Combined Heat and Power (CHP) at Lafayette College: A Feasibility Study

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Our goal in distributing this report is to increase awareness among key stakeholders at Lafayette College and to make information about this initiative accessible to administration, faculty and students. In order for Combined Heat and Power to gain momentum, their needs to be a better understanding of Combined Heat and Power throughout the Lafayette community; and in conducting this analysis, we hope to help further that understanding. It cannot go without mentioning the aid of various faculty at Lafayette specifically within Engineering Studies, Chemical Engineering, Mechanical Engineering, and Facilities Operations, Planning, and Construction, in helping us define the problem and providing insight into understanding discussions previously held about the technology's feasibility.

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Combined Heat and Power (CHP) is a technological system that allows for the production of electricity and steam as a source of heating from one fuel source. Through this process, overall heat and power efficiency is maximized, saving users in operating expenses and creating a cleaner form of energy production for the environment. CHP is gaining popularity within green energy conversations because it reduces fossil fuel consumption and CO_2 emissions, and it is not limited to small-scale applications. In fact, CHP is more cost-beneficial in large-scale applications than in individual homes. Another benefit of this technology is the ability for users to be independent from the grid, which increases their power reliability and therefore their security. With this in mind, the technology is becoming increasingly popular among institutions that have a high power-demand and a need for a "zero downtime" reliability model. For example, St. Jude's Hospital in Bethlehem, PA is strongly considering transitioning to a CHP model due to its critical need for reliable power 24/7. Higher education institutions have also started to implement CHP on their campuses' because of the high power demand and heating networks required for student housing and educational facilities.

Lafayette College has considered CHP in the past, and as a result, our Senior Capstone group conducted a semester-long feasibility analysis to better understand what has prevented CHP from being implemented in the past and to identify the key changes that need to be made in order to advocate for this energy-efficient model. To thoroughly define the problem and research solutions, we, as a team of five, divided the project into five key contexts: social, technical, political, economic, and environmental/energy. Through course material and discussion in our Senior Capstone, we realized the importance of thinking about a problem from various, equally relevant perspectives which led us to approach our analysis in this way. Within each section, we started by interviewing faculty within various departments at Lafayette College including

Chemical Engineering, Mechanical Engineering, and Facilities Operations, Planning, and Construction. From there, we sought additional research through a compilation of scholarly sources and governmental sites to aid us in the creation of a broader context of CHP. By using other schools and even nations as a source of comparison, we developed a deeper understanding of the way in which CHP is being received and adopted in other communities, and a launching point to determining just how feasible a CHP model would be on a campus of our size.

Problem Definition

Through information available to us online and from interviews with faculty, we connected the five different contextual analyses together through the core mission statements and goals posted by the College.

For context, the Lafayette's mission statement states:

> In an environment that fosters the free exchange of ideas, Lafayette College seeks to nurture the inquiring mind and to integrate intellectual, social, and personal growth. The College strives to develop students' skills of critical thinking, verbal communication, and quantitative reasoning and their capacity for creative endeavor; it encourages students to examine the traditions of their own culture and those of others; to develop systems of values that include an understanding of personal, social, and professional responsibility; and to regard education as an indispensable, lifelong process.

The values, stated as subsets of the mission statement, include: diversity and inclusion, sustainability, and community engagement. In addition to these more permanent goals Lafayette's present initiative is to expand the study body from 2,500 to 2,900 students. This requires a variety of changes that need to be made in student housing, dining halls, and in educational facilities in order to accommodate for the growth (Morse, 2016). While there are active environmental initiatives thriving at Lafayette, such as LaFarm, CHP has struggled to gain enough momentum to be a competitive initiative amongst these other pressing priorities due to its large-scale change model. Because we recognized that accomplishing a CHP model was too ambitious within our semester's time restraint and our resources, the goal of our study was to create material to educate and raise awareness about the potential CHP has for our campus.

Section Overviews

Social Analysis

We lead our report with our social analysis, recognizing that this was where we would identify our audience and the key stakeholders at Lafayette. To identify the root of the problem CHP is facing, we asked ourselves what key factors influence the administration's decision-making throughout each of our five contextual analyses. In addition to understanding the history of CHP conversations at the College, we went straight to our school's mission statement and used it as a benchmark within our social analysis to determine whether CHP stands in the prioritization of change on campus. This initial section also looks outside of Lafayette and studies how state and federal committees and environmental activists might enhance CHP conversations on campus.

Technical Analysis

Following the social analysis, we shifted our focus to the technical analysis to gauge what kind of infrastructural changes would need to be made to shift to a CHP model. This analysis holds a lot of weight in our conclusion of how feasible this new technology would be because it addresses ease of implementation and offers different types of CHP depending on demand. This section is divided into sections that look at Lafayette's current infrastructure, define the technology associated with CHP, explain the infrastructural pieces needed, and conclude with a statement about the difficulties that the facility operations team might experience under the proposed transition.

Policy Analysis

In addition to the way our social analysis analyzed political dynamics at the College and in our surrounding governments, our policy analysis also evaluated the political environment from a legislative perspective. The section includes considerations of federal and state policies, in addition to the environmental commitments and designated decision-making processes at Lafayette. In addition to environmental initiatives within the different levels of legislation, this section also addresses the instability of the natural gas fuel market that has been a roadblock in past conversations, both at Lafayette and in other contexts. Key areas for increasing political traction and positively influence the feasibility at Lafayette are identified and further explained in our economic analysis.

Economic Analysis

The economic analysis was another section that was predicted to be one of the key indicators of our feasibility analysis results. This section further discusses the volatility of the natural gas market, estimates costs throughout various CHP technology's useful life to complement the Technical Analysis based largely on governmental data, and concludes with a cash-flow analysis for a complete discourse on the economic feasibility for CHP.

Environmental Analysis

In the fifth analysis we considered how CHP affects the environmental footprint and energy measures. It breaks down the environmental impact of CHP and Lafayette's current energy consumption into a life-cycle analysis, an efficiency analysis, and infrastructural management analysis. From these understandings, we then considered what the environmental implications of moving to a CHP model would be on a technical and cultural level.

Challenges

Throughout all of our studies, the most common challenge across the board was our lack of access to data by the College. While we did have the opportunity to interview faculty that have been active in past CHP dialogues, the majority of quantitative data and statistics available to us is from a previous energy study conducted by Lafayette back in 2012. Because of the nearly five year absence of information available to the public, our evaluations were, at times, limited to explaining how to best determine feasibility in future work, rather than actually being able to run current numbers. The economic, technical, and environmental analyses were most affected by this lack of available information as it left worthwhile calculations up to estimation.

However, as previously stated, the objective of this study was essentially to educate and inform. Knowing that the data will change as the school's infrastructure and facilities age and expand, there is value in the way we documented these analyses as suggested procedures for future action.

Results

Contrary to our initial hypotheses, our analysis of the technical, economic, and environmental aspects of CHP were not the areas that swayed our results in our feasibility analysis. Because we concluded in each of these sections that the feasibility of CHP from these perspectives is high, we were able to identify that the weight of this decision falls to the political constructions and social conversations within the school, and across the nation. While we concluded that our federal, state, and institutional policy is supportive of the growth of CHP, the political dynamics at a social level have restrained CHP from becoming a high priority for key decision-makers at Lafayette. We believe that the majority of this is due to a lack of awareness and education surrounding the conversation and the economic and environmental benefit this technology could bring to the Lafayette campus. Our goal in distributing our report is to increase this awareness among key stakeholders at the College and to make information about this initiative accessible to faculty and students. Overall, for CHP to gain momentum, their needs to be a better understanding of CHP throughout the Lafayette community; and in conducting this analysis, we hope to help further that understanding.

Introduction

The social issues regarding implementing CHP at Lafayette College are surrounded by a much larger framework that include federal energy policy, global climate change, and energy independence as well as energy production and consumption. When analyzing the relevant social contexts at Lafayette College, additional issues such as the age and condition of the equipment at the College's steam plant, the reliability of the grid and the College's facilities during power outages, the College's carbon footprint and standing as a "green campus", as well as the social hierarchy that exists within the College's administration and the Master Planning Committee were all taken into consideration.

When researching CHP in the Lehigh Valley area, a few examples came up, such as the use of CHP at St. Luke's in Bethlehem. However, the CHP system at St. Luke's is not a comparable analogy, as hospitals are required to have alternate sources of energy to maintain temperatures to protect patient health and safety, and for the safe and sanitary storage of provisions per the proposed DHHS rule (National Archives and Records Administration, 2013).

Other schools of similar size and in the surrounding area have converted to CHP, including a few Colleges and Universities in Pennsylvania. For example, in 1998, Bucknell University converted from coal fired boilers to a steam-run cogeneration plant that supplies all of the campus's steam and electricity needs. By switching to CHP, and reducing the amount of electricity purchased, Bucknell University reduced their emissions from more than 60,000 Metric Tons of carbon dioxide equivalents (MTeCO2) in 1996 to 37,756 MTeCO2 in 1997 (Power Plant, n.d.). Additionally, the steam plant currently saves the University over one million dollars a year in utility costs (Buczko, 8). The fact that a school comparable to Lafayette College implemented CHP on their campus almost two decades ago raises the following question, why hasn't CHP been implemented at Lafayette College?

Federal & State Policy

In an effort by Federal and State Governments to enhance emergency preparedness and ensure continued progress towards addressing grid and infrastructure resilience, government regulators, emergency planners, and those in the energy and electricity sector have been working together to help reduce regulatory barriers to CHP (U.S. Department of Energy & Environmental Protection Agency [EPA], 2013, p.3). Currently, there are several factors driving the adoption of CHP, including historically low natural gas prices, favorable Federal tax programs, such as Investment Tax Credits (ITC), national energy security, U.S. government regulatory support, and resilience to future storms of similar magnitude to Hurricane Sandy (EPA, 2013).

On October 30, 2012, Hurricane Sandy swept across some of the nation's most populated communities along the Northeast and Mid-Atlantic, leaving millions of people without access to electricity, utilities, or telecommunication. The resulting infrastructure destruction and the subsequent disruptions caused by super-storm Sandy highlighted the need for U.S. infrastructure investment. As a part of the Hurricane Sandy Rebuilding Task Force, some states affected by Hurricane Sandy, such as New York and New Jersey, have initiated programs to promote CHP (EPA, 2013).

Although Pennsylvania currently does not have a CHP goal, grant or incentive program set up, the Pennsylvania Public Utilities Commission is exploring whether Pennsylvania should adopt some of the programs and changes that have been made in other states to encourage CHP development (Pennsylvania Public Utility Commission [PPUC], 2016, p.4). Due to its low cost and availability, fracking in Pennsylvania has led to an increase in use of natural gases in

Pennsylvania. For an in-depth analysis of the natural gas market, see the Economics section. Therefore, the creation of policies and programs that promote CHP in Pennsylvania is critical to the deployment of CHP, as “investment in CHP, in the absence of state, federal and other investment subsidies, is largely driven by the cost of electricity” (PPUC, 2016, p.4).

Potential Benefits of CHP at Lafayette College

Following Hurricane Sandy, the College remained closed for for almost a week due to power outages (Superstorm Sandy, 2012). In recent years, the College has experienced multiple power outages as a result of storms or severe weather conditions, including an 18-hour outage this past October (Marshall, 2016; Public Safety, Personal Communication, October 28-29, 2016).

CHP not only has environmental benefits and offers significant cost savings, but it also provides reliable primary and emergency power generation for both electricity and heating. Due to CHP’s resiliency, many colleges and universities have taken an interest in it. According to the U.S. Department of Energy & Environmental Protection Agency, “CHP played a successful role in keeping a number of college campuses, multifamily housing, critical medical facilities, sewage treatment plants and other facilities running during the storm and its aftermath,” (EPA, 2013 p.2) as it allowed crucial infrastructure and other facilities to continue their operations when the electric grid went down. This stability—i.e. being able not to interrupt day-to-day business—offers Lafayette benefits in addition to monetary savings. Some of these benefits include not having to cancel class, close dining halls, or send students home due to the unsafe conditions of a campus without power. Furthermore, the reliability that CHP has to offer is not something the College will have while solely relying on the grid.

American College & University Presidents’ Climate Commitment

In January of 2008, Lafayette College President Daniel Weiss signed the American College & University Presidents' Climate Commitment (ACUPCC), thereby uniting Lafayette College with a coalition of colleges and universities across the United States that have committed to reducing their greenhouse gas emissions and work towards achieving climate neutrality (Lafayette College, 2015, p.6; Lafayette College, 2011, p.1). The ACUPCC aims to address climate disruption due to human activities by better preparing future generations to protect the environment by integrating sustainability into research, operations, and curriculums. Institutions are provided with a framework to implement their plans in order to meet the requirements detailed in the ACUPCC (Lafayette College, 2015, p.6).

Greenhouse Gas Inventory

In accordance with the ACUPCC, Lafayette College has prepared and completed three Greenhouse Gas Inventory Reports. These reports provide insight about possible emission reduction strategies, as the reports analyze information about Lafayette's emissions since 2007 (Lafayette College, 2015, p.5). The most recent inventory calculates years 2005 through 2013, and includes greenhouse gas emissions associated with electricity and steam consumption, fuel use, agricultural releases, solid waste management, fugitive refrigerant releases, traffic commuting, and air travel for the entire Lafayette College campus (Lafayette College, 2015, p.10). Some of its most significant findings were that the two largest sources of greenhouse gas emissions were from the purchase of electricity from Metropolitan Edison for campus usage and from the purchase of natural gas and fuel oil for the on-site boiler plant, which fulfills most of the College's heating and hot water needs (Lafayette College, 2015, p.26). The report concludes by stating that, "Increasing the efficiency of equipment for current operations that produce high greenhouse gases, meaning reducing the current and future consumption of fossil fuels as a whole" should be considered in the future to reduce Lafayette's carbon footprint (Lafayette College, 2015, p.29).

Energy Audit

In order to more accurately quantify the greatest contributors to the College's emissions, Entech Engineering conducted a comprehensive energy audit in 2007 (Lafayette College, 2015, p.5; Lafayette College, 2011, p.10). This energy audit, which investigates the amount of energy consumed by campus facilities, is critical to understanding our College's energy production, consumption, and efficiencies/losses, and therefore is essential to the development and implementation of a strategic carbon reduction program.

This study found that, in 2007, the College's buildings accounted for over 86% of campus emissions. Of these emissions, 51 on-campus buildings accounted for over half of all campus emissions (Lafayette College, 2011, p.18). These fifty-one buildings were examined to determine the energy consumption and the annual energy cost for each building, as well as how much each building contributes to the campus carbon footprint (Lafayette College, 2011, p.18). Figure 1 shows that, "The most significant contributors to Lafayette's emission are the science and engineering buildings, Acopian Engineering Center and Hugel Science Center, and the Kirby Sports Center, which require large volumes of conditioned air" (Lafayette College, 2011, p.18). Entech concluded that in order for Lafayette College to make significant reductions in campus emissions, "the College must address its most energy intensive operations" (Lafayette College, 2011, p.18).

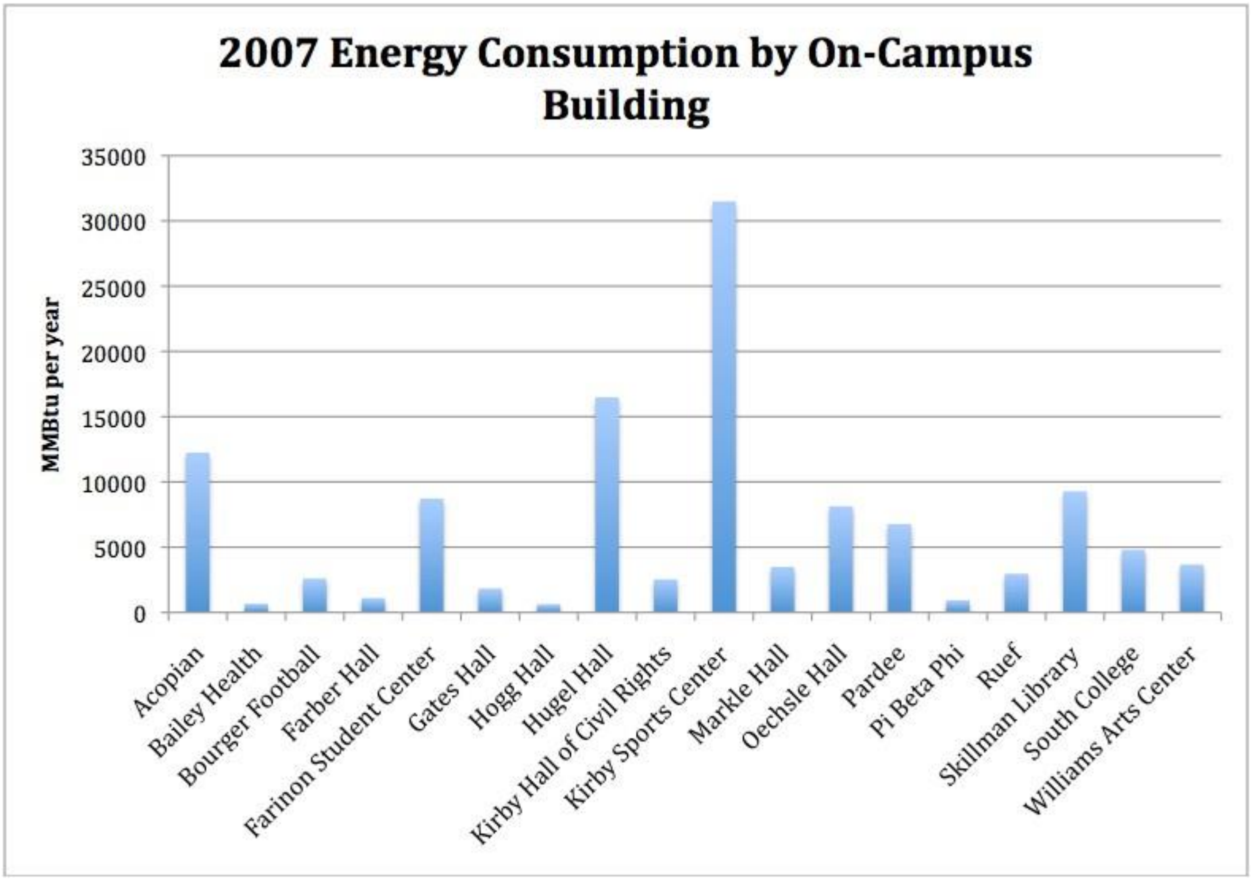

Figure 1: A selection of On-Campus Building's Energy Consumption from Entech's 2007 Energy Audit (Lafayette College, 2011, p. 20).

Climate Action Plan (CAP)

As a result of the 2007 campus energy audit, 485 energy conservation measures (ECMs) were developed and transferred to the College's Energy Planner, which provides an economic analysis of each ECM in order to help the College determine which projects to execute and how to schedule them (Lafayette College, 2011, p.3). Implementation of these ECMs are part of the Campus Emissions Reduction Plan to reduce our campus's greenhouse gas emissions 20% by 2021, relative to the College's baseline 2007 levels (Lafayette College, 2011, p.2). These ECMs are listed in Lafayette College’s Climate Action Plan (CAP), a plan that was created in November of 2011 and details specific strategies that the College will employ to reduce greenhouse gas emissions and ultimately achieve climate neutrality (Lafayette College, 2011, p.2).

In order to make the goals of the Climate Action Plan realistic and achievable, “the College has chosen to work toward climate neutrality by first focusing on reducing its energy consumption rather than purchasing renewable energy credits to offset all of its emissions. A healthy environment does not have to come at the expense of the institution’s financial performance; these two aims are not mutually exclusive” (Lafayette College, 2011, p.6). The Climate Action Plan also states, “The College has committed to invest $400,000 per year for 10 years (2010 through 2020) to finance the scheduled ECMs. The scheduled ECMs are those projects with the shortest payback period and largest MtCO2e reductions, thus allowing the College to quickly realize the expected cost savings and reinvest those savings if desired” (Lafayette College, 2011, p.3). While finances are undoubtedly important when considering whether or not to undertake a project, these excerpts illustrate how the College’s priorities are heavily reliant on project financing, and as a result, making our College a ‘greener campus’ is viewed to be of less importance.

Two of the short-term goals listed in the Climate Action Plan moving forward were to, “Update the Climate Action Plan in 2013 to reflect the decisions and progress made after completing the short-term goals” and to “Update the Climate Action Plan every two years using the Energy Planner” (Lafayette College, 2011, p.4). Unfortunately, the Climate Action Plan has not been updated since its original creation in 2011, and as a result, information regarding decisions and progress that has been made since that time was difficult to find, as most of the information on the College's website regarding sustainable energy and electricity initiatives have not been updated since 2012 (Sustainability Projects, n.d.; Current Sustainability Initiatives, n.d.).

The College's Climate Action Plan also states that their goals were to evaluate the technical and economic feasibility of installing renewable energy or cogeneration, and to update the campus facility condition assessment to identify maintenance and capital renewal projects that were deferred in order to identify opportunities to improve energy efficiency in those systems by December of 2013 (Lafayette College, 2011, p.4). In the College's Greenhouse Gas Inventory, it states that, "This inventory, in conjunction with the campus-wide energy audits, will be the foundation for the development and implementation of a plan with phases and target dates as the College pursues climate neutrality" (Lafayette College, 2011, p. 5). This analysis shows that both the 2013 Greenhouse Gas Inventory and the Energy Audit recommend reducing the College's emissions by improving upon the campus's utilities and infrastructure. Considering that the College was aware of the benefits of CHP back in 2011, we can only assume that the College's administration decided not to implement CHP due to financial concerns.

Z&F Consulting's "Energy Sufficiency" Study

In the aftermath of Hurricane Sandy, Lafayette College administration took an interest in CHP. In 2012, Z&F Consulting conducted an "Energy Sufficiency" study of Lafayette College and determined that creating a cogeneration plant on campus would reduce the College's carbon emissions by 35%. Z&F Consulting found that it would cost $6,260,000 to construct and implement a cogeneration plant at Lafayette College, as shown in Figure 2. Unfortunately, the estimated initial costs to implement CHP would exceed the $400,000/year maximum investment earmarked to reduce the College's GHG emissions. The study concluded that CHP would reduce energy costs by 35%, saving the College $1,120,000/year. Based on these savings and increased efficiency, it is difficult to understand why the College would not implement CHP back in 2012. According to a few faculty members, the Lafayette College administration ultimately decided not to implement CHP due to the difficulty in procuring fuel and the uncertainty of the fuel market (B. Ferretti, personal communication, October 13, 2016; M. Wilford-Hunt, personal communication, October 19, 2016). For further details about the natural gas market, see the Economics Analysis.

Lafayette4	Cummins4MW		
ITEM	Cogeneration		
Construction Cost:	$6,626,000		
Grants/TaxCredit/TaxDepreci:	$0	$0	$0
Campus MWH / YR:	27,425		
Electric Boiler MWH /YR:	0		
Aux Turb, Absorb MWH /YR	0		
MWH Purchased from PJM:	7,987	/	-4,398
MWH from Cogeneration:	24,347	/	-249
MW Demand New:	1.4		
Local Distribution Charge:	$37,955		
PJM - Transmission Charge:	$56,580		
PJM - Capacity Charge:	$75,900		
PJM - Ancillary Charge:	$4,140		
PJM - Energy Charge:	$23,629		
Load Supply Energy Fee:	$31,946		
Gas Usage Cost - Cogen:	$871,695		
Gas Usage Cost - Boiler:	$301,931		
Gas Customer Fee:	$0		
Maintenance/Operation:	$268,471		
New Fuel and Elec $:	**$1,672,246**		
Old / No Cogen Fuel Cost:	$828,867		
Old / No Cogen Electric Cost:	$2,248,866		

Old Fuel Cost $/MCF: $5.5 Old All Elec Cost $/MWH: $82.0

New $ / MWH generation:	$30.8		
Savings:	$1,405,487	46%	Payback: 4.7

STEAM GENERATION

FUEL COST $/MCF: 5.5

Campus Steam - LBS/year:	120,562,518
Waste Boiler - LBS/year:	47,849,815
Electric Boiler - LBS/year:	0
Gas Boiler - LBS/year:	64,156,210

COGENERATION RUN TIME

Percent steam follow:	11%	avg output:	91%
Percent full:	60%	Export Revenue	$211,690
Percent off:	29%	Average OLMP Cost Purchased $/MWH	27.4

Figure 2: Z&F Consulting's proposal for CHP at Lafayette College in August of 2012.

Energy Policy

One of the biggest issues with the College's current campus energy policy is that much of it focuses on the consumption aspect of the energy discussion, rather than the production side. For example, some of the "Specific Measures" listed in the Campus Energy Policy includes the following: "Windows and doors of the conditioned spaces should be kept closed when the systems are running," "Personal computers, other office equipment, lights, window air conditioners and personal heaters should be turned off when not in use," and "The use of personal heaters and air conditioners is discouraged (unless medical conditions deem it necessary)." These policy measures are limited in enforcement, as they are heavily reliant on responsible consumption practices by students, staff, and faculty members.

Additionally, many of the "Specific Measures" listed in the Campus Energy Policy are vague, and include phrases such as "should be considered" and "application where warranted and possible" (Lafayette College, n.d.). The use of words such as "should" minimizes the impact of the policy statement, and reflects the lack of concrete goals our college currently has in place. For instance, under the "New Renovation & Construction" section, it states that, "All new renovations and construction should be designed and built to minimize energy use," however, it does not detail what is considered to be minimizing energy use (Lafayette College, n.d.). Similarly, the only mention of Alternative energy sources in the College's Campus Energy Plan is in the "New Renovation & Construction" section, and states that alternative energy sources, such as co-generation, should be considered along with other strategies that could decrease building energy consumption (Lafayette College, n.d.).

Lafayette College's limited motivation to implement CHP could be attributed to the lack of concrete policy initiatives we currently have in place. The College would likely be more motivated to implement CHP if there was a statement in the College's Energy Policy that stated, for example, that 'Lafayette College will have 30% of their energy production be from alternative fuels or cogeneration by 2020.'

Another problem is that upgrading our facilities is contingent upon available funds. With the numerous projects in development and under construction at Lafayette College, we can assume that funds are available. The issue is that Lafayette College administration does not view CHP as a priority.

Master Plan

There are two ways the College can execute a project, as shown in Appendix A. For further information regarding the specific processes that determine how changes are made and which projects are carried out, see the Policy Analysis section. One way a project can be carried out is through the Campus Master Plan. Every fall, the President's Cabinet asks the department heads for a list of projects they would like to see on campus. The Cabinet members meet with each department head to discuss priorities and then rank the projects in their division based on their priority. The cabinet compiles a list of all the projects, and prioritizes them so that the Master Planning Committee can decide on a capital project in December (Personal Communication, October 19, 2016). The Master Planning Committee consists of students, faculty, staff, alumni, trustees, City of Easton, and residents of College Hill. However, yearly reviews of the Master Plan, known as the Framework Plan, do not include all of these committee members; oftentimes, only trustees and certain faculty and staff members are in attendance.

Of course, funding has a great impact in determining which projects will be carried out. The Controller's office decides the overall budget for a project, which is typically three to four million dollars (M. Wilford-Hunt, personal communication, October 19, 2016). Another way a project may be initiated is through donations, borrowing or gifts; these projects are donor or fund driven. Oftentimes, people who donate money give it to a specific division or donate it for a specific purpose (M. Wilford-Hunt, personal communication, October 19, 2016). Mary Wilford-Hunt, Director of Facilities Planning and Construction, thinks it may be difficult to get people to donate for CHP due to lack of knowledge about the subject-matter, but she is hopeful that someone would be willing to donate because it is such a ‘green’ initiative (personal communication, October 19, 2016).

Institutions generally like to put money into things that attract students, media, and future funding. A system such as CHP is not one of the more visible ways for the college to spend its money, compared to new buildings on campus such as the Oeschle Center for Global Education, the Arts Plaza, and the new Integrated Science Center. However, many rising college students look for schools that have progressive sustainability measures in place.

Interest in sustainability has been rising over the last few years with new clubs and initiatives giving rise to LaFarm, Lafayette Compost Program, and a new dining service provider. Student petitions and protests outside of Markle Hall in 2015 helped secure the hiring of the College’s first Sustainability Coordinator. This past November, Lafayette College welcomed both the new Sustainability Coordinator and Energy Manager.

Creating a cogeneration plant on campus would also provide a variety of educational opportunities for current students at Lafayette College, whether that be through volunteer work, independent research, or part of a course curriculum. Moreover, having a cogeneration plant on campus would be a great way to integrate the liberal arts and engineering programs, thereby creating an interdisciplinary experience that is unique to Lafayette College.

Campus Expansion

On February 24, 2016, President Byerly announced the College's plan to expand the size of our campus, faculty, and student body over the next six to eight years to be competitive with the best institutions in the United States (Byerly, 2016). Although many of the buildings that have been constructed on campus over the past few years meet energy efficiency standards, they also tend to demand more power due to their size and function. As the college continues to grow, in both numbers of people and numbers of buildings, our energy demand will also continue to increase. Therefore, it is imperative that the college considers implementing a system such as CHP that would address our nation's growing concerns about greenhouse gas emissions.

Conclusion

Current issues surrounding the College, such as wanting to be a more self-sustaining campus and power outages due to storms and severe weather conditions, are not new issues for the school. Through our research, we have determined that one of the reasons why the College has not implemented CHP is due to the College's lack of a strong environmental identity, meaning that there is a large discrepancy between what we want to be doing as a College versus what we are doing as a College. This discrepancy may be due to the fact that even though President Weiss signed the Presidents' Climate Commitment, limited action was taken during his time at Lafayette to make it a more sustainable campus (Sustainability Projects). However, President Byerly seems to have a much more active environmental focus (B. Cohen, personal communication, December 8, 2016). In recent years, the College has made great efforts to make our campus more sustainable and environmentally friendly. Yet, initiatives that address the College's energy consumption and production are minimal. We are hopeful that with the hiring of our College's first Sustainability Coordinator and Energy Manager, this will change.

Considering that some of the College's facilities need to be moved to construct the new Integrated Science Center, and that the College plans to expand the size of our campus, faculty, and student body over the next few years, now is the perfect opportunity to implement CHP on campus. Implementing CHP at Lafayette College is feasible, but it is heavily reliant upon student understanding, interest, and initiative, as well as available funds that need to be specifically geared towards updating our College's facilities. More importantly, it is dependent upon whether Lafayette College's administration makes CHP a priority.

In order for CHP to have any future potential at Lafayette College, it is imperative that the college views implementing CHP not just as a way for the college to save money, but also as an opportunity for our institution to be a model for healthier energy use practices. As one of the top ranked institutions in the United States, it is not just our goal, but it is our obligation to be leaders in taking steps to reduce our climate impact, and pave the way for others.

Introduction

This section of the Combined Heat and Power (CHP) feasibility study provides the technical analysis. The goal of this section is to deliver a clear understanding of CHP from a technical point of view. Another goal is to offer Lafayette College an understanding of what they will need in order to capitalize from CHP. This section will begin by providing a brief introduction of CHP, the benefits, and why CHP is needed. The next part of the technical analysis will describe the current central heating and distribution system on the Lafayette College campus. Here, prior studies of potential CHP proposal for Lafayette College will also be reviewed. The analysis will then describe the components of a CHP system, including a description of prime movers, generators, and the distribution grid configuration. Finally, this section will provide suggestions on the components Lafayette College should utilize in designing their CHP system.

Description

Combined Heat and Power (CHP), also known as cogeneration, refers to a system of proven technologies that operate together for the current generation of electricity and useful heat, as seen in Figure 1 (Pew Center on Global Climate Change [Pew], 2011).

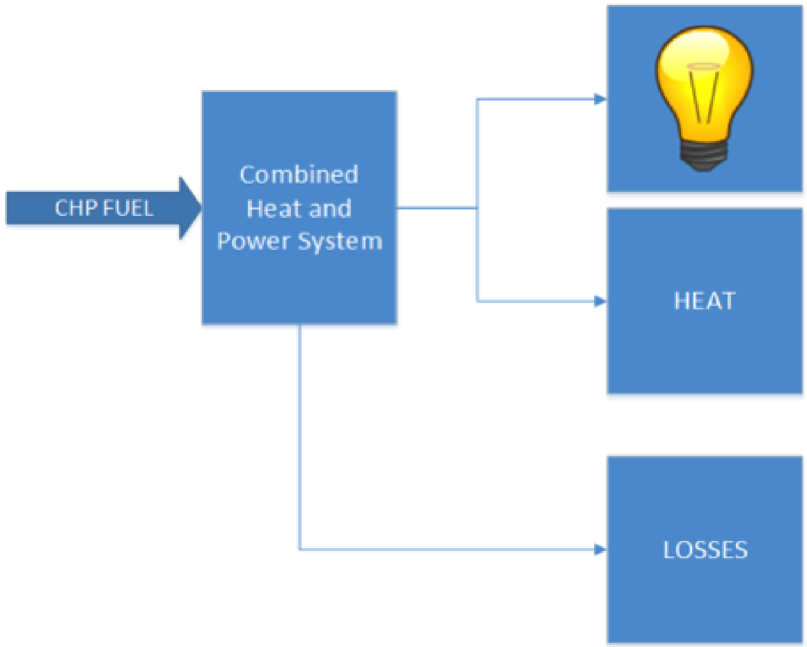

Figure 3: Combined Heat and Power System

According to the Pew Center on Global Climate Change, CHP uses commercially available technologies that decrease total fuel consumption and decrease related greenhouse gas emissions (GHG). Additionally, CHP offers many benefits, which include:

1. Reducing air pollutants
2. Providing on-site electricity that is resilient in the face of grid outages
3. Being powered by a variety of fuels, including natural gas, coal, oil and alternative fuel; this feature of CHP makes the system less vulnerable to fuel availability and volatile commodity prices
4. Achieving 80% efficiency during the Combined Heat and Power process

The past few years have been the hottest on record and the effects of climate change are now more visible than ever. Greenhouse gasses, emitted through widespread massive use of fossil fuels, are directly linked to this disturbance in our climate. Therefore, there is a need for energy systems that provide increased efficiency while reducing GHG emissions and costs, and improving reliability. Also, an increased need for the utilization of CHP exists in the large-scale industrial and/or institutional sectors. These sectors are responsible for a majority of the total energy consumption in the US. These sectors are also responsible for a majority of the US total GHG emissions. The industrial sectors direct GHG emissions account for 20% of the US total emission (Pew, 2011). Therefore, there is an obvious need for CHP in order to reduce GHG emissions, increase efficiency, and improve reliability. Combined Heat and Power is appropriate in situations where a facility has a continuous demand for heating or cooling, as well as a demand for electrical power. Therefore, CHP is an ideal investment for a college campus.

Lafayette College Current Infrastructure

The current central heating system and distribution at Lafayette College consists of 5 boilers located in the heating plant (Paulien & Associates, Inc. [Paulien], 2008 p. 108). The boilers' burners are currently capable of firing either on natural gas, or on #2, #4 or #6 fuel oil. The local utility company provides Lafayette College with interruptible natural gas service (Paulien, 2008, p.110).

Figure 4: Lafayette College Central Heating System, (Paulien, 2008, p.108)

The existing steam loads for the campus buildings are calculated based on unitary load factors and building gross area (Paulien, 2008, p.109). To satisfy peak loads, Lafayette College only needs 2 boilers (Paulien, 2008, p.110). The boilers generate steam for distribution to campus buildings via an underground piping distribution system. The steam is utilized for building heating and for domestic hot water generation (Paulien, 2008, p.111).

Bruce Ferretti, the Director of Facilities Operations, has expressed great desire and interest in CHP for Lafayette. Bruce Ferretti informed us that CHP has been discussed and proposed a few times in the recent past. Lafayette College's administration and Board of Trustees has provided support for CHP projects due to its low investment cost, ability to have a quick payback period, and ability to make Lafayette College more sustainable. The first time CHP had been discussed was in response to a donor's suggestion; the CHP system suggested was a bio-waste system. This system could create electricity and heat from bio-waste; however, this system was not pursued further because it was deemed economically inefficient and technically difficult (B. Ferretti, personal communication, October 13, 2016).

CHP was then seriously discussed again in response to Superstorm Sandy when Lafayette experienced a blackout for extended time. Lafayette has proposed several different CHP designs; however, the college has failed to institute them due to the fuel market instability (B. Ferretti, personal communication, October 13, 2016). The fuel market will be discussed further in the economic analysis section of this feasibility study.

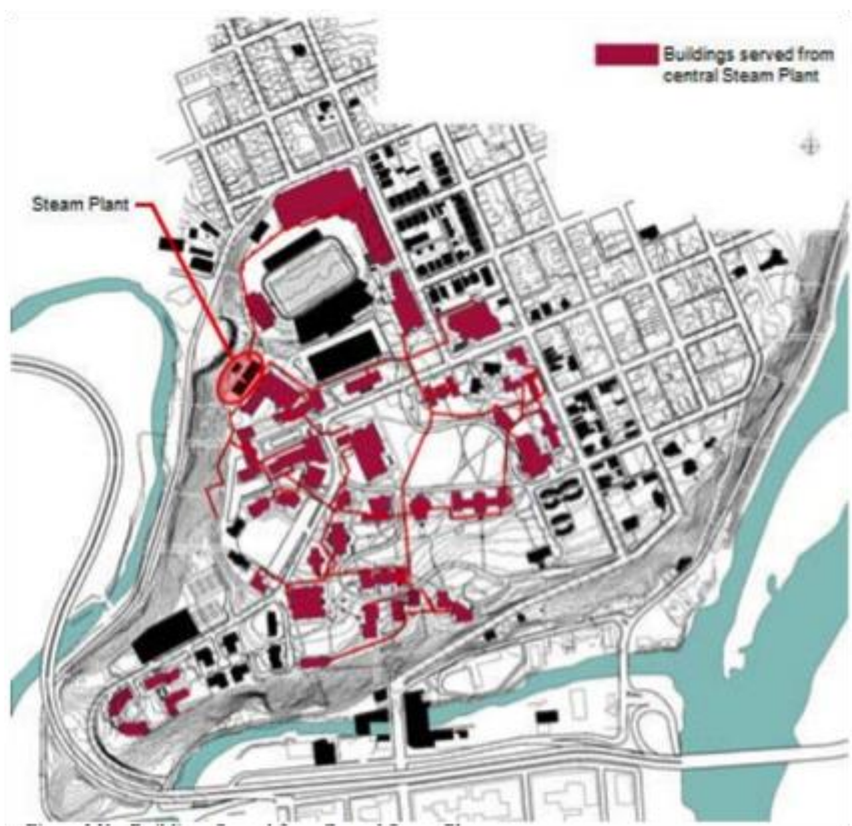

Figure 5: Buildings on Lafayette College's Campus Served from Central Steam Plant, (Paulin, 2008, p.110)

Combined Heat and Power System Design

Combined Heat and Power system has two types of cycles: the "topping cycle" and the "bottoming cycle". The "topping cycle" is the most common; during this cycle the fuel is first used to generate electricity, and then a portion of the waste from the power generation is used to provide useful thermal energy (Pew, 2011). A "bottoming cycle" CHP system first produces useful heat for a manufacturing process via fuel combustion or another heat-generating chemical reaction and then recovers some portion of the exhaust heat to generate electricity (Pew, 2011). CHP systems are designed to meet the needs of each individual customer. System designs are modified based on location, size, and energy requirements (Pew, 2011).

A typical CHP system functions in the following way, the prime movers consume fuel (coal, natural gas, or biomass) via combustion to power a generator to produce electricity, or to drive rotating equipment (Pew, 2011). The prime movers also produce thermal energy that can be captured and used for other on-site processes (Pew, 2011). There are four primary, commercially available prime movers:

1. Gas Turbines
2. Steam Turbines
3. Micro-turbines
4. Fuel Cells

Gas turbines operate where natural gas is combusted and used to turn turbine blades and spin an electrical generator. The system then uses a heat recovery system to capture the heat from the gas turbine's exhaust stream. This exhaust heat can be used for generating steam for industrial processes or generating chilled water through absorption. Gas turbines have capacities between 500 kilowatts and 250 megawatts. The benefits of these systems are that gas turbines are high-grade heat applications and are highly reliable (Pew, 2011). The gas turbine CHP system is illustrated in Figure 4.

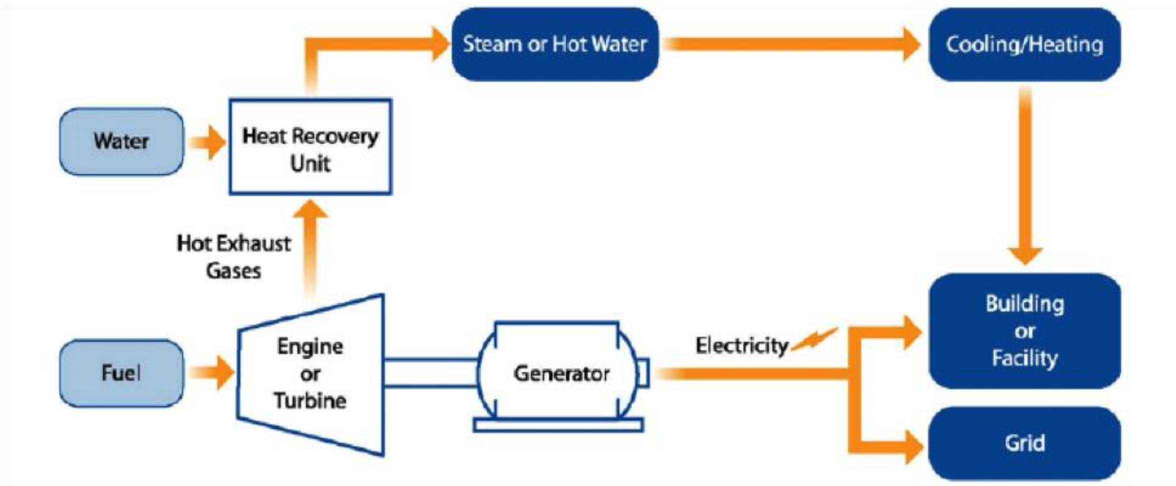

Figure 6: Gas Turbine Combined Heat and Power System, (Pew, 2011)

Steam turbines work by combusting fuel in a boiler to heat water and create high-pressure steam, which turns a turbine to generate electricity. The low-pressure steam that subsequently exits the steam turbine can then be used to provide useful thermal energy. Steam turbines have capacities between 50 kilowatts and 250 megawatts. The benefits of these systems are that they can run from a variety of fuels, are highly reliable, and can meet multiple heat grade requirements. This can be a major benefit for steam turbines because, as seen later in the economic analysis section, fuel prices are a major determining factor for Lafayette not installing CHP. Additionally, reciprocating internal combustion engines are used in combination with steam turbines. Reciprocating engines use one or more reciprocating pistons to convert pressure into a rotating motion. Multiple reciprocating engines can be used to increase system capacity, enhance overall reliability and efficiency (Pew, 2011). The steam CHP system is illustrated in Figure 5.

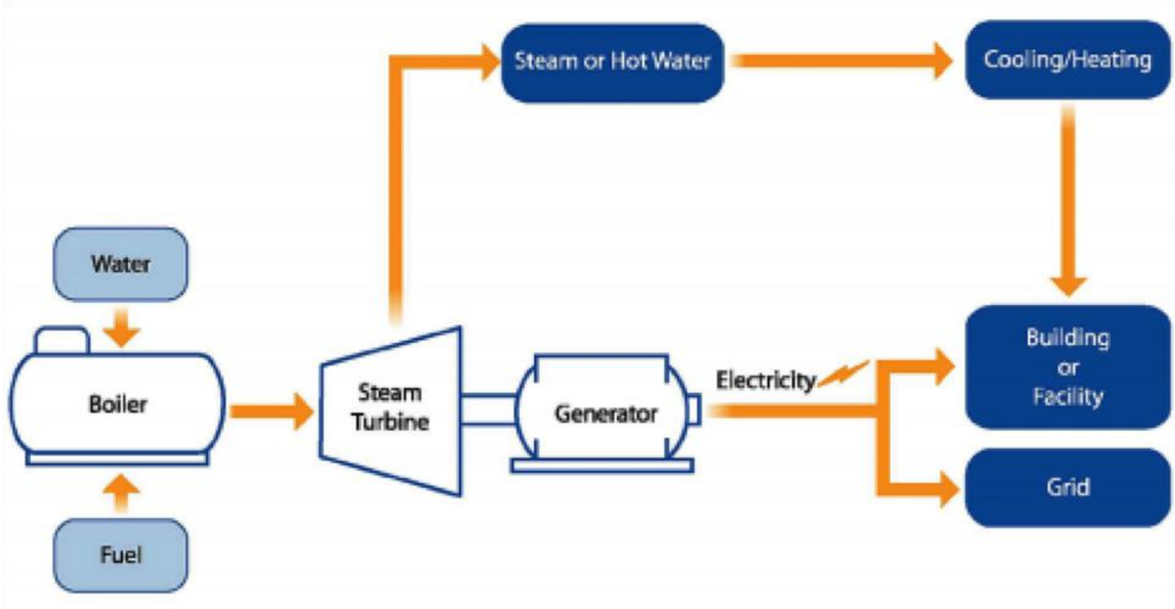

Figure 7: Steam Turbine Combined Heat and Power System, (Pew, 2011)

Micro-turbines and fuel cells will not be discussed in this technical analysis because they do not have the power output to support the energy required by Lafayette College. For more information on micro-turbines and fuel cells please refer to Cogeneration/Combined Heat and Power (CHP) Climate Techbook by Pew Center on Global Climate Change.

The next step in the technical analysis of the feasibility study of CHP for Lafayette College is analyzing the types of generators. There are two types of generators utilized in CHP systems: synchronous generators and induction generators.

Synchronous generators are self-excited generators, meaning they do not need the grid to provide the source of excitation. Therefore, the system has the potential to continue to produce power through grid brownouts and blackouts. CHP owners prefer synchronous generators because of this unique characteristic. Synchronous generators are more complex and costly in order to safely connect to the grid because the interconnection must ensure when the grid is deenergized the CHP system does not export power back to the grid. However, a benefit of synchronous generators is they provide greater electrical power reliability to customers. In addition, these types of generators have an overall positive effect on facilities power factors, which means the total power delivered by a source is used for real work (Midwest CHP Application Center [Midwest], 2007, p. 22).

Induction generators will not be discussed in this technical analysis because they do not have the necessary characteristics required by Lafayette College. For more information on induction generators please refer to Combined Heat & Power (CHP) Resource Guide for Hospital Applications.

The final design component of the CHP system is the common point of interconnection to the local electric utility distribution grid. The distribution grid is a low voltage system, which ties the site to the larger, higher voltage transmission system. The tie between the transmission and distribution grids occurs at the utility substations. There are two types of distribution systems applicable to CHP systems: radial systems, and looped and network systems (Midwest, 2007, p. 25).

The radial system is the most common type of distribution grid system for CHP. It has a single path for power flow to all customers on a single radial feed and the system is made up of multiple radial lines. On the occasion of a fault in a radial feed, only the customers on that feed will be affected. The utility can isolate the fault and keep some portion of the radial feed operating during repairs by using sectionalizing switches. Radial systems are the easiest and least costly preferred system to interconnect with a CHP system (Midwest, 2007, p. 25).

Loop and network systems, unlike radial systems, provide multiple paths for power flow to all customers on the system. On the occasion of a fault in a loop and network system, the utility has the ability to keep more customers online compared to the radial system while isolating and repairing the fault. Loop and network systems are mainly found in large metropolitan areas due to their complexity. Loop and network systems are also more costly and difficult to interconnect to the CHP system (Midwest, 2007, p. 25).

Conclusion

This technical analysis, based on research and interviews conducted with Lafayette personal, makes the following suggestions for the prime mover, the generator, and the distribution grid configuration included in the college CHP system.

The current central heating system and distribution at Lafayette College exists as a steam turbine system; therefore, a change to any new system would not make economic sense. Also, Lafayette College has expressed a desire to have reciprocating engines in order to enhance reliability and efficiency of the system. Reciprocating engines are used in combination with steam turbines; therefore, Lafayette College should maintain their existing steam turbine system and purchase reciprocating engines.

Even though Lafayette College already has the infrastructure to support a steam turbine CHP system on their campus, it would be important to conduct a technical analysis of energy use on campus to ensure that a steam turbine CHP system is the most efficient. This technical analysis of energy use on campus will utilize the thermal to electric (T/P) ratio that can be estimated using Lafayette College's utility bills (Midwest, 2007, p. 21). In order to calculate the T/P ratio for Lafayette College the analysis pictured in Figure 6 needs to be completed to determine the appropriate prime mover technology. The results of Figure 6 would need to be compared to Figure 7.

1. Determine Thermal Use			
a.	**Sum** the number of **Therms** utilized over the *last 12 months* of bills: **Total Therms**		Therms
b.	**Multiply** the **Total Therms** by 100,000 to get Thermal Btu: **Total Thermal Energy Purchased**		Btu
c.	**Multiply** the **Total Thermal Energy Purchased** by Boiler/Equipment Efficiency (typically 0.8) **Total Thermal Energy Delivered/Used**		Btu
2. Determine Electrical Use			
a.	**Sum** the number of **kWh** utilized over the *last 12 months* of bills: **Total kWh**		kWh
b.	**Multiply** the **Total kWh** by 3413 to get Btu **Total Electric**		Btu
3. Determine T/P Ratio			
	Divide Total Thermal *(Btu)* by **Total Electric** *(Btu):* **T/P Ratio**		

Figure 8: Calculating T/P Ratio, (Midwest, 2007, p. 21)

If **T/P =**	
0.5 to 1.5	Consider ***engines***
1 to10	Consider ***gas turbines***
3 to 20	Consider ***steam turbines***

Figure 9: Recommended Prime Mover Based on T/P Ratio, (Midwest, 2007, p.21)

The technical analysis of energy use on campus was one of the goals of the feasibility assessment; however, it could not be completed, as the information required could not be obtained. Regardless, the following suggestion of maintaining the existing steam turbine system as the prime mover and purchase/install reciprocating engines is the best option available based on the research to date.

Through interviews and conversations with faculty, administrators, and professors, it has become apparent that Lafayette College is interested in synchronous generators. Lafayette's faculty, administrators and professors have all expressed a desire to be able to function while the grid is down. This desire has come after experiencing the consequences of long blackouts due to weather conditions like Superstorm Sandy and more recently the power outage experienced on Halloween weekend this past year. Lafayette College would like to avoid having to cancel class, close dining halls, waste food, and send students home due to the unsafe conditions of a campus without power. Therefore, to satisfy these desires Lafayette College should install a synchronous generator.

Lafayette College is already successfully connected to the distribution grid, as stated from interviews conducted with faculty. However, we are unsure about which type of distribution grid configuration Lafayette College is interconnected with due to the unavailability of documentation and information. However, this technical analysis suggests that Lafayette College utilizes a radial system, which is based on the research done on the two types of distribution systems applicable to CHP systems. Lafayette College is not located in a metropolitan area; therefore, it does not need the complexity associated with the loop and network system. Lafayette College's CHP system would run efficiently and be less costly by utilizing a radial system for its interconnection to the local electric utility distribution grid.

As far as the technical application goes, Lafayette College is very close to having an operational Combined Heat and Power system. There are very few technical challenges/decisions to overcome. The next section of the feasibility assessment will provide an analysis of Combined Heat and Power through the context of a policy analysis.

Introduction

The policy analysis section of our report focuses on how the influence of internal processes and external incentivizing can affect the political feasibility for implementing Combined Heat and Power on Lafayette's campus. The purpose of this report is to provide key insights of the current state and future goals of implementing a CHP model on campus. It was important to look at this overall analysis from a political standpoint in order to help identify regulatory factors that are detrimental to CHP's implementation, and additionally, what would need to change, if anything, in order to make CHP a reality in the future.

Specifically, for Lafayette, it was beneficial to identify key stakeholder that would need to be supportive of this initiative in order for it to be successfully utilized on campus. In this section, stakeholders refer to the general methods for implementing change, rather than specific faculty, which is mentioned in the social context section of our report. However, these stakeholders do include economic and environmental policymakers at the federal and state level, in addition to key decision-making teams within the Lafayette community.

Problem Definition

From an overarching political standpoint, there are ranges of factors that affect the popularity of CHP. Many of these problematic factors have been widely acknowledged through a variety of studies, some of which are part of this analysis. Because of this, it was important for us to dig into these policies and gauge how much of an impact they may have on the future of CHP at Lafayette. Dr. Mark Hinnells, from the Environmental Change Institute at Oxford, summarizes that this spectrum of challenges can span a range of contexts including, "government policy towards climate change and carbon emissions, energy policy including trading arrangements, planning and power station consent policy, and fiscal incentives" (Hinnell, 2008). Thus, the success of a new technology, such as CHP, is widely dependent on its relevant markets and regulatory policies.

One roadblock Lafayette has faced in past attempts to switch to CHP is the fiscal risk relating to the instability of the natural gas fuel market (the type of fuel Lafayette would be using for CHP). Research showed us that Lafayette is not alone in this uncertainty. In a study published in *Applied Thermal Engineering*, the researchers reported that as of now, "for CHP applications, natural gas has dynamically entered the market and has become a more profitable fuel compared to oil" (Konstantakos, Pilavachi, Polyzakis, & Theofylaktos, 2012). They went on to say that, "due to unpredictable economic and political factors it is quite difficult to take optimal investment decisions for CHP systems" (Konstantakos et al., 2012). Because natural gas is dependent on international oil prices, the market is subject to severe fluctuations that increase the risk of investment in CHP for many institutions including Lafayette (Konstantakos et al., 2012). As a result, fuel markets and federal incentivizing were included in our scope of analysis, in addition to environmental policy at the state and federal levels. This is a case where the government acts as one of the indirect, yet equally essential, stakeholders in our 'deal-breakers' analysis for CHP installation.

Case Study: Dutch Policy and CHP

The Netherlands is a fantastic example of how a nation used government regulations and incentivizing to increase the popularity of CHP. A study in *Innovation for a Law Carbon Economy* gave an overview of Dutch policy and clearly related it back to conservation efforts and future policy strategy for the United States. The study started with a historical overview of policy development in the Netherlands, and explained that there had been no government action until after 1978. In the 1980's, the government stepped in and created committees to help increase the number of CHP installations. In the 1990's, a market broker was established to steady the fuel market, which increased demand for CHP as energy savings increased (Foxon, Köhler, & Oughton [Foxon], 2008). The success of the programming is reflected by today's numbers, showing that over half of the Dutch electricity is generated by Combined Heat and Power (Foxon, 2008). This market transformation uses, "a mixture of information, incentives and regulations to transform the market for a given product…[and is] a powerful aide to the design of policy over future decades in the attempt to reduce carbon emission" (Foxon, 2008). Each of these efforts to support CHP, from working to decrease carbon emissions to the use of economic incentivizing, are heavily influenced by the stability of the fuel market. Therefore, the stability of the fuel market is one of the biggest factors used in this policy analysis to gauge the feasibility of CHP in the United States and at Lafayette College.

Figure 10: The Diemen CHP plant in Amsterdam, Netherlands. (https://images.robertharding.com/preview/RM/RH/HORIZONTAL/911-9796.jpg)

U.S. Federal Policy Analysis

While the United States has been making progress to increase standards and set goals to promote green energy, we still have not reached the level of success that the Dutch have achieved. However, in 1975, Congress passed the Energy Policy and Conservation Act (EPCA), which established a program for “comparing appliances, a labeling scheme, and a mechanism for examining mandatory efficiency standards” (Foxon, 2008). This system set some necessary groundwork for further action. In additions, the Department of Energy (DOE) and the U.S. Environmental Protections (EPA) established the CHP Partnership program and have been working in collaboration to create a “voluntary program aimed at encouraging CHP growth in the United States” (Kalam, King, Moret, & Weerasinghe [Kalam], 2012). More recently, in 2015 Congress passed the Energy Productivity Innovations Challenge Act (EPIC) that requires the DOE to, “establish a voluntary electric and thermal energy productivity challenge grant program for providing support to states” by 2030 (EPIC Act of 2015, 2015). These progressive changes being made at the federal level show that while we may not yet see the direct influence of them at Lafayette, there are influential changes being made that are working with CHP, rather than against it.

Pennsylvania State Policy Analysis

Another aspect of this analysis focuses on the political conversations regarding CHP support within Pennsylvania (or at the state level). The state legislation is important to Lafayette’s CHP analysis because these policies and regulations have a direct impact on the energy market and providers, in addition to the funding and economic incentivizing that is directly related to Lafayette’s ability to enter this green energy market.

State regulations have had a huge influence on CHP because of the complexity between green energy and the grid's infrastructure. As explained in a scientific report on political barriers for CHP, "the Federal Energy Regulatory Commission has authority over inter-, but not intra-state electricity sales, which means that the state electricity policy has an enormous effect on CHP outcomes" (Kalam, 2012). The Pennsylvania Public Utility Commission (PUC) currently plays one of the larger roles within the state's direct influence on CHP initiatives. This team works to balance the needs of energy consumers and providers. They also claim the responsibility of helping to, "foster new technologies and competitive markets in an environmentally sound manner", which include CHP efforts (Pennsylvania Public Utility Commission, 2016). In addition, the 2004 Pennsylvania Alternative Energy Portfolio Standards (AEPS), also referred to as the Clean Energy Standards, requires each electric generation or distribution supplier to supply 18% of its electricity from renewable energy sources by 2020 (Alternative Energy, n.d.). These enforced benchmarks make it easier for businesses and individuals to invest in alternative energy, and to our benefit, in CHP. Throughout 2016, the PUC has been taking more direct action to create CHP specific initiatives. For example, in February there was a press release which announced plans to encourage the use of CHP by requiring natural gas and energy distribution companies to: make CHP an integral part of their energy market, increase CHP marketing to consumers, design tariffs to improve interconnection standards, and to consider providing incentives for CHP customer (Press Release, 2016). While many of these efforts are in progress, they are included in this analysis because they inform us of the current state for renewable-energy promotion. As these efforts continue to evolve, the potential for CHP in Pennsylvania will do the same.

Lafayette College Environmental Policy

While Federal and State policies influence Lafayette's motivations to move toward CHP, the policies and processes for environmental change at Lafayette are one of the most important stakeholders to consider within the whole political context. Without some changes in the energy market, like regulation to stabilize the natural gas market, the ability for Lafayette to choose CHP is restricted. However, once those are sufficiently mobilized, the full weight of the decision-making and feasibility of the CHP model is placed within the bounds of Lafayette's policies and key stakeholders.

The College went through a period of analysis and policy development to set new goals to move the school towards a greener and more energy efficient model after signing the ACUPCC in 2008. There are statements in this model that support the argument of moving to CHP, such as the College's commitment to maintenance, as the Energy Policy states that, "proper maintenance is required to ensure the systems operate as efficiently as possible… [and that] operational procedures will [include] resource conservation practices so as to reduce waste and minimize energy expenditure to the extent possible" (Lafayette College, n.d.). The Energy Policy also states that, "energy efficient products shall be purchased whenever possible… [and that] alternative energy sources such as solar, wind…, co-generation, and energy recovery should be considered" (Lafayette College, n.d.). This commitment by the school effectively keeps the door open for the CHP conversation and is encouraging for future initiatives. Overall this policy puts CHP in a good place to move forward.

Lafayette College Methodology for Change

While Lafayette's has a formal environmental policy is in place, it is necessary to evaluate Lafayette's how change is decided at the College. Like all institutions of substantial size, Lafayette has a set process and line of policies that allow change and decision-making to be implemented through a streamlined and, ideally, bias-free system. We talked with Mary Wilford-Hunt, Director of Facilities Planning and Construction at Lafayette, to gain a better understanding of the decision-making process at Lafayette. She broke down the different ways infrastructural change is implemented at Lafayette and emphasized that one of the biggest determining factors was funding (M. Wilford-Hunt, personal communication, October 19, 2016). From this feedback, we constructed a diagram of the different pathways available to institute change (Appendix A). The left side branch, 'Annual Call to Division Heads', is not likely to be an option for CHP because the changes proposed are typically smaller and more specific to individual departments. CHP and other campus-wide, structural changes would most likely fall under the "Strategic Projects' branch seen in figure 2. From there, the type of funding for the project drives which direction, of the three routes, would fit best. Again, considering the size of CHP and the respectively large initial investment costs, the project would most likely fall into a Master Plan path and be determined by funding available, as seen in the "Importance of Payback" block in Visual 2.

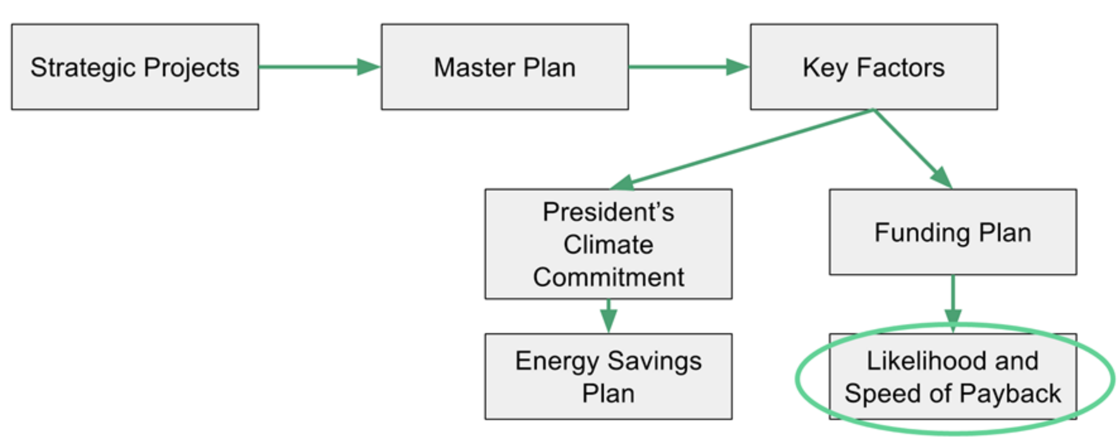

Figure 11: "Strategic Plan" side of Appendix A: Diagram of Change Processes at Lafayette College

If the project was to be considered within the 50-Year Plan, there are revision periods throughout the term that edit and update the plan from a 10-20-year standpoint. In the past, Lafayette has hired consultants to evaluate the campus and develop a plan based on the college's future goals. One of the core visions for Lafayette's campus right now is expansion. While it is unlikely that the school's main initiative would be solely environmental 'greening' of our campus's facilities, other prioritized initiatives could help open the door to opportunities for 'greening', especially considering the President's Climate Commitment. For further analysis of how the student body, faculty, and community organizations can strategically navigate CHP through this system, see the social context section of our report. However, from the results and decision-making end, key political stakeholders include members of the cabinet, in addition to anyone with a connection to funding. The heads of Plant Operations and Facilities Planning additionally hold some influence in the initiatives and implementation strategy.

Conclusion

Overall, the feasibility of CHP from a policy standpoint is dependent on actions from multiple spheres including federal, state, and institutional policy, incentivizing, and process regulation. As a result, there are stakeholders at each level of legislator: federal, state, and institutional. From environmental policymakers at the Capital, to natural gas regulations within the State of PA, as our communities of all scales move in one direction or the next in relation to support for CHP and green energy, the feasibility for a small price school, like Lafayette, to switch to CHP is equally effected. From there, the initiative will have a chance at becoming a reality, depending on how consistently CHP aligns with the future vision for the campus. As of now, while it would be helpful to have more developed federal and state policies to stabilize the natural gas fuel market and to encourage higher efficiency standards in the grand scheme of our feasibility analysis, the influence of these policies is a moderate disadvantage relative to the importance of key stakeholders at Lafayette. Within the Lafayette policy context, there are the energy policies and commitments in place that should support the installation of CHP.

Introduction

This section looks to bring attention to the economic and financial considerations when talking about Combined Heat and Power at Lafayette College. Initially, it is important to realize where this project resides in a larger macro conversation with regards to natural gas and electricity pricing. Moving forward in the section, we shift gears into discussing the scholarly-driven "spark spread" concept to compare natural gas and electricity prices. Types of costs are identified as those being principal or installation, operation and maintenance, and fuel and electricity procurement. Beyond quantifiable costs or benefits, CHP offers various qualitative benefits like grid independence and reductions in CO_2. The bulk of this segment is an engineering economic analysis using largely extrapolated and assumed information of the school's current state and possible future given researched costs of CHP and pricing of natural gas and electricity. The analysis concludes with a summary of present and annual worth analysis of incremental cash flows, as well as a look into payback periods and what Lafayette College needs to consider moving forward.

Market Factors

Combined Heat and Power, from an economic perspective, is highly dependent on fuel prices and procurement. Ideally, Lafayette College will prefer to run its CHP on natural gas. When natural gas prices are low, as they are currently, the price of electricity is also low. The 2012 conversation about CHP varied drastically due to the different energy market. Since the advent of hydraulic fracking in the United States, average wholesale natural gas prices dropped significantly as supply skyrocketed.

Lafayette College Situation

Before going any further, it is important to understand Lafayette College's current conditions. As an institution, the College procures fuel for the boilers to heat the school and electricity from the grid to power it. A large amount of our expenses in utilities lies in electricity purchases from Met-Ed, our electrical provider, making this price highly important in our discussion of CHP feasibility. Met-Ed is part of the larger PJM electrical grid, which includes Pennsylvania, New Jersey, and Maryland. To determine Met-Ed's price, there exists the LMP, which stands for Locational Marginal Price. This price not only takes into consideration the direct cost of the electricity but also includes actual operating condition too (JPM 2016). LMP data is a large factor in decisions around current and future heating and power for Lafayette College (Bruce Feretti, 2016). LMP is also aware of grid strains and efficiencies, which adjust costs appropriately, and for this reason, it is not possible for low-cost generation to be applied throughout the grid system.

Many professors and economists around the United States have tried to understand the economic feasibility of CHP and have gone as far to state that there is a minimum difference between electricity and fuel prices per some unit of energy like therms or mmBTUs that makes CHP beneficial (Mago and Smith, 2014). This minimum difference is known as the "spark spread", and can be displayed as a ratio of these two prices. For our analysis, we do not consider "spark spread" as an indicator of feasibility because of a lack of definitive information from the College's electricity usage and bills. Secondly, information on spark spread lacks a definitive ratio that ensures CHP's competitiveness.

Costs in Combined Heat and Power

What is more valid, in our group's opinion, is to look at the types of cost. Installation of a CHP system will have upfront or principal costs, in the form of installation or investment in the actual system. Annually, CHP systems have costs for fuel, operation and maintenance and electricity (Kalam, King, Moret, Weerasignhe, 2012). Electricity costs will still exist, yet are greatly reduced, as it is largely advisable to have roughly one third of demand covered from grid power. It is hopeful that these annualized costs are below current electricity and natural gas bills.

A perceived benefit to Combined Heat and Power is a reduction in energy costs from natural gas as overall energy consumption is reduced through the increased efficiency of CHP. In our current state, electricity is coming in from the grid to meet an estimated 30,000 MWh demand at unknown prices. What data we have is merely a prediction based off of financial statements. It is assumed that natural gas costs to meet this demand using a Combined Heat and Power system would be cheaper than the current do nothing perspective.

Other Benefits

Beyond quantitative benefits, Lafayette College will see a reduction in CO_2 emissions as part of this reduced energy consumption, which is in line with the mission of the College. Another currently unquantifiable benefit is the independency from the electrical grid. By being able to create power on-site, Lafayette College would be able to separate itself from the dangers of seasonal electricity fluctuations. These fluctuations are impacted by foreign relations and human consumption. (PJM, 2016). In the summer, for example, demand spikes, as more people need to cool their houses, apartments, stores etc. Electricity prices reflect this spike in demand during peak seasons. If everyone cranks on his or her A/Cs, the demand will dramatically increase, and the grid will become strained. To try to accommodate this, supply is shifted and LMP pricing will adjust electricity costs appropriately. Being a part of this larger macro electric system has its downsides as it reacts to seasonal changes in energy usage beyond Lafayette College. A possible benefit, should we choose to keep connection with the grid, is the ability to sell electricity back to the grid during peak loading during summer months (NRDC, 2013). This is especially optimizing for us as a College as our demand drops while students are away on break. Regardless, another benefit tied into grid independence is the ability to be functional during grid outages. This assumes full production of heat and power on-site, something that, as mentioned before, is not entirely advisable. However, as an institution, running classes during blackouts can potentially provide educational benefits that lie outside a dollar value.

Cash Flow Analysis

Getting into the more technical side of the economic analysis, the best way to determine feasibility is to compare cash flows of a CHP reciprocating engine with capacity to meet Lafayette College's heat and power demand, to the do nothing alternative of today. As alluded to earlier, natural gas has proven to be an unpredictable fuel source that highly influences CHP and electricity prices. For this reason, we do not find it beneficial to remain content with Lafayette's feasibility study from 2012, as their data assumes a 2012 cost for electricity and natural gas. Instead, the US Department of Energy provided a catalogue in 2016 of over four major CHP technologies, denoting capital and operating/maintenance costs (DOE, 2016). This data provides a basis for possible principal and O&M expenses for natural gas and steam cogeneration systems.

Using the below Table 1, as provided by the US Department of Energy in July of 2016, we have extrapolated the total plant cost for a reciprocating engine with a nominal capacity of 4000 kW to be roughly $1700/kW and a steam turbine with equal capacity to be roughly $800/kW. Again, it is important to stress that these values are estimates, and do not stand as fact yet provide us with a good jumping off point for our economic examination.

Table 3. Reciprocating Engine Capital and O&M Costs

Description	System				
	1	2	3	4	5
Net Electric Power (kW)	100	633	1,141	3,325	9,341
Engine Type	Rich-burn	Lean-burn	Lean-burn	Lean-burn	Lean-burn
Engine and Generator ($/kW, including heat recovery and emission control)	$1,650	$1,650	$1,380	$1,080	$900
Construction and Installation	$1,250	$1,190	$990	$720	$530
Total Installed Cost	$2,900	$2,840	$2,370	$1,800	$1,430
Total O&M Cost (¢/kWh)	2.4	2.1	1.9	1.6	0.9

Note: *Costs are average values and are not intended to represent a specific product.*

Table 3. Steam Turbine Capital and O&M Costs

Description	System		
	1	2	3
Net Electric Power (kW)	500	3,000	15,000
Steam Turbine and Generator ($/kW)	$668	$401	$392
Installation and Balance of Plant ($/kW, not including boiler and steam system)[6]	$468	$281	$274
Total Installed Cost ($/kW)	$1,136	$682	$666
O&M (¢/kWh, steam turbine and generator)	1.0	0.9	0.6

Figure 12: Reciprocating Engines and Steam Turbine Costs (U.S. Environmental Protection Agency, 2015)

Principal Costs

Likewise, it is important to note that these are average values, not specific to location. Adjusting this project for the Lehigh Valley, we looked at RS Means' localization index to create the most accurate investment price for a 4000 kW reciprocating engine or steam turbine at Lafayette College. This value is 1.042 (RS Means, 2016). By adjusting this initial construction cost for location, and multiplying by the net electric power demand of 4000 kW, we estimate that a reciprocating engine system will have a principal cost $7,085,600 and the steam turbine to have a principal cost of $3,542,800.

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Annual Costs

Mentioned earlier in this economic section, operating and maintenance costs exist and must be accounted for in our analysis. Again, basing our cost estimate off of the US Department of Energy's CHP report with 2016 estimates, we looked at O&M costs per kWh and thought $0.014/kWh to be an appropriate price for reciprocating given the hypothetical capacity. When multiplying these terms by the 40,000,000 kW of natural gas procured, total O&M costs for reciprocating become $560,000. It should be noted that the quantity of natural gas procured is selected with the assumption that these combined heat and power systems function at a conservative 60%.

Natural gas prices were determined by looking at UGI Dec 1, 2015 data on current natural gas prices per mcf, converting to mmBTU, and multiplying it by an approximate 40000 MWh. Paying close attention to units when converting mcf to mmBTU followed by mmBTU to MWh, the following table is produced. This supply makes up a bit more than two thirds of the total MWh of Lafayette College in 2016 of, again an approximate, 30000 MWh. As stated previously, 40000 MWh is used as total procurement of natural gas. The other third is electricity procured from the grid as stated earlier. This other third carries with it a cost derived from JPM's LMP pricing from Met-Ed. An estimated 8000 MWh multiplies the dollar value per MWh set by JPM. Table 2 below has been created above to simplify the associated costs of reciprocating engines and steam turbines.

Costs	Reciprocating Engines	Steam Turbines
Principal	$7,085,600	$3,542,800
Annual >O&M >Natural Gas >Electric	$1,120,625 $560,000 $416,625 $144,000	$880,625 $320,000 $416,625 $144,000

Figure 13: Breakdown of Associated Costs of Reciprocating Engines and Steam Turbines

Assumptions in Analysis

Now we get into the assumptions behind this project's feasibility. As mentioned at the start of this section, natural gas prices are critical concerns for this technology's feasibility. If we are able to meet our energy demand on-site through natural gas at an annual price more attractive than the current model of electricity purchased from Met-Ed, and at a difference large enough to make up the capital cost over its life time, this technology will be economically feasible. To do this, however, we need to make assumptions about natural gas prices at procurement, and inflation rates over the next 20 years. This is something that even the world's best investment banks struggle to do. For this project, we make the risky assumption that natural gas prices and interest rates will remain constant. Thirdly, due to the current lack of 2016 electricity and natural gas cost and usage data at Lafayette College, we are forced to work with a potentially dangerous extrapolation and assumption theory of this information due to Z&F 2012 values compared to Lafayette College's Financial Statements from 2012, 2015, and 2016 (Lafayette College, 2016).

Without an accurate utility bill from the College, our group is left to cross-examine the data from the Z&F 2012 study for electricity and natural gas expenses for the College, we compared this to the Financial Statements from that year and found that electricity made up approximately 70% of the category labeled "utilities" (Lafayette College, 2013). Using this extrapolated data, we went to Lafayette College's Financial Statements for 2015-2016 and approximated 70% of the "Utilities O&M" section. The resulting conclusion is that Lafayette College spends about $ 2,889,453.78 yearly for electricity purchases and steam production under our current system. This quantification is used in calculations throughout the remainder of this report, and therefore carries much weight.

	CHP Reciprocating	CHP Steam	Do Nothing
PW	$ (21,050,831.72)	$ (14,517,151.72)	$ (36,008,373.03)
AW	$ (1,688,890.36)	$ (1,164,757.80)	$ (2,889,453.78)

Figure 14: Present and Annual Worth Calculations

Present and Annual Worth Calculations

Running engineering economic calculations for the three alternatives with a minimal attractive rate of return of 5% per year and a life of 20 years, the following Table 3 is produced.

Looking at the incremental cash flows from a payback period analysis, setting present worth equal to zero, we find that the reciprocating engine CHP has an approximate payback period of 4.1 years and the steam turbine technology to have a brief 1.8 years. This distinction can be largely attributed to the steam turbine's upfront cost being roughly half that of the reciprocating engine, and annual expenditures from operations and maintenance per KWh being a fraction of that for reciprocating engines too. Either way, short payback periods are very important to Lafayette College and make this project economically feasible.

Decisions

Based off of these calculations alone, the steam turbine CHP technology is the most advantageous to Lafayette College as the cost is the least negative presently and over its life cycle. However, due to the interest of increased reliability and the fact that we already have a steam turbine, purchasing a reciprocating engine becomes the next step. In an attempt to compare these CHP two systems to the do nothing alternative, incremental cash flows can be created where the annual cost comes in the form of savings. A cost saving from these technologies is a cash inflow. In other words, since calculated annual costs for O&M and heat/power production is reduced through CHP, these act as savings or cash Lafayette College now "has". Using the same MARR and time period, incremental savings presently and annually are calculated in Table 4 below.

Savings	CHP Reciprocating	CHP Steam
PW	$ 14,957,541.31	$ 21,491,221.31
AW	$ 1,200,563.42	$ 1,724,695.98

Figure 15: Incremental Cash Flows

If Lafayette were prompted with the need to adopt combined heat and power technology, assuming they perform comparably in terms of efficiency as the calculations have assumed, reciprocating engine would be the appropriate alternative. The table above is showing what Lafayette College would experience shifting over to the new technology, as annual costs will drop dramatically, resulting in large savings or fictitious cash inflows. These calculations are all accessible on the excel document on the website, which can be adjusted to yield different results depending on input.

Combined Heat and Power Going Forward

Now that this economic data has been compiled, Lafayette College is again faced with the same questions from 2012. This project is heavily dependent on forecasting, and therefore large amounts of uncertainty. A project with a life of 20 years like this one is tough to fully understand financially as there is a lot of time for market changes. Will natural gas prices spike over the next 20 years due to reduced supply, thus influencing natural gas procurement and electricity grid production? What role will the government have in incentivizing particular fuel sources over others? How will inflation rates, which are dependent on how the Federal Reserve buys and sells federal securities, influence the minimal attractive rate of return for this type of project (Investopedia 2016)? These are all questions, which factor into the overall feeling of uneasiness and uncertainty, which could be an explanation for this technology's denial years ago.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) is a scientific body created by the United Nations to produce objective and scientific conclusions on climate change. In the fifth assessment, harsh and definite words stated that "Human interference with the climate system is occurring, and climate change poses risks for human and natural systems" (IPCC, 2014). The various experiments and data from scientists across the globe have showed that the current warming and extreme weather trends are very likely due to human impact. The 2014 report determines that climate change by humans is leading to deadly and expensive impacts. As such, it has become necessary to value the impacts of human activities on the environment.

Greenhouse gas pollution from fossil fuels is a primary culprit (IPCC - Summary, 2014). The best estimates indicate that about 50% of observed climate change is due to greenhouse gases (NOAA Paleoclimatology Program, 2009) with carbon dioxide equaling 65% of greenhouse gases emissions (Global Greenhouse Gas Emissions Data, 2016). "Carbon dioxide is one of the most important greenhouse gases (GHG) as it traps the solar heat close to the Earth's surface and absorbs infrared radiation at particular wavelength" (Osman, 2006). The current trends show carbon dioxide levels increasing at the same dangerous rate of global temperatures (IPCC - Summary, 2014). The research shows us that we cannot ignore what is happening. If steps are not taken to decrease greenhouse gas emissions, the implications will be deadly.

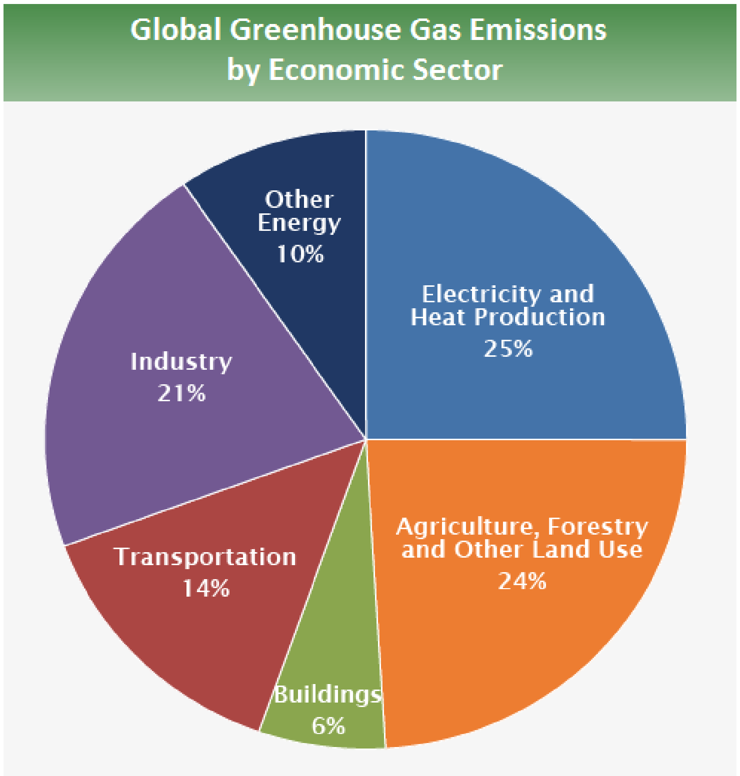


Figure 16: Graph represents information that shows the percent of greenhouse gas emissions from various sector. Information from the IPCC via EPA. (Global Greenhouse Gas Emissions Data, 2016)

Energy and heat consumption and production are extremely important for climate change due to its large impact on GHG emissions. Information from the IPCC report in 2014 shows that GHG emissions from electricity and heat production lead to about 25% of all GHG. With such a large part of the equation, there is a large opportunity to improve GHG emissions in heat and power production. Implementing low-carbon energy options will have the most significant impact on carbon emissions. Low-carbon options include bioenergy, solar energy, geothermal energy, hydropower, ocean energy, and wind energy. Alternative carbon saving options have lower impacts on reducing GHG and climate change, yet are still important opportunities with other fuels (IPCC - Renewable Energy, 2014). Combined heat and power is an energy system option that has been proposed to reduce GHG emission.

An important aspect in determining the feasibility in implementing CHP at Lafayette College's campus understands the environmental benefits and drawbacks. The environmental aspects of CHP pull from social, political, technical, and economical aspects while also having a distinct impact on resource usage and pollution. This analysis presents environmental implications through life cycle analysis, efficiency, infrastructure management, and cultural applications.

Life Cycle Analysis

Life-cycle Analysis (LCA) is a process that evaluates the environmental burden through the identification of inputs, life-cycle chain, products, and emissions. LCA is also known as Life-cycle Assessment, Ecobalance, and Cradle-to-grave Analysis. It is a technique that has various methods and models with numerous different support tools. The basic four steps to LCA are: goal and boundary definition, inventory analysis, impact assessment, and impact interpretation. Most of the differences in LCA come from the goal and boundary definition. Despite the different methods and models, LCAs are extremely helpful in determining both the environmental and economic validity of a product.

Due to the lack of technical information available of Lafayette College's energy usage and steam production, a LCA for implementing CHP on the campus could not be completed at this time. Instead a review of literature on LCA of CHP systems was performed to understand the impact of CHP. It is important to note that this analysis focuses on implementing combined heat and power from a conventional heat generation and grid electricity.

To briefly summarize the research on LCA of CHP, specifically in comparison with conventional systems, combined head and power reduces emissions in the production of heat and electricity at a variation of sizes and fuel types. The case studies and models showed that both the energy generated and energy demand ratio of CHP is more efficient than the conventional system (Keesom, 2009; Dones, 2007) and that the life of the system (construction and hardware, operations and maintenance, decommissioning and disposal) is a reduction of emissions in comparison to the conventional system (Michaelis, 1998; Shen, 2015; Bailis, 2014; Keesom, 2009; Baron, 2004; Kelly, 2014; Osman, 2006; Osman, 2008; Dones, 2007; Roman, 2016; Friesenhan, 2016). The research also showed that the fuel type was important in determining the amount of emissions reductions (Dones, 2007; Osman, 2008, Keesom, 2009). The research showed that for fossil fuel production for combined head and power natural gas had the lowest environmental (emissions and pollution) impact while when only used for electric generation had the highest environmental impact (Osman, 2008). Although there is much to be learned from the various LCAs, the important take away is that implementing CHP from a conventional system will lead to a reduction in heat and electricity generation.

One model that is growing in popularity is the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET). Argonne National Laboratory developed it for vehicles and fleet life cycle analysis. Argonne National Laboratory has constantly updated and upgraded the model so that it has become an expansive vehicle and energy system life-cycle model. Due to the availability and ease, this model is recommended for future modeling of CHP at Lafayette College.

Efficiency

Implementing CHP should lead to major efficiency improvements at Lafayette College, as CHP are fundamentally more efficient systems. Since the objective is to understand CHP in comparison to the current system, the accurate way to compare the systems is through the total efficiency of the system.

$$\eta_o = \frac{W_e + \Sigma Q_{TH}}{Q_{FUEL}}$$

Figure 17: Equation represents the calculation for the total efficiency of a system. (Methods for Calculating Efficiency, 2015)

Determining the efficiency of the system is based off of the fundamental idea of energy in and energy out (Radovic, 1997). It can be calculated by the equation in Figure 17. The variables represent: n_o stands for the system efficiency, W_e for the net useful electric output, Q_{th} stands for the thermal output, and Q_{fuel} is the fuel energy input. Each step of the system from fuel extraction, electric and heat generation, and grid distribution (including lines and connection efficiencies) is important in determining the total system efficiency, with each producing an n_o. To determine the final efficiency the efficiencies of each part of the system are factored together to produce the overall efficiency. Without information on the current systems and its input and output, it is difficult to accurately determine the efficiency of energy and heating generation at Lafayette College.

The current overall efficiency at Lafayette College would be around 30-50% efficient (Cogeneration Plant, 2015; Shen, 2015; Mohan, n.d.). Lafayette College's system efficiency would most likely be lower due to line efficiency (U.S. Energy Information Administration, 2016) and the current steam generation efficiency (B. Ferretti, personal communication, October 13, 2016). While a CHP system at Lafayette College could have 60-90% efficiency, depending on the technical aspects of the system (Cogeneration Plant, 2015; Mohan, n.d.).

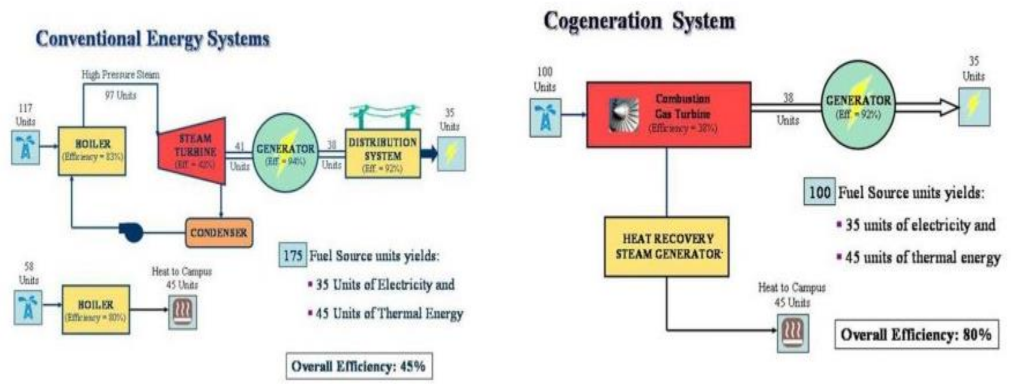


Figure 18: A comparison of the conventional energy system at a college versus a cogeneration system. (Cogeneration Plant, 2015)

The efficiency of CHP would depend on the loads required. The higher the percent loads, the more efficient the electric and thermal efficiency would be, up to 75% part load (Osman, 2006). But with the increased load, comes an increase in pollution. Lafayette College is pursuing a number of expansion projects across campus and all projects will increase the load on campus for both thermal and electric.

TABLE 3: Efficiencies of MT.

	Electrical Efficiency %				Thermal Efficiency %				Overall Efficiency %			
Part Load	*100%*	*75%*	*50%*	*25%*	*100%*	*75%*	*50%*	*25%*	*100%*	*75%*	*50%*	*25%*
60-kW MT	28	24.2	20.0	13.1	52	56.4	56.7	58.0	78.4	80.7	76.7	71.1

TABLE 4: Emission factors of energy systems.

System / Part Load	Electric Grid	Gas Boiler	MT *100%*	MT *75%*	MT *50%*	MT *25%*
PEC [kWh/kWh of energy use]	3.09	1.18	3.99	4.32	5.22	7.97
TOPP [kg TOPP Equiv./kWh]	0.0035	0.00021	0.00083	0.00081	0.0064	0.0038
GWP [kg CO_2 Equiv./kWh]	0.787	0.254	0.749	0.795	1.067	1.479

Figure 19: Table 3 shows the efficiency of different loads. While Table 4 shows the energy use, Tropospheric ozone precursor equivalent TOPP, and CO_2 for different loads. (Osman, 2006)

Ultimately the emissions reductions for Lafayette College will be a result of increased efficiency of the system (Cogeneration Plant, 2015; Hyman, n.d.).

Infrastructure Management

Utility management is planning and operations of above and below ground utilities. The aspects of utility management look at the procurement, generation, distribution, and end-use for energy, heating and cooling, while also considering the potential social and community implications through analyzing how resources are being used and understood. Although there are a number of potential utility management planning and operations implementations this report presents how smart microgrids and tri-generation could improve utility usage at Lafayette College.

A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it in order to efficiently deliver electricity (Hatziargyriou, 2014). Smart grids are more efficient, allow for non-constant energy sources, improve operation and maintenance capabilities, and respond better to extreme weather and disasters (Preparing and Restoring Power, 2016). Smart grids are planed so new technology or systems can be integrated, as the energy field is continuously adapting and changing.

A microgrid is a local energy grid with control capability, meaning it can separate from the grid (Lantero, 2014). Most of the time, microgrids are connected to the national grid but when a disaster strikes it helps isolate a system and keep in online. Microgrids are not new concepts but what makes them different today is the integration with smart grid technology. Some of the many benefits of implementing smart microgrids are that they “enhance local reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially lower costs of energy supply” (Hatziargyriou, 2014, p.24). Another potential benefit is that is can be set up to serve both electric and thermal necessities of local users (Baron, 2004). The different characteristics from a conventional system allow for stronger and more efficient management of the energy system and energy usage. One of the largest potential benefits for microgrids is the integration of renewable energies, in particular solar and wind. Implementing smart microgrid at Lafayette College could allow for future renewable energy construction.

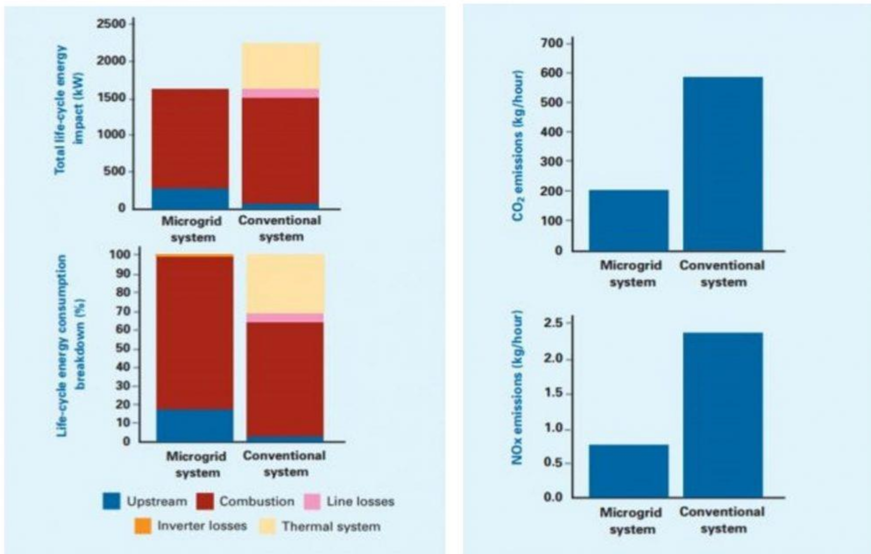


Figure 20: The energy consumption and emissions output of changing from a conventional system to a microgrid system. (Baron, 2004)

To determine the magnitude of potential microgrids in junction with implementing CHP, we can again use LCA. The analysis shows us is that while both systems produce the same amount of energy and heat, it takes less energy to produce and distribute on a local level (Baron, 2004; Hatziargyriou, 2014). When comparing a microgrid and CHP implementation to a conventional system, there are improvements in efficiency and reductions in emissions (Preparing and Restoring Power Grids Using Smart Technologies, 2016). So even when factoring in any construction, maintenance, and disposal, the system has environmental benefits.

Integrating a microgrid at Lafayette College would have social, technical and economic implications, because it would change the conversation around energy. Overall, the system would allow for a local system to be better managed and run, through an increase in data and responsibility. A microgrid would allow Lafayette College to understand how energy is being used and hopefully make changes to decrease loads and usage. It must also be understood that many of the benefits of CHP would not be possible if electricity is connected to the grid instead of being locally distributed to Lafayette College through a smart microgrid. A number of colleges and universities have already seen huge benefits from constructing microgrids (Barnes, 2011).

Trigeneration is one of the most efficient ways for maximizing the utilization of available energy (Mohan, n.d.). Trigeneration or combined cooling, heat and power (CCHP), is the process which heat produced by CHP is used to generate chilled water for air conditioning or refrigeration. Typically an absorption chiller is used to provide the chilled water (Trigeneration, 2016). CCHP has many economic and environmental benefits as trigeneration leads to an increase in energy efficiency, leading to a potential 80-90% efficiency for a CHP system of 50-70% efficiency (Mohan, n.d.). CCHP is not typically recommended for current buildings due to size and cost, but could be a long-term cost effective application for new construction (Nilsson, 2007 pg. 104).

Cultural Applications

When people flip the switch at Lafayette College they think nothing of it. Implementing CHP at Lafayette College will have more impacts then saving energy and reducing pollution. CHP could create a whole new way for the campus to look at energy.

Lafayette College has been working to reduce its emissions yet with building expansion and increased enrollment, net emissions have increased. New buildings are planned such as the 100,000 SF Integrated Science Building and the Multi-Purpose Residence Hall (Byerly, 2016) and they will create increase emissions unless they are built at Zero Net Energy

Building standards. If Lafayette College expects to achieve their goal of reducing its net emissions by 15%, drastic measures are needed.

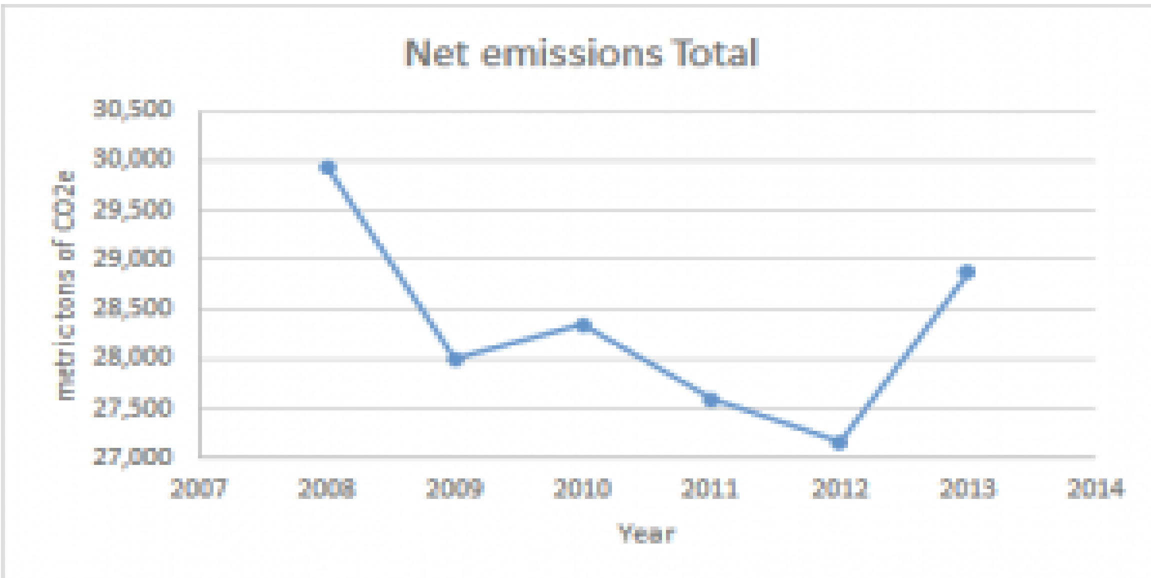


Figure 21: Net total emissions at Lafayette College from 2008 to 2013, data from Second Nature.

Lafayette College can show its commitment to fighting climate change by fulfilling its commitment to reducing emissions and integrating sustainable design. Implementing sustainable development and design in the classroom and across campus is a key to the sustainability and success of college (Majerník, 2015). Some of the benefits of this are that students are better educated and oriented when they graduate and that the College receives long term economic, environmental, and social benefits from the reduction in pollution, decrease in cost burdens, and increase integration across the campus (Majerník, 2015).

The College has already responded to the opportunity to change traditional teaching and research through application of sustainable development and design. Through the environmental engineering degree, engineering studies degree, environmental science degree and various environmental focused design courses, the College has already integrated sustainable design into the curriculum. The College has taken this emphasis a step further by creating a composting program and an organic farm through initiatives started in classrooms or labs. The composting program at Lafayette College has had a long research career through the Society of Environmental Engineers and Scientists (SEES) while also involving student volunteers to help monitor the compost. The organic farm is both a working farm and a community garden that has student employment, EXCEL research opportunities, and community engagement platforms. The farm is also used on various occasions for courses by being a living laboratory for organic farming and community partnerships. Both programs are now valuable and integral parts of Lafayette College that provide educational, economic, and cultural value to campus. Both programs also incorporate a range of disciplines and are representations of the value of a liberal arts degree.

Implementing CHP could go a step further by being not only a product of sustainable design and development at Lafayette College but by also act as a living laboratory. CHP could be used for performance calculations, data reconciliation, instrument bias and stimulation, utility system costing, real gas performance, combustion emissions equilibrium, heat transfer calculations, optimal design and costing, and mechanical repair (Knopf, 2009). Some schools have already integrated CHP into the campus and education experience. Pacific Union College promotes student employment at its 24 hour cogeneration plant (Facilities Management: Cogeneration Plant, 2016). Texas A&M hosts tours at plant. "This year alone, the plant has offered tours to over one thousand visitors. Most of our tours are engineering professors who make the tour part of their class; they will tour early in the semester to get a real-world understanding of the subjects the class covers" (Z. McNew, personal communication, December

5, 2016). Washtenaw Community College in Ann Arbor, MI teaches courses on training future energy professionals on their cogeneration system (Damstra, 2016). LSU goes even further. Models based off real data have been created for courses and labs such as ESRL Module 1 Ideal Gas Performance (Knopf, n.d.). These are all applications that Lafayette College could, and should, implement with the construction of CHP.

Should We Move Away from Fossil Fuels

The biggest environmental issue with CHP is that is still uses fossil fuels as its fuel source. Even with the systems increased efficiency it still produces large environmental impact. Instead of looking to continuing fossil fuel projection, Lafayette College could be looking to implement other renewable energies such as bioenergy, solar energy, geothermal energy, hydropower, ocean energy, and wind energy. The IPCC looked at the current and potential carbon dioxide emissions of different fuel sources. Oil, coal, and natural gas all have higher lifecycle greenhouse gas emissions than renewable energy resources, even at the lowest emissions, without Carbon Dioxide Capture and Sequestration (CCS)(IPCC, 2014). Instead of investing further in fossil fuels, Lafayette College should invest in creating a smart microgrid and connecting renewable energies, as this would have a better impact on the environment (Osman, 2006; IPCC 2014; Shen 2015).

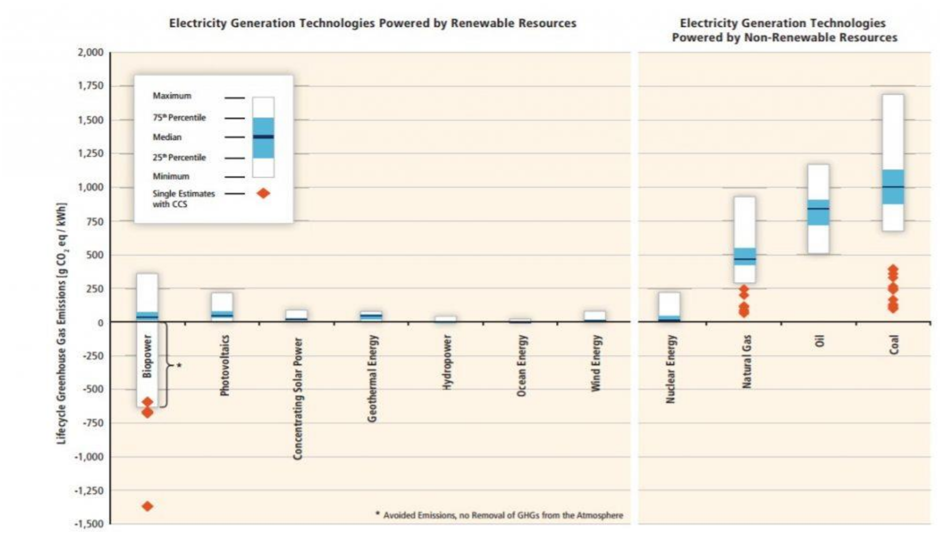


Figure 22: Lifecycle Greenhouse gas emissions for various fuel resources. (IPCC - Summary, 2014)

Despite these concerns about the continuation of fossil fuel usage, CHP is still recommended. This is due to the simple technical application of CHP for Lafayette College and the quick environmental and economic benefits. Lafayette College is a very close to having CHP and implementing it would be a step in the right direction. The environmental research and analysis conducted showed that in comparison to a conventional system, CHP has a reduced environmental impact. If Lafayette College was considering constructing a whole new natural gas CHP plant, this report would most likely produce a different recommendation.

Recommendations

Overall, Lafayette College could achieve a number of environmental benefits from implementing CHP at Lafayette College. The system is a more efficiency system that would increase Lafayette College's responsibility on generation and consumption. Regardless, Lafayette

College should consider constructing a smart microgrid that would allow for better utility management and future renewable energy growth.

After analyzing the social, technical, policy, economic, and environmental aspects, we have determined that due to the high potential benefits of Combined Heat and Power at Lafayette College, implementation of the integrated heat and energy systems should be pursued. The technical, economic and environmental sections of this report, although inconclusive due to the lack of Lafayette College data, showed tremendous potential. While the political and social sections presented both supportive and deterring situations and politics that will act as supports and hurdles for CHP applications as it has in the past. The sections each produce varying recommendations that are important as CHP moves forward.

Conclusions and Next Steps

Social analysis showed that implementing CHP at Lafayette College is feasible, but it is heavily reliant upon student understanding, interest, and initiative, as well as available funds that need to be specifically geared towards updating our College's facilities. We concluded that the feasibility will be directly dependent on the support by the Master Planning Committee. Moving forward support from the new sustainability coordinator and energy manager on campus will be key to gain support. As the campus moves forward with its expansion, it will be important to integrate CHP into the process.

The technical analysis concluded an initial recommended the prime mover, the generator, and the distribution grid configuration for implementation of CHP. Lafayette College is very close to having an operational Combined Heat and Power system technically. There are very few technical challenges/decisions to overcome. The next steps for the technical aspect of CHP will be finalizing the recommendation based for Lafayette College's current system and energy and steam data.

Conclusion

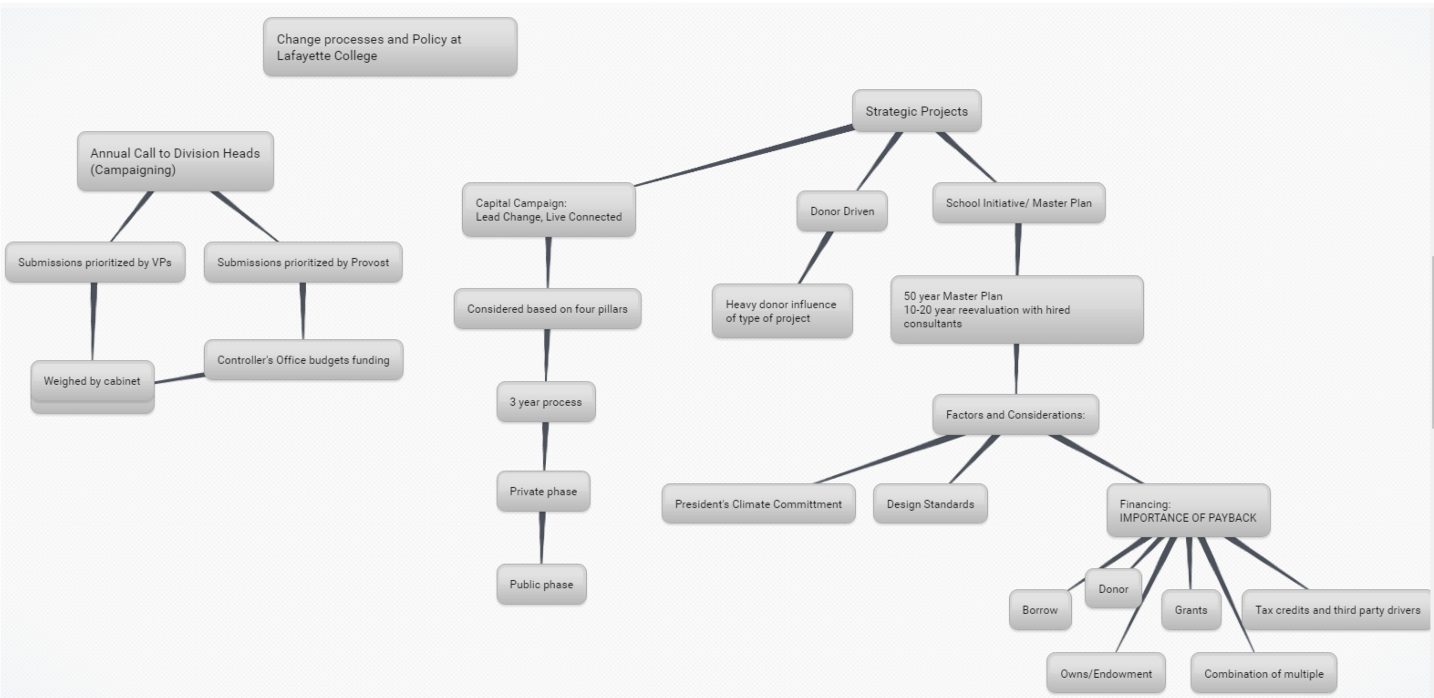
The policy feasibility of CHP is dependent on actions from multiple spheres including federal, states, and institutional policy, incentivizing, and process regulation. Although there are some aspects that help promote CHP, it would be helpful to have more developed federal and state policies to stabilize the natural gas fuel market and to encourage higher efficiency standards in the grand scheme of our feasibility analysis. The influence of these policies is a moderate disadvantage relative to the important of key stakeholders at Lafayette. Within the Lafayette policy analysis, there are the energy policies and commitments in place that should support the installation of CHP.

The economic analysis concluded that based off the basic information available steam turbines would be the appropriate application for economic return. Shifting over to the new technology would lead to drops in annual costs, resulting in large savings or fictitious cash inflows. This analysis will need to be finalized for Lafayette's College's current system and energy and steam data.

Environmental context showed that Lafayette College could achieve several environmental benefits from implementing CHP at Lafayette College. The CHP is more efficient system that would potentially reduce emissions while also increasing Lafayette College's responsibility on generation and consumption. Similarly to the economic and technical analysis, the environmental assements, including the Life-cycle Analysis and system efficiency, will need to be completed from Lafayette College's current systems, energy and stead data. Additionally, the College should consider the benefits of implementing a smart microgrid regardless of CHP.

We hope that the analyses and recommendations presented in this report will help reignite the conversation around energy production at Lafayette College as the campus grows and changes over the new few years.

Appendix A: Diagram of Change Processes at Lafayette College



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