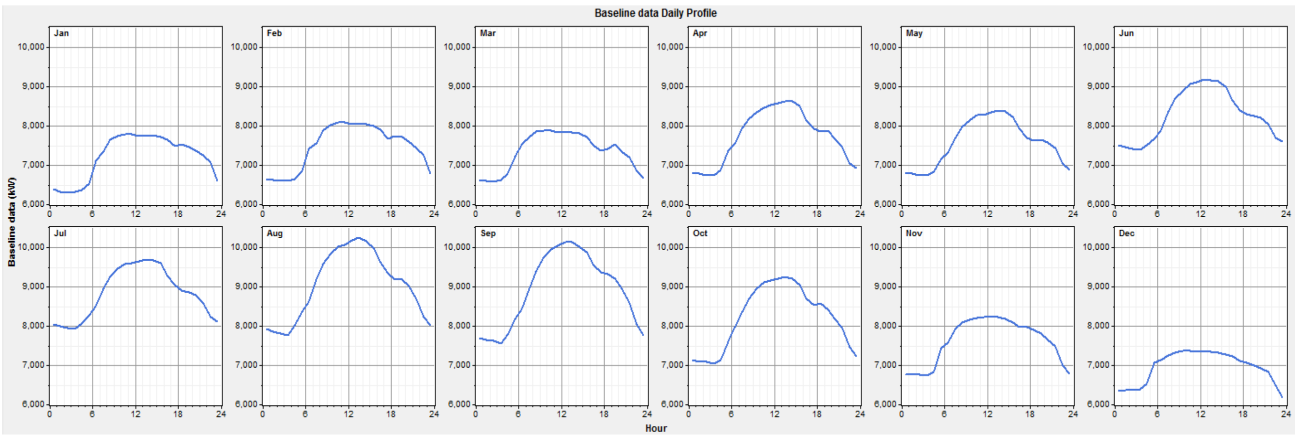


Figure 21: Load Daily Profile

These charts show clearly that the Academic Corridor generally experiences the highest loads during the warmest months, and especially at the start of the fall semester. The daily loads generally peak between 12:00PM and 1:00PM. Furthermore, statistical analysis performed by HOMER shows a day-to-day variability of 8.65%, and time-step-to-time-step variability of 4.06%. The annual average is equal to 190,378 KWh/d, with an average interval load of 7,932 kW, an average peaking load of 11,817 kW, and a load factor of 0.672.

Relationship with Utility

The University’s relationship with the electric utility determines the annual cost of power, which can be used as an input in HOMER. On a broader level, the utility regulates how its customers can connect and interact with the grid, which can effectively determine whether or not GSU would even be allowed to implement a microgrid.

Rate Structure

The GSU campus is serviced with electricity supplied by Georgia Power Company. It is divided into seven major sections, with two proposed future sections. These sections are organized under one rate structure, although billing is managed by the administration of each respective zone. Georgia Southern's rate is likely a variation of the Full Use Service to Governmental Institutions: G17 electric service tariff. This rate is shown in Figure 22.

MONTHLY RATE:

Energy Charge Including Demand Charge

Basic Service Charge $69.00

All consumption (kWh) not greater than
300 hours times the billing demand:
First 50,000 kWh..7.1038¢ per kWh
Next 150,000 kWh..6.8844¢ per kWh
Next 800,000 kWh..5.2279¢ per kWh
Over 1,000,000 kWh...4.8292¢ per kWh
All consumption (kWh) in excess of
300 hours times the billing demand...1.3597¢ per kWh

Minimum Monthly Bill:

$69.00 Basic Service Charge plus $9.56 per kW of Billing Demand, but not less than $4,106.00 per month, plus excess kVAR charges, plus Environmental Compliance Cost Recovery, plus Nuclear Construction Cost Recovery, plus appropriate Demand Side Management Schedule, plus Fuel Cost Recovery (FCR) as applied to the current month kWh, plus Municipal Franchise Fee.

Figure 22: G17 Electric Service Tariff

With an average load of 190,378 KWh/d, the price assessed to the Academic Corridor is generally around 7c/kWh. However, Georgia Southern may stand to benefit from a real time pricing arrangement if a microgrid is implemented. Under this structure, customers are notified each day of forecasted electricity prices for each hour of the following day, and those prices are updated until an hour before the respective rate becomes effective. A microgrid might take advantage of this arrangement by identifying energy or cost saving opportunities via the Energy Manager Module. The Real Time Pricing – Hour Ahead Schedule: “RTP-HA-4” is the current tariff of this type offered by Georgia Power. Its bill determination methodology is shown in Figure 23.

$$\text{RTP-HA Bill}_{\text{Mo.}} = \text{Standard Bill}_{\text{Mo.}} + \Sigma\ \text{Price}_{\text{Hr.}} \times [\text{Load}_{\text{Hr.}} - \text{CBL}_{\text{Hr.}}]$$

Where:

$\text{RTP-HA Bill}_{\text{Mo.}}$	=	Customer's bill for service under this tariff in a specific month
$\text{Standard Bill}_{\text{Mo.}}$	=	Customer's bill for a specific month based on usage as defined by the CBL and billed under the standard firm tariff
Σ	=	Sum over all hours of the monthly billing period
$\text{Price}_{\text{Hr.}}$	=	Hourly RTP-HA price based on marginal costs
$\text{Load}_{\text{Hr.}}$	=	Customer's actual load in an hour
$\text{CBL}_{\text{Hr.}}$	=	Customer Baseline Load shape on an hourly basis

Figure 23: RTP-HA-4 Electric Service Tariff

Parallel Operation of Generation

Southern Company allows for the parallel operation of distributed generation sources with its grid, making the implementation of a microgrid feasible with respect to the utility. Specifically, it allows single and three phase generators, including synchronous, induction, and inverter controlled systems, with a combined capacity of up to 20,000 kW and voltages up to 34.5kV (Southern Company 2005). This ability may be granted after pre-interconnection studies are performed to ensure the system meets the required equipment and interconnection standards. Section 11.11 lists requirements for units 1,001 to 20,000 kW, which would be the range our proposed microgrid would fall in. These requirements are:

- Accessible, lockable, visible break disconnect switch at the service entrance.
- Over-current protection.
- Over/under voltage trip.
- Over/under frequency trip.
- Automatic synchronizing (may omit if not capable of standalone operation).
- Ground fault detection and tripping.
- Reverse power tripping, if not exporting.
- Automatic voltage regulation, with settings determined by the Company.

Bidirectional metering is allowed, which allows the customer to sell only the electric energy generated in excess of usage (Southern Company 2005). Unfortunately, net metering is prohibited. If Georgia Southern were to build enough generation capacity to meet its peak needs and sell any excess, it would need to enter into an agreement with Georgia Power as a Qualifying Facility (Georgia Power 2009). As a facility with a capacity of less than 30MW, the payment for any energy sold to the grid would be the utility's avoided cost. Table 5 displays projections for average avoided cost rates.

Table 5: Utility Avoided Costs

	Avoided Capacity Cost	Avoided Energy Cost		
Year	$/KW-yr	Peak Season: Peak Hours $/MWh	Peak Season: Off-Peak Hours $/MWh	Annual All Hours $/MWh
2009	0.00	78.37	55.44	55.68
2010	0.00	90.30	58.81	61.03
2011	0.00	92.05	60.08	61.85
2012	0.00	123.26	75.12	74.16
2013	0.00	139.98	81.23	80.12
2014	0.00	146.76	84.49	83.33
2015	92.31	146.25	85.82	84.94
2016	95.30	151.27	88.56	87.87
2017	98.38	151.64	87.58	88.88
2018	101.57	156.67	90.61	91.56

Future Requirements

To meet the increased demand of the aforementioned growth and expansion of the campus, recommendations are made to increase power distribution capacity to "address the impacts of additional renovation and new construction", as well as to ensure the "flexibility of energy sources" (Georgia Southern University 2008). Furthermore, it is noted that the GSU Campus has many buildings "in need of major mechanical/electrical systems replacement", and that projections of future infrastructure requirements "will consider options to create reliable, planned building infrastructure capacities".

It has been noted that the current electrical distribution system is heavily loaded, with the peak demand on the campus circuit exceeding 600A. Subsequent studies found that the main circuit is approximately 80% loaded during peak use. It was recommended in the 2008 Master Plan that "reducing the connected load on this circuit should be a priority". This document further recommends that additional buildings could be added in the future by transferring loads to the power company, freeing up amperage capacity on the internal system. Specifically, existing and future cooling facilities could be served directly by the power company, effectively negating their current and projected load on the internal system. This would allow new buildings to be added "through 2024 while reducing the system capacity from 89% loaded to 69% loaded" (Georgia Southern University 2008).

Summary

The Academic Corridor was identified as being the most suitable area for the implementation of a microgrid. The current power delivery system serving the Academic Corridor is relatively modern in terms of design and components, yet may require expansion in the near future as a result of the strong growth demonstrated by the university. Furthermore, although listed in the Princeton Review as one of 322 Green Colleges, the campus lacks renewable energy resources. Given these situations, a microgrid may be perfectly suited for implementation at Georgia Southern: it would decrease the system congestion by increasing available power at the local level; it can be implemented modularly, allowing it to grow with the needs of the campus; and its use of distributed energy resources makes it an excellent way to increase the university's perceived sustainability.

CHAPTER 6

IDENTIFICATION OF APPROPRIATE DISTRIBUTED ENERGY RESOURCES

A major constituent of a modern microgrid is its use of distributed energy resources (DERs). This section attempts to determine which resources are most appropriate to Georgia Southern University, in terms of availability and performance. They are then categorized by a simple qualitative ranking of “None” to “Very Good” suitability to the GSU campus.

Combustion

It was determined that the existing diesel and natural gas backup generators described in the preceding chapter be used as microgrid generation sources. These are already networked into the Academic Corridor, and could possibly be used as always-on or optimized sources, as they have very good load-following capability. This allows the option of “peak load shaving”, in which the generators are only used when the system experiences its highest loads. This in turn has the effect of flattening the load profile observed by the utility, as less power must be purchased to meet the required load. Employing peak load shaving techniques in the way has the potential to reduce overall energy costs by avoiding the need to buy power when it is most expensive.

Combustion engines are a very mature technology, and generally exhibit an attractive price point when compared to other generation technologies. Their disadvantages include high rates of emissions and low levels of efficiency, as well as the dwindling supply of hydrocarbon fuels. Still, their low costs, current availability, and operation flexibility lead to an appropriateness level of “Very High”.

Solar Photovoltaics

Photovoltaic technology has been historically expensive, which has prevented widespread adoption. However, many studies project steadily decreasing costs in future years (Feldman et al. 2012). It is well known that western states generally have the greatest potential for solar power in the United States in terms of average insolation, as shown in Figure 24.

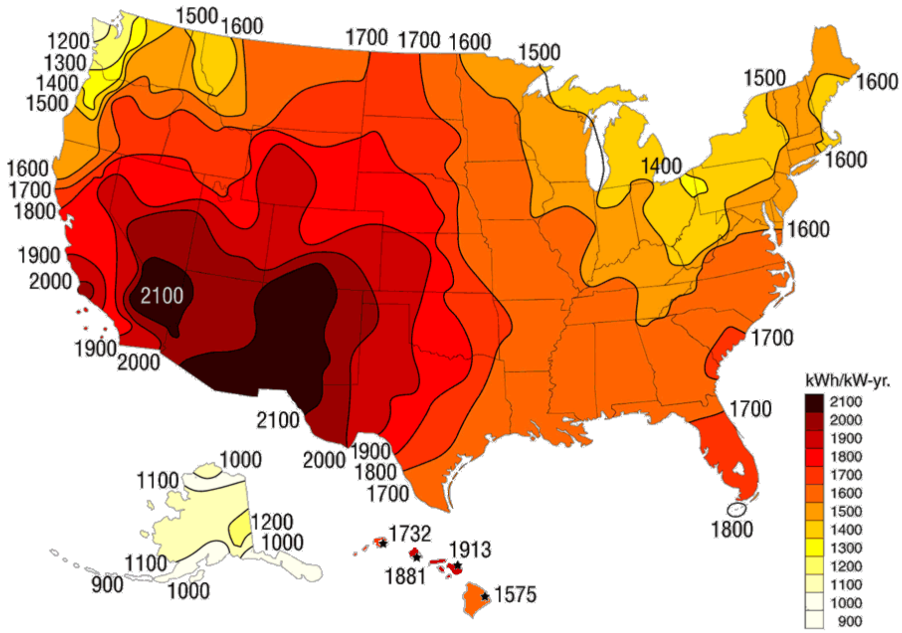


Figure 24: Average Insolation in the United States (kWh/kW-yr)

The capacity of a photovoltaic system is a function of its efficiency in converting solar irradiation, expressed in kWh/m^2, to electrical power, and is thus limited not only by available solar resource, but also by available space. The only available space in the Academic Corridor for such a system is on top of its buildings. Prior research involving the planning and design of a PV system in Statesboro found that GSU's Recreational

Activity Center (RAC), a sprawling two-story building of about 215,000 square feet, could support a photovoltaic system with a total capacity of 97.23kW (Kalaani and Nichols 2011). Additionally, a large shopping mall in the Statesboro area had enough space on its roof to support a 286.44kW system (Nichols and Kalaani 2011). Although the design methodology described in these papers could be applied for the entire GSU campus in future research, it can safely be said that the Academic Corridor is unlikely to support over 1MW worth of photovoltaic capacity. As such, solar energy should be considered to have a “Medium” level of suitability for use in a microgrid system at GSU.

Wind

Wind turbine generation is similar to photovoltaic generation in that it is a completely renewable source that functions intermittently. Its level of appropriateness can be considered a function of its geospatial location; that is, economic benefit will only be realized if the wind turbine is installed in a location where wind speed is consistently relatively high. Unfortunately, high levels of wind resource are found in most areas of the United States except for the Southeast, as shown in Figure 25.

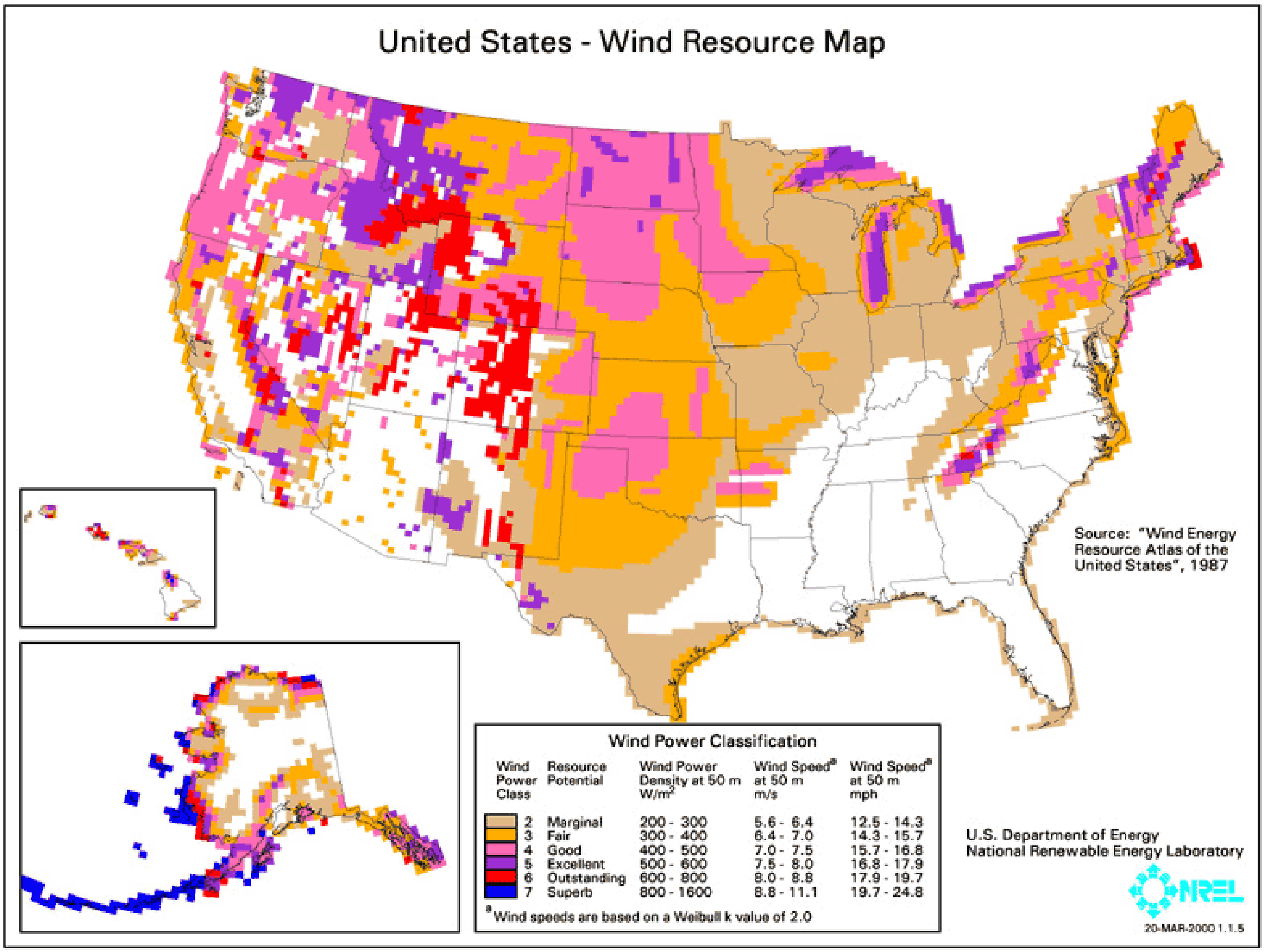


Figure 25: Wind Resources in the United States

A map of Georgia's average annual wind speed is even more disheartening: in a state that already has little to no available wind resource, Statesboro is located in an area which exhibits the smallest average annual wind speeds. The only areas of Georgia that might be appropriate for wind turbine generation are the mountainous regions in the north, or perhaps offshore wind turbine generation along the Atlantic coast. Figure 26 shows the map of Georgia's average annual wind speeds.

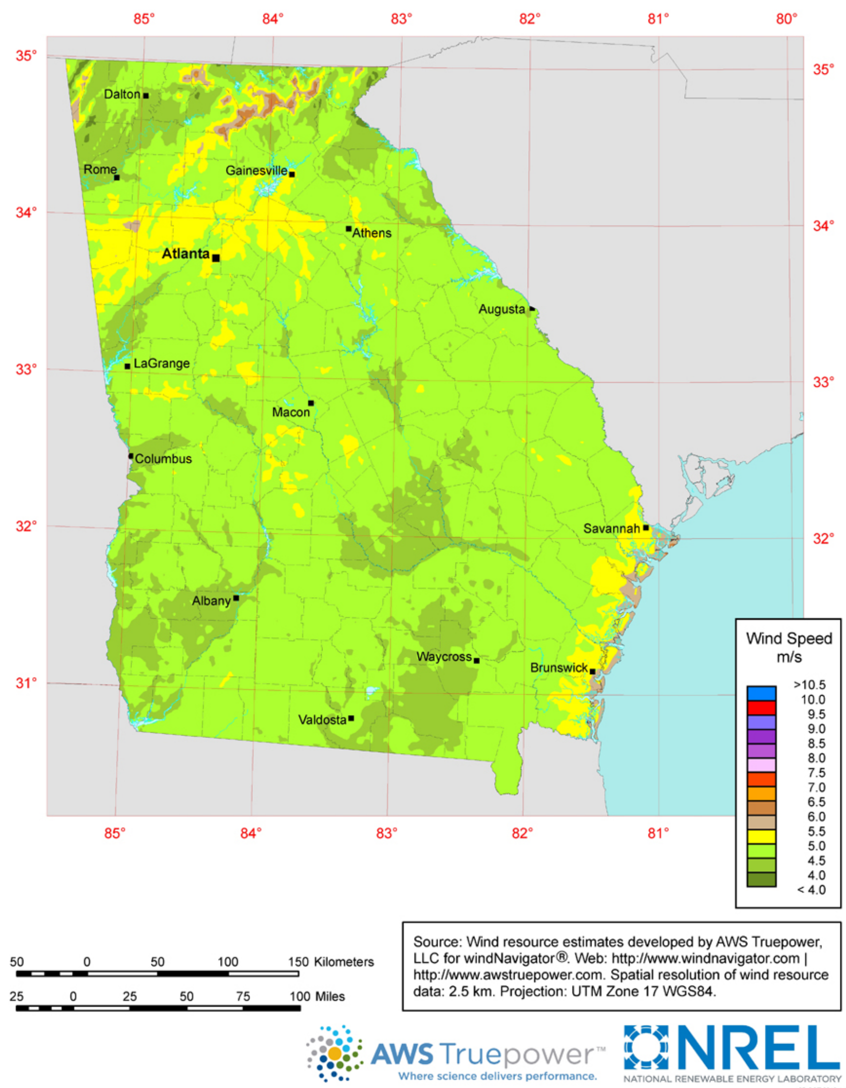


Figure 26: Annual Average Wind Speed in Georgia

Due to this lack of available resource, the appropriateness of wind turbine generation at Georgia Southern University can be considered to be "Very Low".

Biopower

Biopower refers to the conversion of biomass into electrical energy through direct-firing, cofiring, gasification, pyrolysis, and anaerobic digestion (NREL 2010). In general, direct-firing systems mated to steam turbines are the most common, as they can utilize a wide assortment of biomass fuels and have relatively low capital cost requirements.

This high availability of biomass has already been recognized by other researchers at Georgia Southern: much of the current research into renewable energy is conducted at the Renewable Energy & Engines Laboratory at GSU, which focuses largely on biofuels and their implementation. Additionally, in 2013 the Herty Advanced Materials Development Center, a part of Georgia Southern University, opened the first fully-integrated pilot pellet mill in the United States (Herty AMDC 2014). These pellets are created from a wide range of feedstock and biomass, and can be used in biopower configurations to produce electricity.

However, although significant research and investments have been made into biopower at GSU, the technology is still considered immature. No single design methodology has been standardized, and implementation prices remain high as a result. Until prices decrease for this technology, its general appropriateness for use at Georgia Southern should be considered "Low".

Fuel Cell

Fuel cells create electricity through the direct conversion of chemical energy stored in a fuel. This technology has existed quite some time, but still exhibits relatively high costs. Table 6 displays various fuel cell types and their characteristics.

Table 6: Comparison of Fuel Cell Technologies

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212° typically 80°C	< 1kW–100kW	60% transportation 35% stationary	• Backup power • Portable power • Distributed generation • Transporation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Sensitive to CO_2 in fuel and air • Electrolyte management
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%	• Distributed generation	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• Pt catalyst • Long start up time • Low current and power
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/ or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	45-50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits

Adapted from EERE 2011

High-temperature fuel cells have the added advantage of being able to be used in cogeneration systems, which can significantly increase their overall efficiency. However, adoption rates for fuel cells continue to be low due to the fragmentation of the technology and the relatively high capital cost. The technology is therefore rated as having a "Low" suitability for a campus microgrid.

Hydroelectric

There are no viable sources of hydroelectric energy on the Georgia Southern Campus, and so this technology is discounted.

Summary

Various technologies were considered as potential sources for electricity generation. The technology with the highest suitability was found to be the internal combustion engine, as examples are already found on the Georgia Southern University campus. Photovoltaics are likely to exhibit weaker performance, but can still be considered as having a medium suitability. Two others, including biopower and fuel cell technologies, were considered less appropriate or feasible but were still considered for completeness. Wind turbine generation was considered to infeasible in terms of performance relative to the campus's location. Hydroelectric technology was found to be impossible to implement, and thus infeasible. Table 7 illustrates these results.

Table 7: Generation Technology Suitability

Generation Technology	Fuel Type	Fuel Availability	Already on campus?	Overall Suitability
Internal Combustion Engine	Diesel, Nat. Gas	High	Yes	High
Biopower Steam Turbine	Biofuels	High	No	Low
Photovoltaic	Solar	Medium	No	Medium
Wind Turbine	Wind	Low	No	Very Low
Hydroelectric	Water flow	None	No	None
Fuel Cell	*various*	*various*	No	Low

Those generation technologies deemed technically feasible are compared for siting considerations and electrical characteristic, as shown in Tables 8 and 9, respectively.

Table 8: Generation Technology Siting Considerations

Generation Technology	Typical Application Size	Site Footprint	Reliability	Siting Issues
Internal	All sizes	Good	Very Good	Noise, fuel

Combustion Engine				supply, emissions
Biopower Steam Turbine	100 – 5,000 kW	Excellent	Excellent	Noise, fuel supply, emissions
Photovoltaic	All sizes	Poor	Intermittent	Visual
Fuel Cell	4 – 3,000 kW	Good	Very Good	Fuel supply

Adapted from Herman 2001, Table 2-2

Table 9: Generation Technology Electrical Characteristics

Generation Technology	Typical Power Converter	Load Following Capability	Relative Efficiency at Less than Peak Load	Fault Current (per unit of Rated Current)
Internal Combustion Engine	Synchronous Generator	Very Good	Fair/Good	90-96%
Biopower Steam Turbine	Synchronous Generator	Poor	Fair	*unknown*
Photovoltaic	Inverter	None (without storage)	N/A	8-25%
Fuel Cell	Inverter	Fair/Good	Fair/Good	90-95%

Adapted from Herman 2001, Table 2-3

CHAPTER 7

ECONOMIC ANALYSIS OF MICROGRID SYSTEM

The final stage of the thesis research involved performing optimization and sensitivity analysis operations using HOMER, a software package developed by the NREL. Other software packages were considered before HOMER was finally selected; various authors have identified and compared the available software (Phrakonkham et al. 2010), (Stamp 2011), while others designed their own modeling software using MATLAB or proprietary architectures (Mohamed 2006), (S Rahman and Pipattanasomporn 2010). HOMER was selected for this research largely because it is the most-used software for microgrid economic feasibility simulation.

This economic analysis was designed according to the technical framework described in Chapters 5 and 6. Many of the required inputs were satisfied using data obtained in Chapter 5, while the actual equipment considered for use was determined in Chapter 6. Figure 27 displays the relationship between the technical and economic sides of the problem.

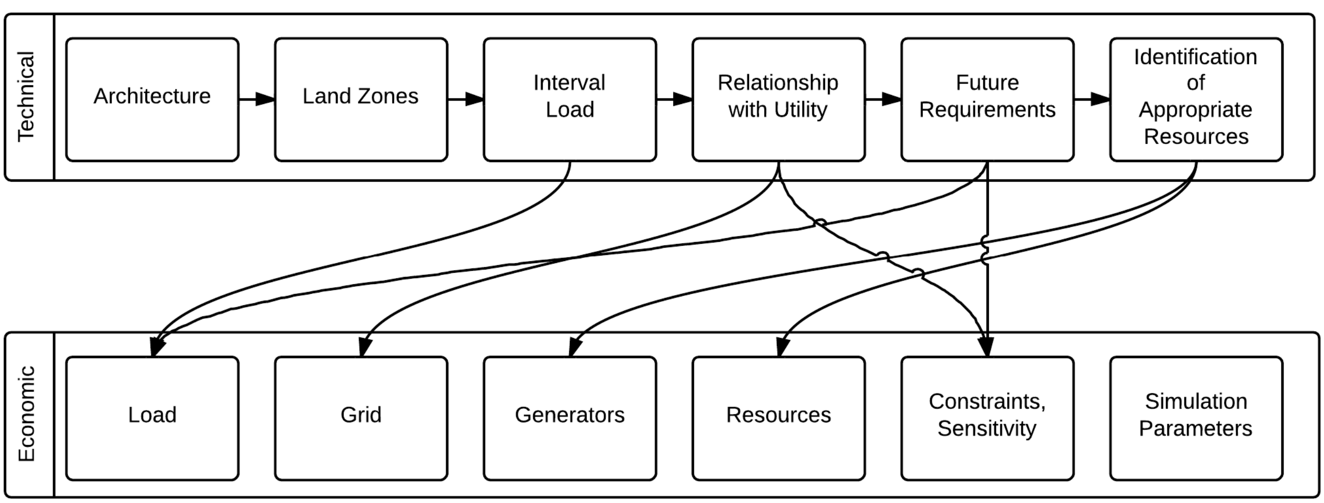


Figure 27: Relationship of Technical and Economic Feasibility Considerations

HOMER Overview

HOMER energy modeling software is the most popular tool used to design and analyze hybrid power systems such as microgrids. Designed by the National Renewable Energy Laboratory (NREL) and then licensed to Homer Energy LLC in 2009, it is used to determine the economic feasibility of various system configurations and optimize their final design.

HOMER's functionality can be grouped into three principle tasks: simulation, optimization, and sensitivity analysis (Gilman, Lilienthal, and Tom Lambert 2006). In the simulation process, HOMER models the performance of a given configuration in specified time increments. In the optimization process, many configurations are simulated and sorted according to how well they satisfy given restraints. In the sensitivity analysis, HOMER performs multiple optimizations with different input value. In this way it can be used to simulate multiple microgrid configurations at once, using optimization and sensitivity analysis to select the "best fit" based on the user's constraints, allowing the user to compare many different scenarios and goals. This functional relationship is shown in Figure 28.

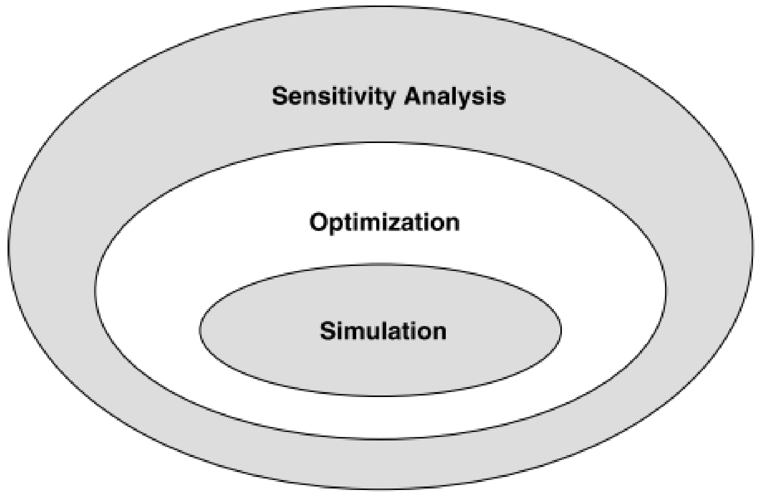


Figure 28: HOMER Operations
Microgrid System Modeling with HOMER. Gilman, 2006

Its interface is relatively simple, yet grows in complexity as more data as entered. Figure 29 shows the interface when a new project is created. The leftmost column includes Equipment and Resource data, while the large rightmost column contains the simulation results. All fields are empty at this point.

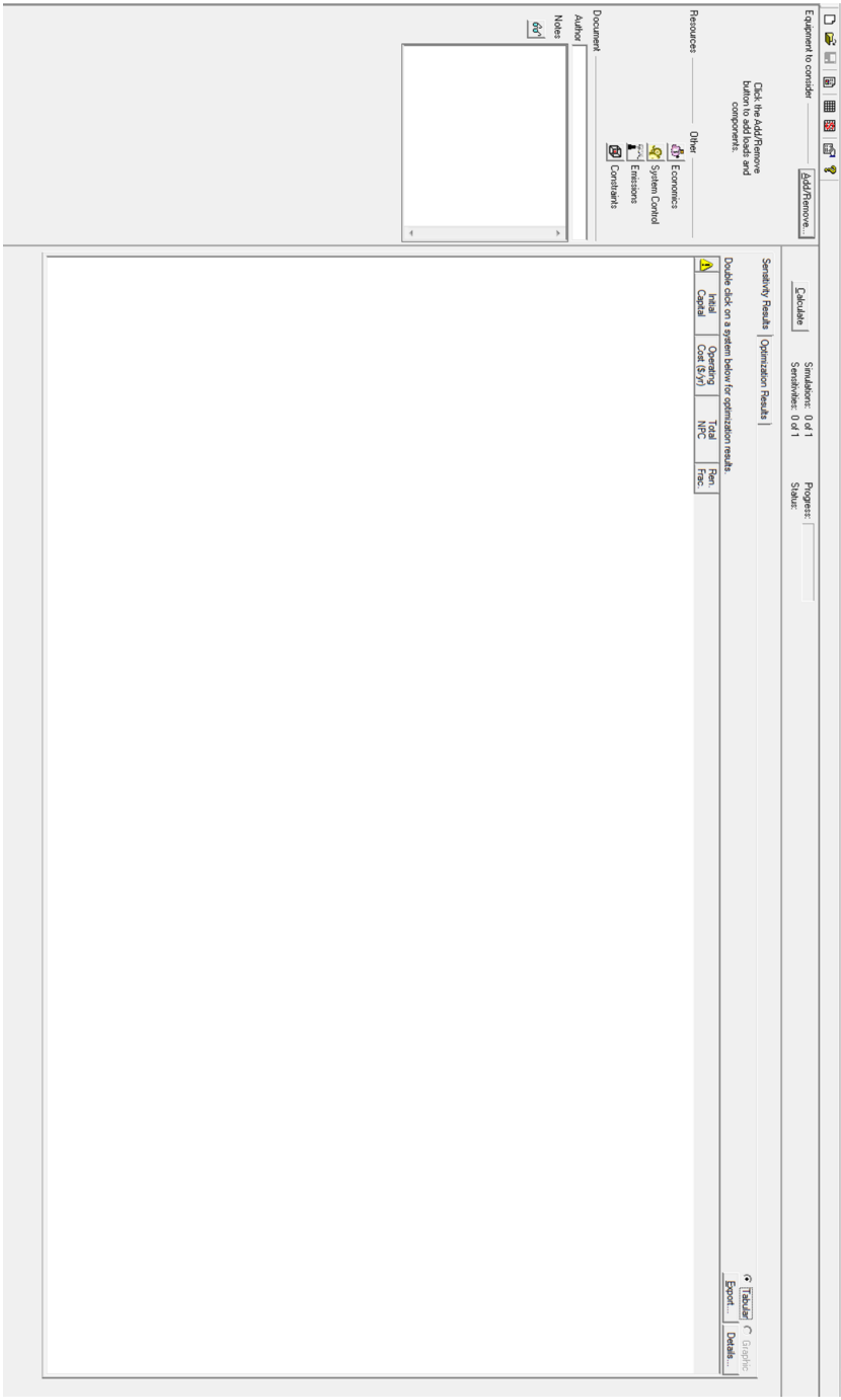


Figure 29: HOMER Interface

Equipment

Based on the findings of the Identification of Appropriate Distributed Resources section, the components considered for simulation are diesel and natural gas generators, a biogas-fueled generator, photovoltaic generation, a fuel cell, and DC/AC converter. Only a single primary load will be considered, and the system will be modeled as being connected to the grid. Figure 30 displays the Add/Remove Equipment dialog.

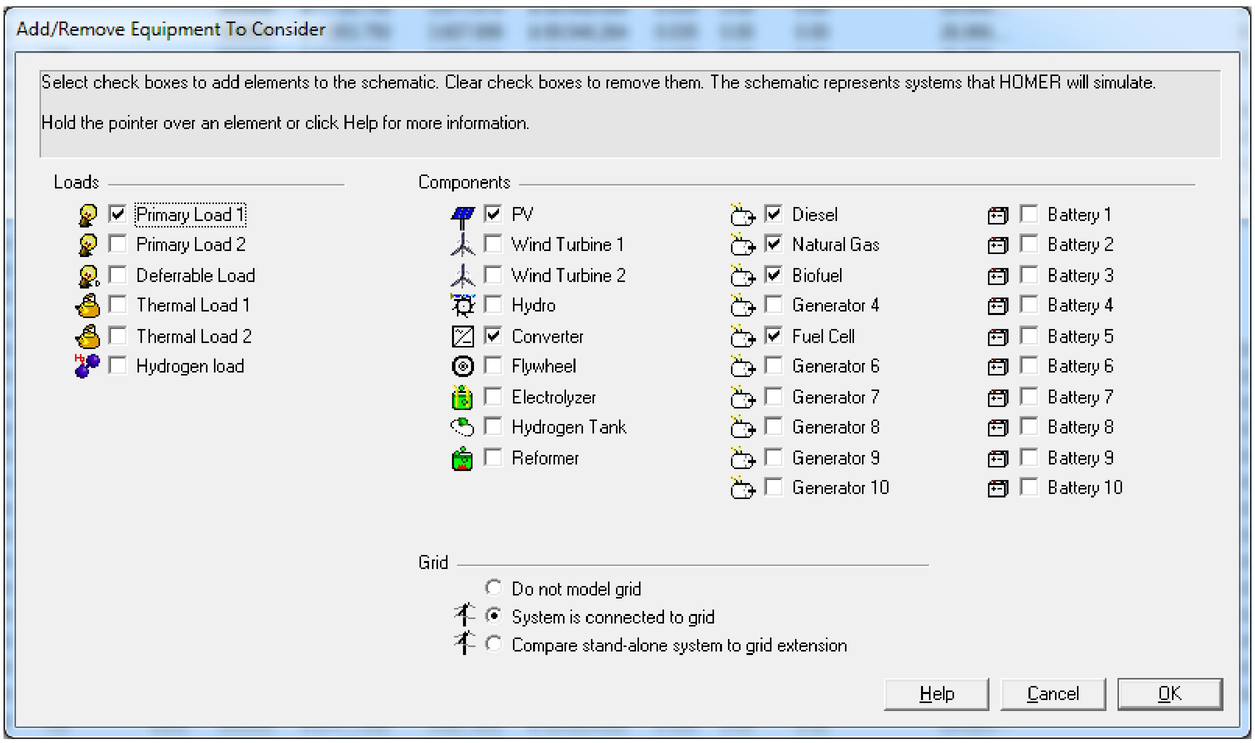


Figure 30: HOMER Equipment Dialog

Primary Load

The primary load dialog window is shown in Figure 31. As discussed in Chapter 5, this load data was obtained from the Physical Plant and represents the load experienced by the Academic Corridor in 2013. This data, originally in Comma Separated Value format, was reformatted for use by HOMER by removing all data except the interval magnitude, then specifying a 30-minute timestep in HOMER.

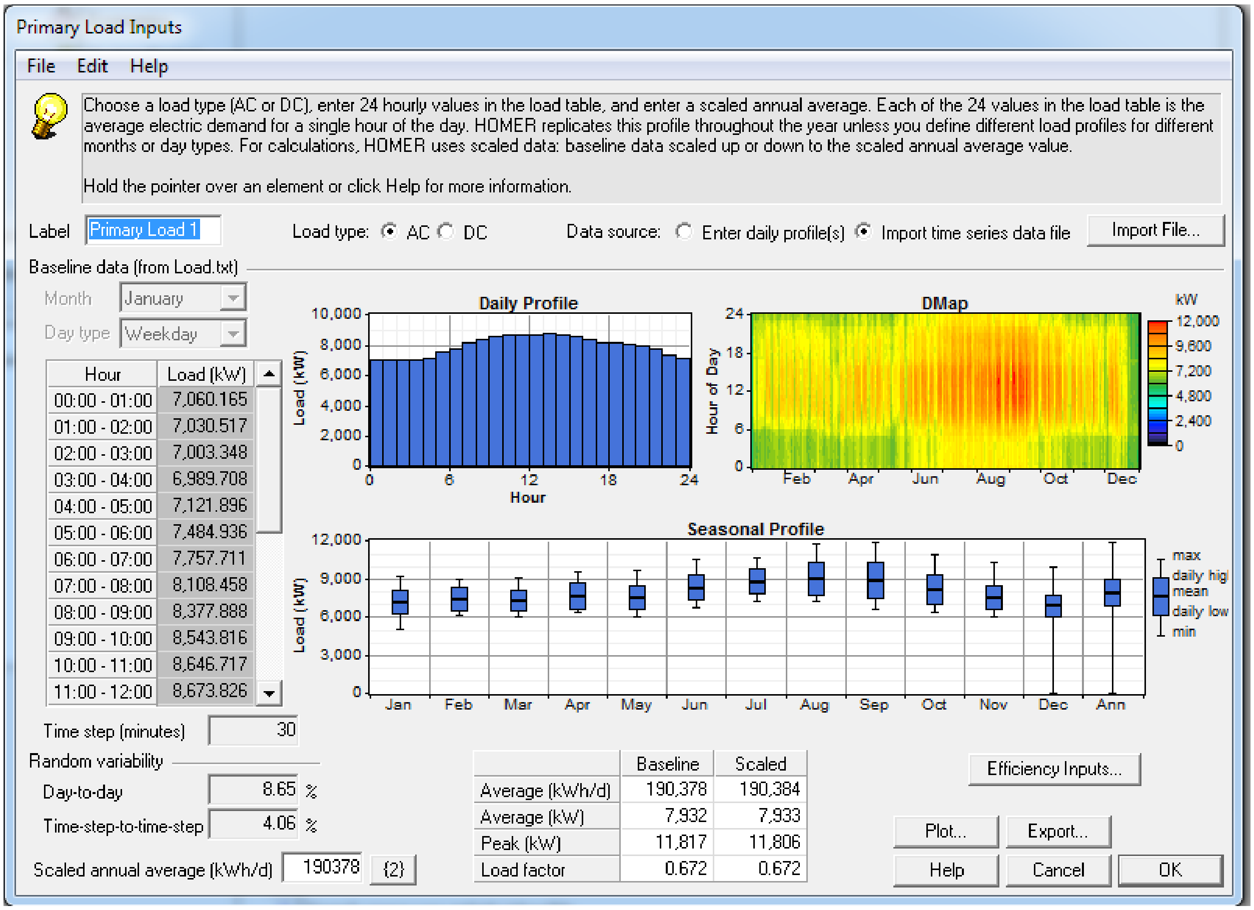


Figure 31: Primary Load

Grid

The external grid is modeled as a component on the AC bus that serves the Primary Load. Here we can define its relationship to the system in terms of rate and interconnection performance. Although it was stated that the RTP-HA-4 tariff would likely be beneficial for a microgrid system, no historical real time pricing data exists for

GSU, and so the current G17 tariff is selected for modeling instead. The G17 tariff bases its price on tiered consumption and is not subject to seasonal fluctuations. However, HOMER does not have a tiered pricing capability, and so an estimated annual average price of $0.07/kWh was assigned for all times and all months. The sellback rate was given a range of $0.00 to $0.07/kWh to allow sensitivity analysis of the effects of sellback to the utility. The demand rate was set to $9.56/kW/mo, as defined by G17. Net metering was left unchecked. Figure 32 displays the Rates tab inputs.

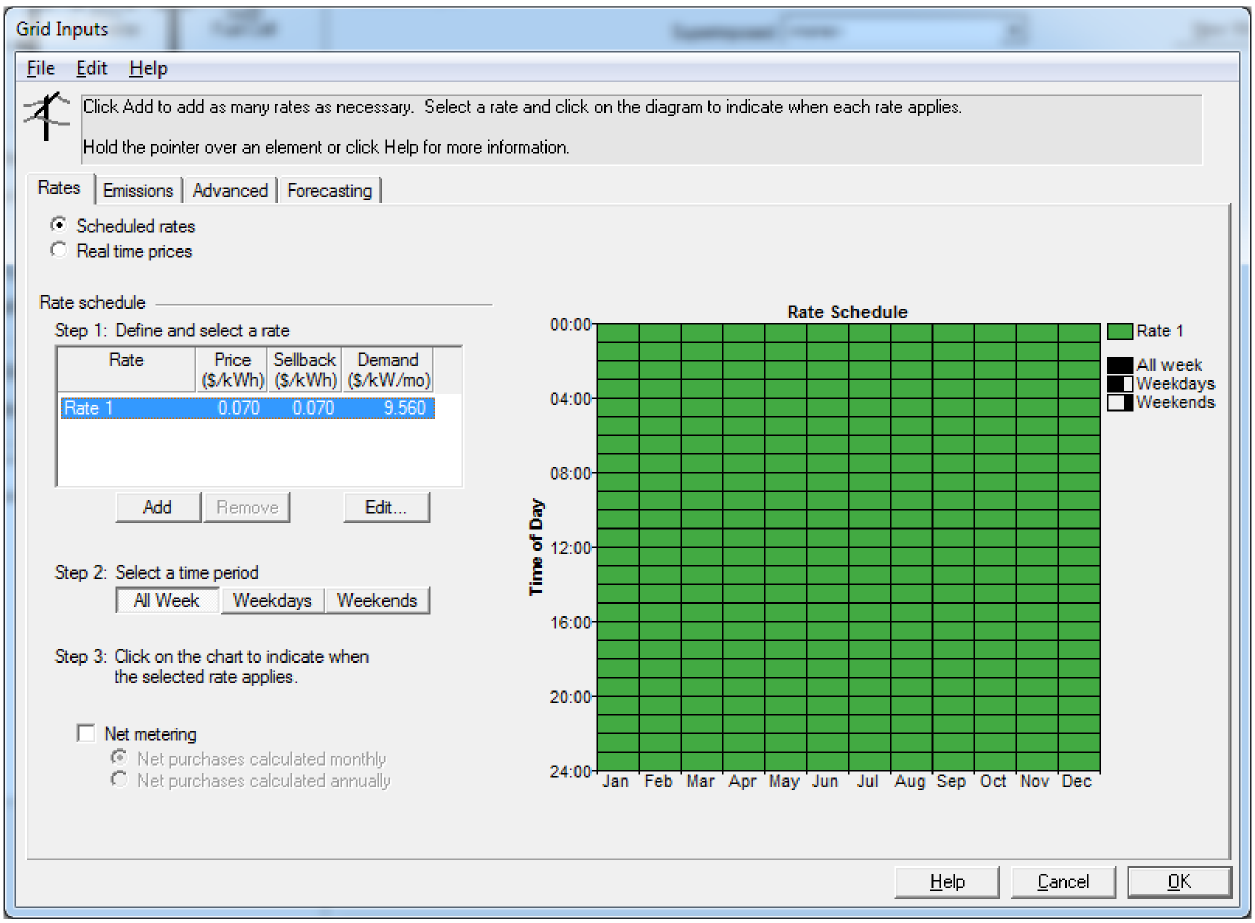


Figure 32: Grid Rates

The Emissions tab contains inputs for assigning emissions factors towards grid power. This can be useful if the user is attempting to estimate the environmental benefits of a microgrid, but this is outside the scope of this research. Figure 33 displays the Emissions tab with the default values left unchanged.

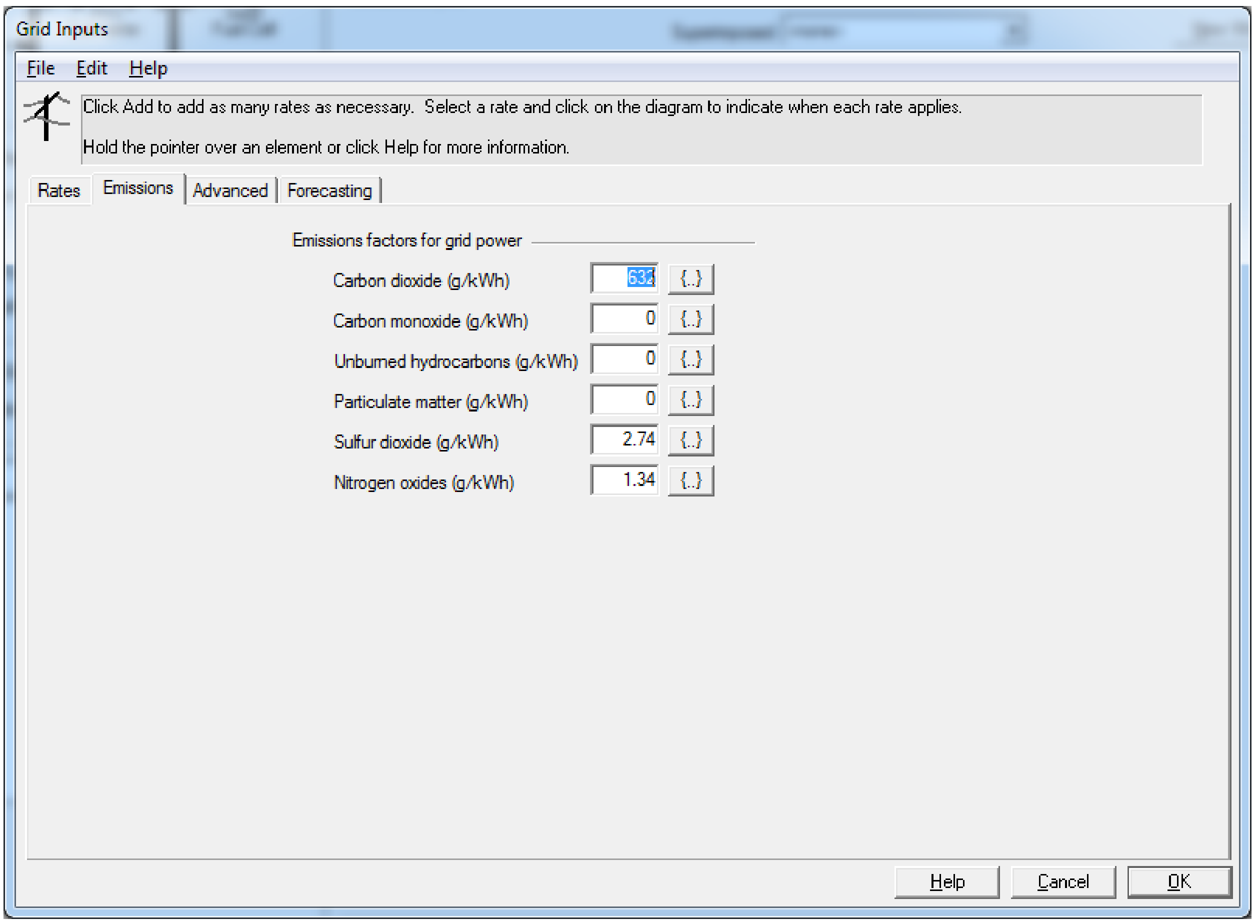


Figure 33: Grid Emissions

The Advanced tab allows for the modeling of various special conditions. These were mostly left unchanged, except for the purchase and sales capacities. A sales capacity of 20,000 kW was set pursuant to Southern Company's stated requirements for parallel operation with the grid. Purchase capacities of 0 kW, 8000 kW, and 99,999 kW were defined in order to model grid outage/island mode, peak load shaving, and "normal" operation, respectively. Modeling a capacity of 0 kW implies that no energy is being drawn from the grid, which occurs when the microgrid switches to island mode. The economic results won't be relevant in this case, but it will show which configurations are capable of islanding in terms of capacity. The 8000 kW choice effectively directs HOMER to assign limits above the Academic Corridor's average load, which models the situation in which onsite DERs are used to serve peaking load instead of continuing to draw the power from the utility. This may have the effect of decreasing costs arising from the demand rate. The 99,999 kW option is a rather clumsy method of telling HOMER to not assign any limits on the purchase capacity; it is much higher than our peak load of 12,000, and so will allow the system to draw as much power as it needs to meet the load. The Advanced tab is shown in Figure 34.

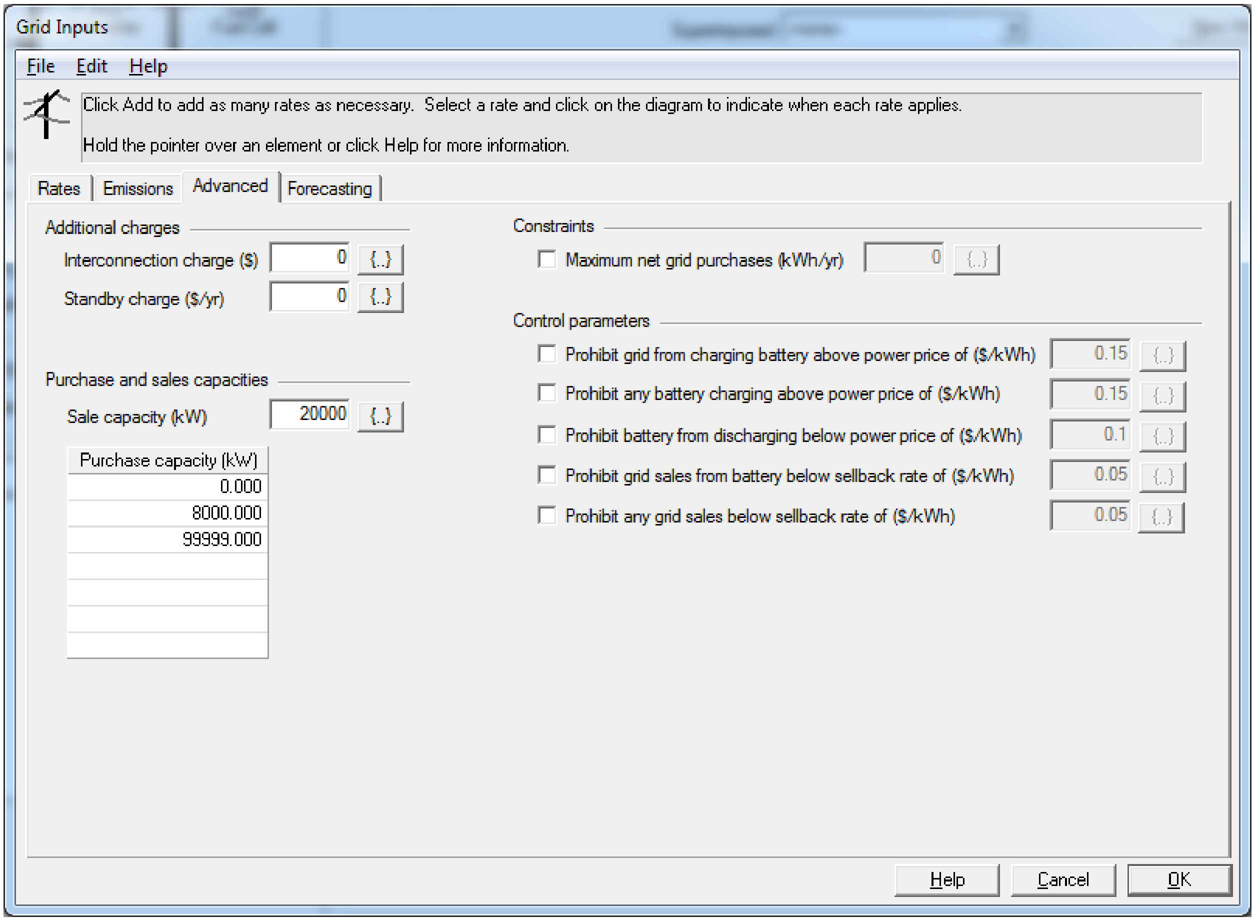


Figure 34: Grid Advanced Settings

The last tab involves power sales forecasting, which is not used in this system. It does not come into play at all in this simulation, and is thus not presented. However, this forecasting simulation ability would become useful if GSU were to switch to the RTP-HA-4 tariff described in Chapter 5.

Diesel Generators

The existing diesel backup generators can be modeled as a single Generator component in HOMER. Costs were assigned on a per kW basis and then extrapolated for various sizes. These base cost values were estimated by comparing the costs of similar generators. Because 525kW worth of diesel generators already exist, the capital requirement for this value was changed from $78,750 to $0, and the capital costs for higher sizes was set as the respective extrapolated value minus the extrapolated value of the 525kW size, as this generation capacity represents the existing backup generators which are already purchased and installed. This allows for the consideration of the cost to buy *additional* gensets. The sizes considered were 0kW, or “none”; 525kW, which is the current total output; 1000kW, 2500kW, and 5000kW to model the performance of additional generation; and 12000kW, to meet the peak load. This allows HOMER to consider the possibility that this generator type is optimal for the entire system during islanding situations: otherwise, it would only consider configurations with combinations of this generator type with other generator types. In effect, modeling a 12000kW generator could be considered as modeling a power plant. The lifetime was set to 25,000 operating hours to model the lifetime of a typical combustion generator. The minimum load ratio was set to 30%, which is considered a “best practice” technique to increase the longevity of a genset. In particular, “wet stacking” can occur in diesel generators running below the recommended minimum load ratio: this condition is marked by a black ooze forming around the exhaust stack as a result of unburned fuel passing through the system. Figure 35 displays the diesel generator Cost Inputs.

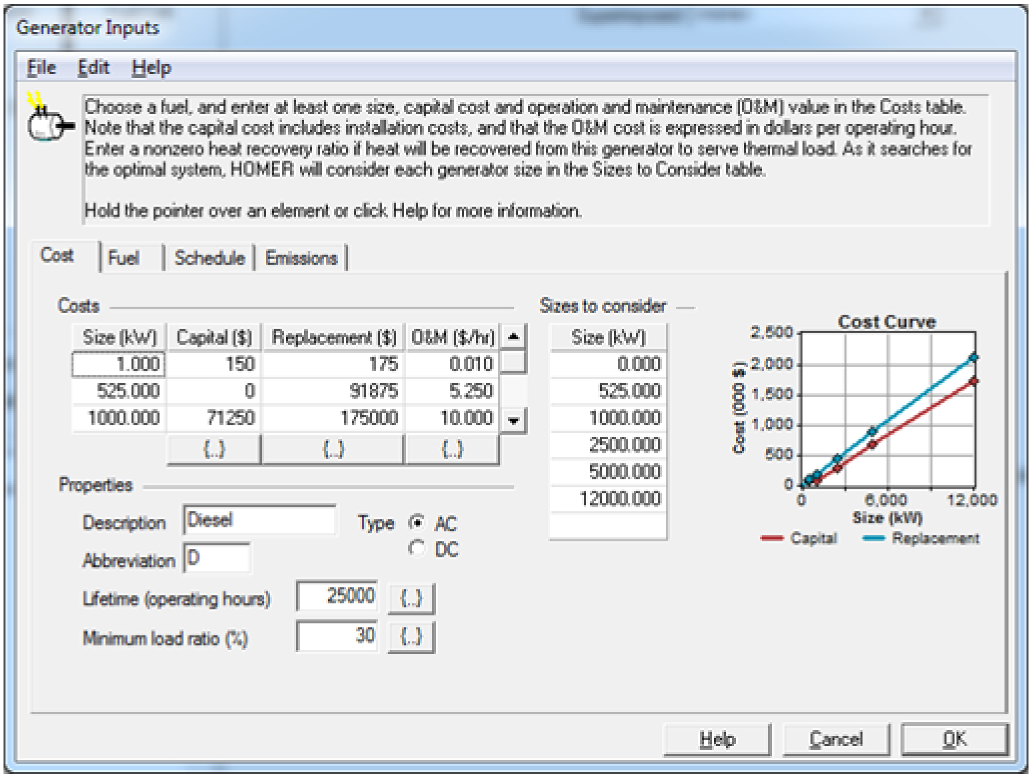


Figure 35: Diesel Generator Cost Inputs

Next was the Fuel tab. This allowed for the creation of a Fuel Curve by using a Fuel Curve Calculator, which used inputted fuel consumption data to create an Efficiency Curve, itself comparing the efficiency percentage to output in kilowatts. The fuel consumption data was obtained via a data sheet for a diesel genset with similar characteristics to those found on campus (Cummins Power Generation 2008a). The heat recovery ratio was left at zero due to the negligible opportunity for cogeneration at the campus, and the option to cofire with biogas was left unchecked. Figure 36 shows the Fuel Curve Calculator input. Figure 37 shows the Fuel tab.

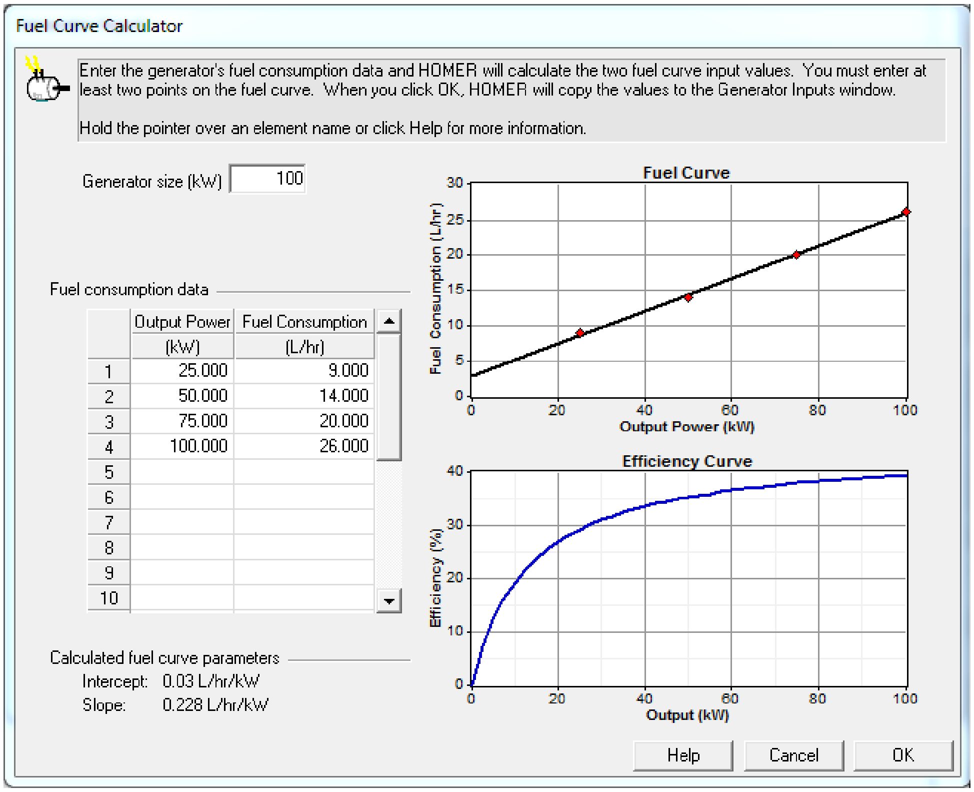


Figure 36: Fuel Curve Calculator

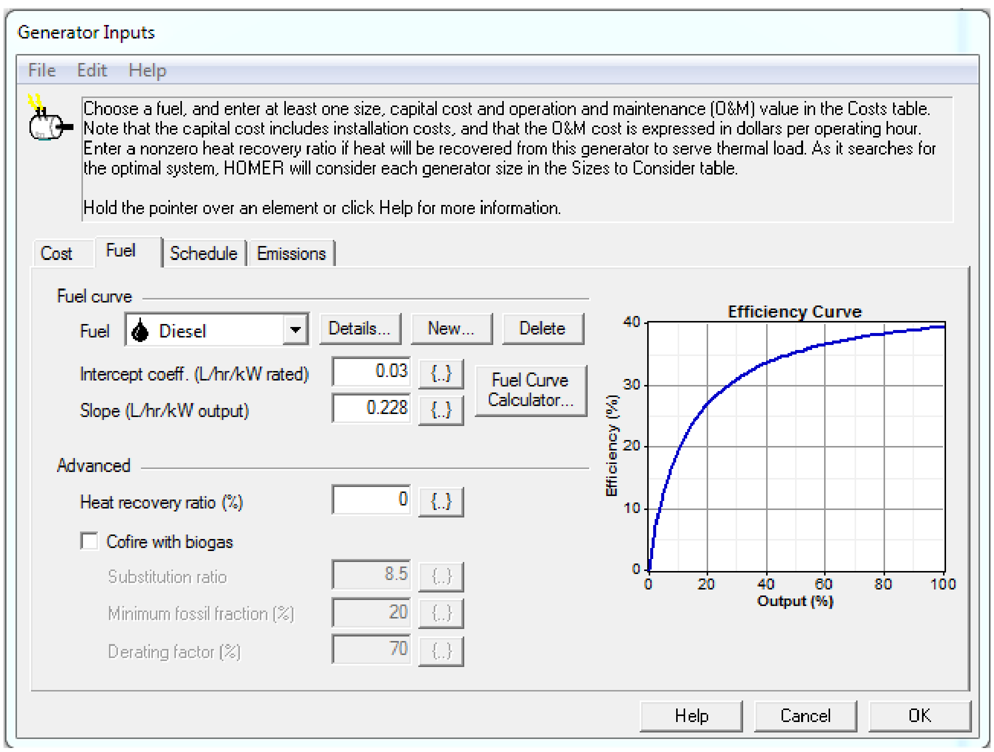


Figure 37: Diesel Generator Fuel Inputs

The Schedule tab allows the user to define when the generator is in operation. The “optimized” operating mode was selected to allow HOMER to decide based on the electrical demand and the economics of the generator versus other power sources (Lambert 2004). Figure 38 displays the Schedule tab.

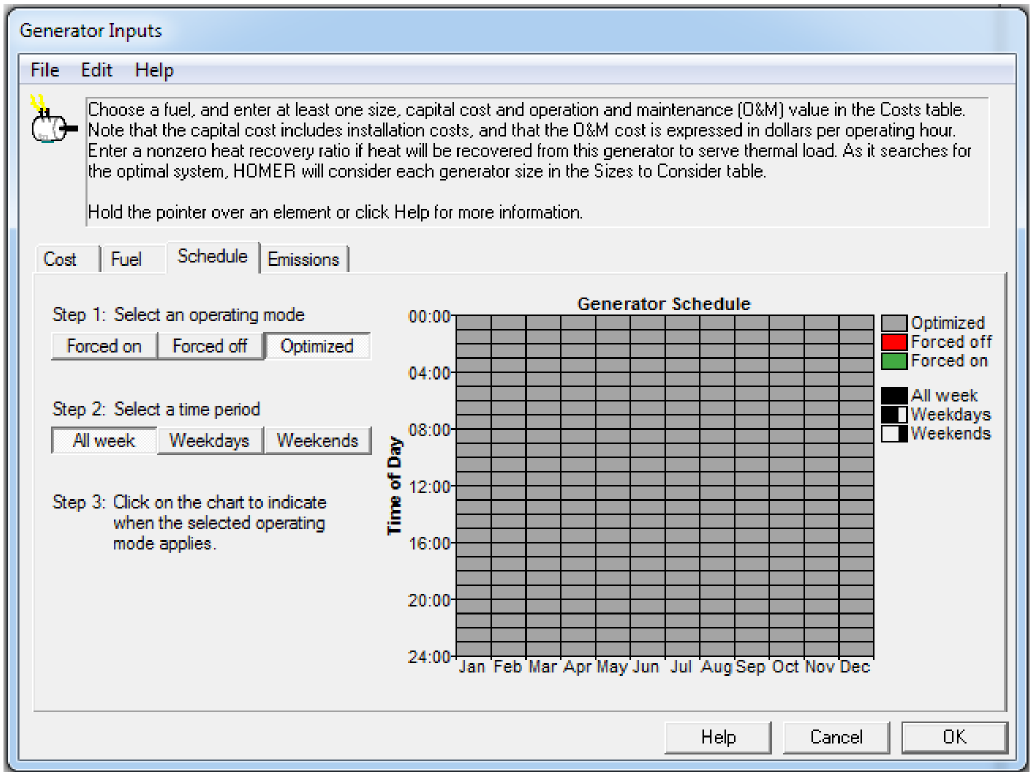


Figure 38: Diesel Generator Schedule

The final tab, Emissions, allows the user to model emissions per generator source. This can be useful in exploring the overall environmental impact of a microgrid configuration, but this is outside the scope of this research. Figure 39 shows the Emissions tab with the default values unchanged.

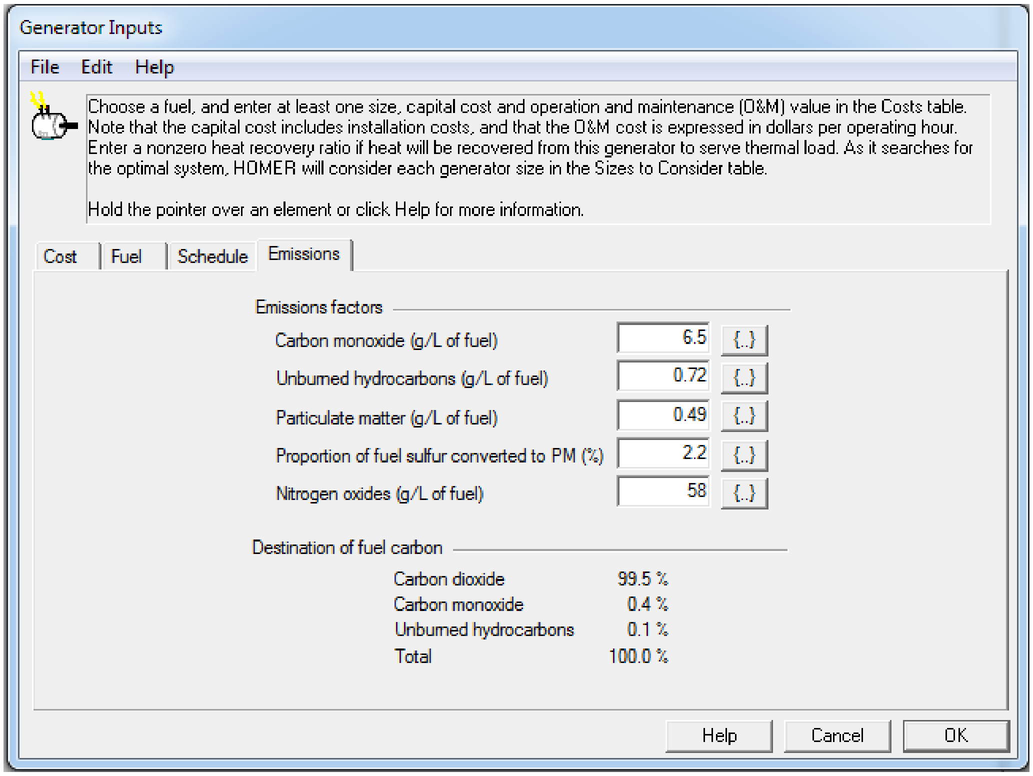


Figure 39: Diesel Generator Emissions Inputs

Natural Gas Generators

The existing natural gas generators were modeled with much the same rationale as the diesel generators. The 950kW of reported generation capacity was modeled with the same scaled cost data, with HOMER considering 0kW, 950kW, 2500kW, 5000kW, and 12000kW. Capital costs for 950kW were set to $0, as this amount of capacity is already existing. The Fuel and Efficiency Curves were derived from a data sheet of a natural gas generator with similar characteristics (Cummins Power Generation 2008b). The Schedule was again set to “optimized”, and the Emissions were left unchanged. Figures 40 and 41 display the Cost tab and Fuel tab.

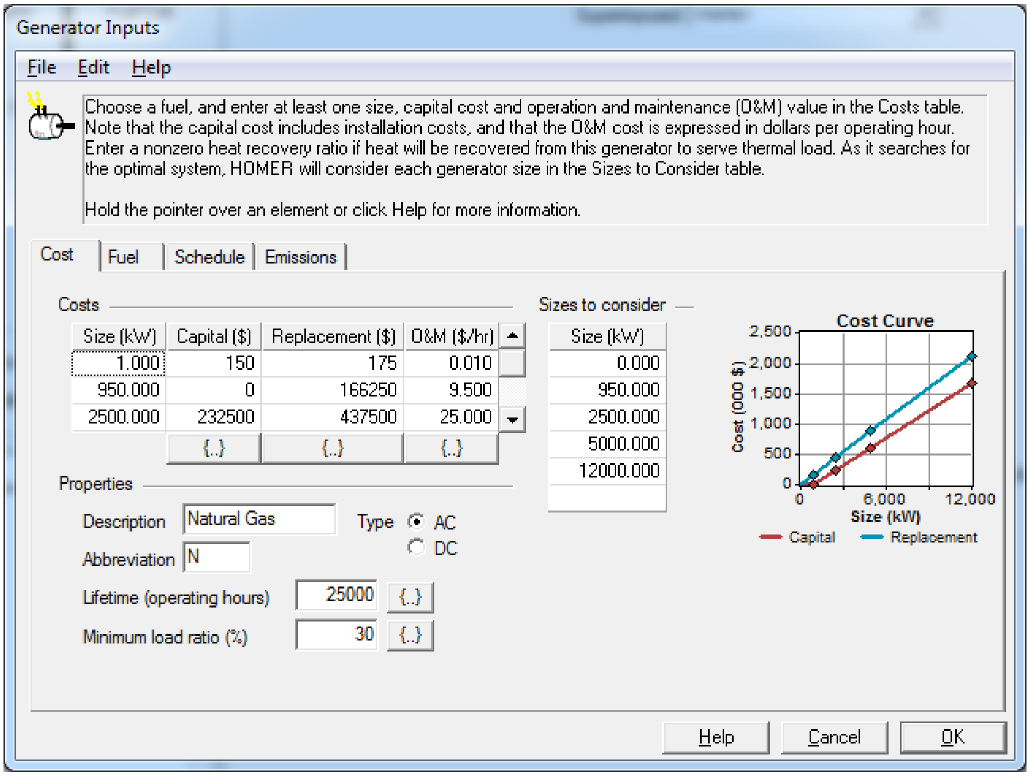


Figure 40: Natural Gas Cost Inputs

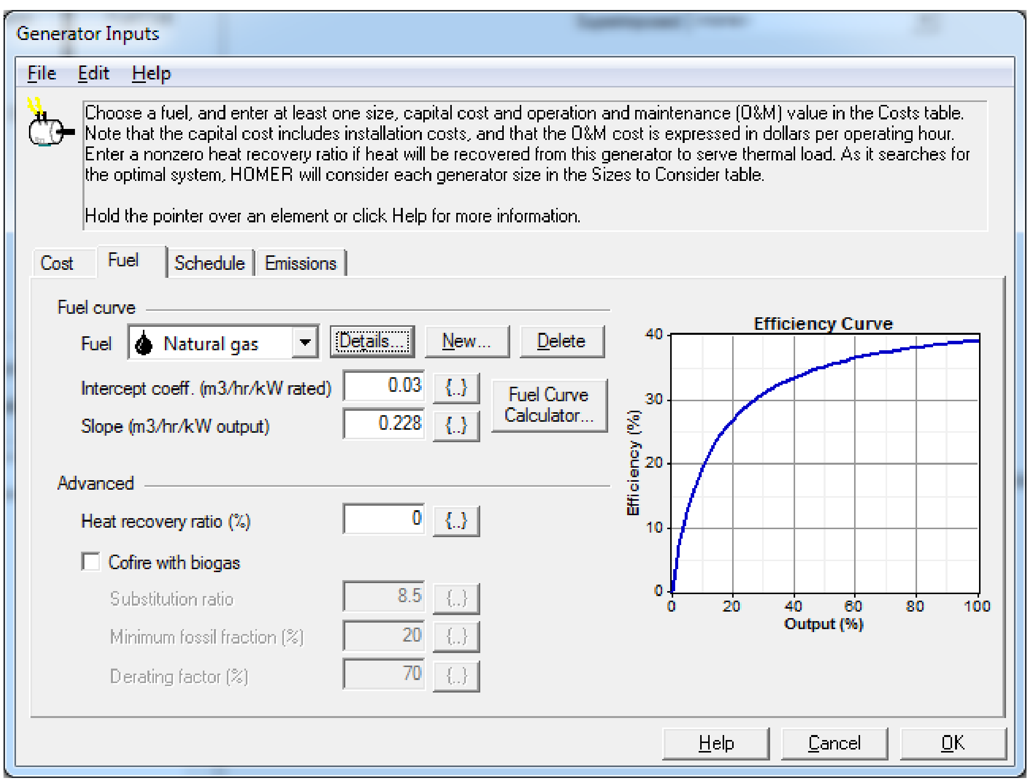


Figure 41: Natural Gas Fuel Inputs

Photovoltaic Module

The PV component was modeled similarly to that of the generators, with costs assigned on a kilowatt bases and extrapolated across sizes. Figures 42 and 43 display projected overnight capital cost per kilowatt and fixed operating cost per year, respectively. These values were acquired from the Transparent Cost Database.

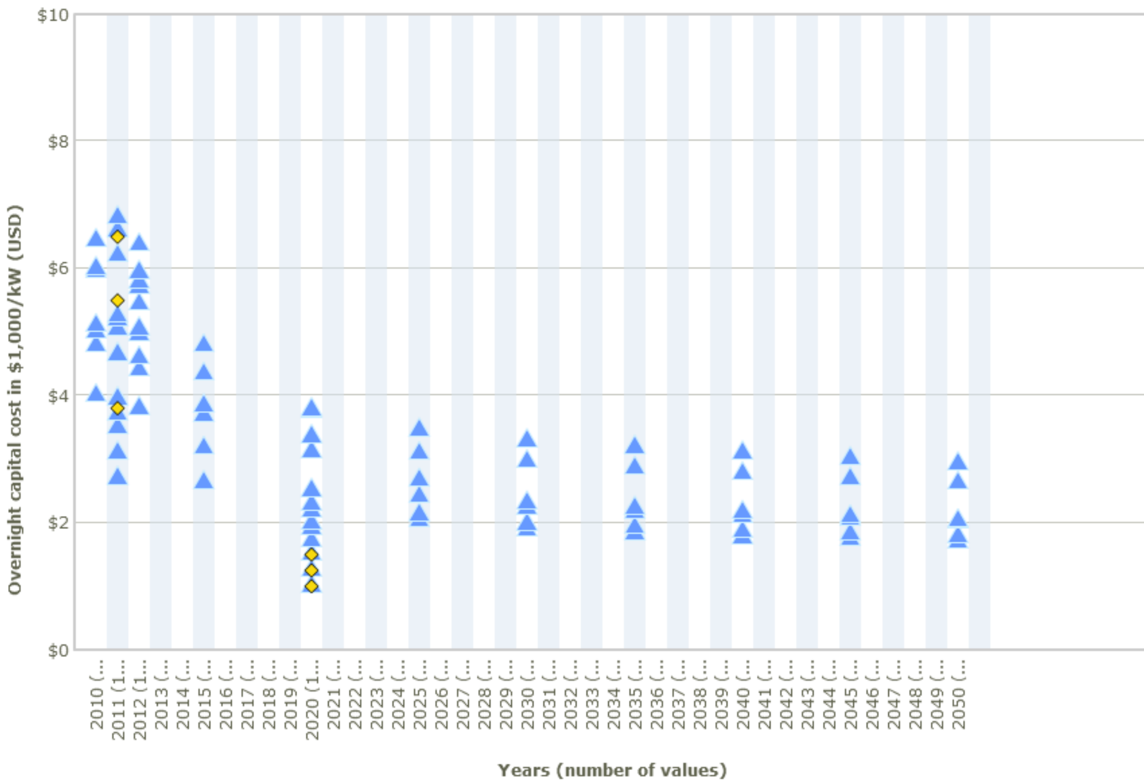


Figure 42: Photovoltaic Capital Cost

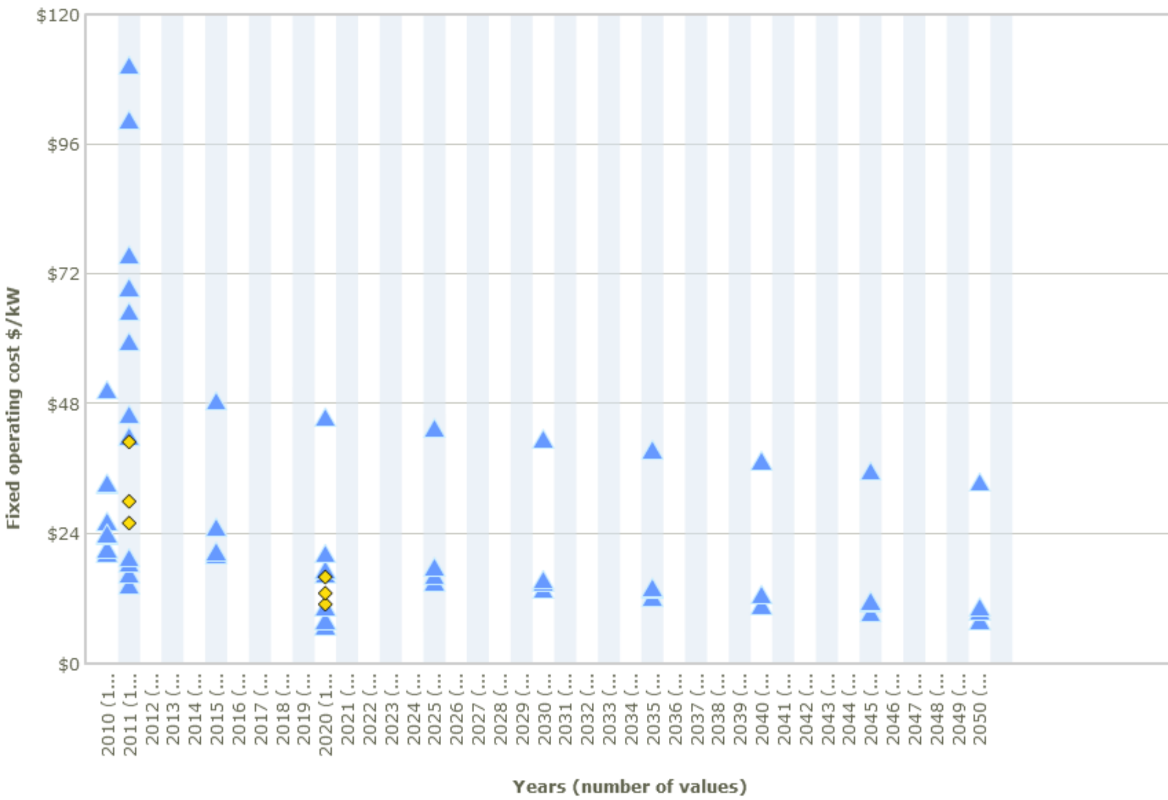


Figure 43: Photovoltaic O&M Costs

Because solar prices are widely projected to continue to decrease, the lowest capital cost for 2012, the closest year with historical data, was selected. The replacement cost was acquired from the lowest projected capital cost of 2035 to account for a 20 year expected lifetime. O&M costs in the form of fixed operating costs were selected from the low-cost projection for 2015, at about $20/yr. The sizes to consider, limited by the available space and solar resource, were chosen as 0 kW, 100 kW, 250kW, 500 kW, and 1000 kW. The slope of the panel was set according to Statesboro latitude. All other inputs were left as default values. Figure 44 displays the PV cost inputs.

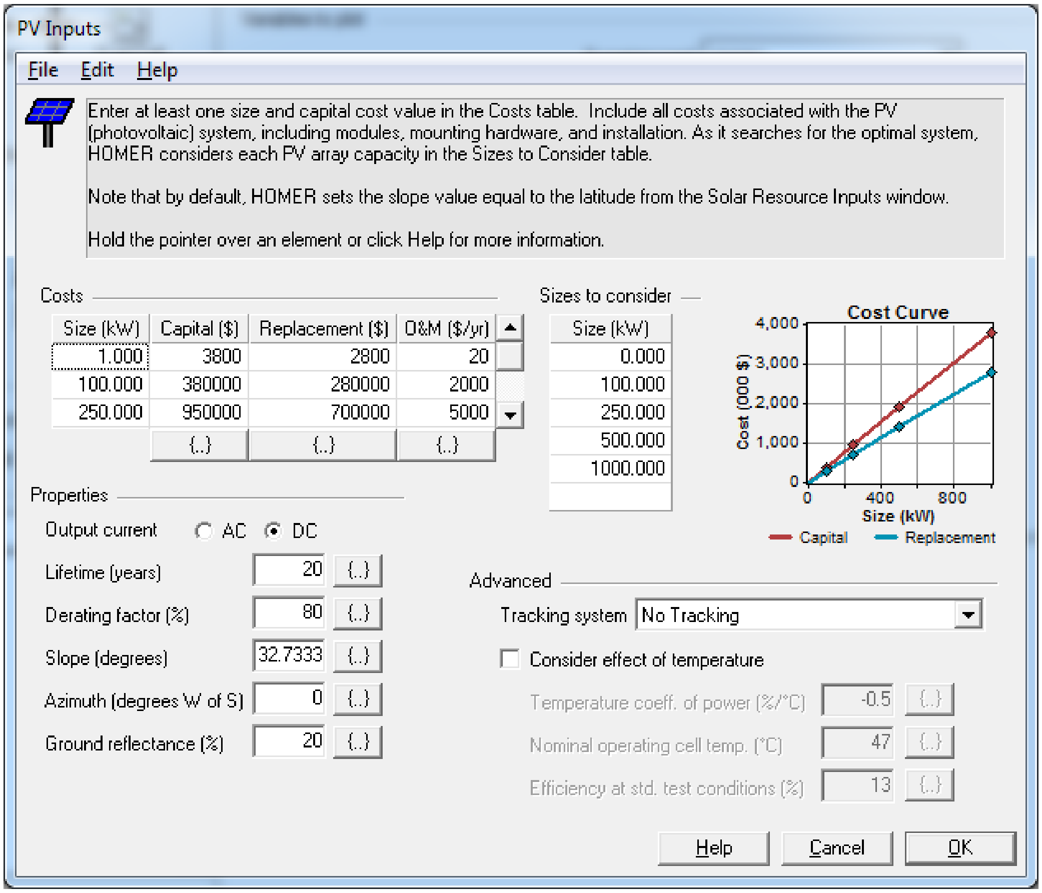


Figure 44: PV Cost Inputs

Biopower Generator

A single biofuel-powered generator is modeled in the same way the other generators were. As shown in Figure 45, overnight capital costs vary dramatically according to the technology used. After looking at the charts sources, it was found that a medium-sized steam turbine type exhibits a cost of about $3800/kW.

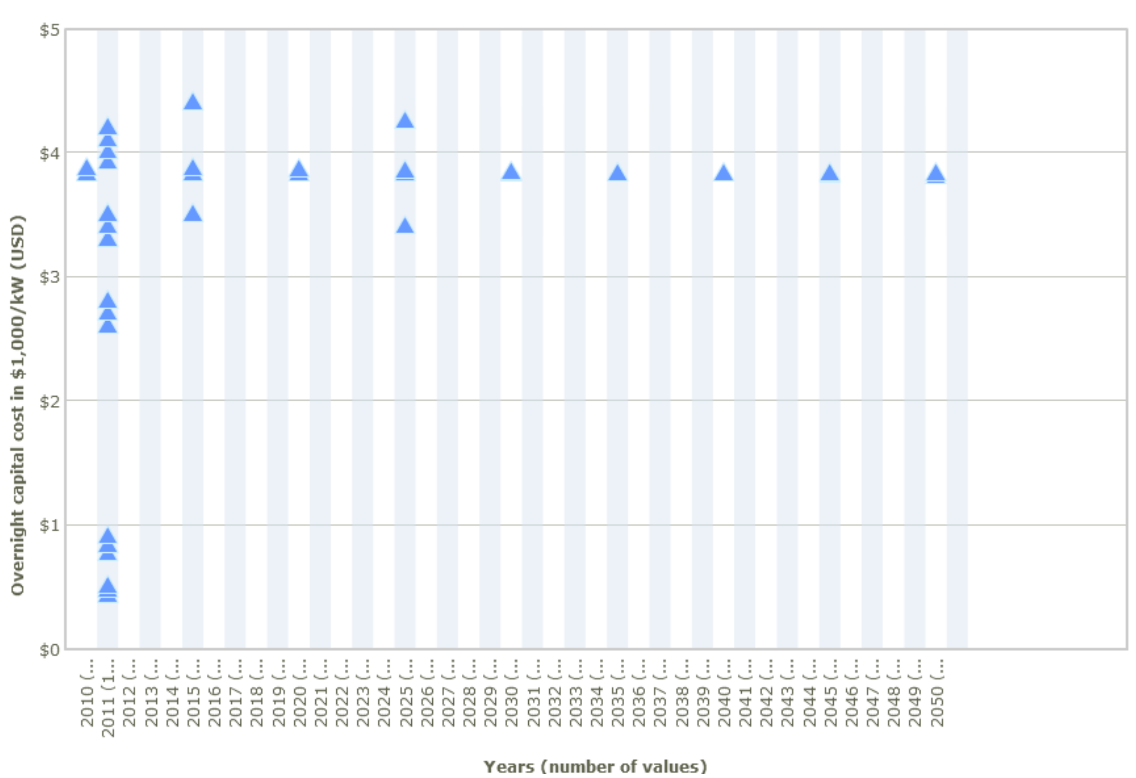


Figure 45: Biopower Capital Cost

Similarly, the cost of O&M was highly contingent on the type of biopower considered, as shown in Figure 46. The value of $0.0046/kWh was selected for this simulation.

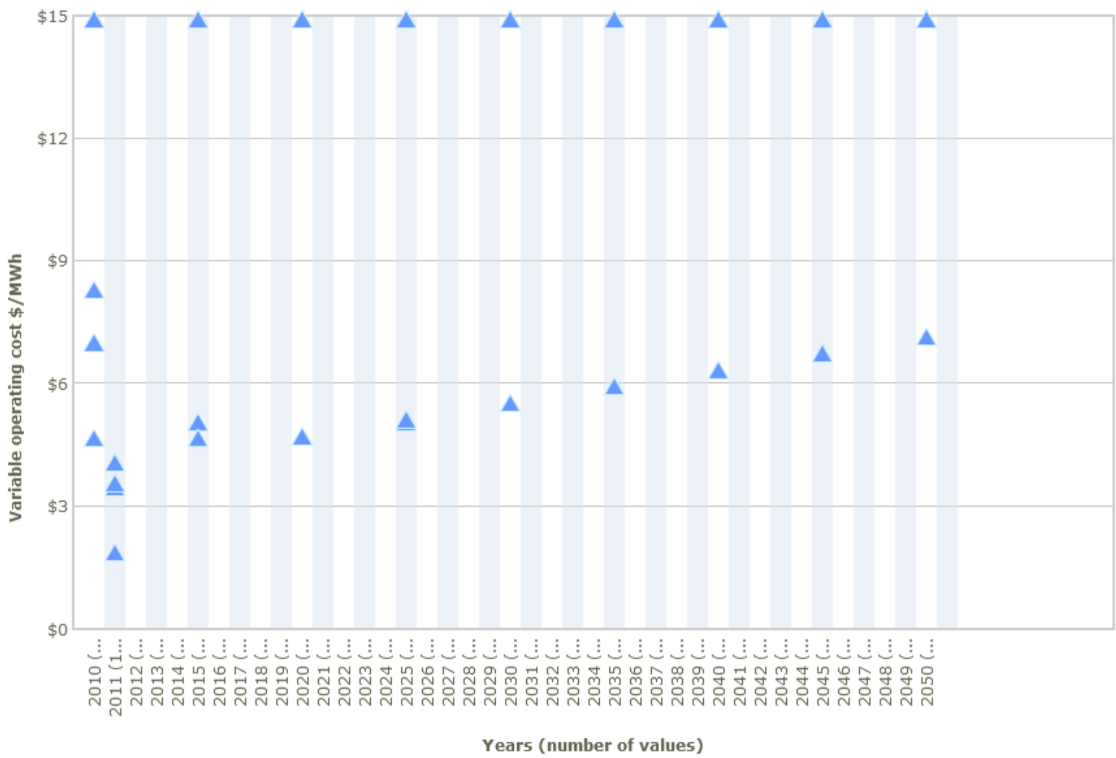


Figure 46: Biopower O&M Costs

Figures 47 and 48 display the Cost and Fuel tabs. The Schedule and Emissions tabs are identical to those of the diesel and natural gas generators.

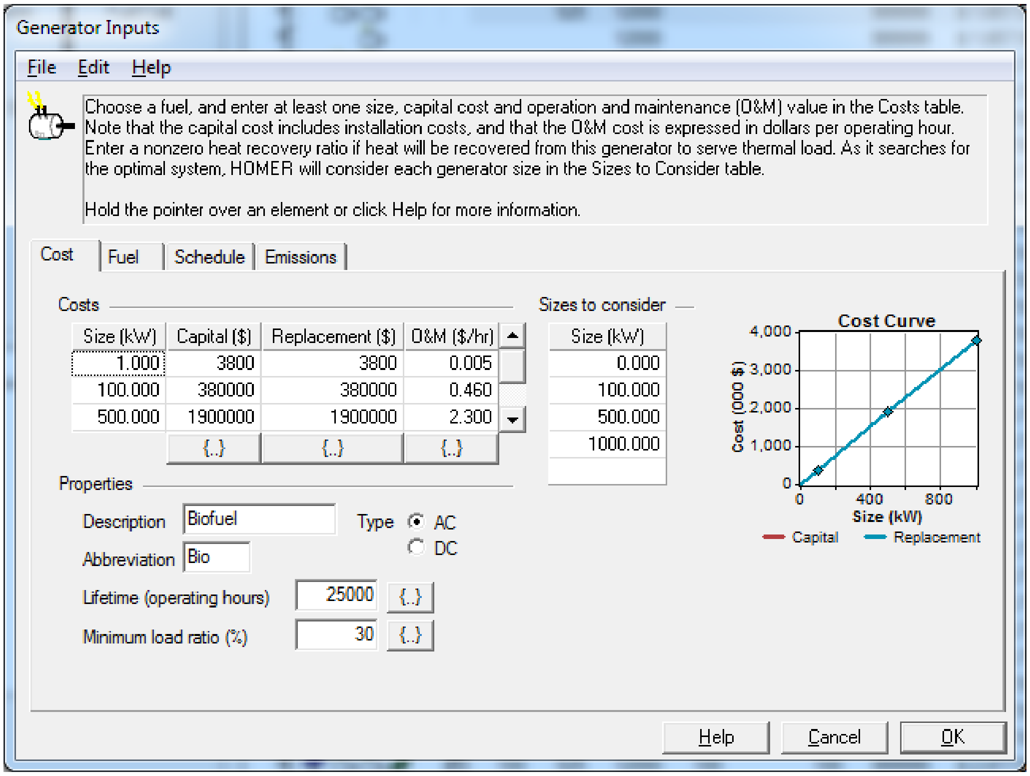


Figure 47: Biopower Cost Inputs

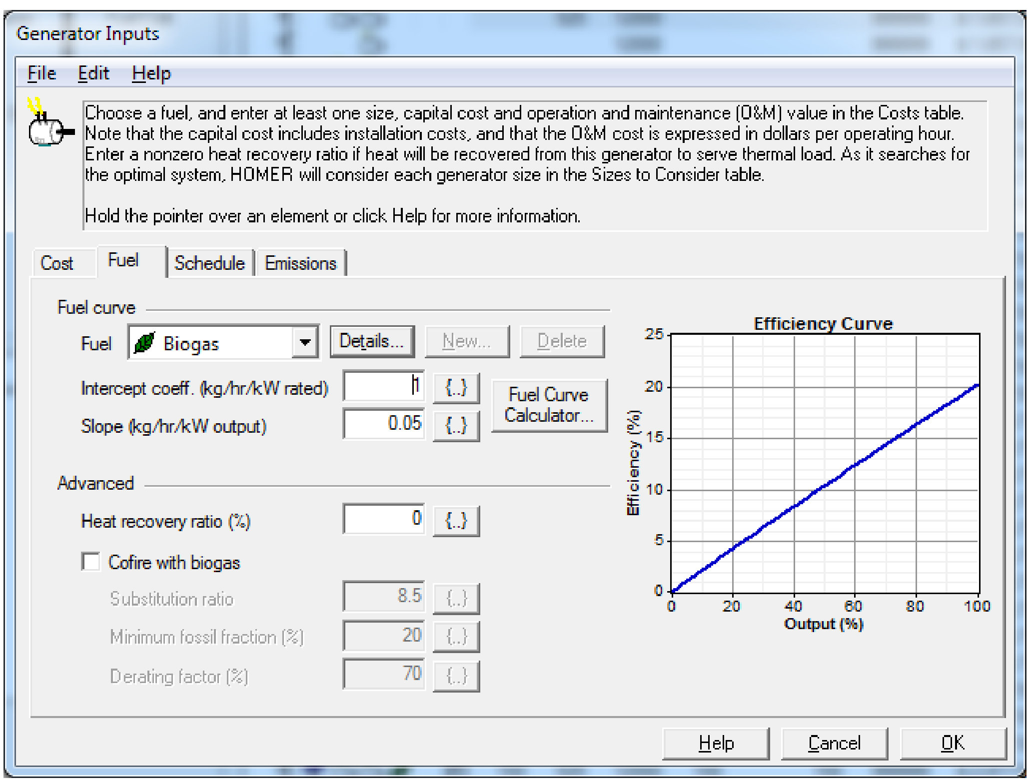


Figure 48: Biopower Fuel Inputs

Fuel Cell

The fuel cell component was modeled as a generator with type set to DC. Its capital and O&M cost data was acquired from the Transparent Cost Database, as shown in Figures 49 and 50, respectively.

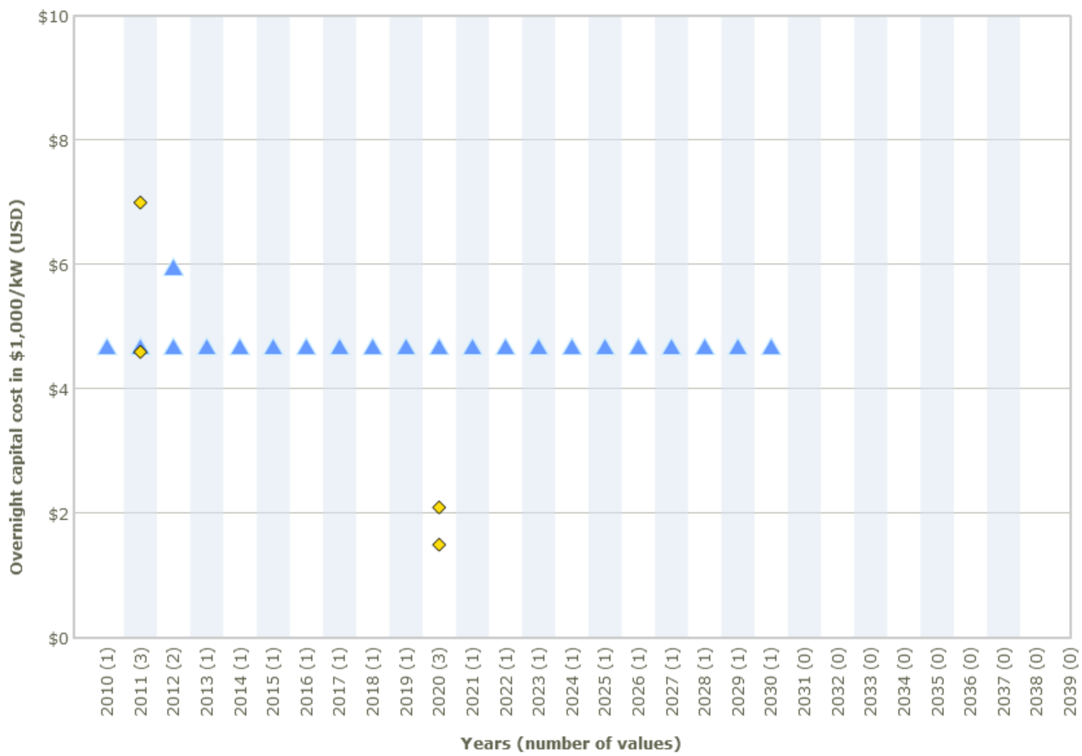


Figure 49: Fuel Cell Capital Cost

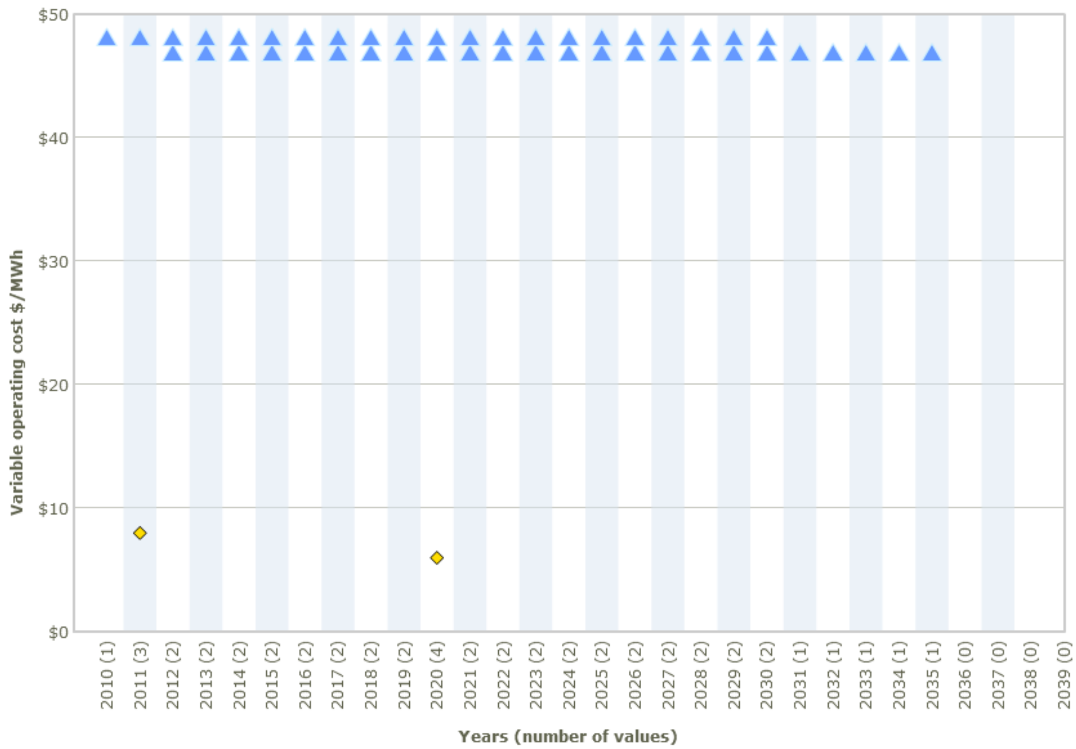


Figure 50: Fuel Cell O&M Costs

Due to the relative expense per kilowatt exhibited by this generation type, we kept the sizes to consider to 300 and 600 kW. In terms of fuel, a new fuel type called "Fuel Cell Fuel" was created. A relatively high efficiency was defined for this fuel. Figure 51 displays the Cost tab. Figure 52 shows the Fuel tab. The schedule was again set to "optimized", and emissions left unchanged.

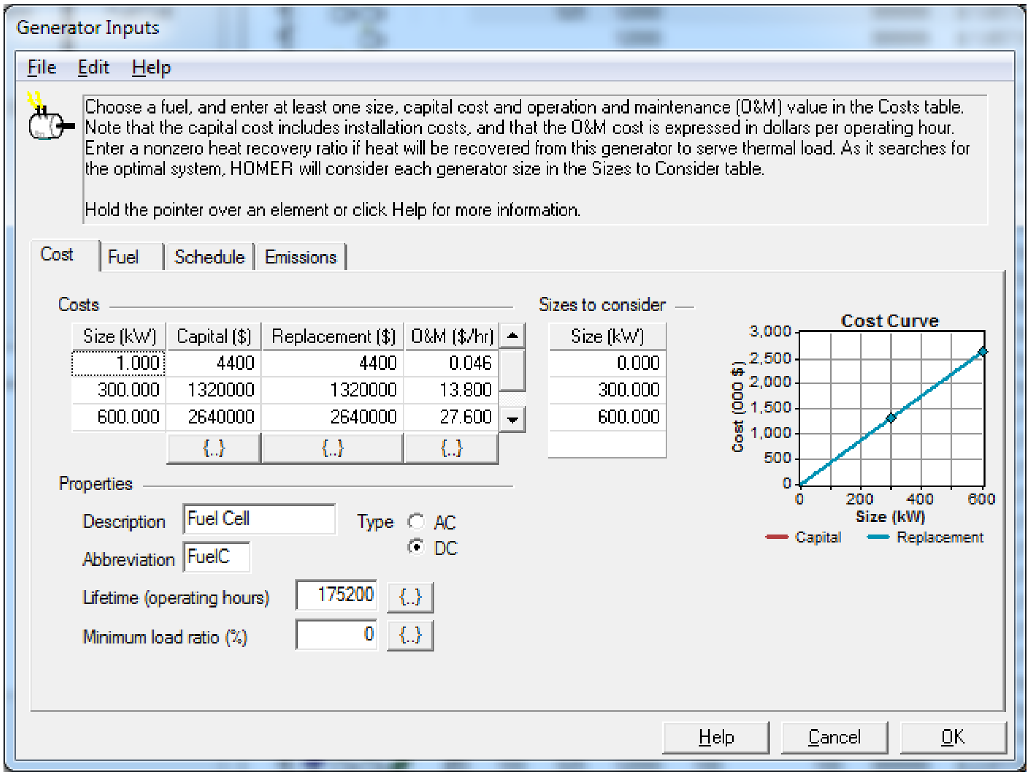


Figure 51: Fuel Cell Cost Inputs

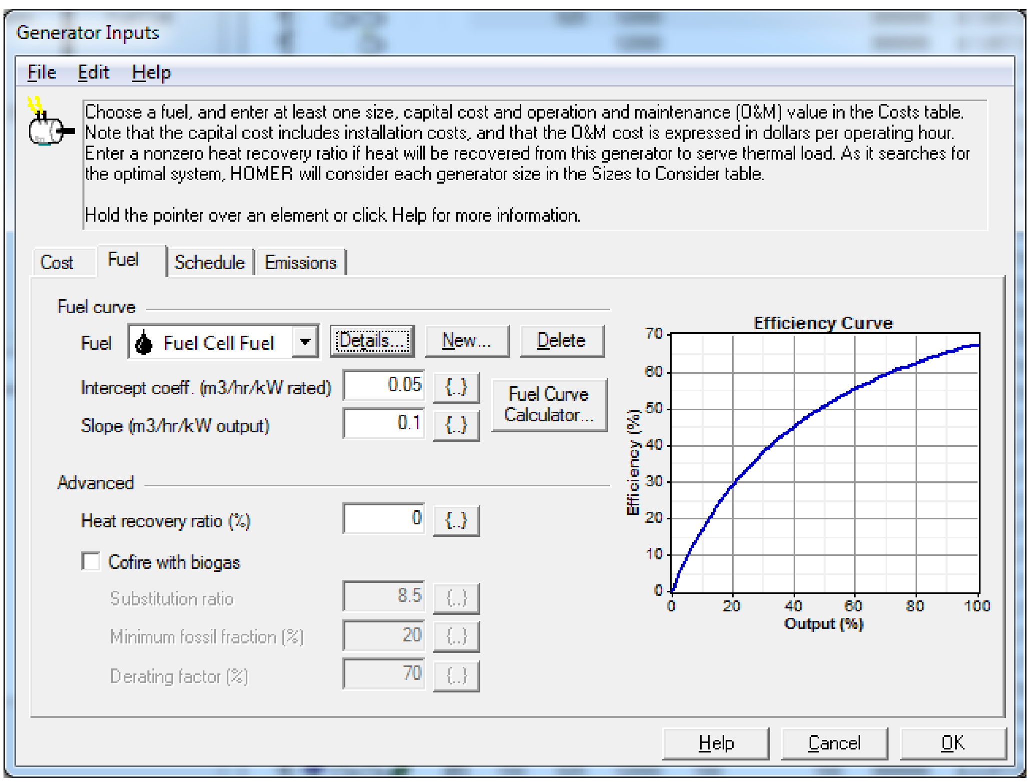


Figure 52: Fuel Cell Fuel Inputs

Converter

A converter component was required to bridge the DC generation types with the AC generation types. As the only load considered was the AC Primary Load, this component was necessary for the PV and Fuel Cell components to contribute to the load. However, the costs of a converter were already built into the data obtained for these components, and so the costs for the Converter component were set to zero. The sizes considered were scaled with the available sizes of the DC generators. All other inputs were left as defaults. Figure 53 shows the Converter inputs.

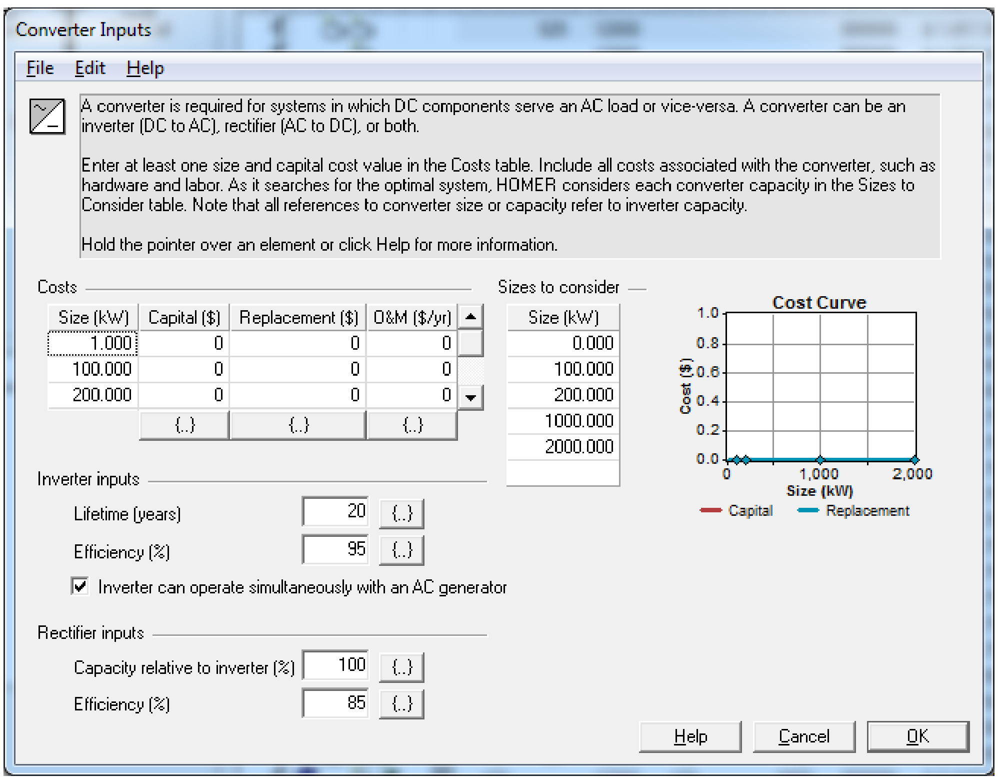


Figure 53: Converter Inputs

Resources

HOMER uses “Resources” to define the availability and performance of each “Equipment” type. This can include geospatial availability of renewable resources or the cost of fuel. It also includes overall system parameters and simulation options.

Solar Resource

The Solar Resource Inputs window exists to help the user estimate the available solar resource in the project area. Daily Radiation, measured in kWh/m^2/day is combined with a Clearness Index to calculate a scaled annual average, also measured in kWh/m^2/day. We can achieve moderately precise results by using the NREL’s RE Atlas tool to find the average insolation reported in Bulloch County, as shown in Figure 54.

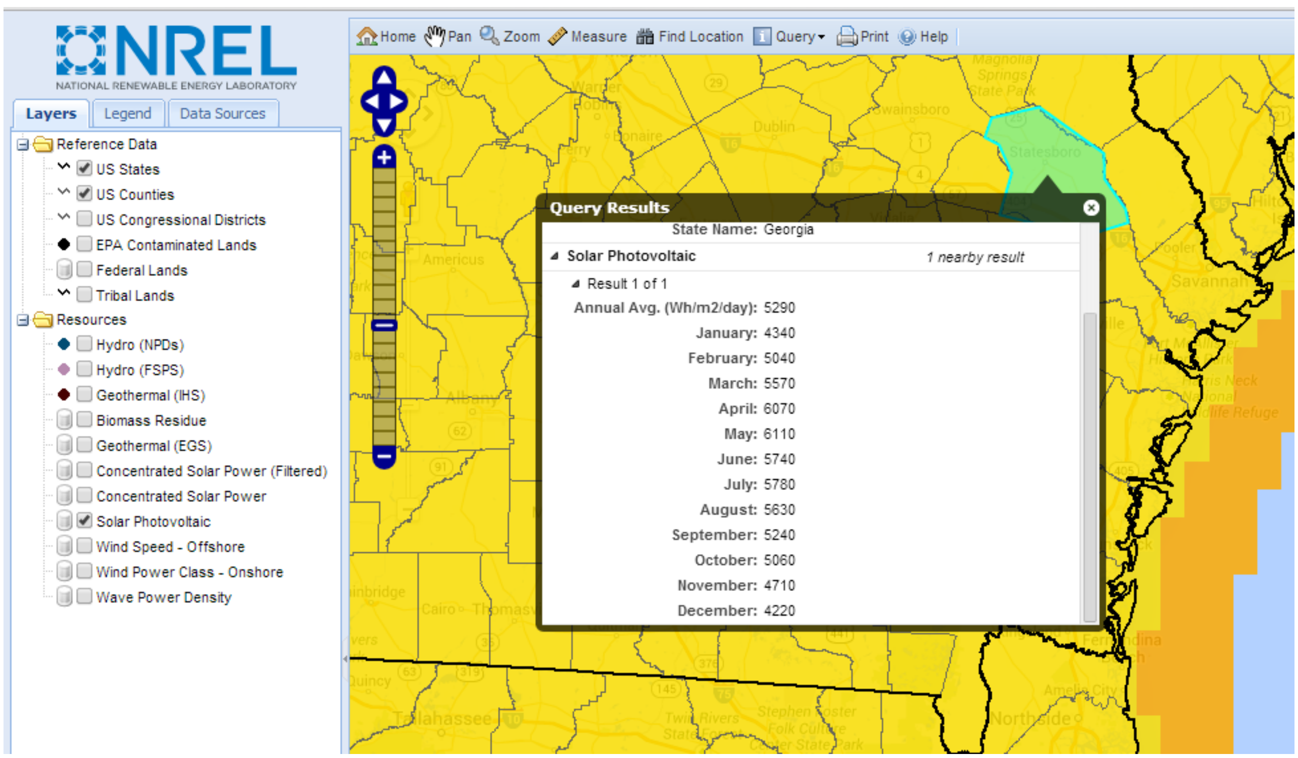


Figure 54: Average Insolation in Bulloch County via RE Atlas

This data can be inputted manually into the Solar Resource Inputs dialog. However, HOMER allows the user to import data obtained via a NASA Atmospheric Science Data Center internet resource, which is then used to populate the solar resource baseline data. To obtain this data, latitudinal and longitudinal data for Statesboro, GA is entered and “Get Data Via Internet” is selected. Figure 55 displays the Solar Resource Inputs window.

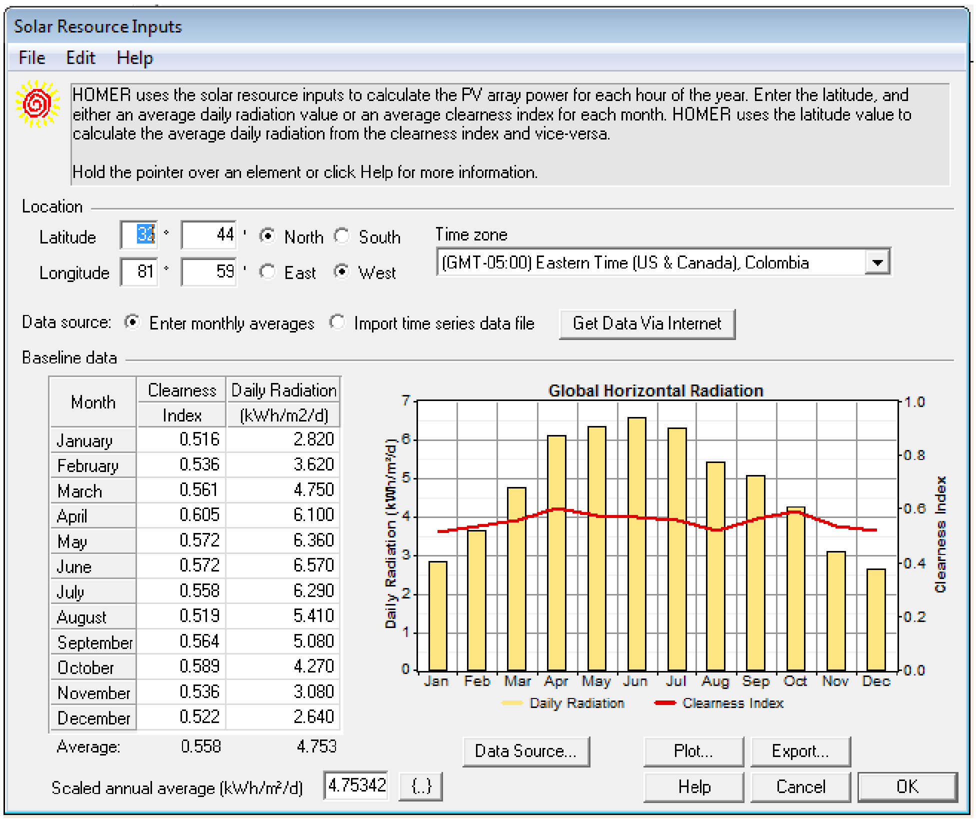
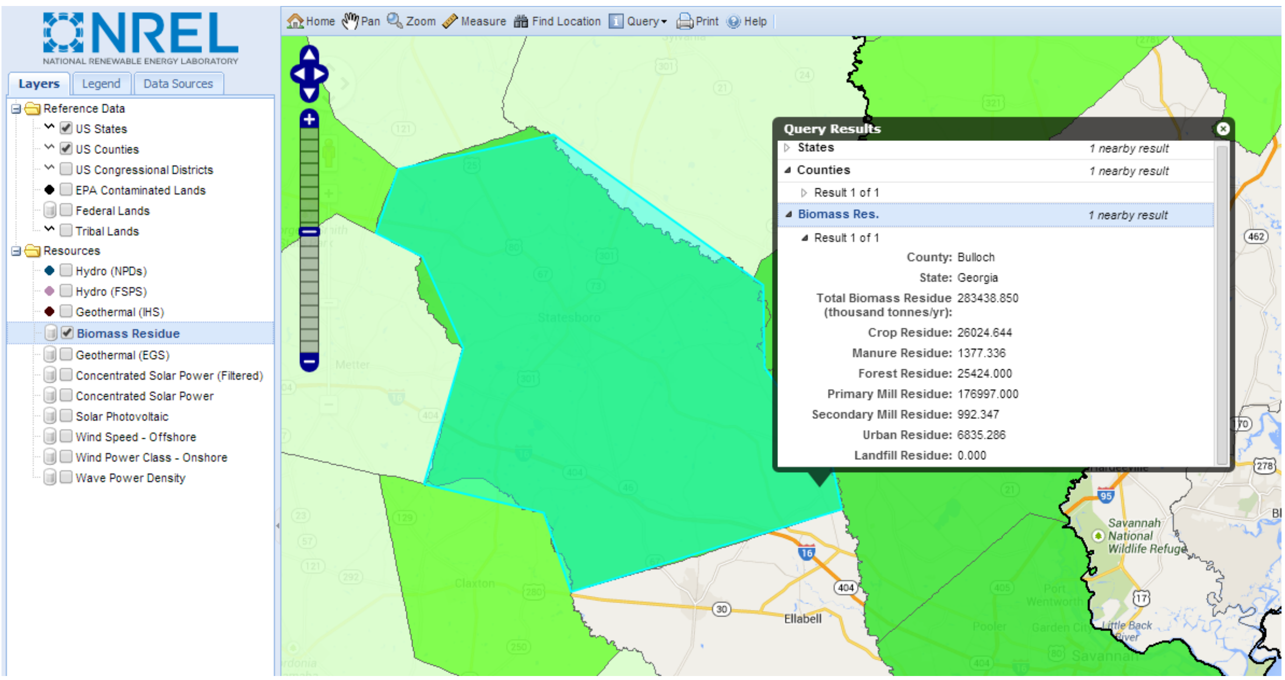


Figure 55: Solar Resource Inputs

Biomass Resource

As shown in Figure 56, the total biomass residue in this area is 283,438 thousand tonnes per year. This is converted to tonnes per day as required by HOMER via $\frac{\frac{283438*1000\ tonnes}{yr}}{365\ d}$ = 776,542 tonnes/d. Because this value is obtained from an annual average, it was entered for every month. Although this may not be a precise measurement of biomass actually available for use as biopower, it does set an upper limit.



http://maps.nrel.gov/re_atlas

Table 10 displays various biomass fuels and their associated costs. As we do not know exactly what fuels may be supplied, we will assume the source to be chipped biomass for this simulation.

Table 10: Comparison of Various Fuels ($/Mbtu)

Source	Units	Cost to User per unit ($ U.S.)	Efficiency	Btu/unit	$ per Mbtu
Chipped biomass	$/green ton	$50.00	75%	13,500,000	$4.94
Wheat straw bales	$/ton	$55.00	70%	14,000,000	$5.61
Natural gas	$/therm	$0.50	85%	100,000	$5.88
Wood/ag pellets	$/ton	$130.00	80%	15,000,000	$10.83
Natural gas	$/therm	$1.00	85%	100,000	$11.76
Wood/ag pellets	$/ton	$160.00	80%	15,000,000	$13.33
Hardwood pellets	$/ton	$185.00	80%	16,600,000	$13.93
Natural gas	$/therm	$1.50	85%	100,000	$17.65
Fuel oil	$/gallon	$2.25	85%	135,000	$19.61
Natural gas	$/therm	$1.75	85%	100,000	$20.59
Propane	$/gallon	$2.25	85%	91,600	$28.90
Electricity	$/kWh	$0.10	100%	3,413	$29.30

Peterson and Haase 2009

Additional information from Peterson and Haase provided the rest of the inputs. In keeping with the chipped biomass assumption, the average price was set to $50/t, carbon content to 5%, gasification ratio to 75%, and LHV was rounded to about 17 MJ/kg. Figure 56 displays the Biomass Resource inputs.

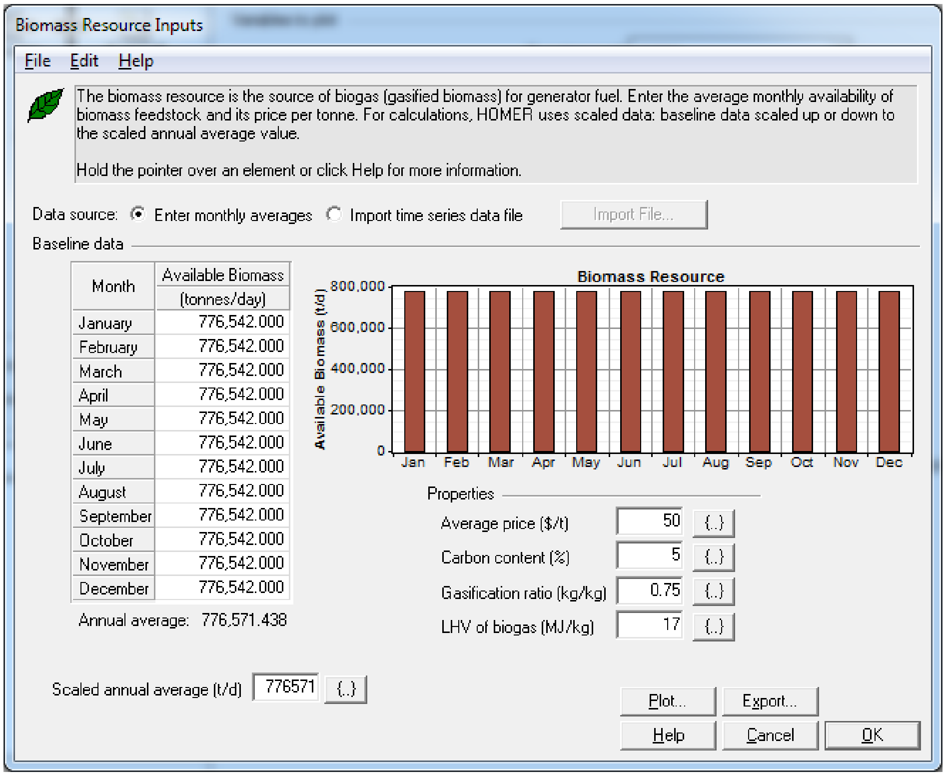


Figure 56: Biomass Resource Inputs

Diesel

Figure 57 displays the average cost of distillate petroleum, or diesel, to the electric power sector. This data was obtained via the AEO Table Browser (EIA 2014), which used data compiled in the Annual Energy Outlook 2013 publication (Hutzler 2012).

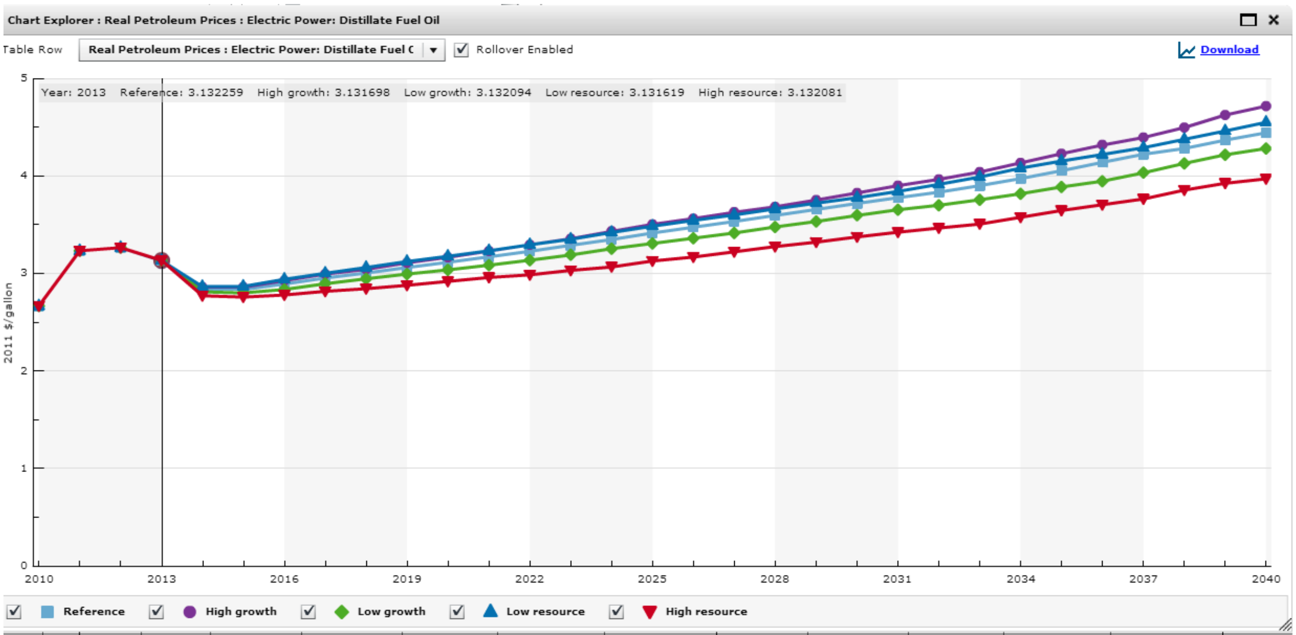


Figure 57: Real Petroleum Prices by End-Use Sector and Fuel

The 2013 reference value of 3.132 is in terms of \$/gallon. However, HOMER requires a diesel fuel input price in terms of \$/liter: this is achieved via $\frac{\frac{\$3.132}{1\,gal}}{3.78541\,l} = \$0.8274/l$. The Diesel resource inputs are shown in Figure 58.

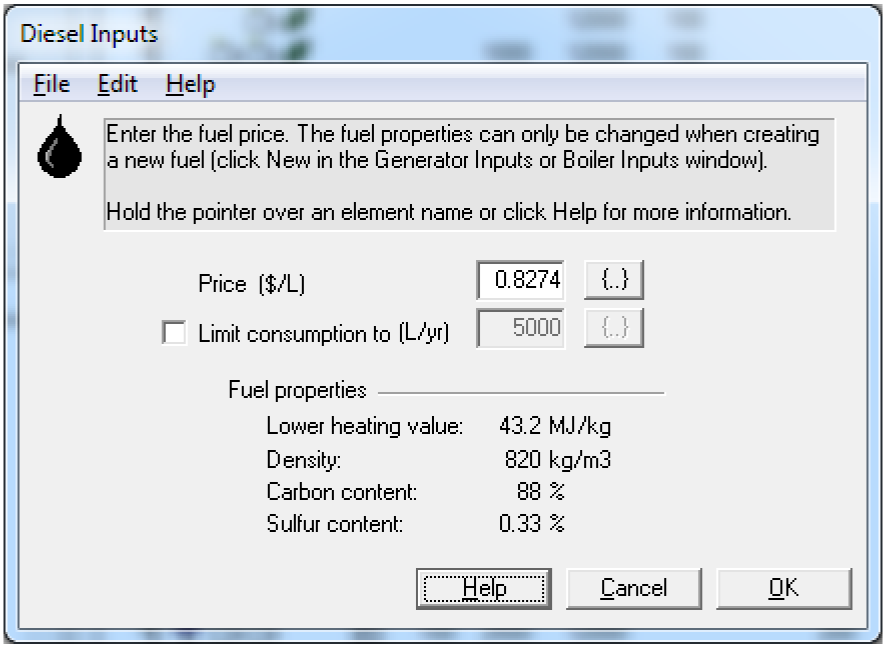


Figure 58: Diesel Fuel Inputs

Natural Gas

The natural gas generators are exceptionally interesting due to projected decreases in fuel costs due to increases in domestic production. Figure 59 demonstrates the projected costs for delivered natural gas for electric power in the South Atlantic region. We can see that the economic viability of onsite electricity production via natural gas combustion has a distinct correlation to the level of domestic natural gas production in terms of cost of fuel, with values ranging between close to $4/thou cu ft with high available resource to more than $10/thou cu ft with low available resource.

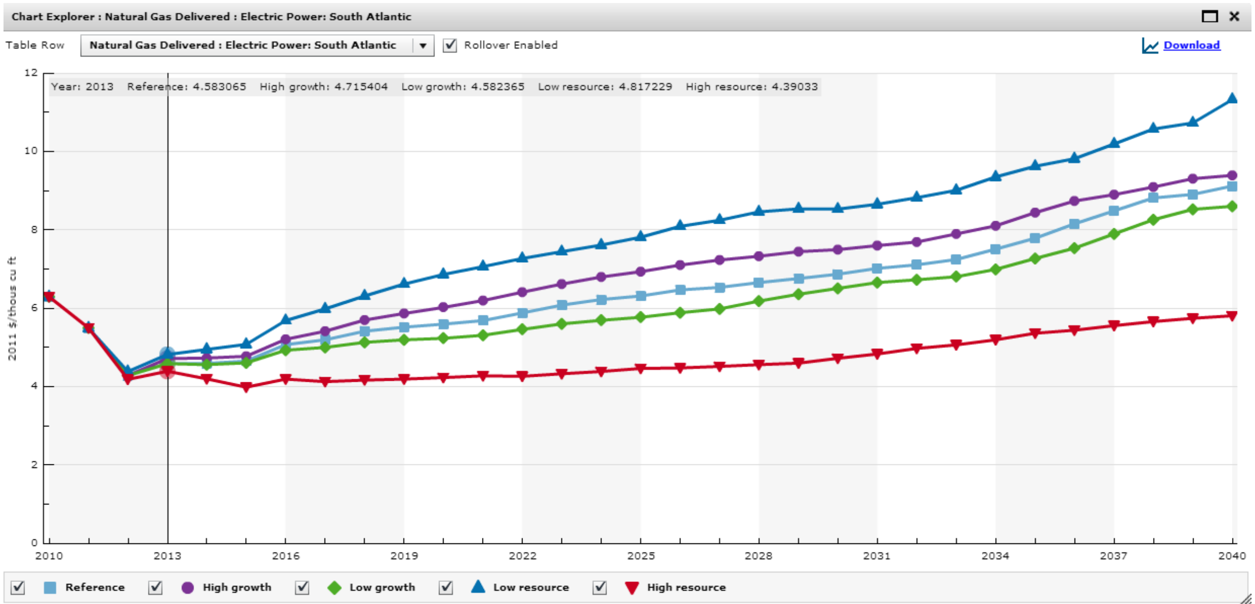


Figure 59: Natural Gas Delivered Prices by End-Use Sector and Census Division: Electric Power, South Atlantic

We select the reference value of $4.5 per thousand cubic ft, which converts to about $0.16 per cubic meter. The natural gas resource inputs window is shown in Figure 60.

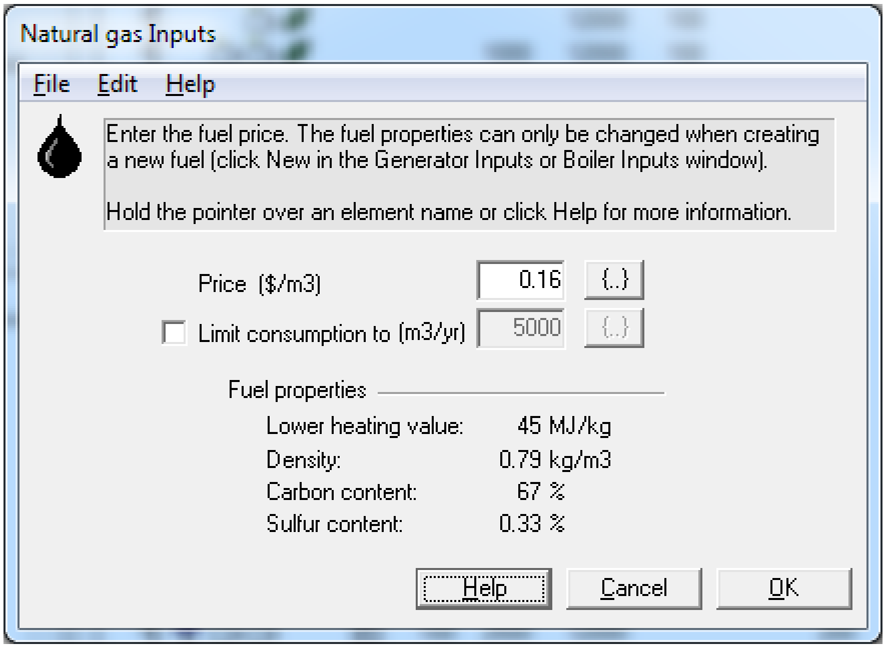


Figure 60: Natural Gas Fuel Inputs

Fuel Cell Fuel

A new fuel resource named “Fuel Cell Fuel” was created for the Fuel Cell component. Because its cost was carried by the O&M cost for this particular item, we defined a cost of $0/m3 for the fuel input. This is shown in Figure 61.

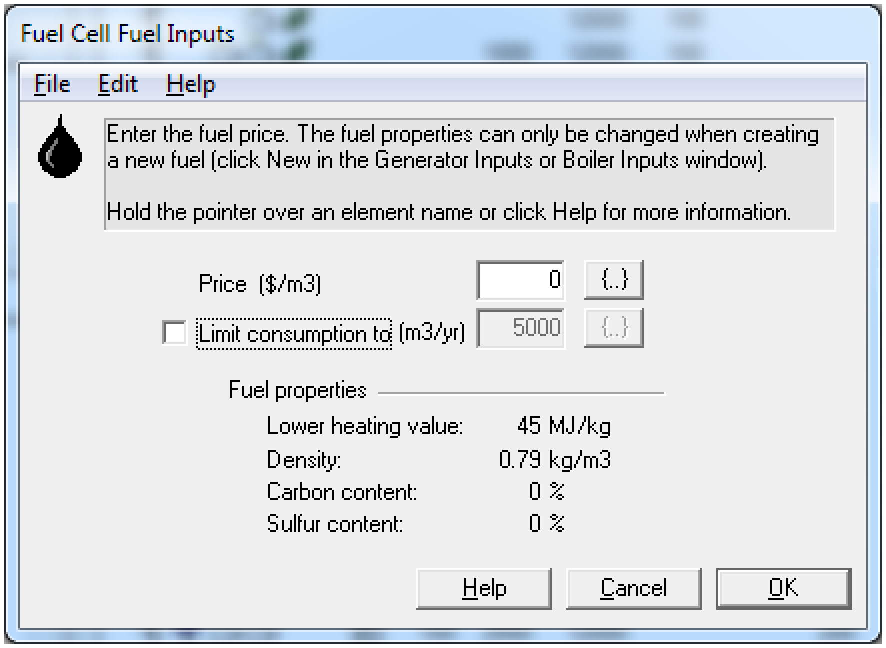


Figure 61: Fuel Cell Fuel Inputs

Economics

The Economics inputs are used for each system HOMER simulates, and is primarily used to calculate the system's NPC. We used an interest rate of 2.7% to model the average rate of inflation; if one was considering the feasibility of implementing a microgrid by obtaining a loan, this number would necessarily change. The project lifetime was set to 40 years in order to model the economic effects of replacing certain generation types, and in recognition of the long project lifetimes generally seen in infrastructure investments. All other costs were left as zero, as prior simulation demonstrated that these costs are simply added to each generation type. These inputs would be useful if the user was attempting to obtain an exact figure of the cost of investment, but we were mainly interested in comparative values between generation types. Figure 62 displays the Economic inputs.

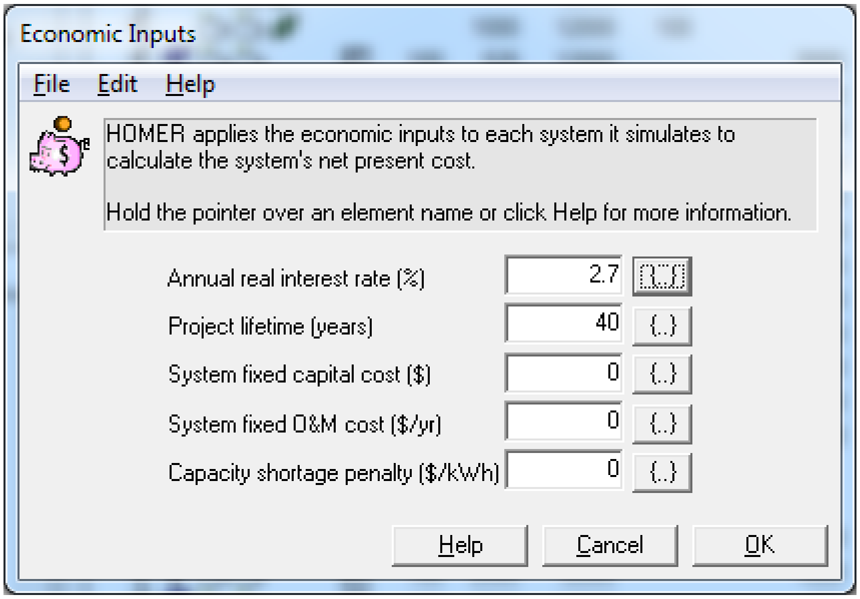


Figure 62: Economic Inputs

System Control

The System Control dialog defines the parameters HOMER uses during simulation, such as time step, dispatch strategy, and generator settings. The time step was set to 60 minutes in order to accurately average the 30 minute load intervals supplied by the school in terms of kWh. The dispatch strategy inputs generally refer to battery operation, and so were left as the default mode of load following. The generator control inputs were set to allow HOMER to consider all combinations of generator components. Figure 63 displays the System Control inputs.

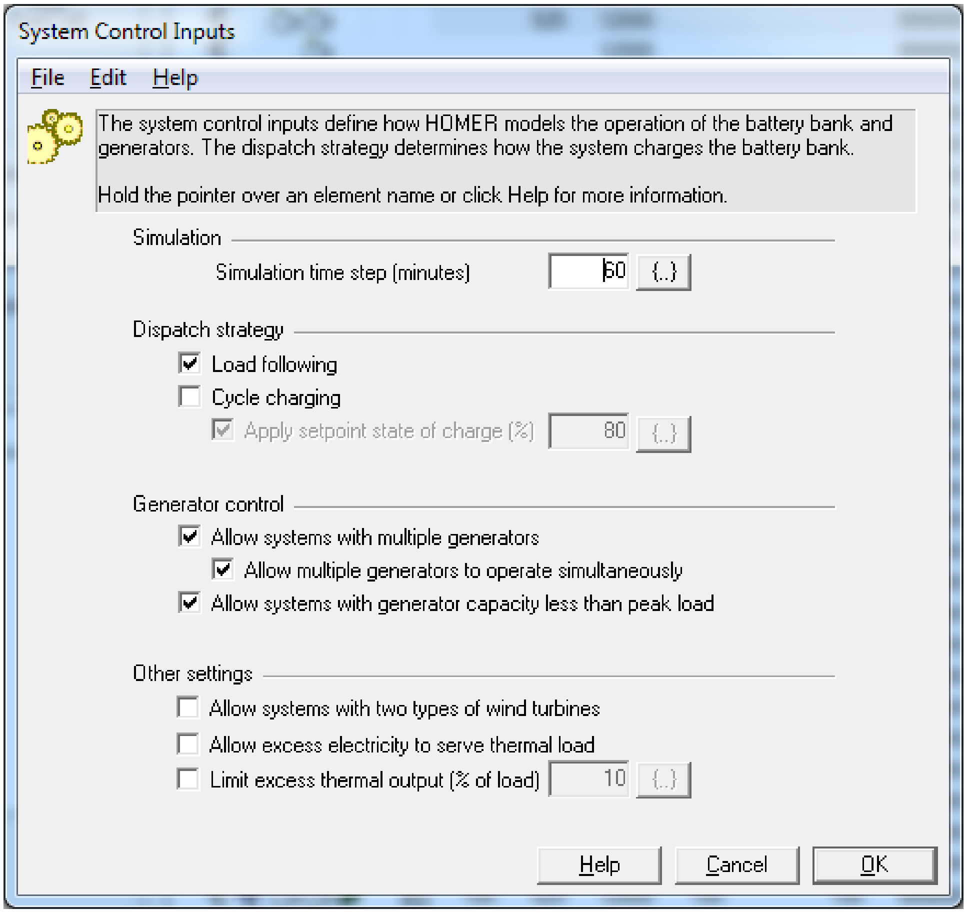


Figure 63: System Control Inputs

Emissions

The Emissions inputs allow the user to model scenarios in which economic penalties are assigned for various emissions; this can be useful to explore the effects of future environmental legislation on the system. Additionally, hard limits can be set for each emission. As this study does not consider the effect of emissions, all inputs were left as zero, as shown in Figure 64.

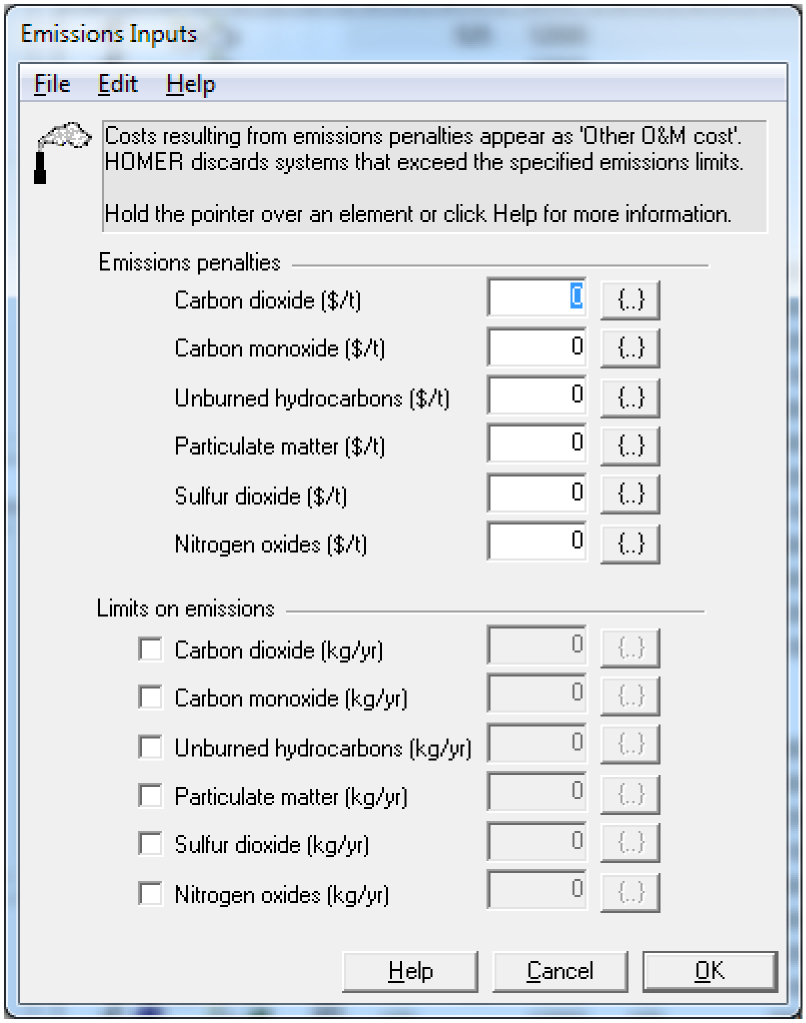


Figure 64: Emissions Inputs

Constraints

The final input category is that of Constraints. These inputs allow the user to define requirements a given system must meet in order to be considered feasible; infeasible systems are discounted by HOMER and are not shown in the results of the simulation. The only constraint relevant to this study is that of “maximum annual capacity shortage”. The input references the capacity shortage fraction, which is equal to the total capacity shortage divided by the total electrical demand (Lambert 2004).

Defining a maximum annual capacity shortage of 0% tells HOMER to ignore systems which at any time cannot meet the required load. This can hide many system results, including those which fail to meet a suddenly peaking load. As such, we also include in our sensitivity inputs the possibility of a percentage of 10%.

The operating reserve constraints are largely irrelevant for a system connected to the grid; if the generation capacity fails to meet a load, it can simply draw the required power from the grid. Primary energy savings are not included, as we want to see as many results as possible at this point. Figure 65 displays the Constraints inputs.

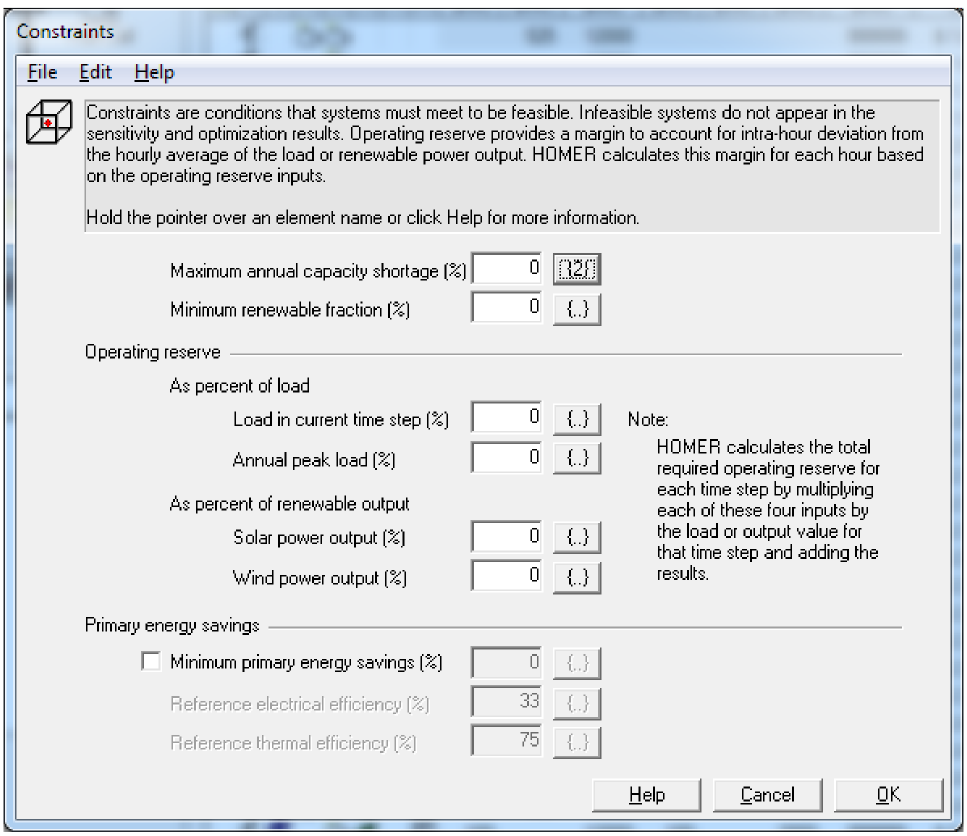


Figure 65: Constraints

Sensitivity

The sensitivity inputs are shown in Figure 66. Not that we have scaled the grid sellback rate from $0.00 to $0.07/kWh and the grid sales capacity from 0 to 20,000kW. This allows us to view how the ability and attractiveness of selling power back to the grid can affect the selection of the best system.

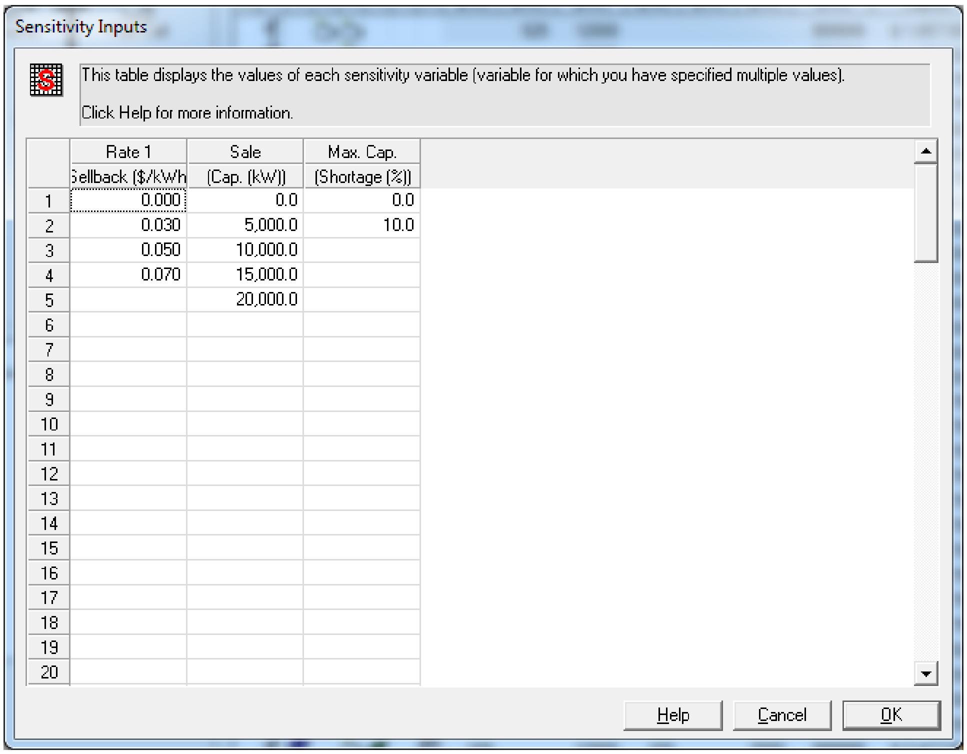


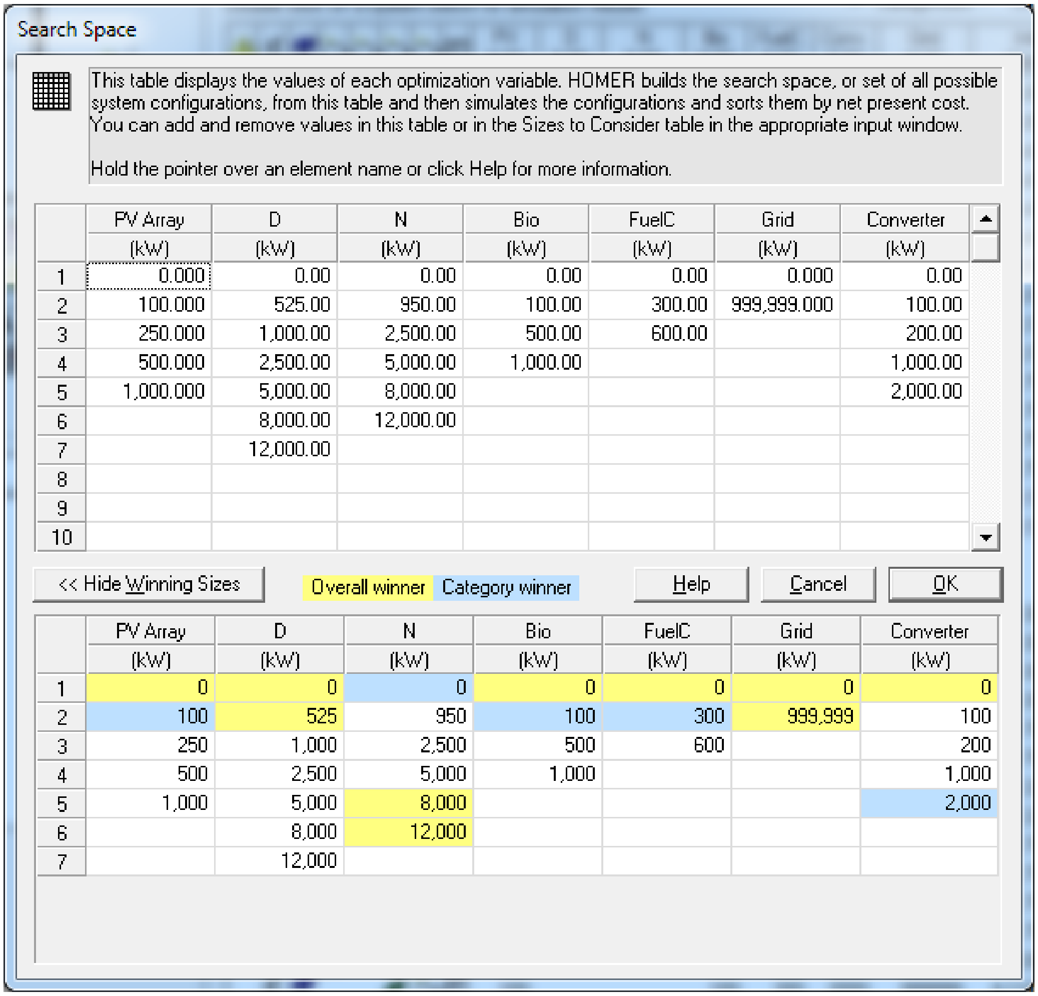
Figure 66: Sensitivity Inputs

CHAPTER 8

FORMULATION OF PROPOSED ACTION AND ALTERNATIVES

HOMER Results

After comparing 40 separate sensitivities with 25200 simulations each, HOMER displayed a categorized list of optimization results. These were determined via the search space, which included all component sizes. HOMER simulated the economic performance of the system for each combination of components and sizes, then determined the “winner” based on the lowest Net Present Cost within the established constraints. Figure 67 displays the search space and its winners. The total results of the simulation are found in Appendix I.



Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

Hold the pointer over an element name or click Help for more information.

	PV Array (kW)	D (kW)	N (kW)	Bio (kW)	FuelC (kW)	Grid (kW)	Converter (kW)
1	0.000	0.00	0.00	0.00	0.00	0.000	0.00
2	100.000	525.00	950.00	100.00	300.00	999,999.000	100.00
3	250.000	1,000.00	2,500.00	500.00	600.00		200.00
4	500.000	2,500.00	5,000.00	1,000.00			1,000.00
5	1,000.000	5,000.00	8,000.00				2,000.00
6		8,000.00	12,000.00				
7		12,000.00					
8							
9							
10							

<< Hide Winning Sizes | Overall winner | Category winner | Help | Cancel | OK

	PV Array (kW)	D (kW)	N (kW)	Bio (kW)	FuelC (kW)	Grid (kW)	Converter (kW)
1	0	0	0	0	0	0	0
2	100	525	950	100	300	999,999	100
3	250	1,000	2,500	500	600		200
4	500	2,500	5,000	1,000			1,000
5	1,000	5,000	8,000				2,000
6		8,000	12,000				
7		12,000					

Figure 67: Analysis Search Space

Formulation of Alternatives

The results obtained from the HOMER simulation allow for the analysis of many situations. All the variations and combinations of inputs can be sorted in such a way that the user can identify which configuration is best for a specific situation. For this research, it was decided that recommended actions and alternatives could be formulated on the basis of components used. That is, the effect of adding each generation technology was simulated, optimized for economic performance, and sorted according to least NPC. These results are presented below.

No Action Alternative

The “No Action Alternative” models the performance of a grid-only system; that is, the performance of the system without the implementation of a microgrid or any generation sources. A total NPC of $241,133,072 was calculated for a lifetime of 40 years, with an annual operating cost of $6,028,327/yr. This can be considered a reference configuration when comparing the other alternatives and their configurations.

Alternative 1 (Recommended Action): Use of Existing Generators

It was found that the combination of equipment with the lowest NPC over 40 years was that of the system utilizing only diesel and natural gas generators. However, when looking at the system, it is seen that HOMER determined that it was more economical to run the natural gas generators at full capacity, while the diesel generators were unused.

As expected, NPC significantly decreased with increased sellback rates and sale capacity, as the ability to sell excess power to the grid offset total operation costs.

Figure 68 displays the optimized system NPC as a function sales capacity and sellback rate. This demonstrates that with increased grid sales capacity, total NPC is inversely related to the sellback rate.

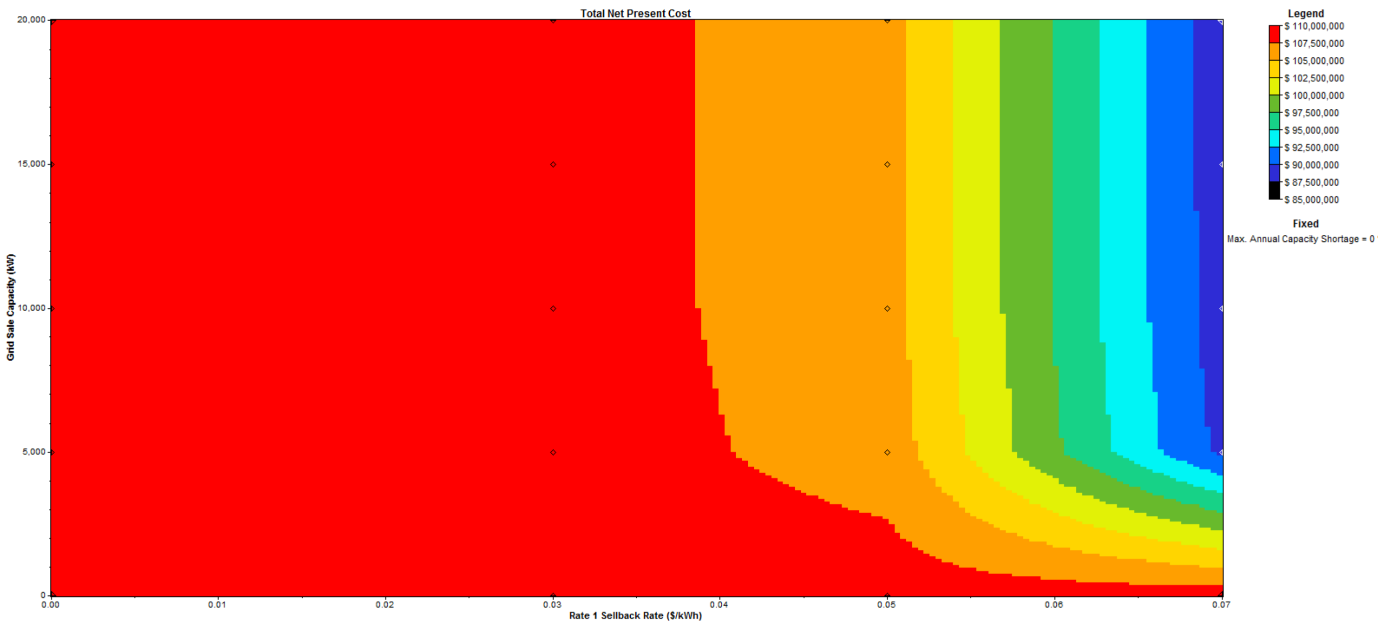


Figure 68: NPC with respect to Grid Sale Capacity vs. Sellback Rate

Similarly, Figure 69 displays the net grid purchases as a function of capacity and sellback rate. These values range from negative to positive, with negative grid purchases representing grid sales. Interestingly, we see that HOMER found it optimal to export more power to the grid than it imported when sellback rates were about $0.032 or greater. This can be considered to be the minimum rate to make sellback to the utility worthwhile.

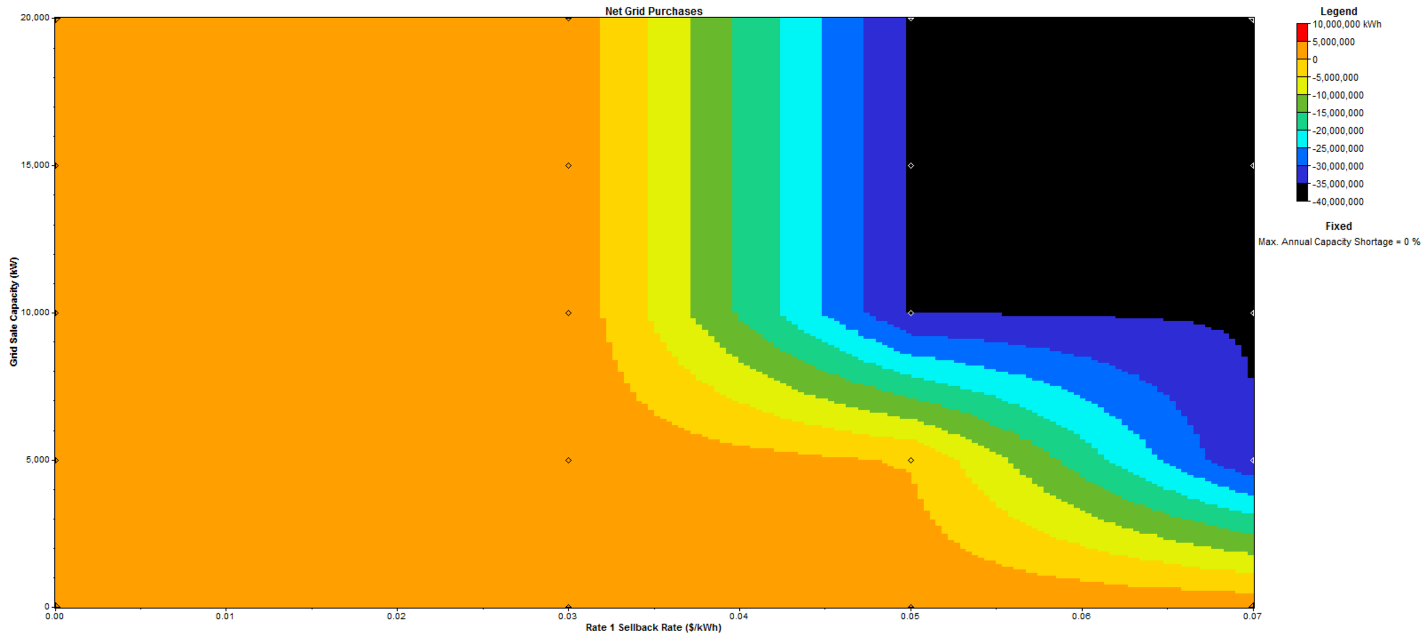


Figure 69: Net Grid Purchases with respect to Grid Sale Capacity vs. Sellback Rate

The relationships defined in these charts point to an optimized system that sells power back to the grid. As a result of the attractive price of natural gas, HOMER chose to increase natural gas generator capacity to 8000kW if the system was unable to sell back to the grid, and 12000kW if grid sales were allowed. This implies that if Georgia Southern were to implement a microgrid and increase its generating capacity, it should maximize and increase the use of natural gas generators with respect to all other generation sources- contingent, of course, to future price variations.

Maximizing the natural gas generation capacity would require an initial capital of $3,379,750. If we use a moderate sellback rate of $0.05/kWh, this system exhibits a total NPC of $172,955,344 over 40 years, with an operating cost of about $4,239,415/yr. When compared to the No Action Alternative it is seen that the savings are substantial, with an annual savings of $1,704,443/yr, total PW of $68,177,736 and simple payback of 1.4 years. Figure 70 displays the cumulative cash flow of Alternative 1 compared to that of the base case, the No Action Alternative.

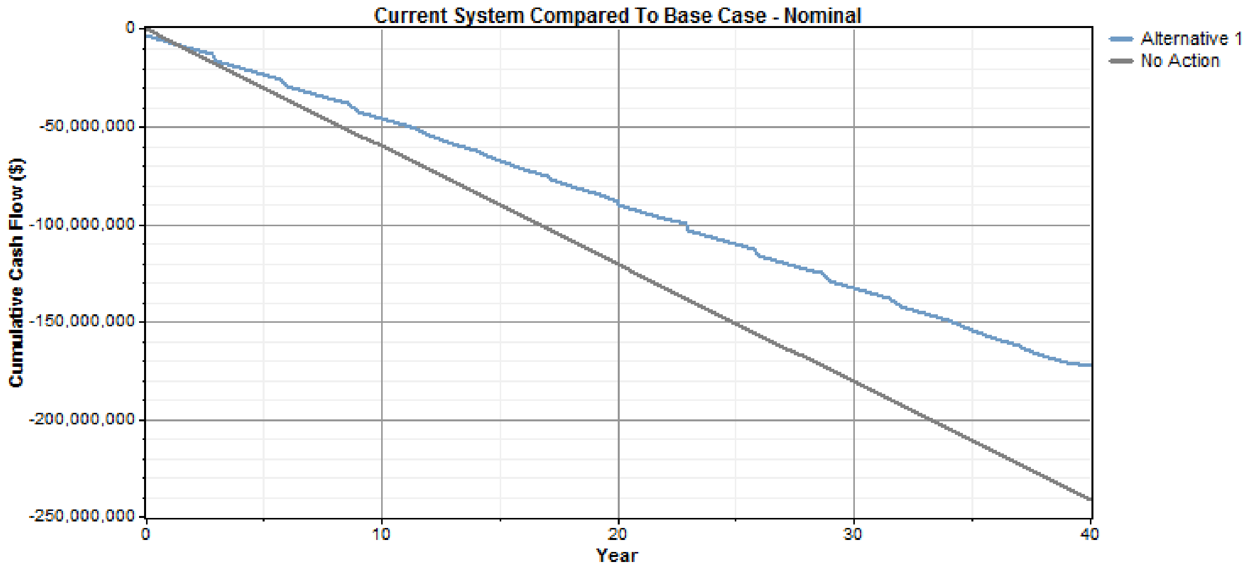


Figure 70: Alternative 1 vs. No Action

Alternative 2: Construction of Power Plant

The high performance of maximized natural gas generator capacity led to the consideration of implementing a power plant for the campus- one that could supply all or most of the required load. This concept has been explored in the past by campus engineers as a way to meet future growth and potentially reduce energy costs, although the high cost of investment- close to $20M- discouraged any further progress. Still, the very attractive economic performance observed in this simulation warrants the inclusion of the idea as the second-best alternative.

The economic feasibility of a power plant is highly dependent on the price of different energy sources. Specifically, the cost of natural gas must be at a suitably low level to warrant the use of a power plant instead of the existing natural gas generators.

The cost of drawing power from the grid can also have an effect. This relationship is shown in Figure 71.

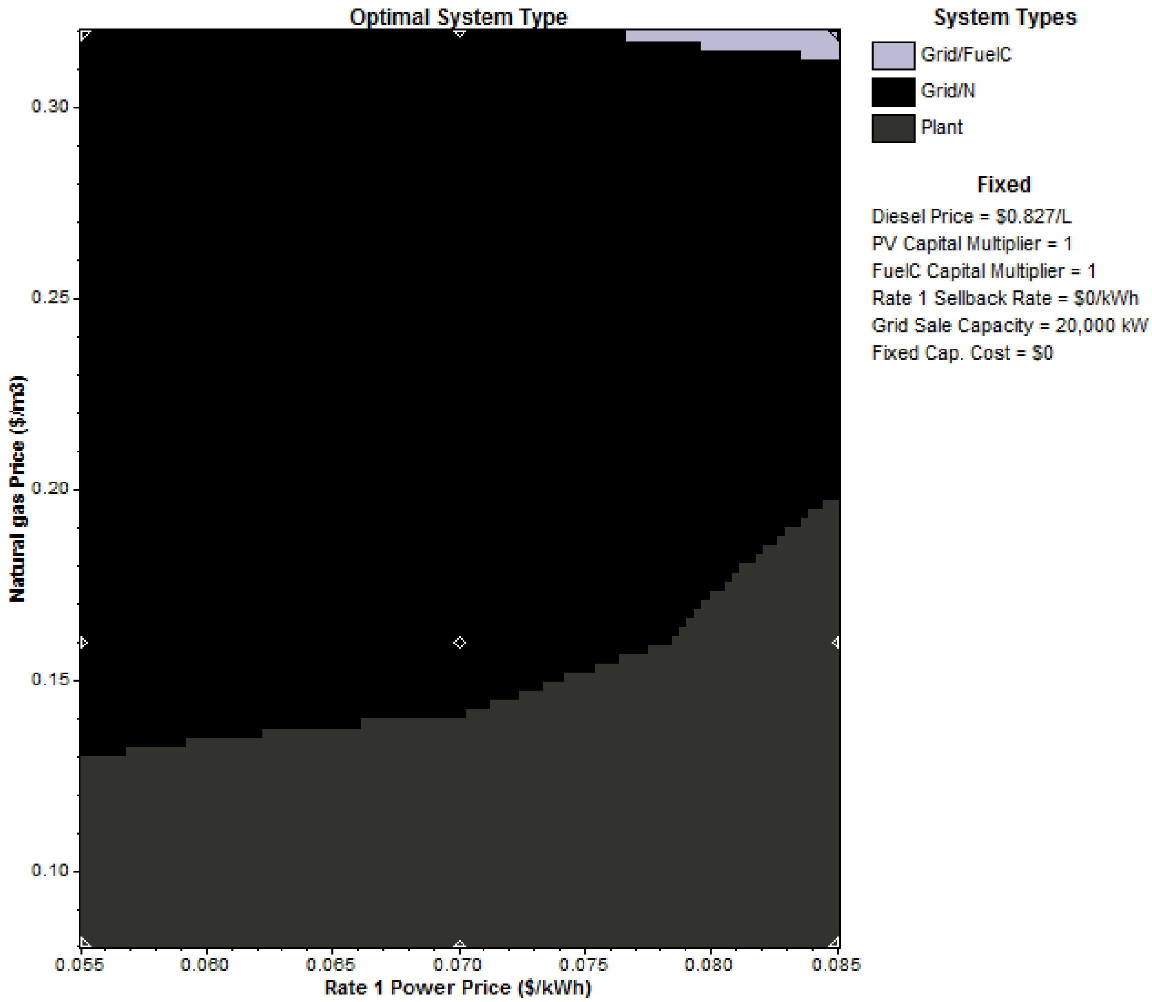


Figure 71: Optimal System Type with respect to Natural Gas Price and Power Price

Similarly, the ability to sell power back to the grid has an effect on the feasibility of using a power plant as a resource. In general, higher sellback rates increase the attractiveness of a power plant until natural gas prices cross a threshold of about $0.30/m3. This relationship is shown in Figure 72.

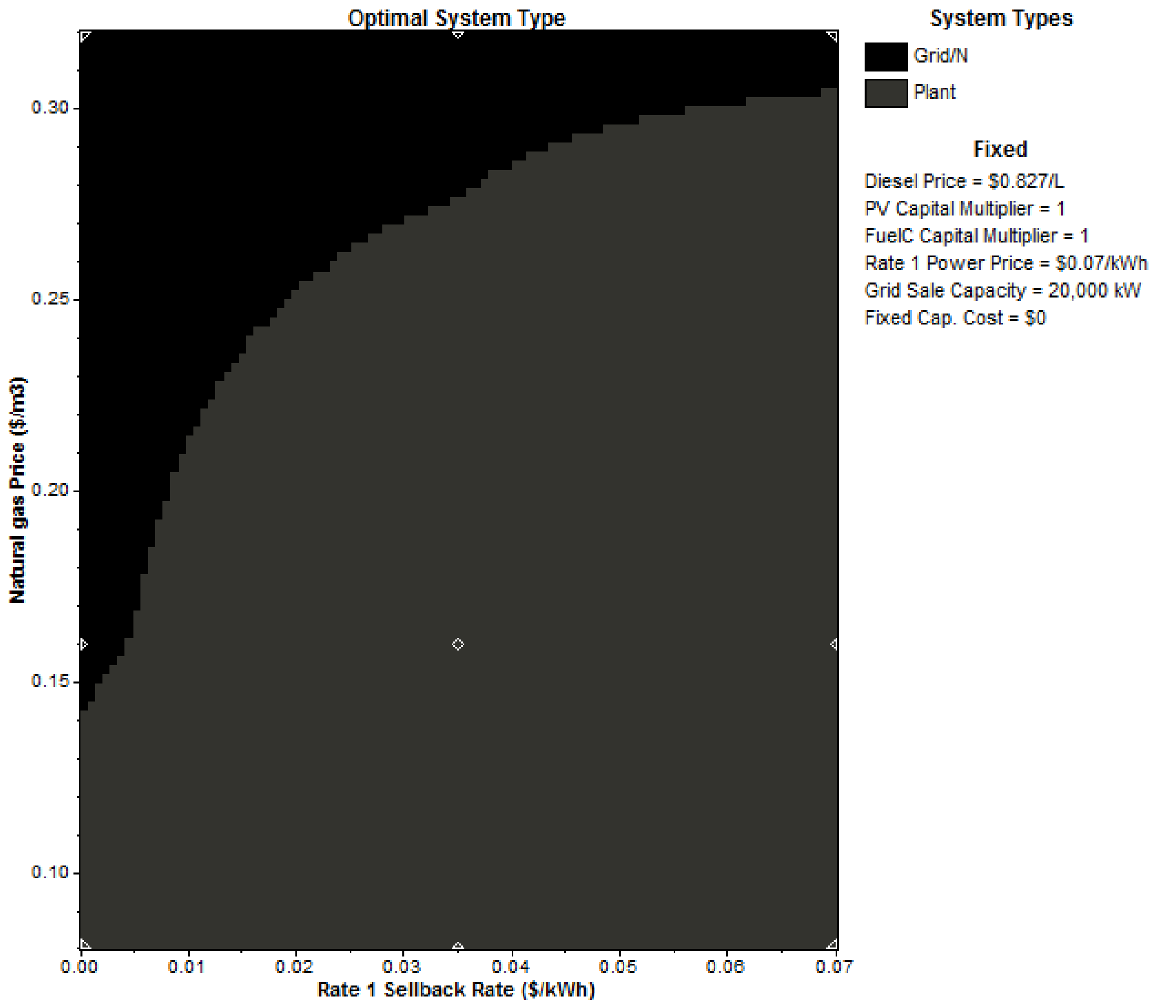


Figure 72: Optimal System Type with respect to Natural Gas Price and Sellback Rate

If no sellback is allowed, a system powered by a natural gas plant exhibits a total benefit of $21,039,828 over the No Action Alternative over 40 years, or $866,622/yr. A discounted payback of 13.3 years is also observed. The cash flow of Alternative 2 versus the No Action Alternative is shown in Figure 73.

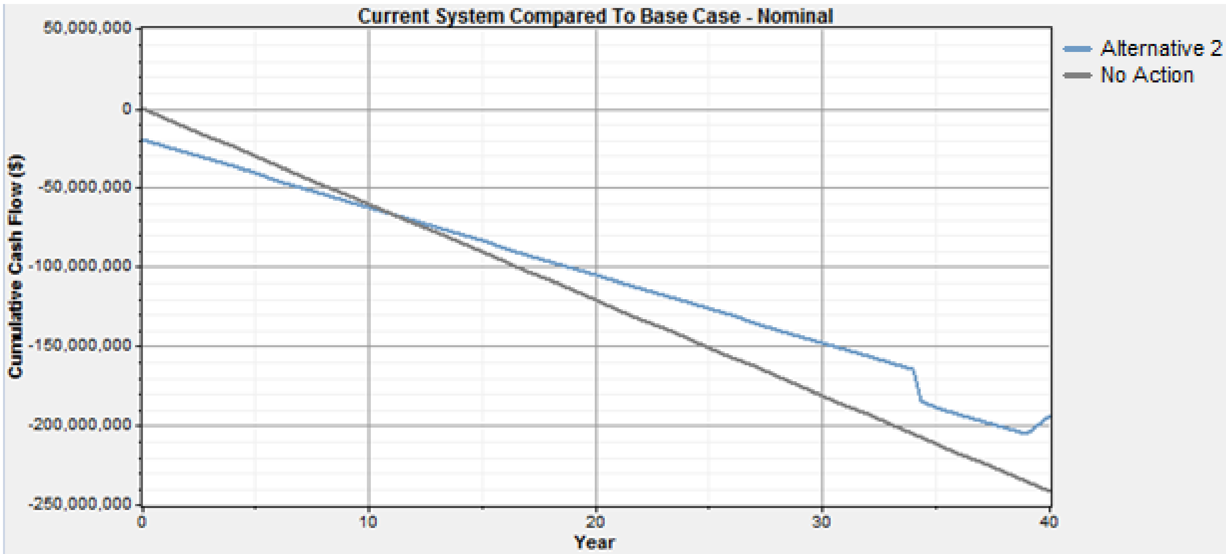


Figure 73: Cash Flow of Alternative 2 vs. No Action (Sellback Disallowed)

If sellback is allowed at the moderate rate of $0.05/kWh, the benefit increases to $61,414,088, or $2,529,621/yr, with a discounted payback period of 6.26 years. The cash flow for this situation is shown in Figure 74.

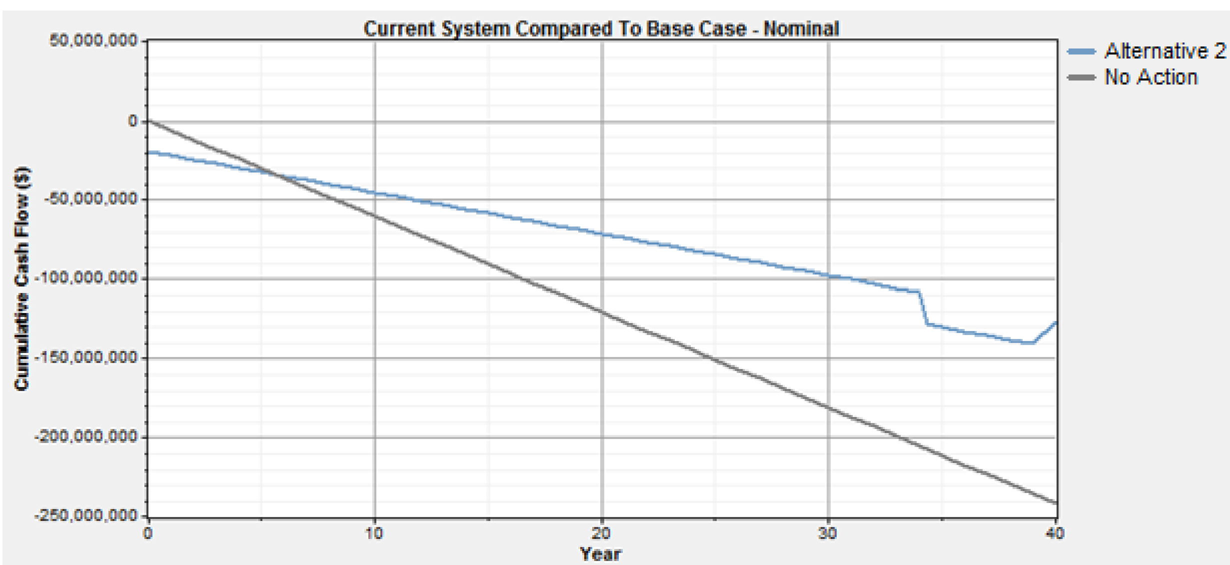


Figure 74: Cash Flow of Alternative 2 vs. No Action (Sellback Allowed)

Alternative 3: Addition of Solar Photovoltaics

Alternative 3 expands on Alternative 1 by adding photovoltaic generation. Although it has been established that there is not much available solar resource to drive this capacity, it can be considered attractive if the goal is to add renewable capacity to the system. However, the use of PV generation seems only economically attractive when acting as a supplement to other generation type; no combination of sensitivity values result in PV as the singular optimal system type. This is likely due to its limited capacity and effective efficiency. As such, its appropriateness even as a supplemental generation source is dependent on its price as well as sensitivities that affect the primary generator.

By comparing changes in natural gas prices and the PV capital multiplier, we see that it is not economically useful to add PV to the existing natural gas fired generators unless natural gas prices are over $0.14/m3 and the cost of PV has decreased by over 30%, as shown in Figure 75. Other combinations are dependent on the cost of natural gas.

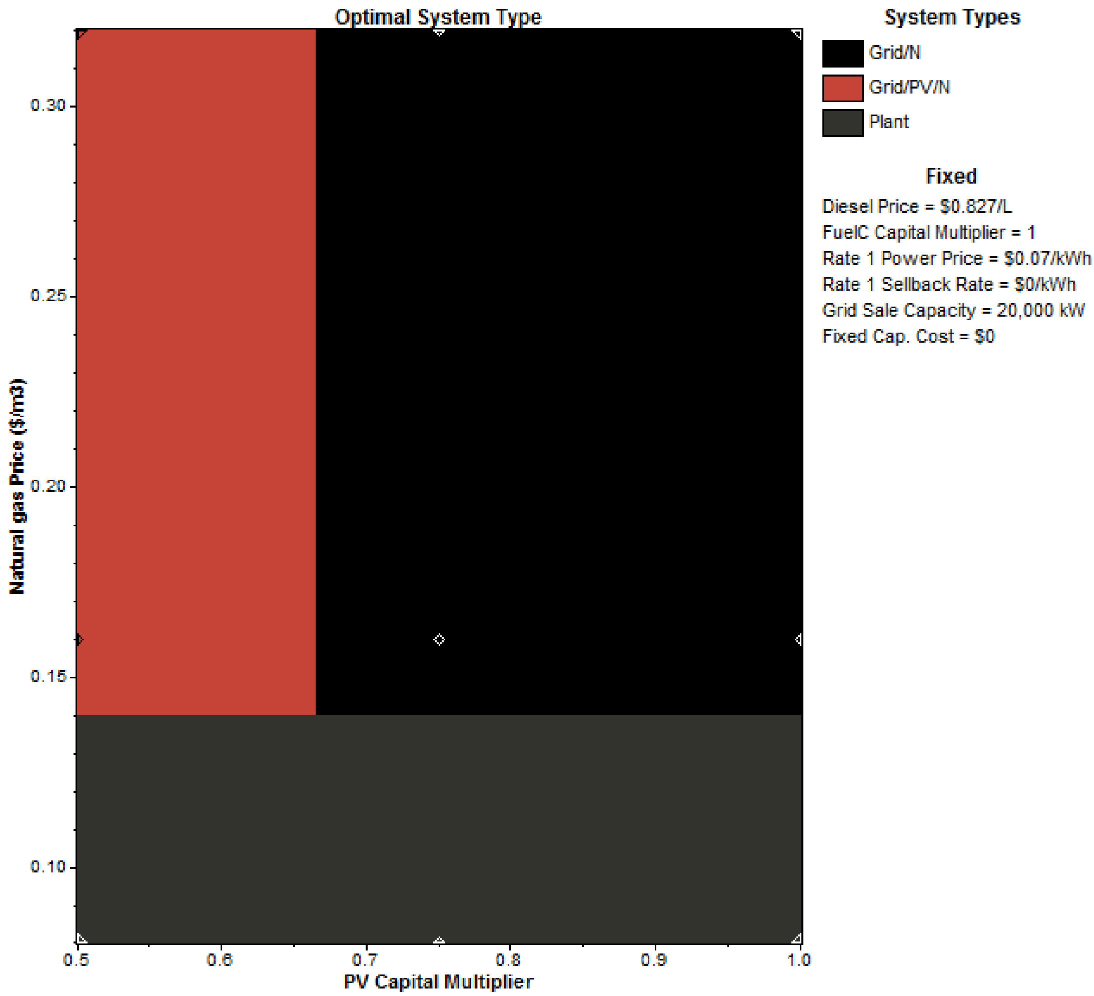


Figure 75: Optimal System Type with respect to Natural Gas Price and PV Capital Multiplier

If the PV generation type is isolated and compared to the No Action Alternative, we see a total NW of -$123,040 and -$3,076/yr, signifying that it would cost more than a grid-only system. Because it would never recover its cost, there is no associated payback period.

Alternative 4: Additional of Fuel Cell

The generation of electricity via fuel cell is not as attractive as other sources, but could still be considered for use as a high-capacity renewable energy source if the goal was to increase renewable penetration. The implementation of a 600kW fuel cell system would require an initial capital of about $2,230,000. By setting the natural gas price to the y-axis and fuel cell capital cost multiplier to the x-axis, we can see that the generation of electricity via fuel cell does not become economically feasible with respect to other generation choices until natural gas prices increase to over $0.30/m3 and fuel cell costs decrease by almost 15%, as shown in Figure 76. Differences in grid sellback rate and sale capacity have no effect on the feasibility of fuel cell generation.

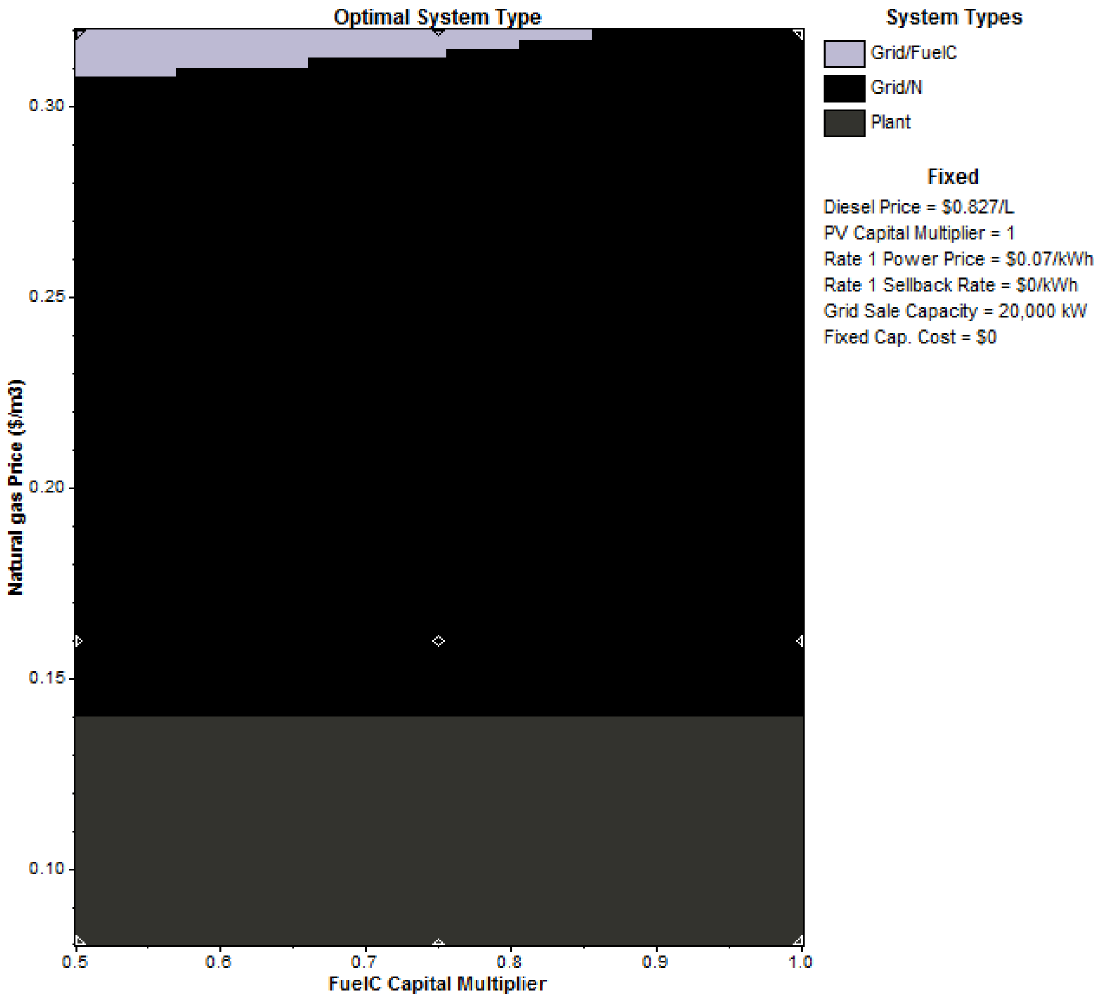


Figure 76: Optimal System Type with respect to Natural Gas Price and Fuel Cell Capital Multiplier

When compared to the base case, a fuel cell generation system whose cost has decreased by 25% could save $1,059,507 over 40 years, or $43,641 per year. This translates into a payback period of 13.9 years.

Alternative 5: Addition of Biopower

At no point is biofuel-powered generation listed as an optimal system. This is not unexpected, due its status as a very novel technology; as the technology matures, prices are likely to decrease and economic efficiency increase. With current values, however, a 100 kW biopower plant exhibits a total NPW of -$15,200 when compared to a grid-only system, and an annual worth of -$380 per year. However, this is not too poor of a performance considering the scale of the analysis; as such, biopower can be considered a plausible alternative for integration into a microgrid, and will likely become more attractive in the coming years. The fact that Georgia Southern has already produced extensive research in this field makes it all the more appealing.

Future Case Considerations

While the Recommended Action and Alternatives described in the previous section can be used to determine the best combination of generation sources to implement according to various costs, they do not consider the effect of increased future load requirements.

Implementing increased future load is relatively simple in HOMER: in our case, additional sensitivity values ranging from 190,378 to 266,000 (kWh/d) are added in the "Scaled annual average" input. The upper limit of 266,000 was selected on the admittedly rough estimate of average daily energy usage increasing by 1% per year of the analysis. Because this data is scaled, it retains the shape and statistical characteristics of the baseline data, but differs in magnitude (Lambert 2004). In this way we are able to determine the best generation source or combination of sources as the load requirement grows. Because a microgrid system can add distributed generation as needed, this data can be considered a "roadmap" of which generation sources to add as the system grows.

Figure 77 displays the optimal system type when changes in load and changes in sellback rate are considered. We see that the Proposed Action is optimal with the current required load as well as all future load requirements as the sellback rate approaches about $0.05/kWh. With sellback rates below this value, however, different generation types are added. Note that Alternative 2 is not considered, as a power plant would supply all required loads by definition.

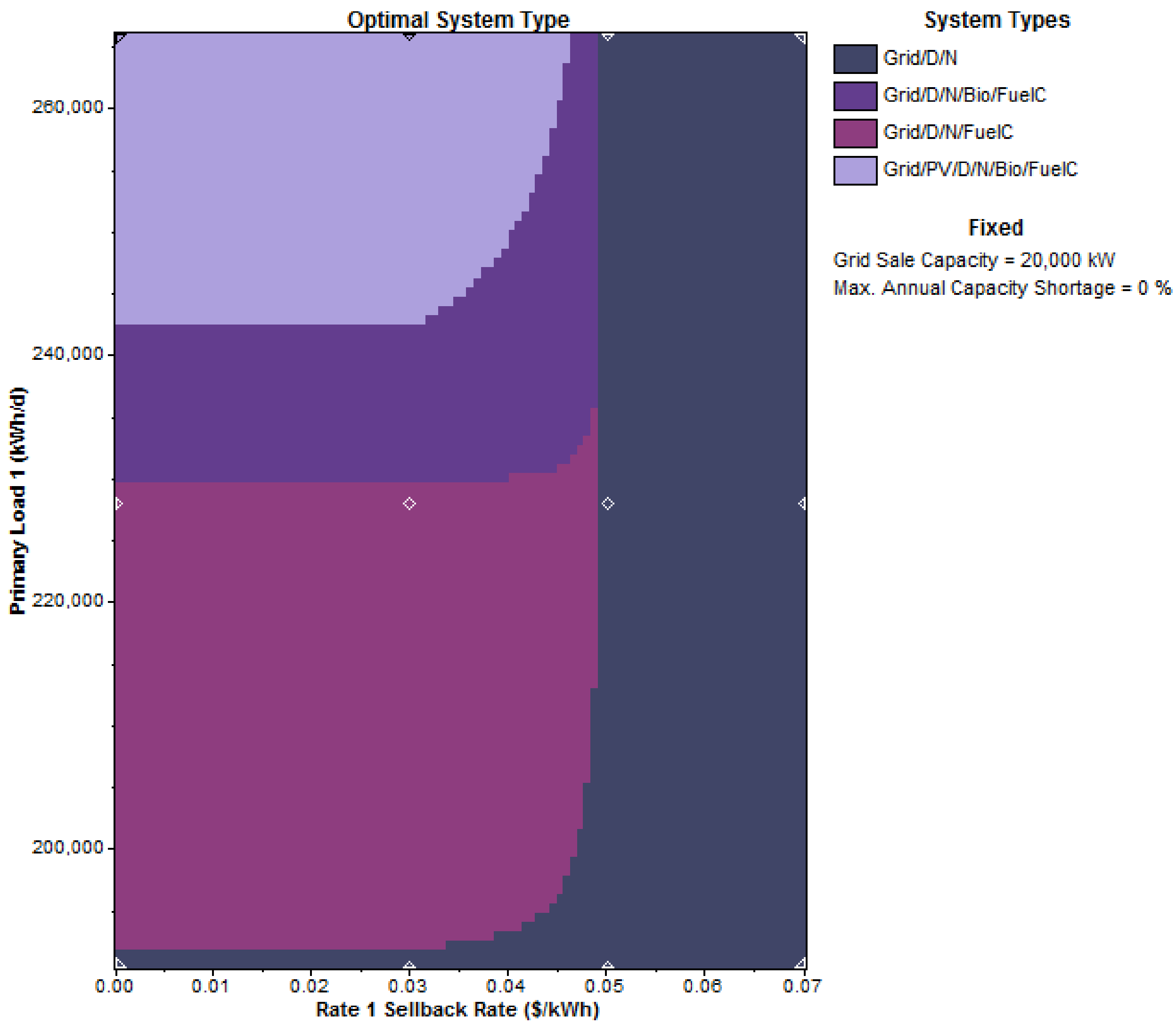


Figure 77: Optimal System Type with Respect to Primary Load and Sellback Rate

We can consider this data in terms of the Alternatives developed. That is, if sellback rate remains below $0.05/kWh, equipment prices remain unchanged, and required load increases marginally, Alternative 4 should be implemented by adding fuel cell generation capacity. If the required load increases to above 230,000 kWh/d, Alternative 5's biopower should be added to supply the additional load. Lastly, the solar photovoltaic capacity of Alternative 3 should be added if the required load increases to above about 242,000 kWh/d.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

After considering the technical requirements of implementing a microgrid and simulating the economic performance of such a system, it was determined that implementing a microgrid could benefit Georgia Southern University and that it could be considered feasible to do so.

The current power delivery system at Georgia Southern University is modernized to the point where implementing a microgrid would be relatively simple. Its current topography lends itself well to conversion to a microgrid, and it was shown that a microgrid could satisfy the current and future requirements of the campus. The existence of backup generators further increases the attractiveness of converting the system to a microgrid.

Multiple generations sources were found to be appropriate for use in a potential microgrid at GSU, and analysis via HOMER identified the parameters at which a specific generation source would be more feasible than the others, in terms of electrical and economic performance. This data was used to develop a Recommended Action and its Alternatives, as well as which alternatives should have priority for implementation with increasing load requirements.

Limitations

The results of the HOMER simulation are highly dependent upon the accuracy of the assumptions made; in this case, all assumptions were “best-case” scenarios, and therefore the results obtained should be considered to be an upper limit. Furthermore, many of the inputs were modeled as static values, not fluctuating throughout the simulation period as they would in reality. This is especially significant for the grid electricity rate and fuel cost. This simulation determined that the natural gas generators exhibited superior performance to the other generation types; this could easily change with changing fuel prices or availability. Likewise, any change to the costs to install and operate other generation types would likely change the results. Because of the many assumptions made, the information presented in the HOMER model should not be taken to be representative of the true performance of a microgrid at Georgia Southern.

Additionally, while the costs of interconnection were included in the capital costs for each generation source, they did not include the indirect costs of adding or replacing certain electrical components that must be matched to the capacity of the system. Moreover, the costs of additional communication and control systems were not considered. These costs would have to be considered if a microgrid were to be considered beyond the feasibility stage.

Future Work

If the University ever does consider actively pursuing a microgrid, the model developed in HOMER can be reapplied with updated information and realistic constraints. Additional cost savings, such as the cost of outages and disturbances, could be used in an external economic analysis. These costs are briefly considered in Appendix II.

Additionally, long-term load forecasting could be employed to obtain a more accurate value to use in the HOMER model. Unfortunately, long-term forecasting, whether through parametric or artificial intelligence methods, are inaccurate by nature, as they cannot account for future weather conditions or economic data, regardless of the volume of historical data employed (Ghods and Kalantar 2011). As it is, current models are only used for eight to fifteen year spans, and so could not be used for the 40-year lifespan of the microgrid considered in the HOMER model; however, they could be useful in the design phase of a microgrid.

The effects of environmental pollution were not considered in this research, although HOMER does offer flexible methods to design a microgrid according to environmental concerns. Future research may wish to consider setting constraints on total system emissions; this may be especially useful in the case of potential increases in carbon taxes and other penalties for emissions. HOMER does allow the user to set penalties for various emissions in terms of dollars per ton, so this would be relatively simple to implement.

Microgrids are considered by many to be the future of electrical power delivery, and will likely shape future transmission and distribution practices in coming years. As a leading academic institution, Georgia Southern University would stand to benefit from the increased exposure gained as an early adopter. Although it would require substantial investment and design work to realize such a system, the potential benefits and economic payback warrant its consideration.

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APPENDICES

Appendix I: HOMER Results

Inputs

File name: everything.hmr

File version: 2.81

Author:

AC Load: Primary Load 1

Data source: Load.txt

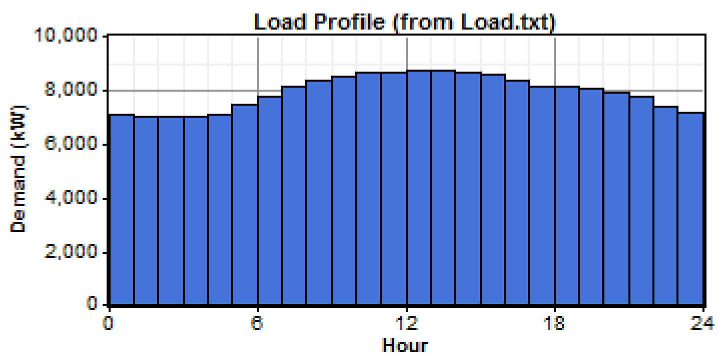
Daily noise: 8.65%

Hourly noise: 4.06%

Scaled annual average: 190,378 kWh/d

Scaled peak load: 11,805 kW

Load factor: 0.672



PV

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	3,800	2,800	20
100.000	380,000	280,000	2,000
250.000	950,000	700,000	5,000
500.000	1,900,000	1,400,000	10,000
1,000.000	3,800,000	2,800,000	20,000

Sizes to consider: 0, 100, 250, 500, 1,000 kW

Lifetime: 20 yr

Derating factor: 80%

Tracking system: No Tracking

Slope: 32.7 deg

Azimuth: 0 deg

Ground reflectance: 20%

Solar Resource

Latitude: 32 degrees 44 minutes North

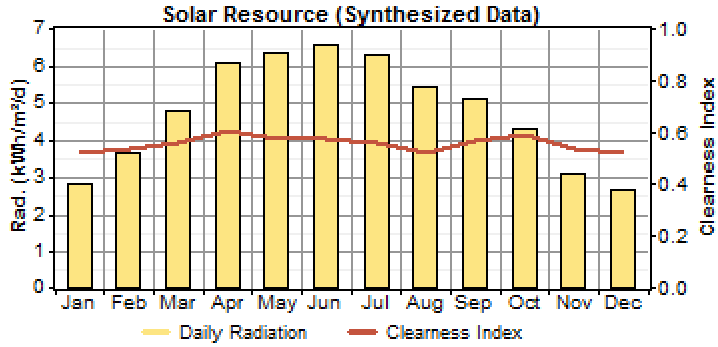
Longitude: 81 degrees 59 minutes West

Time zone: GMT -5:00

Data source: Synthetic

Month	Clearness Index	Average Radiation
		($kWh/m^2/day$)
Jan	0.516	2.820
Feb	0.536	3.620
Mar	0.561	4.750
Apr	0.605	6.100
May	0.572	6.360
Jun	0.572	6.570
Jul	0.558	6.290
Aug	0.519	5.410
Sep	0.564	5.080
Oct	0.589	4.270
Nov	0.536	3.080
Dec	0.522	2.640

Scaled annual average: 4.75 $kWh/m^2/d$



AC Generator: Diesel

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1.000	150	175	0.010
525.000	0	91,875	5.250
1,000.000	71,250	175,000	10.000
2,500.000	296,250	437,500	25.000
5,000.000	671,250	875,000	50.000
12,000.000	1,721,250	2,100,000	120.000

Sizes to consider: 0, 525, 1,000, 2,500, 5,000, 8,000, 12,000 kW

Lifetime: 25,000 hrs

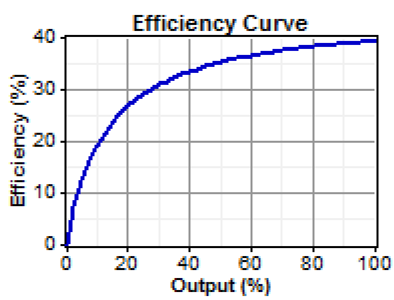
Min. load ratio: 30%

Heat recovery ratio: 0%

Fuel used: Diesel

Fuel curve intercept: 0.03 L/hr/kW

Fuel curve slope: 0.228 L/hr/kW



AC Generator: Natural Gas

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)

1.000	150	175	0.010
950.000	0	166,250	9.500
2,500.000	232,500	437,500	25.000
5,000.000	607,500	875,000	50.000
12,000.000	1,657,500	2,100,000	120.000

Sizes to consider: 0, 950, 2,500, 5,000, 8,000, 12,000 kW

Lifetime: 25,000 hrs

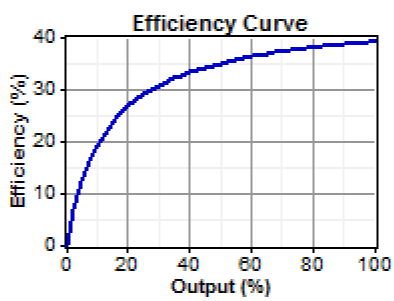
Min. load ratio: 30%

Heat recovery ratio: 0%

Fuel used: Natural gas

Fuel curve intercept: 0.03 L/hr/kW

Fuel curve slope: 0.228 L/hr/kW



AC Generator: Biofuel

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1.000	3,800	3,800	0.005
100.000	380,000	380,000	0.460
500.000	1,900,000	1,900,000	2.300
1,000.000	3,800,000	3,800,000	4.600

Sizes to consider: 0, 100, 500, 1,000 kW

Lifetime: 25,000 hrs

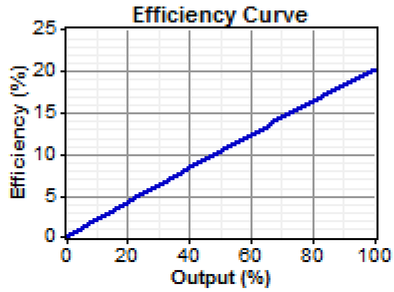
Min. load ratio: 30%

Heat recovery ratio: 0%

Fuel used: Biomass

Fuel curve intercept: 1 L/hr/kW

Fuel curve slope: 0.05 L/hr/kW



DC Generator: Fuel Cell

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1.000	4,400	4,400	0.046
300.000	1,320,000	1,320,000	13.800
600.000	2,640,000	2,640,000	27.600

Sizes to consider: 0, 300, 600 kW

Lifetime: 175,200 hrs

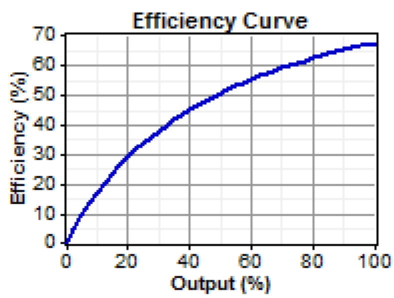
Min. load ratio: 0%

Heat recovery ratio: 0%

Fuel used: Fuel Cell Fuel

Fuel curve intercept: 0.05 L/hr/kW

Fuel curve slope: 0.1 L/hr/kW



Fuel: Diesel

Price: $ 0.827/L

Lower heating value: 43.2 MJ/kg

Density: 820 kg/m3

Carbon content: 88.0%

Sulfur content: 0.330%

Fuel: Natural gas

Price: $ 0.16/m3

Lower heating value: 45.0 MJ/kg

Density: 0.790 kg/m3

Carbon content: 67.0%

Sulfur content: 0.330%

Fuel: Fuel Cell Fuel

Price: $ 0/m3

Lower heating value: 45.0 MJ/kg

Density: 0.790 kg/m3

Carbon content: 0.00%

Sulfur content: 0.00%

Biomass Resource

Data source: Synthetic

Month	Available Biomass (tonnes/day)
Jan	776,542
Feb	776,542
Mar	776,542
Apr	776,542
May	776,542
Jun	776,542
Jul	776,542
Aug	776,542
Sep	776,542
Oct	776,542
Nov	776,542
Dec	776,542

Scaled annual average: 776,571 t/d

Average price:	$ 50/t
Carbon content:	5%
Gasification ratio:	0.75 kg gas/kg biomass
LHV of biogas:	17 MJ/kg

Converter

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	0	0	0
100.000	0	0	0
200.000	0	0	0
1,000.000	0	0	0
2,000.000	0	0	0

Sizes to consider:	0, 100, 200, 1,000, 2,000 kW
Lifetime:	20 yr
Inverter efficiency:	95%
Inverter can parallel with AC generator:	Yes
Rectifier relative capacity:	100%
Rectifier efficiency:	85%

Grid

Rate	Power Price	Sellback Rate	Demand Rate	Applicable
	$/kWh	$/kWh	$/kW/mo.	
Rate 1	0.07	0.00, 0.03, 0.05, 0.07	9.56	Jan-Dec All week 00:00-24:00

CO2 emissions factor:	632 g/kWh
CO emissions factor:	0 g/kWh
UHC emissions factor:	0 g/kWh
PM emissions factor:	0 g/kWh
SO2 emissions factor:	2.74 g/kWh
NOx emissions factor:	1.34 g/kWh
Interconnection cost:	$ 0
Standby charge:	$ 0/yr
Purchase capacity:	0, 999,999 kW

Sale capacity: 0, 5,000, 10,000, 15,000, 20,000 kW

Economics

Annual real interest rate: 2.7%

Project lifetime: 40 yr

Capacity shortage penalty: $ 0/kWh

System fixed capital cost: $ 0

System fixed O&M cost: $ 0/yr

Generator control

Check load following: Yes

Check cycle charging: No

Allow systems with multiple generators: Yes

Allow multiple generators to operate simultaneously: Yes

Allow systems with generator capacity less than peak load: Yes

Emissions

Carbon dioxide penalty: $ 0/t

Carbon monoxide penalty: $ 0/t

Unburned hydrocarbons penalty: $ 0/t

Particulate matter penalty: $ 0/t

Sulfur dioxide penalty: $ 0/t

Nitrogen oxides penalty: $ 0/t

Constraints

Maximum annual capacity shortage: 0, 10%

Minimum renewable fraction: 0%

Operating reserve as percentage of hourly load: 0%

Operating reserve as percentage of peak load: 0%

Operating reserve as percentage of solar power output: 0%

Operating reserve as percentage of wind power output: 0%

PV (kW) D (kW) N (kW) Bio (kW) FuelC (kW) Converter Grid (kW) Initial capital Operating Total NPC COE ($/kW Renewable Capacity shDiesel
(L) Natural gas (m Fuel Cell FuBiomass (t) D (hrs) N (hrs) Bio (hrs) FuelC (hrs)

	525	8000			999999	$1,057,500	4,434,931	$108,728,664	0.064	0	0	17,077,274	0	8,722	
		8000			999999	$1,057,500	4,436,182	$108,759,048	0.064	0	0	17,077,274		8,722	
	1000	8000			999999	$1,128,750	4,433,799	$108,772,424	0.064	0	0	17,077,274	0	8,722	
	2500	8000			999999	$1,353,750	4,430,222	$108,910,600	0.065	0	0	17,077,274	0	8,722	
	525	8000	100		999999	$1,437,500	4,429,754	$108,982,984	0.065	0	0	17,077,274	0	8,722	0
100	525	8000		2000	999999	$1,437,500	4,430,040	$108,989,928	0.065	0	0	17,067,184	0	8,722	
100	525	8000		1000	999999	$1,437,500	4,430,040	$108,989,928	0.065	0	0	17,067,184	0	8,722	
100	525	8000		200	999999	$1,437,500	4,430,040	$108,989,928	0.065	0	0	17,067,184	0	8,722	
100	525	8000		100	999999	$1,437,500	4,430,040	$108,989,928	0.065	0	0	17,067,184	0	8,722	
		8000	100		999999	$1,437,500	4,431,006	$109,013,368	0.065	0	0	17,077,274		8,722	0
100		8000		2000	999999	$1,437,500	4,431,292	$109,020,312	0.065	0	0	17,067,184		8,722	
100		8000		1000	999999	$1,437,500	4,431,292	$109,020,312	0.065	0	0	17,067,184		8,722	
100		8000		200	999999	$1,437,500	4,431,292	$109,020,312	0.065	0	0	17,067,184		8,722	
100		8000		100	999999	$1,437,500	4,431,292	$109,020,312	0.065	0	0	17,067,184		8,722	
	1000	8000	100		999999	$1,508,750	4,428,622	$109,026,752	0.065	0	0	17,077,274	0	8,722	0
100	1000	8000		2000	999999	$1,508,750	4,428,908	$109,033,688	0.065	0	0	17,067,184	0	8,722	
100	1000	8000		1000	999999	$1,508,750	4,428,908	$109,033,688	0.065	0	0	17,067,184	0	8,722	
100	1000	8000		200	999999	$1,508,750	4,428,908	$109,033,688	0.065	0	0	17,067,184	0	8,722	
100	1000	8000		100	999999	$1,508,750	4,428,908	$109,033,688	0.065	0	0	17,067,184	0	8,722	
	5000	8000			999999	$1,728,750	4,424,263	$109,140,912	0.065	0	0	17,077,274	0	8,722	
	2500	8000	100		999999	$1,733,750	4,425,046	$109,164,928	0.065	0	0	17,077,274	0	8,722	0
100	2500	8000		2000	999999	$1,733,750	4,425,332	$109,171,880	0.065	0	0	17,067,184	0	8,722	
100	2500	8000		1000	999999	$1,733,750	4,425,332	$109,171,880	0.065	0	0	17,067,184	0	8,722	
100	2500	8000		200	999999	$1,733,750	4,425,332	$109,171,880	0.065	0	0	17,067,184	0	8,722	
100	2500	8000		100	999999	$1,733,750	4,425,332	$109,171,880	0.065	0	0	17,067,184	0	8,722	
100	525	8000	100	2000	999999	$1,817,500	4,424,864	$109,244,256	0.065	0	0	17,067,184	0	8,722	0
100	525	8000	100	1000	999999	$1,817,500	4,424,864	$109,244,256	0.065	0	0	17,067,184	0	8,722	0
100	525	8000	100	200	999999	$1,817,500	4,424,864	$109,244,256	0.065	0	0	17,067,184	0	8,722	0
100	525	8000	100	100	999999	$1,817,500	4,424,864	$109,244,256	0.065	0	0	17,067,184	0	8,722	0
100		8000	100	2000	999999	$1,817,500	4,426,115	$109,274,640	0.065	0	0	17,067,184		8,722	0
100		8000	100	1000	999999	$1,817,500	4,426,115	$109,274,640	0.065	0	0	17,067,184		8,722	0
100		8000	100	200	999999	$1,817,500	4,426,115	$109,274,640	0.065	0	0	17,067,184		8,722	0
100		8000	100	100	999999	$1,817,500	4,426,115	$109,274,640	0.065	0	0	17,067,184		8,722	0
100	1000	8000	100	2000	999999	$1,888,750	4,423,731	$109,288,016	0.065	0	0	17,067,184	0	8,722	0
100	1000	8000	100	1000	999999	$1,888,750	4,423,731	$109,288,016	0.065	0	0	17,067,184	0	8,722	0
100	1000	8000	100	200	999999	$1,888,750	4,423,731	$109,288,016	0.065	0	0	17,067,184	0	8,722	0
100	1000	8000	100	100	999999	$1,888,750	4,423,731	$109,288,016	0.065	0	0	17,067,184	0	8,722	0
	5000	8000	100		999999	$2,108,750	4,419,086	$109,395,240	0.065	0	0	17,077,274	0	8,722	0
100	5000	8000		2000	999999	$2,108,750	4,419,373	$109,402,192	0.065	0	0	17,067,184	0	8,722	
100	5000	8000		1000	999999	$2,108,750	4,419,373	$109,402,192	0.065	0	0	17,067,184	0	8,722	
100	5000	8000		200	999999	$2,108,750	4,419,373	$109,402,192	0.065	0	0	17,067,184	0	8,722	
100	5000	8000		100	999999	$2,108,750	4,419,373	$109,402,192	0.065	0	0	17,067,184	0	8,722	
250	525	8000		2000	999999	$2,007,500	4,423,829	$109,409,128	0.065	0.01	0	17,051,434	0	8,722	
250	525	8000		1000	999999	$2,007,500	4,423,829	$109,409,128	0.065	0.01	0	17,051,434	0	8,722	
250	525	8000		200	999999	$2,007,500	4,424,047	$109,414,432	0.065	0.01	0	17,051,600	0	8,722	
	8000	8000			999999	$2,178,750	4,417,111	$109,417,296	0.065	0	0	17,077,274	0	8,722	
100	2500	8000	100	2000	999999	$2,113,750	4,420,156	$109,426,208	0.065	0	0	17,067,184	0	8,722	0
100	2500	8000	100	1000	999999	$2,113,750	4,420,156	$109,426,208	0.065	0	0	17,067,184	0	8,722	0
100	2500	8000	100	200	999999	$2,113,750	4,420,156	$109,426,208	0.065	0	0	17,067,184	0	8,722	0
100	2500	8000	100	100	999999	$2,113,750	4,420,156	$109,426,208	0.065	0	0	17,067,184	0	8,722	0
250		8000		2000	999999	$2,007,500	4,425,080	$109,439,512	0.065	0.01	0	17,051,434		8,722	
250		8000		1000	999999	$2,007,500	4,425,080	$109,439,512	0.065	0.01	0	17,051,434		8,722	
250		8000		200	999999	$2,007,500	4,425,299	$109,444,816	0.065	0.01	0	17,051,600		8,722	
250	1000	8000		2000	999999	$2,078,750	4,422,696	$109,452,888	0.065	0.01	0	17,051,434	0	8,722	
250	1000	8000		1000	999999	$2,078,750	4,422,696	$109,452,888	0.065	0.01	0	17,051,434	0	8,722	
250	1000	8000		200	999999	$2,078,750	4,422,915	$109,458,192	0.065	0.01	0	17,051,600	0	8,722	

250	2500	8000			2000	999999	$2,303,750	4,419,120	$109,591,064	0.065	0.01	0	17,051,434	0	8,722		
250	2500	8000			1000	999999	$2,303,750	4,419,120	$109,591,064	0.065	0.01	0	17,051,434	0	8,722		
250	2500	8000			200	999999	$2,303,750	4,419,339	$109,596,368	0.065	0.01	0	17,051,600	0	8,722		
250	525	8000			100	999999	$2,007,500	4,431,934	$109,605,896	0.065	0	0	17,057,898	0	8,722		
	525	8000		300	2000	999999	$2,377,500	4,416,950	$109,612,112	0.065	0	0	17,077,274	0	8,722		0
	525	8000		300	1000	999999	$2,377,500	4,416,950	$109,612,112	0.065	0	0	17,077,274	0	8,722		0
	525	8000		300	200	999999	$2,377,500	4,416,950	$109,612,112	0.065	0	0	17,077,274	0	8,722		0
	525	8000		300	100	999999	$2,377,500	4,416,950	$109,612,112	0.065	0	0	17,077,274	0	8,722		0
250		8000			100	999999	$2,007,500	4,433,185	$109,636,280	0.065	0	0	17,057,898		8,722		
		8000		300	2000	999999	$2,377,500	4,418,201	$109,642,496	0.065	0	0	17,077,274		8,722		0
		8000		300	1000	999999	$2,377,500	4,418,201	$109,642,496	0.065	0	0	17,077,274		8,722		0
		8000		300	200	999999	$2,377,500	4,418,201	$109,642,496	0.065	0	0	17,077,274		8,722		0
		8000		300	100	999999	$2,377,500	4,418,201	$109,642,496	0.065	0	0	17,077,274		8,722		0
250	1000	8000			100	999999	$2,078,750	4,430,801	$109,649,664	0.065	0	0	17,057,898	0	8,722		
	1000	8000		300	2000	999999	$2,448,750	4,415,817	$109,655,872	0.065	0	0	17,077,274	0	8,722		0
	1000	8000		300	1000	999999	$2,448,750	4,415,817	$109,655,872	0.065	0	0	17,077,274	0	8,722		0
	1000	8000		300	200	999999	$2,448,750	4,415,817	$109,655,872	0.065	0	0	17,077,274	0	8,722		0
	1000	8000		300	100	999999	$2,448,750	4,415,817	$109,655,872	0.065	0	0	17,077,274	0	8,722		0
100	5000	8000	100		2000	999999	$2,488,750	4,414,196	$109,656,520	0.065	0	0	17,067,184	0	8,722	0	
100	5000	8000	100		1000	999999	$2,488,750	4,414,196	$109,656,520	0.065	0	0	17,067,184	0	8,722	0	
100	5000	8000	100		200	999999	$2,488,750	4,414,196	$109,656,520	0.065	0	0	17,067,184	0	8,722	0	
100	5000	8000	100		100	999999	$2,488,750	4,414,196	$109,656,520	0.065	0	0	17,067,184	0	8,722	0	
250	525	8000	100		2000	999999	$2,387,500	4,418,652	$109,663,448	0.065	0.01	0	17,051,434	0	8,722	0	
250	525	8000	100		1000	999999	$2,387,500	4,418,652	$109,663,448	0.065	0.01	0	17,051,434	0	8,722	0	
250	525	8000	100		200	999999	$2,387,500	4,418,871	$109,668,752	0.065	0.01	0	17,051,600	0	8,722	0	
	8000	8000	100			999999	$2,558,750	4,411,935	$109,671,616	0.065	0	0	17,077,274	0	8,722	0	
100	8000	8000			2000	999999	$2,558,750	4,412,221	$109,678,560	0.065	0	0	17,067,184	0	8,722		
100	8000	8000			1000	999999	$2,558,750	4,412,221	$109,678,560	0.065	0	0	17,067,184	0	8,722		
100	8000	8000			200	999999	$2,558,750	4,412,221	$109,678,560	0.065	0	0	17,067,184	0	8,722		
100	8000	8000			100	999999	$2,558,750	4,412,221	$109,678,560	0.065	0	0	17,067,184	0	8,722		
250		8000	100		2000	999999	$2,387,500	4,419,904	$109,693,832	0.065	0.01	0	17,051,434		8,722	0	
250		8000	100		1000	999999	$2,387,500	4,419,904	$109,693,832	0.065	0.01	0	17,051,434		8,722	0	
250		8000	100		200	999999	$2,387,500	4,420,122	$109,699,136	0.065	0.01	0	17,051,600		8,722	0	
250	1000	8000	100		2000	999999	$2,458,750	4,417,520	$109,707,208	0.065	0.01	0	17,051,434	0	8,722	0	
250	1000	8000	100		1000	999999	$2,458,750	4,417,520	$109,707,208	0.065	0.01	0	17,051,434	0	8,722	0	
250	1000	8000	100		200	999999	$2,458,750	4,417,738	$109,712,520	0.065	0.01	0	17,051,600	0	8,722	0	
	12000	8000				999999	$2,778,750	4,407,576	$109,785,784	0.065	0	0	17,077,274	0	8,722		
250	2500	8000			100	999999	$2,303,750	4,427,226	$109,787,848	0.065	0	0	17,057,898	0	8,722		
	2500	8000		300	2000	999999	$2,673,750	4,412,241	$109,794,056	0.065	0	0	17,077,274	0	8,722		0
	2500	8000		300	1000	999999	$2,673,750	4,412,241	$109,794,056	0.065	0	0	17,077,274	0	8,722		0
	2500	8000		300	200	999999	$2,673,750	4,412,241	$109,794,056	0.065	0	0	17,077,274	0	8,722		0
	2500	8000		300	100	999999	$2,673,750	4,412,241	$109,794,056	0.065	0	0	17,077,274	0	8,722		0
250	5000	8000			2000	999999	$2,678,750	4,413,161	$109,821,376	0.065	0.01	0	17,051,434	0	8,722		
250	5000	8000			1000	999999	$2,678,750	4,413,161	$109,821,376	0.065	0.01	0	17,051,434	0	8,722		
250	5000	8000			200	999999	$2,678,750	4,413,379	$109,826,680	0.065	0.01	0	17,051,600	0	8,722		
250	2500	8000	100		2000	999999	$2,683,750	4,413,944	$109,845,392	0.065	0.01	0	17,051,434	0	8,722	0	
250	2500	8000	100		1000	999999	$2,683,750	4,413,944	$109,845,392	0.065	0.01	0	17,051,434	0	8,722	0	
250	2500	8000	100		200	999999	$2,683,750	4,414,162	$109,850,696	0.065	0.01	0	17,051,600	0	8,722	0	
250	525	8000	100		100	999999	$2,387,500	4,426,757	$109,860,224	0.065	0	0	17,057,898	0	8,722	0	
	525	8000	100	300	2000	999999	$2,757,500	4,411,773	$109,866,440	0.065	0	0	17,077,274	0	8,722	0	0
	525	8000	100	300	1000	999999	$2,757,500	4,411,773	$109,866,440	0.065	0	0	17,077,274	0	8,722	0	0
	525	8000	100	300	200	999999	$2,757,500	4,411,773	$109,866,440	0.065	0	0	17,077,274	0	8,722	0	0
	525	8000	100	300	100	999999	$2,757,500	4,411,773	$109,866,440	0.065	0	0	17,077,274	0	8,722	0	0
100	525	8000		300	2000	999999	$2,757,500	4,412,059	$109,873,384	0.065	0	0	17,067,184	0	8,722		0
100	525	8000		300	1000	999999	$2,757,500	4,412,059	$109,873,384	0.065	0	0	17,067,184	0	8,722		0
100	525	8000		300	200	999999	$2,757,500	4,412,059	$109,873,384	0.065	0	0	17,067,184	0	8,722		0
100	525	8000		300	100	999999	$2,757,500	4,412,059	$109,873,384	0.065	0	0	17,067,184	0	8,722		0

250		8000	100		100	999999	$2,387,500	4,428,009	$109,890,608	0.065	0	0	17,057,898		8,722	0	
		8000	100	300	2000	999999	$2,757,500	4,413,024	$109,896,824	0.065	0	0	17,077,274		8,722	0	0
		8000	100	300	1000	999999	$2,757,500	4,413,024	$109,896,824	0.065	0	0	17,077,274		8,722	0	0
		8000	100	300	200	999999	$2,757,500	4,413,024	$109,896,824	0.065	0	0	17,077,274		8,722	0	0
		8000	100	300	100	999999	$2,757,500	4,413,024	$109,896,824	0.065	0	0	17,077,274		8,722	0	0
100		8000		300	2000	999999	$2,757,500	4,413,310	$109,903,768	0.065	0	0	17,067,184		8,722		0
100		8000		300	1000	999999	$2,757,500	4,413,310	$109,903,768	0.065	0	0	17,067,184		8,722		0
100		8000		300	200	999999	$2,757,500	4,413,310	$109,903,768	0.065	0	0	17,067,184		8,722		0
100		8000		300	100	999999	$2,757,500	4,413,310	$109,903,768	0.065	0	0	17,067,184		8,722		0
250	1000	8000	100		100	999999	$2,458,750	4,425,625	$109,903,984	0.065	0	0	17,057,898	0	8,722	0	
	1000	8000	100	300	2000	999999	$2,828,750	4,410,641	$109,910,200	0.065	0	0	17,077,274	0	8,722	0	0
	1000	8000	100	300	1000	999999	$2,828,750	4,410,641	$109,910,200	0.065	0	0	17,077,274	0	8,722	0	0
	1000	8000	100	300	200	999999	$2,828,750	4,410,641	$109,910,200	0.065	0	0	17,077,274	0	8,722	0	0
	1000	8000	100	300	100	999999	$2,828,750	4,410,641	$109,910,200	0.065	0	0	17,077,274	0	8,722	0	0
100	1000	8000		300	2000	999999	$2,828,750	4,410,927	$109,917,144	0.065	0	0	17,067,184	0	8,722		0
100	1000	8000		300	1000	999999	$2,828,750	4,410,927	$109,917,144	0.065	0	0	17,067,184	0	8,722		0
100	1000	8000		300	200	999999	$2,828,750	4,410,927	$109,917,144	0.065	0	0	17,067,184	0	8,722		0
100	1000	8000		300	100	999999	$2,828,750	4,410,927	$109,917,144	0.065	0	0	17,067,184	0	8,722		0
100	8000	8000	100		2000	999999	$2,938,750	4,407,044	$109,932,888	0.065	0	0	17,067,184	0	8,722	0	
100	8000	8000	100		1000	999999	$2,938,750	4,407,044	$109,932,888	0.065	0	0	17,067,184	0	8,722	0	
100	8000	8000	100		200	999999	$2,938,750	4,407,044	$109,932,888	0.065	0	0	17,067,184	0	8,722	0	
100	8000	8000	100		100	999999	$2,938,750	4,407,044	$109,932,888	0.065	0	0	17,067,184	0	8,722	0	
	525	8000	500			999999	$2,957,500	4,409,049	$110,000,304	0.065	0	0	17,077,274	0	8,722	0	
250	5000	8000			100	999999	$2,678,750	4,421,266	$110,018,152	0.065	0	0	17,057,898	0	8,722		
	5000	8000		300	2000	999999	$3,048,750	4,406,281	$110,024,368	0.065	0	0	17,077,274	0	8,722		0
	5000	8000		300	1000	999999	$3,048,750	4,406,281	$110,024,368	0.065	0	0	17,077,274	0	8,722		0
	5000	8000		300	200	999999	$3,048,750	4,406,281	$110,024,368	0.065	0	0	17,077,274	0	8,722		0
	5000	8000		300	100	999999	$3,048,750	4,406,281	$110,024,368	0.065	0	0	17,077,274	0	8,722		0
		8000	500			999999	$2,957,500	4,410,301	$110,030,688	0.065	0	0	17,077,274		8,722	0	
	12000	8000	100			999999	$3,158,750	4,402,399	$110,040,112	0.065	0	0	17,077,274	0	8,722	0	
250	2500	8000	100		100	999999	$2,683,750	4,422,049	$110,042,176	0.065	0	0	17,057,898	0	8,722	0	
	1000	8000	500			999999	$3,028,750	4,407,917	$110,044,072	0.065	0	0	17,077,274	0	8,722	0	
100	12000	8000			2000	999999	$3,158,750	4,402,686	$110,047,064	0.065	0	0	17,067,184	0	8,722		
100	12000	8000			1000	999999	$3,158,750	4,402,686	$110,047,064	0.065	0	0	17,067,184	0	8,722		
100	12000	8000			200	999999	$3,158,750	4,402,686	$110,047,064	0.065	0	0	17,067,184	0	8,722		
100	12000	8000			100	999999	$3,158,750	4,402,686	$110,047,064	0.065	0	0	17,067,184	0	8,722		
	2500	8000	100	300	2000	999999	$3,053,750	4,407,065	$110,048,376	0.065	0	0	17,077,274	0	8,722	0	0
	2500	8000	100	300	1000	999999	$3,053,750	4,407,065	$110,048,376	0.065	0	0	17,077,274	0	8,722	0	0
	2500	8000	100	300	200	999999	$3,053,750	4,407,065	$110,048,376	0.065	0	0	17,077,274	0	8,722	0	0
	2500	8000	100	300	100	999999	$3,053,750	4,407,065	$110,048,376	0.065	0	0	17,077,274	0	8,722	0	0
100	2500	8000		300	2000	999999	$3,053,750	4,407,351	$110,055,336	0.065	0	0	17,067,184	0	8,722		0
100	2500	8000		300	1000	999999	$3,053,750	4,407,351	$110,055,336	0.065	0	0	17,067,184	0	8,722		0
100	2500	8000		300	200	999999	$3,053,750	4,407,351	$110,055,336	0.065	0	0	17,067,184	0	8,722		0
100	2500	8000		300	100	999999	$3,053,750	4,407,351	$110,055,336	0.065	0	0	17,067,184	0	8,722		0
250	5000	8000	100		2000	999999	$3,058,750	4,407,984	$110,075,704	0.065	0.01	0	17,051,434	0	8,722	0	
250	5000	8000	100		1000	999999	$3,058,750	4,407,984	$110,075,704	0.065	0.01	0	17,051,434	0	8,722	0	
250	5000	8000	100		200	999999	$3,058,750	4,408,203	$110,081,008	0.065	0.01	0	17,051,600	0	8,722	0	
250	8000	8000			2000	999999	$3,128,750	4,406,009	$110,097,760	0.065	0.01	0	17,051,434	0	8,722		
250	8000	8000			1000	999999	$3,128,750	4,406,009	$110,097,760	0.065	0.01	0	17,051,434	0	8,722		
250	8000	8000			200	999999	$3,128,750	4,406,228	$110,103,064	0.065	0.01	0	17,051,600	0	8,722		
100	525	8000	100	300	2000	999999	$3,137,500	4,406,882	$110,127,704	0.065	0	0	17,067,184	0	8,722	0	0
100	525	8000	100	300	1000	999999	$3,137,500	4,406,882	$110,127,704	0.065	0	0	17,067,184	0	8,722	0	0
100	525	8000	100	300	200	999999	$3,137,500	4,406,882	$110,127,704	0.065	0	0	17,067,184	0	8,722	0	0
100	525	8000	100	300	100	999999	$3,137,500	4,406,882	$110,127,704	0.065	0	0	17,067,184	0	8,722	0	0
100		8000	100	300	2000	999999	$3,137,500	4,408,134	$110,158,088	0.065	0	0	17,067,184		8,722	0	0
100		8000	100	300	1000	999999	$3,137,500	4,408,134	$110,158,088	0.065	0	0	17,067,184		8,722	0	0
100		8000	100	300	200	999999	$3,137,500	4,408,134	$110,158,088	0.065	0	0	17,067,184		8,722	0	0

100		8000	100	300	100	999999	$3,137,500	4,408,134	$110,158,088	0.065	0	0	17,067,184		8,722	0	0
500	525	8000			2000	999999	$2,957,500	4,415,703	$110,161,856	0.065	0.01	0	17,023,160	0	8,722		
500	525	8000			1000	999999	$2,957,500	4,415,703	$110,161,856	0.065	0.01	0	17,023,160	0	8,722		
100	1000	8000	100	300	2000	999999	$3,208,750	4,405,750	$110,171,464	0.065	0	0	17,067,184	0	8,722	0	0
100	1000	8000	100	300	1000	999999	$3,208,750	4,405,750	$110,171,464	0.065	0	0	17,067,184	0	8,722	0	0
100	1000	8000	100	300	200	999999	$3,208,750	4,405,750	$110,171,464	0.065	0	0	17,067,184	0	8,722	0	0
100	1000	8000	100	300	100	999999	$3,208,750	4,405,750	$110,171,464	0.065	0	0	17,067,184	0	8,722	0	0
	2500	8000	500			999999	$3,253,750	4,404,341	$110,182,248	0.065	0	0	17,077,274	0	8,722	0	
500		8000			2000	999999	$2,957,500	4,416,955	$110,192,240	0.065	0.01	0	17,023,160		8,722		
500		8000			1000	999999	$2,957,500	4,416,955	$110,192,240	0.065	0.01	0	17,023,160		8,722		
500	1000	8000			2000	999999	$3,028,750	4,414,571	$110,205,616	0.065	0.01	0	17,023,160	0	8,722		
500	1000	8000			1000	999999	$3,028,750	4,414,571	$110,205,616	0.065	0.01	0	17,023,160	0	8,722		
100	525	8000	500		2000	999999	$3,337,500	4,404,159	$110,261,576	0.065	0	0	17,067,184	0	8,722	0	
100	525	8000	500		1000	999999	$3,337,500	4,404,159	$110,261,576	0.065	0	0	17,067,184	0	8,722	0	
100	525	8000	500		200	999999	$3,337,500	4,404,159	$110,261,576	0.065	0	0	17,067,184	0	8,722	0	
100	525	8000	500		100	999999	$3,337,500	4,404,159	$110,261,576	0.065	0	0	17,067,184	0	8,722	0	
250	5000	8000	100		100	999999	$3,058,750	4,416,089	$110,272,472	0.065	0	0	17,057,898	0	8,722	0	
	5000	8000	100	300	2000	999999	$3,428,750	4,401,105	$110,278,688	0.065	0	0	17,077,274	0	8,722	0	0
	5000	8000	100	300	1000	999999	$3,428,750	4,401,105	$110,278,688	0.065	0	0	17,077,274	0	8,722	0	0
	5000	8000	100	300	200	999999	$3,428,750	4,401,105	$110,278,688	0.065	0	0	17,077,274	0	8,722	0	0
	5000	8000	100	300	100	999999	$3,428,750	4,401,105	$110,278,688	0.065	0	0	17,077,274	0	8,722	0	0
100	5000	8000		300	2000	999999	$3,428,750	4,401,391	$110,285,648	0.065	0	0	17,067,184	0	8,722		0
100	5000	8000		300	1000	999999	$3,428,750	4,401,391	$110,285,648	0.065	0	0	17,067,184	0	8,722		0
100	5000	8000		300	200	999999	$3,428,750	4,401,391	$110,285,648	0.065	0	0	17,067,184	0	8,722		0
100	5000	8000		300	100	999999	$3,428,750	4,401,391	$110,285,648	0.065	0	0	17,067,184	0	8,722		0
100		8000	500		2000	999999	$3,337,500	4,405,410	$110,291,960	0.065	0	0	17,067,184		8,722	0	
100		8000	500		1000	999999	$3,337,500	4,405,410	$110,291,960	0.065	0	0	17,067,184		8,722	0	
100		8000	500		200	999999	$3,337,500	4,405,410	$110,291,960	0.065	0	0	17,067,184		8,722	0	
100		8000	500		100	999999	$3,337,500	4,405,410	$110,291,960	0.065	0	0	17,067,184		8,722	0	
250	525	8000		300	2000	999999	$3,327,500	4,405,847	$110,292,576	0.065	0.01	0	17,051,434	0	8,722		0

Appendix II: Indirect Costs

While microgrid systems necessarily have higher overall direct costs than traditional power delivery systems, value-added effects such as increased reliability may have positive economic influence on indirect costs. That is, the overall reliability of a power system has a direct effect on the costs to the customer. Microgrids can increase system flexibility and robustness, contributing to overall reliability (Executive Office of the President 2013).

Power outages can result in a type of opportunity loss for a facility or campus: employees are still being paid, but exhibit decreased productivity. Customers or students are unable to benefits from promised services. A loss of power to a sensitive load may result in extremely costly or irreparable damage. It follows that if a microgrid can increase the system's reliability by decreasing outages, it can reduce the overall operating cost of the facility or campus. Additionally, the quality of power delivered, or lack thereof, can be considered an indirect cost. Equipment that operates on low-quality power can exhibit decreased lifespans and increased frequency of maintenance: this cost manifests itself in equipment O&M and replacement frequency. If a microgrid can increase the quality of power by decreasing transients, harmonic content, and other issues, it can possibly reduce overall operating costs- especially for those systems with many components.

Georgia Southern has demonstrated a very high level of reliability in terms of power quality and outage frequency. The advanced metering and diagnostic system has noted no reduction in power quality that would require correction. Campus engineers maintain a modernized, underground distribution system that largely protects from outages resulting from weather conditions. However, this system has no protection from loss of power at the supply side, with the exception of backup generators that serve specific buildings. This fact was emphasized in the early spring of 2014, when inclement weather caused severe power outages across much of the southeastern portion of the United States. Georgia Southern experienced a sustained outage for more than a full day, having to cancel classes, events, and services as it waited for Georgia Power to restore power.

A rough estimate can be obtained using the Interruption Cost Estimate Calculator (icecalculator.com), provided by the U.S. Department of Energy. Although this tool is designed to estimate costs to multiple customers within a region, we can manipulate the inputs for our purposes. Reliability inputs, the number of customers, and the state are entered. A value of 1 is chosen for both SAIFI and the number of customers, as we are trying to model the university as a single entity, and the entire campus is affected in the event of a sustained outage. SAIDI is set to 480 minutes, as that is the highest allowable value. Figure 78 shows these inputs.

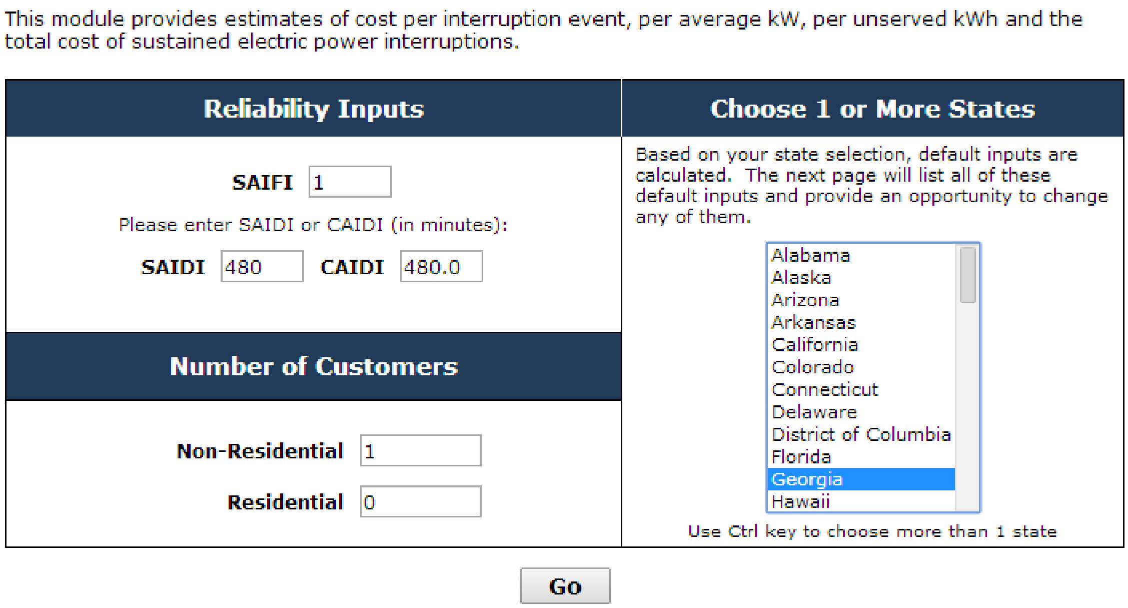


Figure 78: Interruption Cost Estimate Calculator

The next page allows us to define the average usage per customer, as well as industry percentages within the category. We enter an average usage of 69.5 MWh for the Medium and Large C&I, and a value of 1 for the others to satisfy the input requirements. A value of 100% is assigned to “Public Administration”, as no other industries seem appropriate. A value of 100% is assigned for “Backup Generation and Power Conditioning”. Figure 79 shows these inputs.

Customer Category	No. of Customers	Average Usage (Annual MWh)
Medium and Large C&I (Over 50,000 Annual kWh)	1	69.5
Small C&I (Under 50,000 Annual kWh)	0	1
Residential	0	1
C&I Industry Percentages	**Medium and Large C&I**	**Small C&I**
Agriculture, Forestry and Fishing	0	0.5%
Mining	0	0.1%
Construction	0	10.5%
Manufacturing	0	3.7%
Transportation, Communication & Utilities	0	4.4%
Wholesale & Retail Trade	0	20.5%
Finance, Insurance & Real Estate	0	11.2%
Services	0	49.1%
Public Administration	100	0.0%
Unknown Industry	0	0.1%
Total (must add to 100%)	100.0%	100.0%
Percent of C&I Customers with:	**Medium and Large C&I**	**Small C&I**
No or Unknown Backup Equipment	0	70.4%
Backup Generation or Power Conditioning	0	26.2%
Backup Generation and Power Conditioning	100	3.4%
Total (must add to 100%)	100.0%	100.0%

Figure 79: Outage Cost Inputs: Customer

The next section allows us to input percentages respective to the time of day, time of year, time of week, and advanced warning. Because we are attempting to find an average value irrespective of seasonal influences, we assign even percentages to the time of day and year. We assign a value of 100% to “Weekday” to keep it relevant to an academic institution, and 100% to “Advanced Warning Not Provided”. These inputs are shown in Figure 80.

Distribution of Outages by Time of Day	Estimated Percentage
Morning (6 am to 12 pm)	25.0%
Afternoon (12 pm to 5 pm)	25
Evening (5 pm to 10 pm)	25
Night (10 pm to 6 am)	25
Total (must add to 100%)	100.0%
Distribution of Outages by Time of Year	**Estimated Percentage**
Summer (Jun thru Sep)	50.0%
Non-Summer (Oct thru May)	50.0%
Total (must add to 100%)	100.0%
Distribution of Outages by Time of Week	**Estimated Percentage**
Weekday (Mon thru Fri)	100
Weekend (Sat/Sun/Holiday)	0
Total (must add to 100%)	100.0%
Distribution of Outages by Advanced Warning	**Estimated Percentage**
Advanced Warning Provided	0.0%
Advanced Warning Not Provided	100.0%
Total (must add to 100%)	100.0%

Figure 80: Outtage Cost Inputs: Time and Warning

These estimated inputs result in an interruption cost estimate of $12,714.60 for a four-hour outage. This value, although rough, seems appropriate. The results are shown in Figure 81. If historical outage data was obtained, one could extrapolate total annual costs by summing the cost of each outage respective to its SAIDI duration time.

Interruption Cost Estimates

Sector	No. of Customers	Cost per Event (2011$)	Cost per Average kW (2011$)	Cost per Unserved kWh (2011$)	Total Cost of Sustained Interruptions (2011$)
Medium and Large C&I	1	$12,714.6	$1,602.6	$200.3	$12,714.6

Figure 81: Outage Cost Ouput