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

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PROJECT GOAL AND ACKNOWLEDGEMENTS

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 faculty and students. Overall, in order for CHP to gain momentum, there needs to be a better understanding of CHP 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 the Engineering Studies, Chemical Engineering, Mechanical Engineering departments, as well as within the Facilities Operations and Planning and Construction division, in helping us define the problem and providing insight into understanding discussions previously held about the technology's feasibility.

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INTRODUCTION

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 and has been considered at Lafayette College in the past. 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. In an effort 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.

Problem Definition

Based on our research and analysis of the College, we were able to recognize that while there are environmental initiatives growing and thriving on campus, the magnitude of a change like CHP is a much larger proposition. As a result, we were faced with the challenge of how to help CHP gain enough momentum to be a competitive initiative amongst these other pressing priorities. Because 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. Our greatest challenge in accomplishing this was acquiring the necessary data and statistics from Lafayette to fully complete a detailed feasibility analysis. However, regardless, we feel we came away with a strong summary of the relationship between Lafayette and the CHP conversation for future advocates.

Results

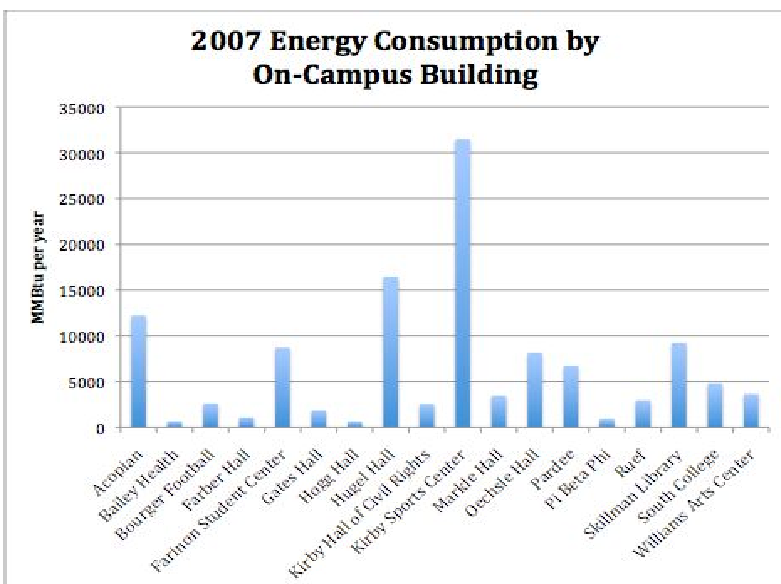
Contrary to our initial hypotheses, our analysis of the Technical and Economic aspects of CHP were not the areas that swayed our results in our feasibility analysis. Because we concluded in each of these sections that the feasibility of CHP from these perspectives is high, we were able to identify that 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 restrains 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.

SOCIAL ANALYSIS

Introduction

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 Combined Heat and Power (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, n.d., p. 8). If a nearby school of similar size was able to implement CHP on campus almost two decades ago, why hasn't Lafayette College?

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. The issue is 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. Two significant studies the college invested in—an energy audit conducted by Entech Engineering and a proposal (Figure 1) for CHP at Lafayette College by Z&F Consulting—as well as three reports written by the College, clearly demonstrate that the college is aware of the energy changes that need to be made in order to reduce our College's Greenhouse Gas (GHG) emissions.



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

Figure 1 (right): Z&F Consulting's proposal for CHP at Lafayette College in August of 2012.

Figure 2 (left): A selection of On-Campus Building's Energy Consumption from Entech's 2007 Energy Audit (Lafayette College, 2011, p. 20).

In accordance with the American College and University Presidents' Climate Commitment (ACUPCC), Lafayette College has prepared and completed three Greenhouse Gas Inventory Reports. The most recent inventory, which analyzes years 2005 through 2013, found that the two largest sources of GHG emissions were from the purchase of electricity from Metropolitan Edison for campus buildings, and from the purchase of natural gas and fuel oil for the on-site boiler plant that provides most of the campus's heat and hot water (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).

In 2007, Entech Engineering was hired by Lafayette College to investigate the amount of energy consumed by campus facilities in order to better understand the College's energy production, consumption, and efficiencies. The study discovered that the science and engineering buildings and Kirby Sports Center are the significant contributors to the College's emissions, as shown in Figure 2 (Lafayette College, 2011, p.18). 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).

One of the biggest issues with the College's Energy Policy is that much of it focuses on the consumption aspect of the energy discussion, rather than the production side (Lafayette College, n.d.). Most of Lafayette's specific energy policy measures are limited in enforcement, as they are heavily reliant on student and faculty's actions. Consistent with the College's Energy Policy, the Climate Action Plan (CAP) states that, "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 truth of the matter is, there are funds available. The issue is, the College administration does not view CHP as a priority.

The CAP states that, "The College has committed to invest $400,000 per year for 10 years (2010 through 2020) to finance the scheduled ECMs [energy conservation measures]. The scheduled ECMs are those projects with the shortest payback period and largest MtCO2e reductions" (Lafayette College, 2011, p. 3). Unfortunately, the cost to implement CHP at Lafayette College would exceed this amount, as determined in the economic section. The problem is, 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 Lafayette to spend its money, compared to new constructions on campus such as the Oeschle Center for Global Education, the Arts Plaza, the new Integrated Science Center, and the proposed glass elevator.

Considering the fact that our College's facilities need to be moved in order to construct the new Integrated Science Center, and the fact 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, CHP must be made a priority by Lafayette College's administration. In order for CHP to have any future potential at Lafayette College, it is imperative that the College views implementing CHP as an opportunity for our institution to be a model for healthier energy use practices.

TECHNICAL ANALYSIS

Introduction

Based on research and interviews conducted with Lafayette personnel, this technical analysis makes the following suggestions for each of the components included in the college CHP system.

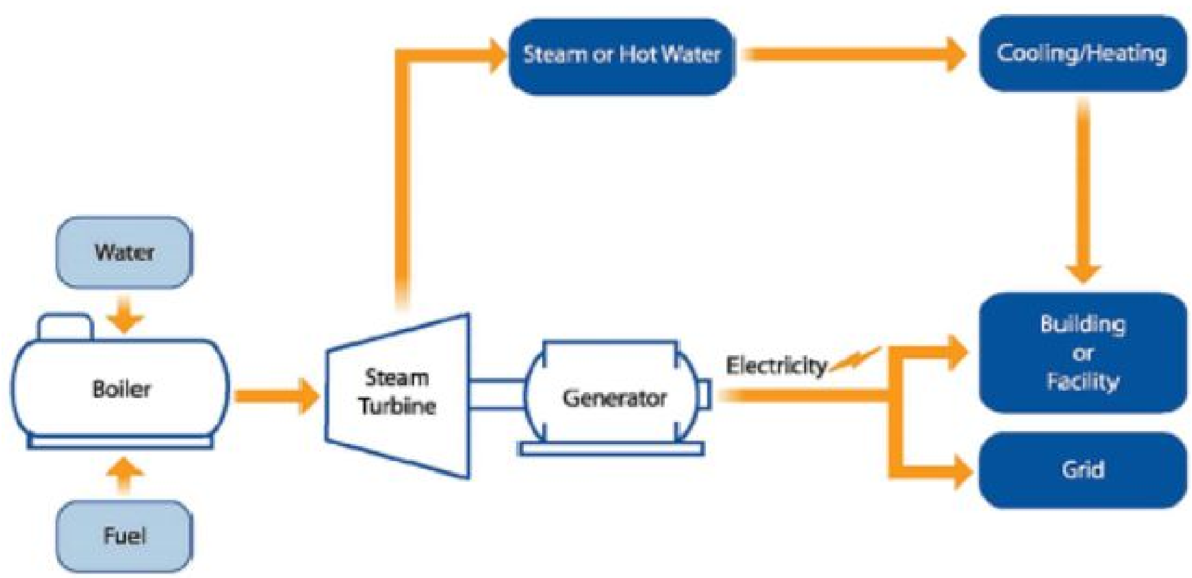


Figure 3: Steam Turbine Combined Heat and Power Diagram (Pew Center on Global Climate Change [Pew] 2011)

Prime Mover

The current central heating system and distribution at Lafayette College exists as a steam turbine system. Also, Lafayette College has expressed a desire to have reciprocating engines in order to enhance reliability and efficiency of the system. This feasibility assessment suggests that Lafayette College maintain the existing steam turbine system as the prime mover and install reciprocating engines as the best option available based on the research to date.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 include, the ability to operate using a variety of fuels, high reliability, and the ability to meet multiple heat grade requirements. 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, and enhance overall reliability and efficiency (Pew, 2011).

Generators

Lafayette College as 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. To satisfy the desires/wants of Lafayette College this feasibility assessment suggests that Lafayette College install synchronous generators. Synchronous generators are self-excited, 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. Synchronous generators are more complex and costly in order to safely connect to the grid because the interconnection must ensure that when the grid is de-energized the CHP system does not export back to the grid. A benefit of synchronous generators is that they provide greater electrical power reliability to customers. In addition, these 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).

Distribution Grid Configuration

This feasibility assessment suggests Lafayette College to utilize a radial system, which is based on the research done on the two types of distribution systems applicable to CHP systems. Although Lafayette College is already successfully connected to the distribution grid, the radial system for CHP is still suggested for Lafayette College. Radial systems are the most common type of distribution grid systems 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 customer 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 preferred system to interconnect with CHP systems because they are easiest and least costly (Midwest, 2007).

Figure 4: A CHP Plant in the Netherlands; www.robertharding.com

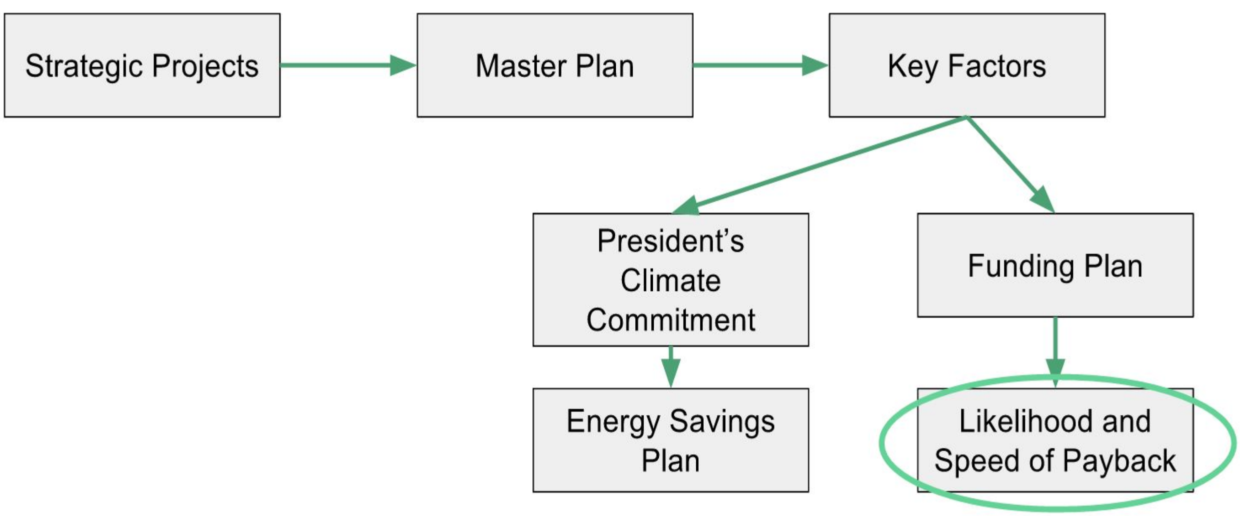


Figure 5: Lafayette College Change Implementation Tree

Introduction

The Policy Analysis section of our report focused on how the influence of internal processes and external incentivizing might affect the overall feasibility for implementing CHP on Lafayette's campus. It was important to look at the problem from a political standpoint to help identify regulatory factors that are beneficial or detrimental to CHP's implementation, and additionally, what would need to change, if anything, in order to make CHP a reality in the future.

CHP in a Larger Political Context

Because the political feasibility at Lafayette is dependent on actions from multiple spheres of politics, including federal, state, and institutional levels, we found that Lafayette has less control over some of the challenges presented within policy. For example, as evaluated from an economic perspective as well, the instability of the natural gas fuel market has started conversations about the need for government regulation in order to assist in furthering green initiatives. Our analysis considered the Netherlands as an example for how to do so and then went on to evaluate the current state of our own policy from a state and federal level. We found that while there are existing committees for environmental growth and general policies to incentivize green energy, there needs to be more that specifically addresses CHP technology and fuel standards if there is to be a direct positive impact on CHP at Lafayette. There are new conversations emerging, specifically at the state level which look optimistic towards incentivizing fuel providers to assist CHP customers.

Lafayette's Policy Perspective

Taking a closer look at the institutional level, we evaluated the policies that determine how changes are made at Lafayette, in addition to any environmental goals and commitments already in place. According descriptions from Mary Wilford-Hunt, Director of Facilities Planning and Construction at Lafayette, we constructed the diagram pictured in Figure 5 to demonstrate the different ways that infrastructural changes are made. We found that most influential factor that would determine which of the proposed changes were implemented was funding.

As far as environmental commitments go, Lafayette signed the President's Climate Condition in 2008 and additionally added environmental sustainability to its values statement. Although there was some concerned raised in our Social Analysis about how influential these commitments are to CHP's feasibility and overall likelihood, from a strict policy standpoint, the official statements are in place that should support the idea of moving towards a CHP model.

Decision

Overall, from a political perspective, we determined that CHP is feasible, although there are always improvements that could be made. As state and federal initiatives continue to evolve, the feasibility of CHP will only improve. The biggest challenges that remains is the stability of the natural gas fuel market, and we believe that regulation in that area would greatly increase Lafayette's ability to comfortably move to Combined Heat and Power.

ECONOMIC ANALYSIS

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

Table 1: Breakdown of Associated Costs of Reciprocating Engines and Steam Turbines

	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)

Table 2: Present and Annual Worth Calculations

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

Table 3: Incremental Cash Flows

Introduction

This section looks to bring attention to the economic and financial considerations when talking about combined heat and power and Lafayette College. Initially, it is important to realize where this projects resides in a larger macro light in regards to natural gas and electricity pricing. Moving forward in the section, the subject matter shifts towards the scholarly-driven discussion of “spark spread” to compare these prices. Types of costs are identified too, 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. A brief conclusion is offered based off of present and annual worth analysis of incremental cash flows, as well as a breakeven analysis to give a sense of payback periods.

Cash Flow Analysis

Using data tables on CHP costs from the US Department of Energy in July of 2016, Table 1 to the left has been created to simplify calculated associated costs of reciprocating engines and steam turbines (US Dept. of Energy 2016). 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, Table 2 was produced to aid in our analysis.

Comparisons to Current System

Looking at the incremental cash flows from a payback period analysis, setting present worth equal to zero, we found 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.

Decision

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. 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 3 on the side.

If Lafayette were prompted with the need to adopt a combined heat and power technology, assuming they perform comparably in terms of efficiency as the calculations have assumed, steam turbines would be the appropriate alternative. Table 3 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.

ENVIRONMENTAL/ENERGY ANALYSIS

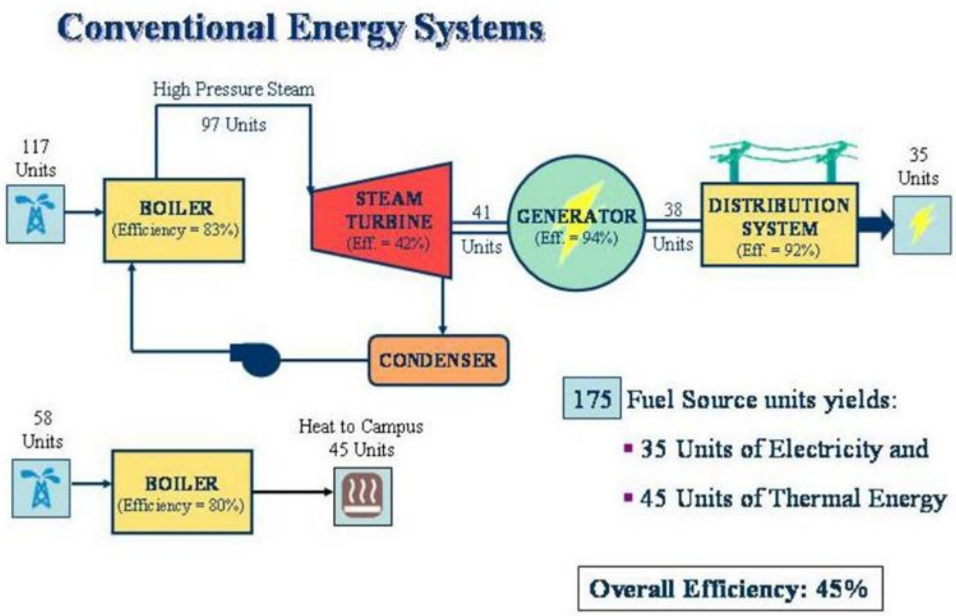


Figure 6: Conventional Lafayette College Production Efficiency (Cogeneration Plant, 2015)

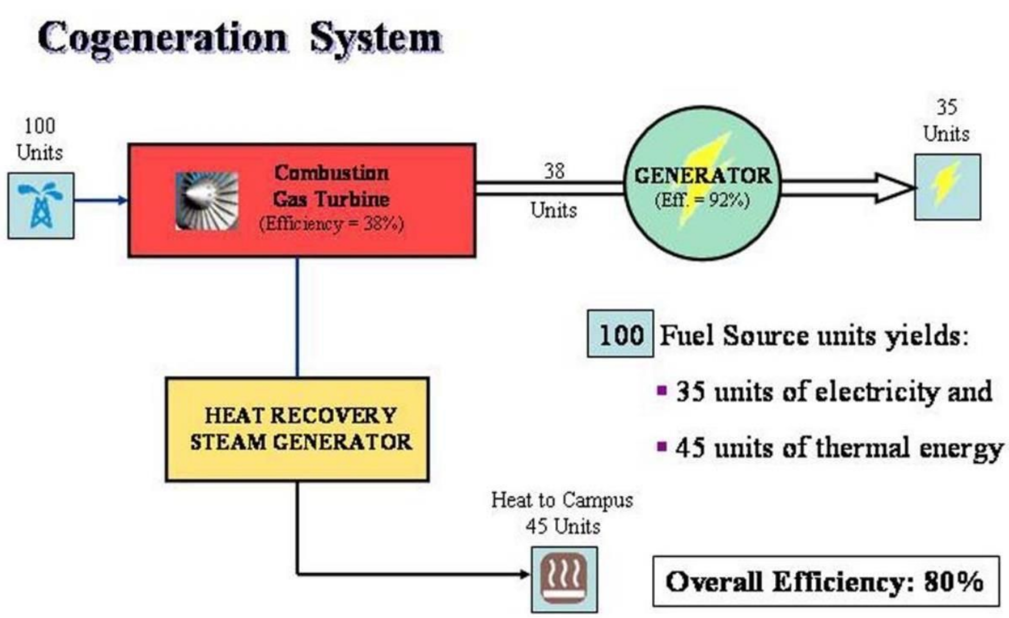


Figure 7: CHP Production Efficiency (Cogeneration Plant, 2015)

Introduction

An important aspect in determining the feasibility in implementing CHP at Lafayette College's campus is understanding the Environmental benefits and drawbacks. The environmental aspect of CHP pull from the aforementioned contexts while having a distinct impact in relationship to 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. In comparison with conventional systems LCA showed that CHP reduces emissions in the production in heat and electricity at a variation of sizes and fuel types. The 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 reduced emissions in comparison to the conventional system (Michaelis, 1998; Shen, 2015; Bailis, 2014; Keesom, 2009; Kelly, 2014; Osman, 2006; Osman, 2008; Dones, 2007; Roman, 2016; Friesenhan, 2016). Switching to CHP from a conventional system will lead to a reduction in heat and electricity generation.

Efficiency

Implementing CHP will lead to major efficiency improvements at Lafayette College, as CHP are fundamentally more efficient systems. The current system at Lafayette College overall efficiency would be around 30-50% efficient (Cogeneration Plant at Amherst College, 2015; Shen, 2015; Mohan). There is a change that this is even lower, depending on the efficiency of the boilers. While a CHP system at Lafayette College could have a 60-90% efficiency, depending on the technical aspects of the system(Cogeneration Plant at Amherst College, 2015; Shen, 2015; Mohan). Emissions will be reduced at Lafayette College with CHP's increased efficiency.

Cultural Applications

Implementing CHP would go a step further by being not only a product of sustainable design and development at Lafayette College but 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 through student employment, tours for courses, and real data classroom and lab lessons. These are all applications that Lafayette College could, and should, implement with the construction of CHP.

Recommendation

Overall, Lafayette College could achieve a number of environmental benefits from implementing CHP. CHP is a more efficient system that potentially reduce emissions while also increasing Lafayette College's responsibility on generation and consumption.

CONCLUSION

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 system 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 factors that will act as supports and hurdles for future CHP conversations. The sections each produce varying recommendations that are important as CHP moves forward.

Next Steps

Social analysis showed that implementing CHP at Lafayette College is feasible, but it is heavily reliant upon community awareness, 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 its support by the Master Planning Committee. Moving forward, support from the new sustainability coordinator and energy manager on campus will be key to initiating new conversations. 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. From a strictly technical perspective, Lafayette College is very close to having an operational Combined Heat and Power system. There are very few technical challenges to overcome. The next steps for the technical aspect of CHP will be finalizing the recommendations based for Lafayette College's current system and energy and steam data.

The policy feasibility of CHP is dependent on actions from multiple spheres including federal, state, 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 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.

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 a decrease in annual cost, resulting in large savings or fictitious cash inflows. This analysis will need to be finalized for Lafayette College's current system and energy and steam data.

Environmental analysis showed that Lafayette College could achieve several environmental benefits from implementing CHP at Lafayette College. Environmental assessments, including LCA Analysis and system efficiency, from data on Lafayette College will need to be completed to fully understand the environmental benefits. Additionally, Lafayette

College should consider the many benefits of implementing a smart microgrid regardless of CHP.

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