Energy Savings Project: On-site Cogeneration Plant

Final Report

Engineering 333 Section B

To: Professor M. Heun and Jack Phillips

Date: December 19, 2017

Objective

Currently, Calvin College spends $2.8M on electricity and natural gas. In the recent past Calvin has alleviated some of these costs by running a cogeneration system that combusts fuel and produces electricity and heat, this old system has since been removed due to age. With the old system removed Calvin is fully reliant on grid, leading to increased electricity cost. In addition to saving Calvin money, President Leroy formally signed the President's Carbon Commitment that announced Calvin's intent to be Carbon neutral by 2057. To meet both the cost and emissions saving needs, the objective of the energy savings project is: What would it take for Calvin to save $150,000 per year on energy costs (mostly electricity) using a new on-site cogeneration system.

Methods & Analysis

The class split up into 5 teams to accomplish the goal of saving $150k in electricity cost. Teams can be seen in Table 1.

Table 1: Class Breakdown

Section-Group	Team
B-1	Engine Selection
B-2	Interconnections
B-3	Natural Gas Savings
B-4	CO2 Savings
B-5	Finance

Each team began the semester with research around Calvin's current energy and heat consumption. The engine selection research consisted of obtaining information on various types of cogeneration systems. It involved exploring and comparing technical specifications between the different engine types, as well as different models and manufacturers. The interconnection team focused their research on the electrical and heating loops of the college and how the new co-gen unit would fit into Calvin's current infrastructure. This team considered where the new unit would go, the structure to house the unit, and how it would tie into Calvin's energy system. The natural gas saving team calculated the entire project savings. This team calculated the cost to produce electricity with the co-gen compared to current usage. On top of electrical savings, the cogeneration system will provide additional savings on heating costs. The CO_2 savings team broke up their research into three sections: primary emissions, secondary emissions, and post processing. Their goal was to determine if the college would produce fewer primary emissions, getting one step closer to carbon neutrality. In looking at the secondary emissions the team chose to only consider emissions relating to the steel production of the engine, natural gas harvesting, and construction materials of the building. Finally, the finance team assigned one person to each of the other teams to determine the financial costs and savings within each section, then combined those values to determine a final annual savings value.

Conclusions & Recommendations

From the team's research and analysis, the GE Jenbacher 4 J416 GS-B86 cogeneration system was selected to provide electricity and heat to Calvin College's campus. This system was selected because it can operate continuously to provide a baseline electricity output to the campus, as well as the fact that Calvin's physical plant was familiar with this type of engine, and the maintenance it requires. The proposed system would be installed on the south-east side of Commons Dining Hall as a part of further expansion plans with a projected infrastructure cost of $93,000. The project was projected to save $504,000 on electricity and heat annually if fully funded, and $420,000 annually if paying off a four year loan. The monthly savings of electricity costs for Calvin's campus are shown in Figure 1. In addition to financial savings, the cogeneration system is projected to reduce carbon emissions of the central campus by 25%, and reduce Calvin's heating costs by up to 30%.

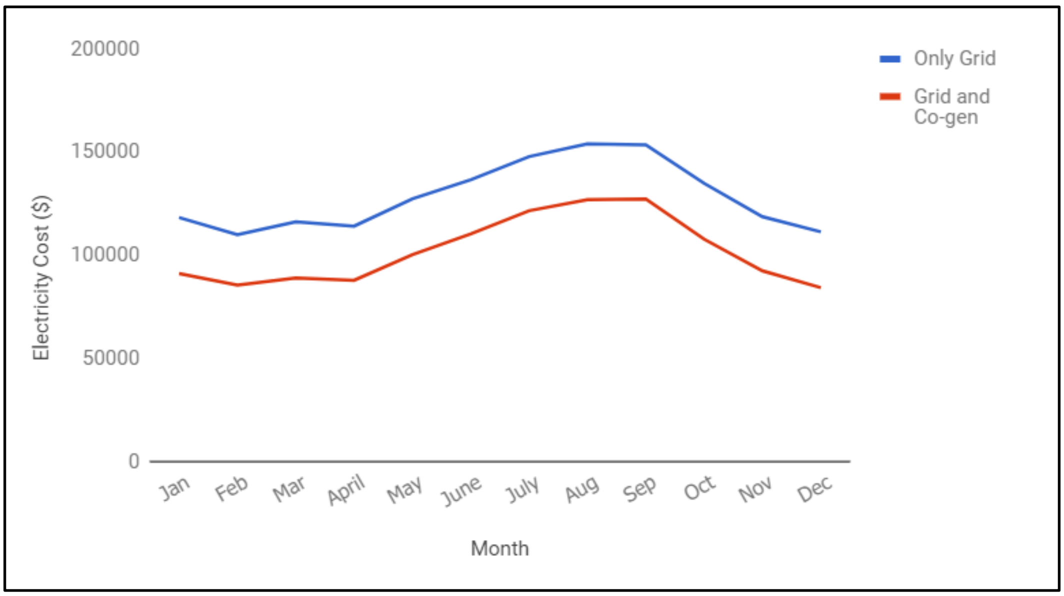

Figure 1: Electrical Savings with the Cogeneration System.

The purchase and implementation of this cogeneration plant would be a massive step forward towards making Calvin College a carbon neutral campus, as pledged by President LeRoy on December 7, 2017 in his signing of the President's Carbon Commitment. Since the results immediate cost savings and environmental benefits, the cogeneration project is recommended to be implemented as soon as possible.

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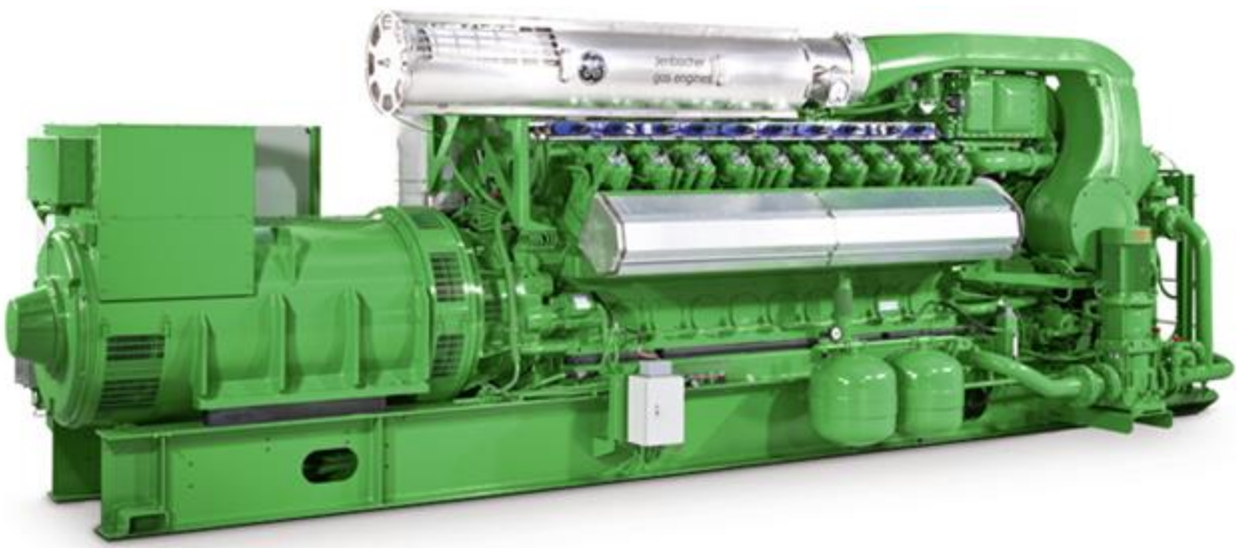
Appendix 1 - Engine Selection



https://www.google.com/search?q=ge+

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Objective

The objective of the Engine Selection group was to research potential natural gas fueled cogeneration systems for the campus, and to select a specific system based on analysis of Calvin's yearly electricity consumption.

Research

The initial research conducted by the engine selection group revolved around comparing different types of cogeneration engines. Two main types were considered: gas turbine engines and reciprocating engines. Gas turbine engines utilize the Brayton cycle to produce power and consist of a rotating compressor and turbine connected via a shaft, with a combustion chamber located between them. They are used to power jet aircraft, trains, ships, and high output electrical power plants. Reciprocating engines utilize the Otto cycle to produce power, where fuel combusts to force a piston to reciprocate inside a cylinder to rotate a crankshaft. These engines are most commonly used in automobiles, but are used in electrical power generation as well. Since both types of engines are able to provide cogeneration to the campus, it was essential to explore and compare technical specifications between the two engine types, as well as different models and manufacturers. Some important engine specifications are: power output, overall size, engine cycle, fuel consumption, and efficiencies. Three companies that produce cogeneration engines with a wide range of engine sizes are: Kawasaki, Enerblu, GE. These companies provided numerous options for selecting an engine.

Methods & Analysis

The electrical usage of Calvin's campus from 5/31/2016 to 5/31/2017 was obtained from Daniel Slager, the Energy Management Technician. Data points for the electrical consumption of the campus were provided in 15 minute intervals and plotted to examine the minimum and peak loads. The power consumption profile on the day of maximum electrical usage, which occurred in September 2016, is shown in Figure 1.A.1. Further analysis showed the maximum load experienced on campus was 5.25 MW, and a minimum of 1.34 MW. Three methods of sizing the cogeneration system were considered given the load characteristics.

The first sizing method covers all electrical usage with the cogeneration engine. A minimum power production of 5.25 MW would be needed from the system to accommodate the load at any given time. During times of excess production, the excess electrical power produced by the system would be sold back to Consumers Energy, the power provider that services Calvin's electrical grid.

The second option sizes the engine for the median load experienced by campus (approximately 3 MW). During times of supply shortage, Calvin would purchase power from Consumers Energy and sell back power during times of excess production.

The last option for sizing the system has a production rate equal to the minimum load. The rest of the electrical energy required by the campus would be purchased from the grid, since the system would not produce enough energy to cover the campus requirement. The system would run all year, with the exception of 10% maintenance time (90% utilization).

Results

After researching multiple engines, the Engine Selection team decided to select GE's Jenbacher Type 4 J416 GS-B86 cogeneration engine. There were numerous reasons involved in this selection.

First, Jack Phillips, the mechanical assistant director at the Calvin College Physical Plant, told the team that Calvin wanted an engine with an electrical power output of 1 MW. Having an engine with an electrical power output of 1 MW would allow Calvin to constantly have the engine running without having to worry about producing more than the college requires. By not producing more power than needed, Calvin would not have to deal with trying to sell power back to the grid at a lower rate than it would cost to purchase. GE's Jenbacher Type 4 J416 GS-B86 cogeneration engine has an electrical power output of 1.14 MW, which successfully meets Calvin's requirement.

Secondly, communication with GE Power was remarkable. The GE representative Jared Cherni was eager to communicate with the Engine Selection team and provided information readily, unlike many of the other companies that were considered. Contacting companies such as Enerblu and Kawasaki proved difficult; Enerblu is located in Italy, and communication was hampered by the time difference, whereas Kawasaki was slow at responding.

Finally, the Jenbacher Type 4 J416 GS-B86 is similar to the previous cogeneration engine that Calvin once had. The Jenbacher Type 4 runs on an Otto cycle to produce power, like the previous cogeneration engine. Having the new cogeneration engine be similar to the previous engine is an additional benefit to Calvin's Physical Plant employees, as the employees will be familiar with this type of engine, and the maintenance it will require. This feature will come in handy for installing the engine and for maintenance in the future. Additionally, GE Power includes a multi-year agreement for maintenance parts with the purchase of the Jenbacher Type 4 engine, making it easy for Calvin's Physical Plant to obtain parts needed for repairs. Using the cost of natural gas obtained from the natural gas savings group, it was calculated that this engine costs $0.038 / kWh to run, which is around $0.04 / kWh less expensive than purchasing directly from Consumers Energy. These calculations can be seen in Appendix 1.C.

Conclusions & Recommendations

To conclude, the Engine Selection team chose the Jenbacher Type 4 J416 GS-B86 cogeneration engine from GE. With an electrical power output of 1.14 MW, this engine best fit Calvin's electricity demands. Having a cogeneration engine with a power output slightly less than what the campus continuously consumes allows Calvin to run the engine constantly to provide a baseline power output. The overall cost of the engine, assuming that Calvin’s Physical Plant employees would install the engine themselves, is approximately $1.4 million. The total savings accrued from using this engine is $500,000/year, which leads to an overall project payback period of three years.

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Appendix 1.A: Maximum Daily Electricity Consumption

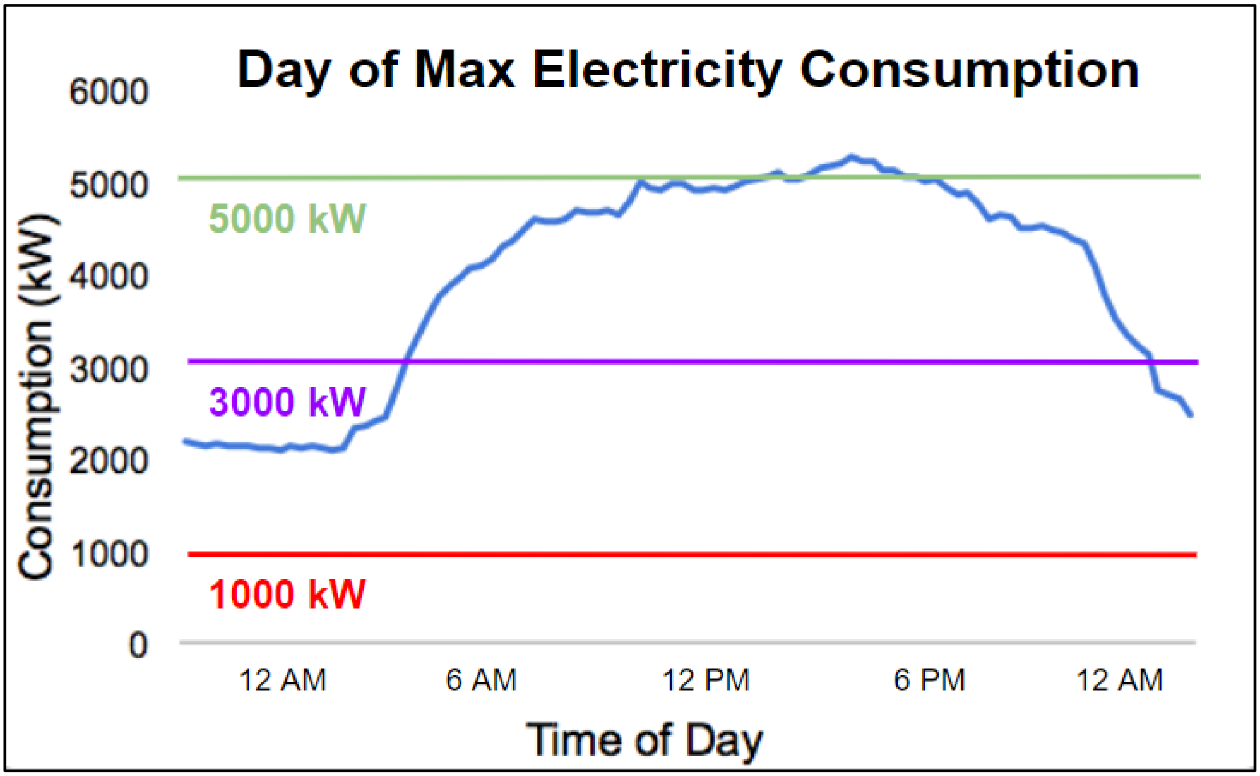

Figure 1.A.1: Maximum Power Consumption Profile with Engine Sizing Considerations

Appendix 1.B: GE Jenbacher J416 Product Specifications

Table 1.B.1: Technical Specifications of GE J416 Cogeneration System

Jenbacher Type 4	J416
Electrical Output (kW)	1137
Energy Input (kW)	2754
Thermal Efficiency	47.1 %
Electrical Efficiency	41.3 %
Total Efficiency	88.4 %
Dimensions [LxWxH]	40.3 ft x 9.9 ft x 8.9 ft
Weight (kg)	14,100

Appendix 1.C: Engine Fuel Cost Calculations

Unit cost of Fuel (Natural Gas):

$$\frac{\$0.53}{100\ ft^3}\left(\frac{100\ ft^3}{2.83\ m^3}\right)=\frac{\$0.187}{m^3}$$

[1.C.1]

Fuel Flow Rate (Energy Input):

$$2754\ \frac{kJ}{s}\left(\frac{1\ m^3}{43{,}000\ kJ}\right)=0.064\ \frac{m^3}{s}\ \rightarrow 230.6\ \frac{m^3}{h}$$

[1.C.2]

Fuel Cost Rate:

$$230.6\ \frac{m^3}{h}\left(\frac{\$0.187}{m^3}\right)=\frac{\$43.12}{h}$$

[1.C.3]

Cost per kWh:

$$\frac{\$43.12/h}{1137\ kW}=\frac{\$0.038}{kWh}$$

[1.C.4]

<u>Energy Saving Project: On-site Cogeneration Plant</u>

Appendix 2 - Interconnections

https://www.google.com/search?q=

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Objective

The interconnections team was tasked with determining the location and interconnections for the new cogeneration plant. The new cogeneration plant would need to tie into the current infrastructure for heating and providing electricity at Calvin. Installation and housing for the new cogeneration were also considered by the team.

Research

In 1990, Calvin installed a Superior model 6GTLB-1 cogeneration unit, which was installed on the lower level of Commons Dining Hall. It was located in the same room as the Commons Power Plant and tied into the boilers housed there. Three cinder block walls were then constructed around the cogeneration unit, essentially closing it off from the rest of the power plant room other than two access doors. While operating, this unit provided 585-600 KW of electricity to campus as well as 2,548,474 Btu for campus heating. Eventually the old cogeneration unit became too expensive to repair as replacement parts became hard to find. In the early 2000's Calvin stopped operating the cogeneration unit and recently dismantled it. Due to the small enclosure area and limited space in the Commons Power Plant room, the unit had to be taken apart and removed in pieces.

Heating of the main campus is done using hot water distributed throughout campus. Boilers from four different power plants located around campus provide this hot water. Knollcrest Power Plant feeds hot water to the residence halls on the north east side of campus. The Commons Power Plant, Engineering Power plant, and Library Power plant provide the hot water for the remaining residence halls and academic buildings as well as DeVos Communications Center and the Prince Conference Center. Buildings outside the main campus loop such as the physical plant, Knollcrest East Apartments, and seminary have their own heating. A drawing of Calvin's heating system can be seen in Appendix 2.B**.**

Electricity from Consumers Energy enters campus on the east side of campus by the Knollcrest East Apartments and is distributed at 12,470 Volts. From the substation it is distributed on the east side of campus then crosses underground under the Beltline where it loops around the main campus. Each building steps down the voltage to 480 Volts. Redundancies are in place within the loop incase a line breaks and power is lost to a portion of campus. All power lines are underground for safety and aesthetic purposes. A drawing of Calvin's primary electric lines can be seen in Appendix 2.A**.**

Methods & Analysis

While designing the space and interconnections for the new cogeneration unit, several constraints guided the team while making decisions. The new cogeneration unit needed to connect to the current Calvin infrastructure of heating and electricity. The building would need to accommodate installation of such a large machine as well as not hinder maintenance. The machine would produce exhaust which would need to be vented to the roof or other non-populated area. Aesthetically the building would need to fit into the current campus look and not be an eyesore. The sound of the machine would also need to be dissipated to a safe level and not be an annoyance to those in the area. Three different design locations were considered by the interconnections team and assessed based off the constraints and input from Calvin's Physical Plant.

Design Constraints

One of the primary constraints the team considered was ease of access, and therefore ease of maintaining the cogeneration plant. One prominent complaint on Calvin's previous cogeneration plant was the location. This engine sat in the basement of Commons, with quick access that a maintenance truck could get to. This made general care, routine inspection and part replacement much more laborious. The team wanted to prevent any further experience of this nature, and aimed to keep the new cogeneration location at ground level, and with one quick-access door that would drive-up maintenance.

A second constraint was to put the cogeneration plant in a location on campus that tied in easily with the pre-existing infrastructure on campus. To guide this decision, figures in Appendices 2.A and 2.B were referenced frequently. The unit would have to be placed in a location such that there would be minimal work to connect power output to the campus grid, and vice versa for the campus heating loop. Proximity of the location to the underground infrastructure was certainly considered.

The cogeneration system also could not be out of place with regard to public spaces. The new housing for this plant was to fit the aesthetic of Calvin's campus, and also not detract from current commonly used spaces. The risk of students, staff, faculty and campus visitors thinking of this addition as a campus eyesore was considered when determining location.

Design Alternatives

Consideration 1: Old co-gen location

The first location considered by the interconnections team was in the same location as the old co-gen, in the Commons basement. The attractiveness of this option is that the heating and electricity loops already pass through there, so tying into the existing loops would be made very easy. The old co-gen used steam in which the heat was transferred into the water based heating loops, so there are already steam to water heat exchangers at the location. At the time this location was considered, the exact engine was not known. As it turned out, the engine we chose used water, so no conversion would be needed.

The main issue with this location is that the existing co-gen room is less than half the size needed for the proposed co-gen. To install the new co-gen in this location, some major deconstruction of the inner room and Commons east wall would need to take place, as well as further external construction to fully house it. This location makes installation and maintenance of the engine extremely inconvenient for the maintenance staff.

Figure 2.1: Installation of Previous Co-gen (1990)

Consideration 2: New student union (Calvin Master Plan)

The second location considered by the interconnections team was an extension onto the upcoming student union. According to the Calvin Master Plan, there will be a new student union connecting the Calvin Crossing, Hekman Library, and the Covenant Fine Arts Center (CFAC). Construction of this new student union is planned to begin 5-7 years from now, which is when the co-gen would be implemented. Besides the existing construction plans, a major benefit of having the co-gen in this location is placing redundancy in the main electricity loop. As seen in Appendix 2A, electricity from the grid enters Calvin at a substation along Burton St. on east campus, to which it then crosses East Beltline and connects to the main electricity loop that feeds all the academic buildings, dining halls, and dorms. At the substation, the electricity splits in two directions but then converges under the north CFAC parking lot, before connecting to the main loop. Having the co-gen at the new student union would force there to be redundancy in the electricity main, so that if there were to ever be a break in the electricity line under the north CFAC parking lot, west campus would still have power. Another benefit is that there are already hot water pipes located underneath the new student union location, minimizing the need for additional infrastructure.

The main issue with having the new co-gen in this location is that the shed or extension would likely be a major aesthetic eyesore or loud. The new student union is likely to be made out of a lot of glass and other sleek looking construction materials. If Calvin wanted this shed to aesthetically conform to the student union, then glass would likely be used, showcasing the dirty engine room. If this was the case, the engine would be very loud as well. If Calvin wanted the engine noise to be muffled, then a brick shed matching the rest of campus could be used, making it an eyesore compared to the student union. The new student union would likely be the crown jewel of Calvin, showcasing campus, and a co-gen in this location would likely inhibit that. It should also be noted that the construction of the student union itself ought to fix the redundancy issue.

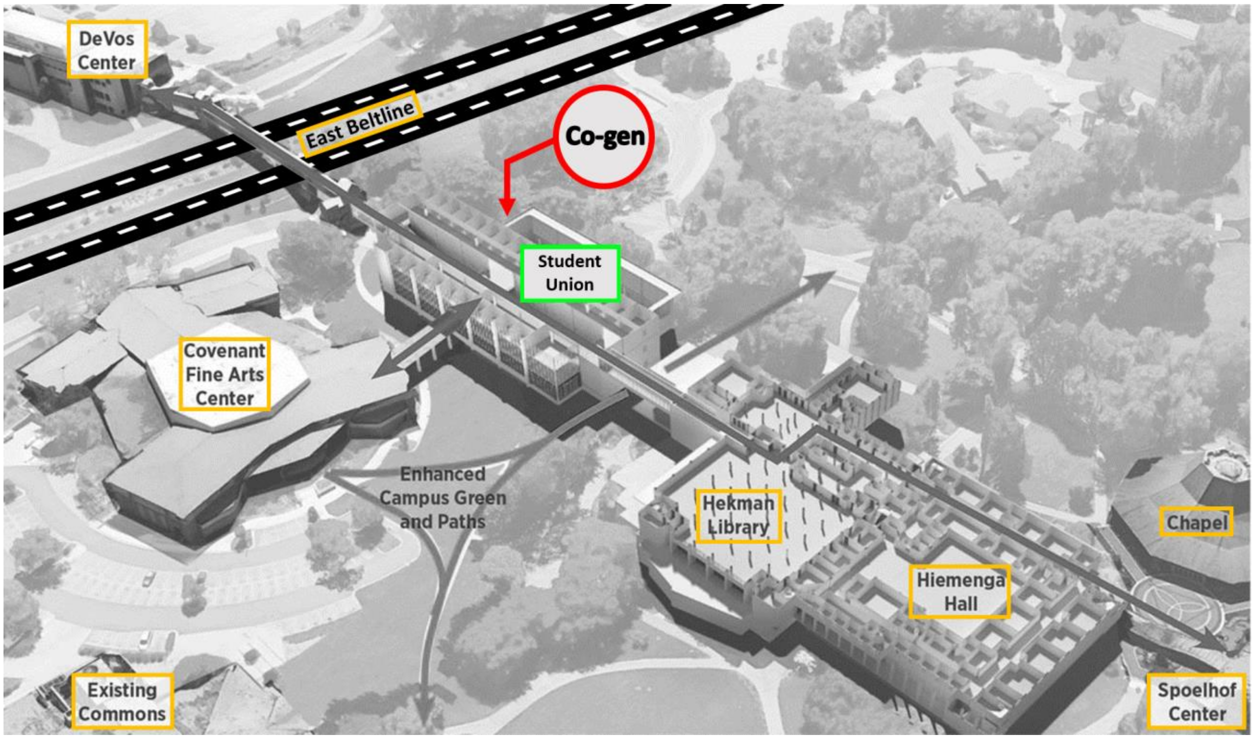

Figure 2.2: Consideration 2- Near New Student Union

Results

Proposed Location

The third location considered by the interconnections team was an extension onto the upcoming loading dock expansion to the existing Commons building. According to the Director of Mechanical of Physical Plant, this expansion of two semi-truck loading docks will be completed 1-8 years from now, which is when the co-gen could be implemented. The major benefit of having the co-gen in this location is the accessibility to already present infrastructure from the previous system. Fewer pipes and other necessary hardware would need to be installed at this location. Another benefit to this location is that of having more machines in one location makes for easier operation for physical plant as there is already two main campus boilers in this location. The only drawback would be the concern of noise pollution to the nearest residents hall.

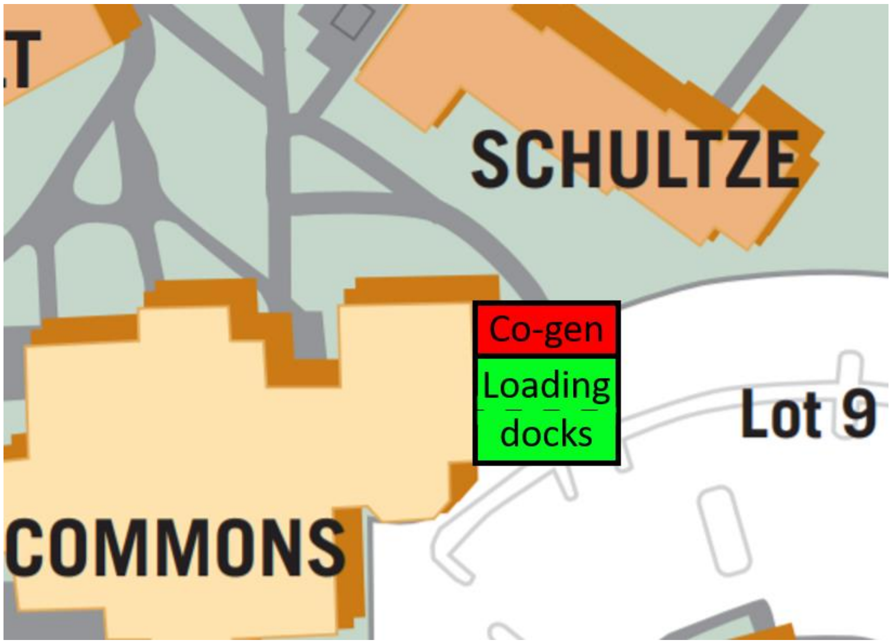

Figure 2.3: Proposed Co-gen Location

Sound Considerations

One the biggest complaints commonly made in a community of individuals living together is noise pollution, whether that's someone mowing their lawn, music to loud or even dogs barking. Society likes to keep everything industrial separated from that of residential, for this very reason sound pollution from this cogeneration plant was a very real concern. Several proposals were made for the final location of the co-gen plant the best proposal was placing it in an addition to the already existing Commons mechanical room; the biggest concern was the impact the plant would have on the residents of Schultze-Eldersveld, a nearby calvin dorm. The interconnections team took the sound magnitude data that GE provided for the chosen co-gen system, and met with Professor Dejong the resident sound, and vibrations expert here at Calvin College. The meeting not only gave clarity to what the given data ment, but also gave a direction to go towards to insure the safety and satisfaction of those living around it. The co-gen plant produced 100 dB one meter away and using a simple Inverse Square Law equation which can be seen below:

$$\frac{I_2}{I_1} = \left[\frac{d_1}{d_2}\right]^2 \qquad [2.1]$$

The sound level can be computed as result of distance from the source. It was than determined that with use of a sound deadening material made by a company called All Noise Control, the magnitude of sound could be reduced from 100 dB to less than that of a normal conversation in less than 65 feet from the source. Refer to Appendix 2.D for graphical representations of calculated sound behavior.

Conclusions & Recommendations

The interconnections team would recommend placing the new co-gen unit on the east side of Commons as a part of the future loading dock expansion plan. This would cost Calvin an estimated $93,000. The infrastructure is already present in this location, thus reducing the potential cost of construction. A new building allows for easy installation, plenty of room for maintenance, and easy removal if need be in the future. Once constructed, and with sound insulation, the housing structure will deaden the sound pollution to a level that is hardly detectable. This location best meets the needs of the new cogeneration unit and Calvin College.

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Appendix 2.A:Campus Main Electricity Loop

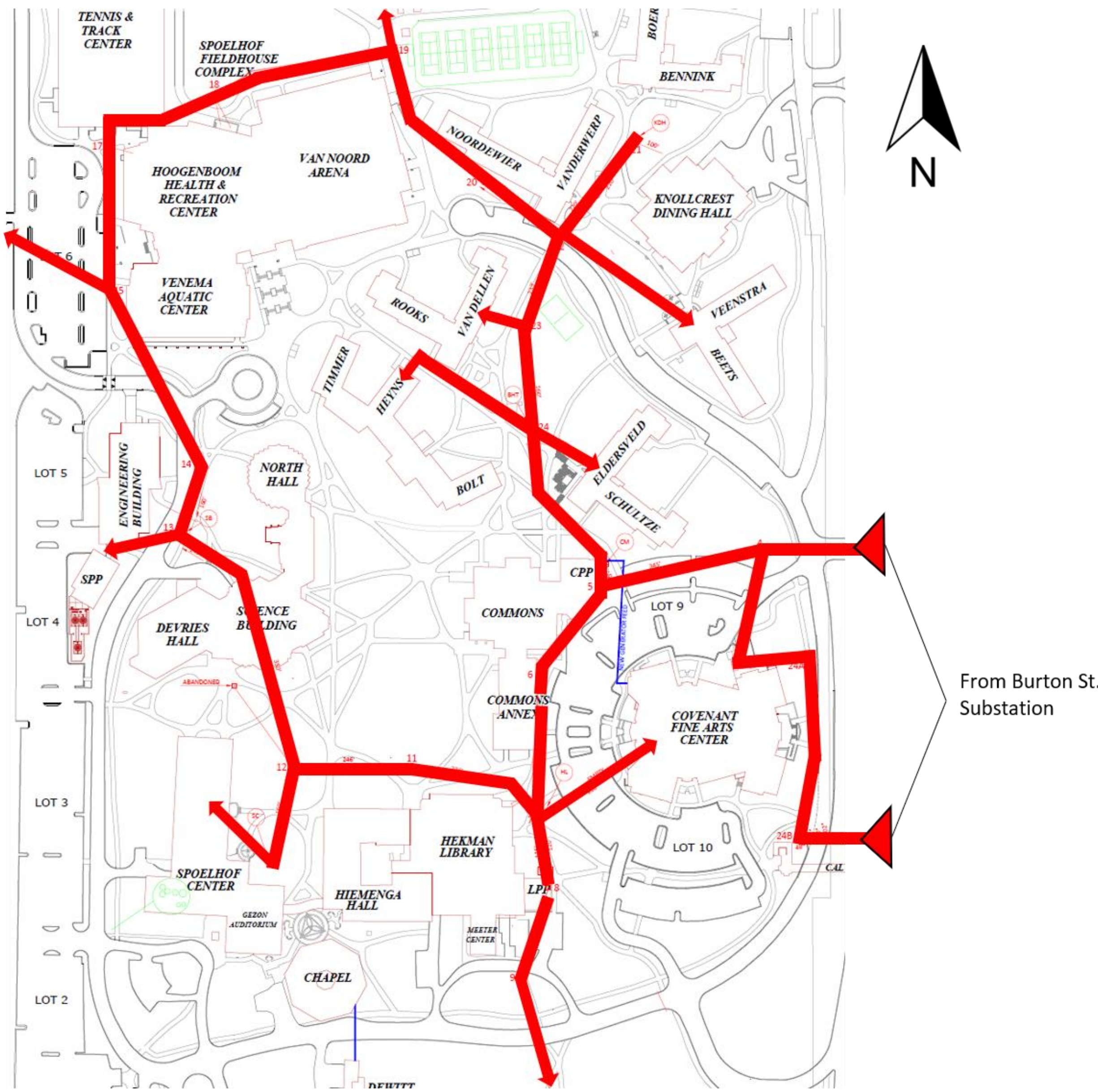


Figure 2.A.1: Campus Main Electricity Loop

Appendix 2.B: Campus Main Heating Loop

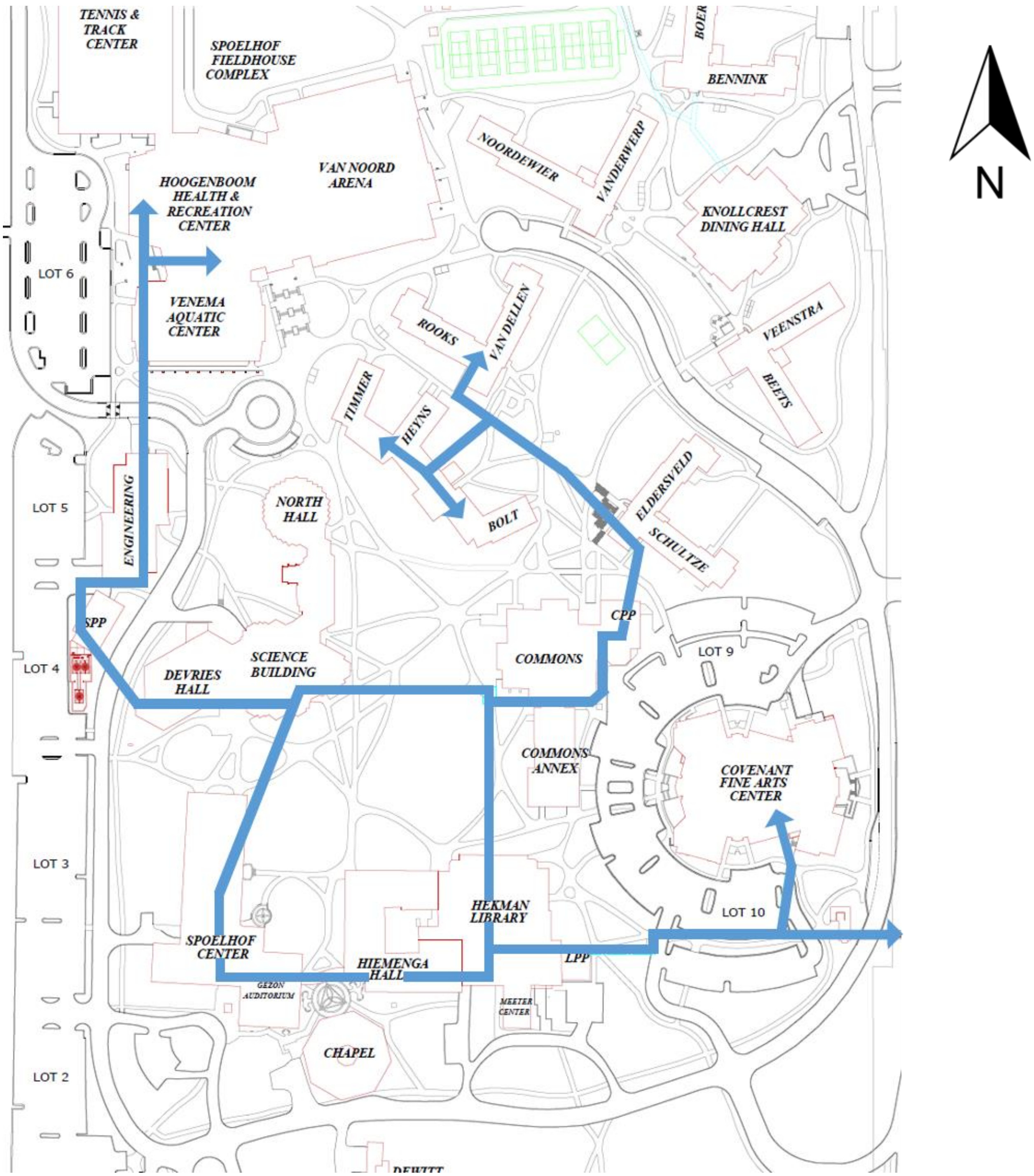
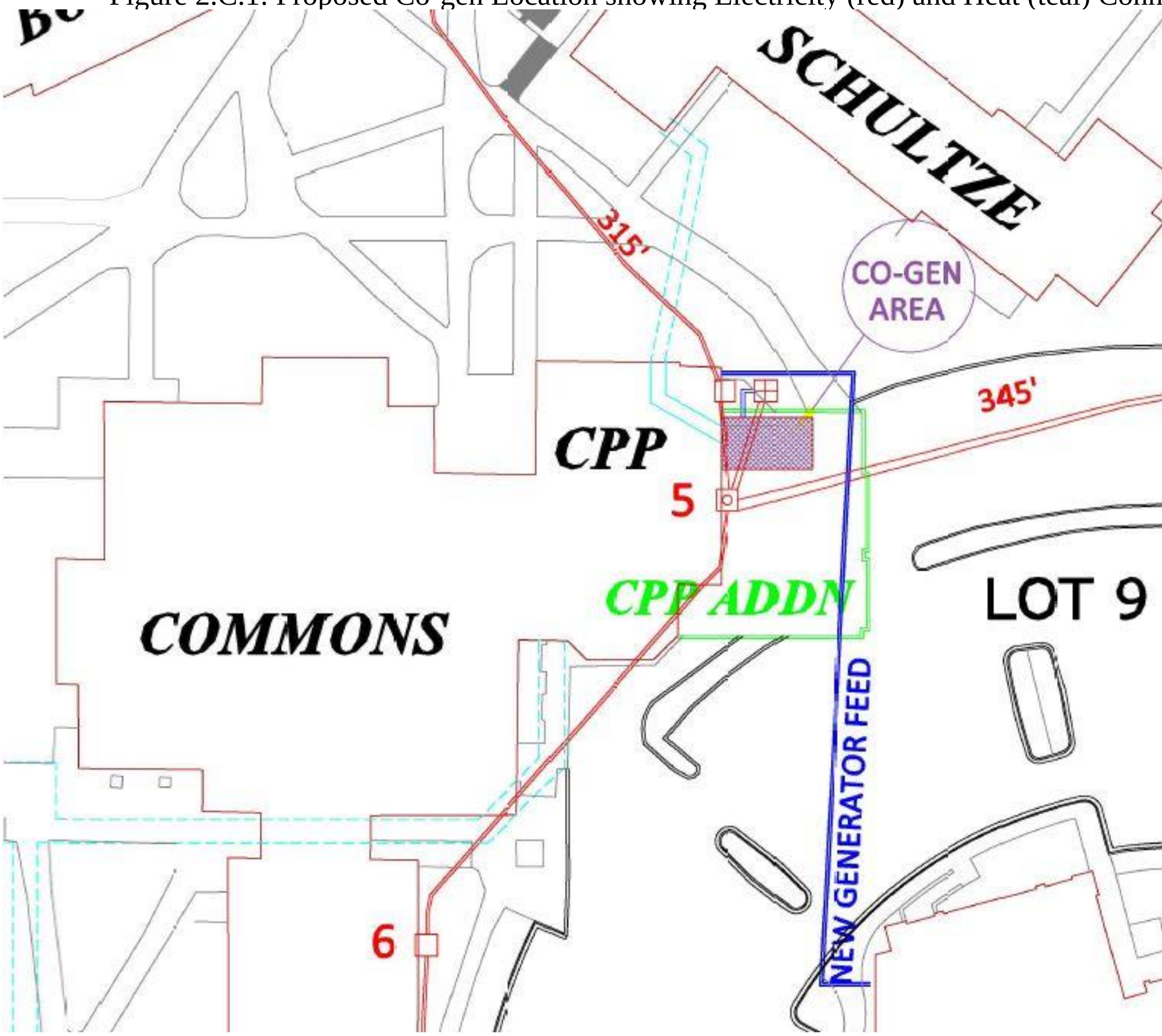


Figure 2.B.1: Campus Main Heating Loop

Appendix 2.C: Proposed Location

Figure 2.C.1: Proposed Co-gen Location showing Electricity (red) and Heat (teal) Connections



Appendix 2.D: Estimated Sound Level Behavior

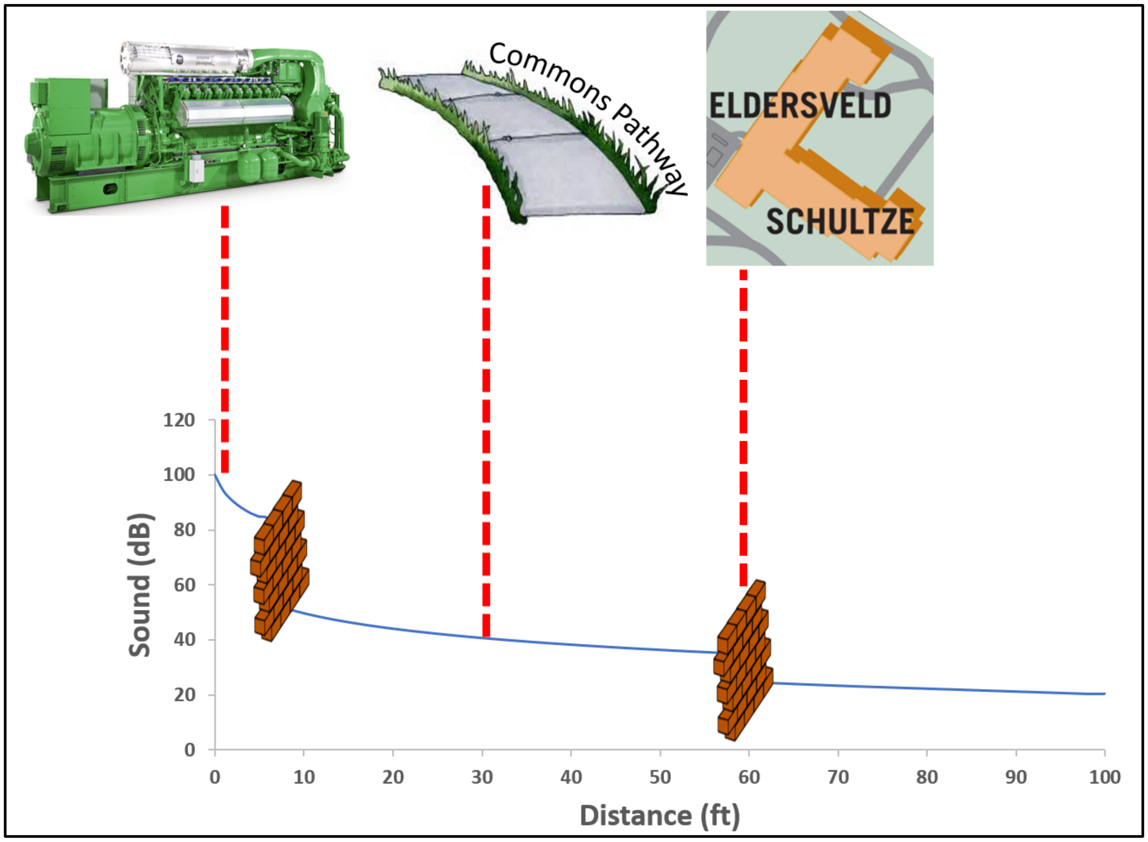


Figure 2.D.1: Sound as a Function of Distance from Co-gen

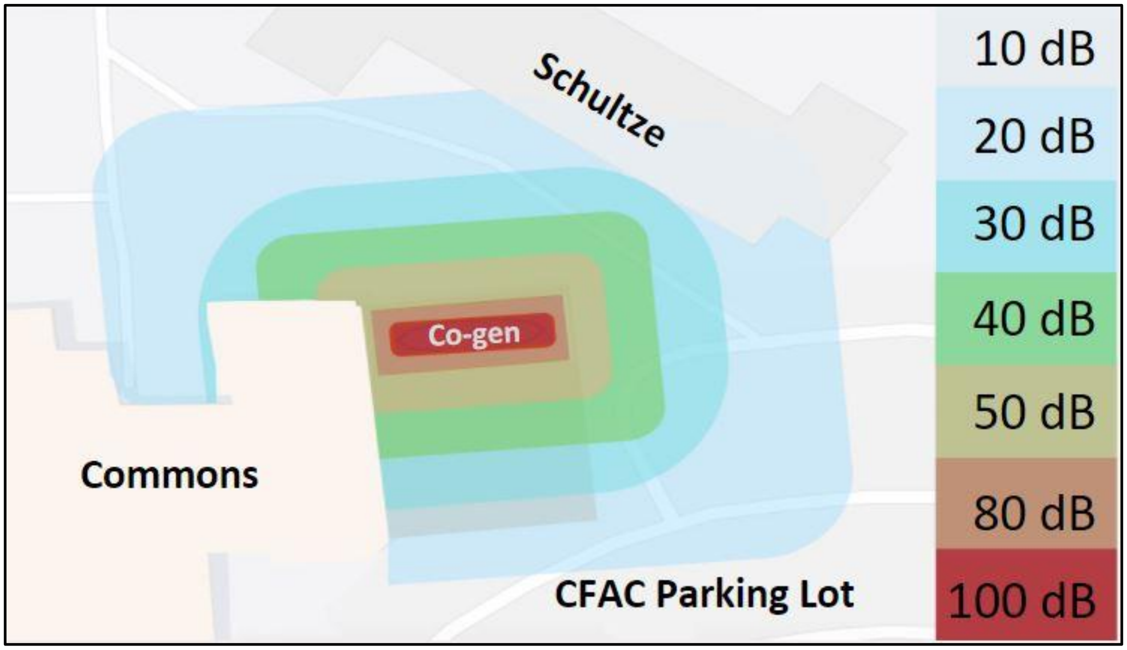


Figure 2.D.2: Sound Map for Proposed Co-gen Location

Appendix 2.E: Crane & Gantry Costing

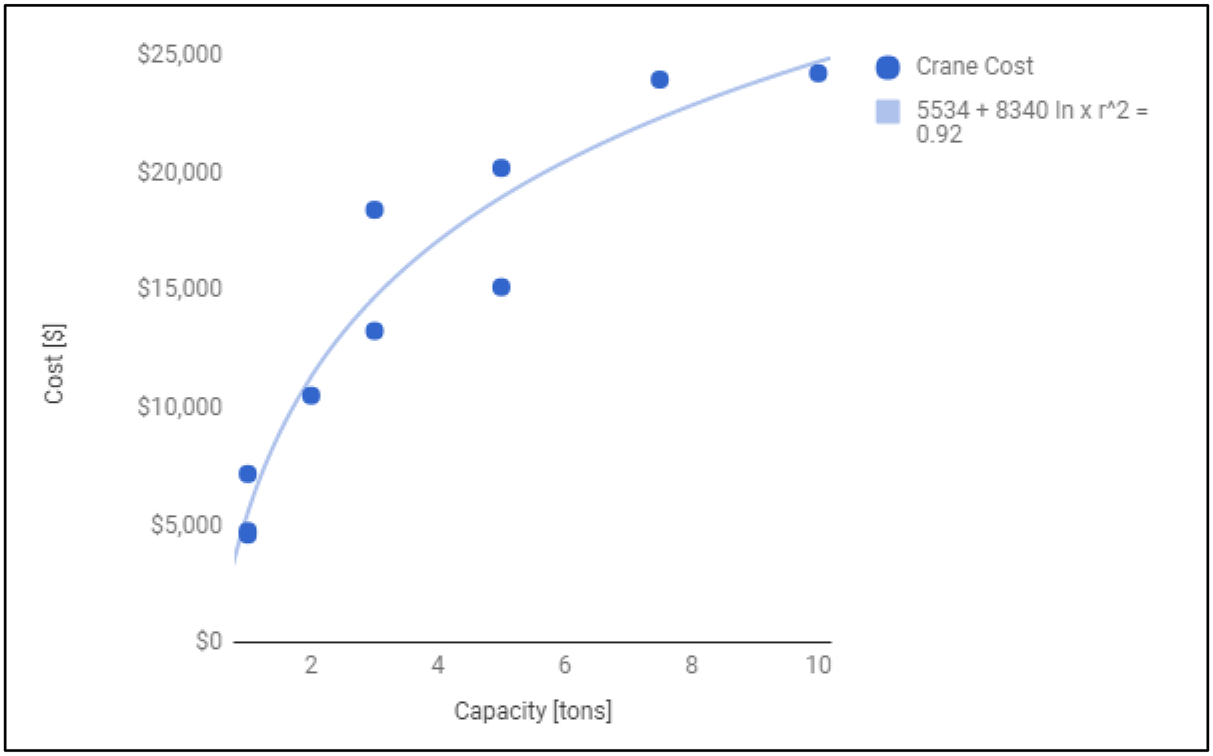


Figure 2.E.1: Expected Cost Curve for Crane & Gantry

Appendix 2.F: Estimated Bill of Material and Total Cost

Table 2.F.1: Estimated Bill of Materials and Total Costs

Item	Quantity		Unit Cost	Total Cost
Concrete	26.92	Cu Yards	$90	$2,423
Cinder Blocks	1988	ft2	$10	$20,635
Red Brick	2478	ft2	$13	$30,975
Roofing (BUR)	1060	ft2	$8	$8,995
Utilitech Pro Strip Shop Light (Common: 4-ft; Actual: 3.23-in x 48.03-in)	8	EA	$47	$376
Legrand 15/20-Amp Single Pole Light Almond Toggle Indoor Light Switch	4	EA	$16	$64
Pass & Seymour/Legrand Radiant 10-Pack 15-Amp 125-Volt White Indoor Decorator	1	EA	$20	$20
Southwire Romex SIMpull 250-ft 14-2 Non-Metallic Wire (By-the-Roll)	1	EA	$46	$46
Utilitech 50-Amp 250-Volt Black Indoor Round Wall Rv Power Outlet	2	EA	$10	$20
6" 17.25# 1045 I BEAM 6.00 X 3.565 .465 WEB	1	EA	$616	$616
6" 17.25# 1045 I BEAM 6.00 X 3.565 .465 WEB	1	EA	$616	$616
Garage Door	1	EA	$2,400	$2,400
Access Door	2	EA	$300	$600
Pipe Insulation (ft), ($/ft)	175	ft	$4	$700
Ambient Air exhaust Fan	2	EA	$305	$610
Natural Gas Line (ft), ($/ft)	100	ft	$31	$3,053
Power Generator Transfer Switch (400 AMP)	2	EA	$2,500	$5,000
4 Size Electrical Wire rated for 400 Amp (ft), ($/ft)	100	ft	$1	$75
Strobic fan	1	EA	$986	$986
Joist 18K8	18	EA	$368	$6,624
Exhaust Pipe (10')	2	EA	$700	$1,400
Exhaust elbows	2	EA	$330	$660
Sound deadening material	572	ft^2	$2	$1,419
Water piping (10')	10	EA	$480	$4,800
			TOTAL:	**$93,112**

Energy Saving Project: On-site Cogeneration Plant

Appendix 3 - Natural Gas Savings

https://www.google.com/search?q=consumers+ene

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Objective
The objective of the natural gas savings group was to determine potential resource and financial savings of installing a cogeneration system. To accomplish this, the history of Calvin's electrical and natural gas consumption was analyzed and compared to the cost of producing this same energy using the cogeneration system. The team worked closely with the engine selection and finance group to ensure correct values. The final natural gas and electricity savings became the project's overall savings, and financially justified the cogeneration project.

Research
The first stage of research was composed of gathering information of Calvin's current electrical and natural gas usage. These values would be used to assess Calvin's needs and later determine savings. These values can be found in Figure 3.A. 1 and Table 3.B.1. A large amount of this information was provided by Phil Beezhold. One of those pieces was natural gas purchasing receipts by Calvin. This information was given in amount of natural gas purchased monthly (in units of one hundred cubic feet) and the price paid for this natural gas. Knowing the amount of gas purchased and the quantity, an average was taken to find the price Calvin pays for natural gas. This number was used to simplify calculations on natural gas savings. In addition to this information, Phil also provided the record of natural gas bought by Calvin to heat the school for one year. This information was broken down, showing how much fuel was used per boiler on Calvin's campus (seen in Table 3.A.1). Working with interconnections it was determined that the thermal savings would only be applicable to the main hot water loop including the science, library and commons boilers. Therefore, the savings were only applied to the main loop. This was used in financial savings on the thermal side of the project.

After gathering natural gas information, Phil provided electricity information. Originally, the group was only given the monthly consumption of electricity used at Calvin. Later, the team was provided with Calvin's electricity consumption in fifteen minute increments for the past year. This information was used to model the savings Calvin would see using the cogen (seen in Figure 3.1).

Additional research was done to ensure accurate values and assumptions. First the calculated price of natural gas was compared to the market value (see Figure 3.A.1). From this research, Calvin's calculated value of gas proved to be an overestimate from current prices. The team left the value high, to ensure a safe final savings value. Additionally, other cogeneration projects were researched. Almerst College (a college around the size of Calvin) implemented a cogeneration system. Their results were similar to the final proposal submitted.

Methods & Analysis
The main goal of the team was assessing the cost of electricity currently consumed by Calvin and analyzing savings from the cogeneration system implementation. The calculated cost of

electricity with the cogeneration system is a bit more complicated. First, the cost of one kilowatt hour produced by the co-gen is calculated using natural gas costs. Natural gas costs are calculated (in one hundred cubic feet) are calculated using natural gas receipts of the previous year. The result is $0.53 per one hundred cubic feet. Using the energy input from the selected engine (found in Table 1.B.1) and the electrical output, the appropriate conversions were made to result in a final cost of $0.038 per kilowatt hour from the engine. This value was within range of what Calvin currently pays for electricity. The lowest price Calvin pays is $0.07 per kilowatt during off peak hours, while paying $0.14 during peak hours in the summer. The cost of one kilowatt hour with the cog-en, is cheaper than the cost of buying from the grid at any point.

Since the engine selected runs 1137 kilowatts at full speed, and Calvin's electricity usage peaks at over 5000 kilowatts, additional electricity must be purchased from the grid. While the power company has a 7-layer model, the team used a simplified version to make calculations. Prices varied for on- peak vs off peak times and season. Using these prices and the fifteen-minute interval usage data points, the team calculated how much additional electricity would have to be purchased at any point. This additional electricity priced between fourteen and seven cents depending of the time of usage. This cost was added to the cost of natural gas to run the cogeneration system to give a total cost for electricity with the cogeneration system installed.

In addition to producing electricity, the cogeneration system gives off excess heat. This heat can be used for heating campus and reducing the cost of running the boilers. In the summer, the heat would mostly be wasted, but has the potential to be used for heating water. The engine selected outputs 4.485 million Btu/hr. Since this thermal energy can only be applied to the science, library, and commons powerplant, the savings were only applied to these areas. This analysis was done assuming that the boilers run at an average efficiency of 70% and that the cogeneration plant will run 90% of the year. The information from Phil and the thermal output of the cogeneration plant were converted to 100 cubic feet per month of natural gas. After this was done, the amount of heat produced from the plant was subtracted from the total amount needed. Taking the difference between the total amount needed without the plant and the total with the plant, savings were calculated. Finally applying the assumed cost of natural gas ($0.53/ccf) this value could be converted into dollar amounts. To show a perspective of the potential savings from this cogeneration plant, the average amount of thermal savings per month is 33.6% this analysis is shown below in Table 3.A.1.

Results

The final savings from electricity with the cogeneration system is $318,000. With the additional cost of a loan to install the system, the team would still be over the $175,000 target. In addition to the natural gas savings, the savings on Calvin's heating system were substantial. The team calculated that the cogeneration system will produce about thirty percent of the heat needed by Calvin. This reduces the cost of running the boilers by $187,000.

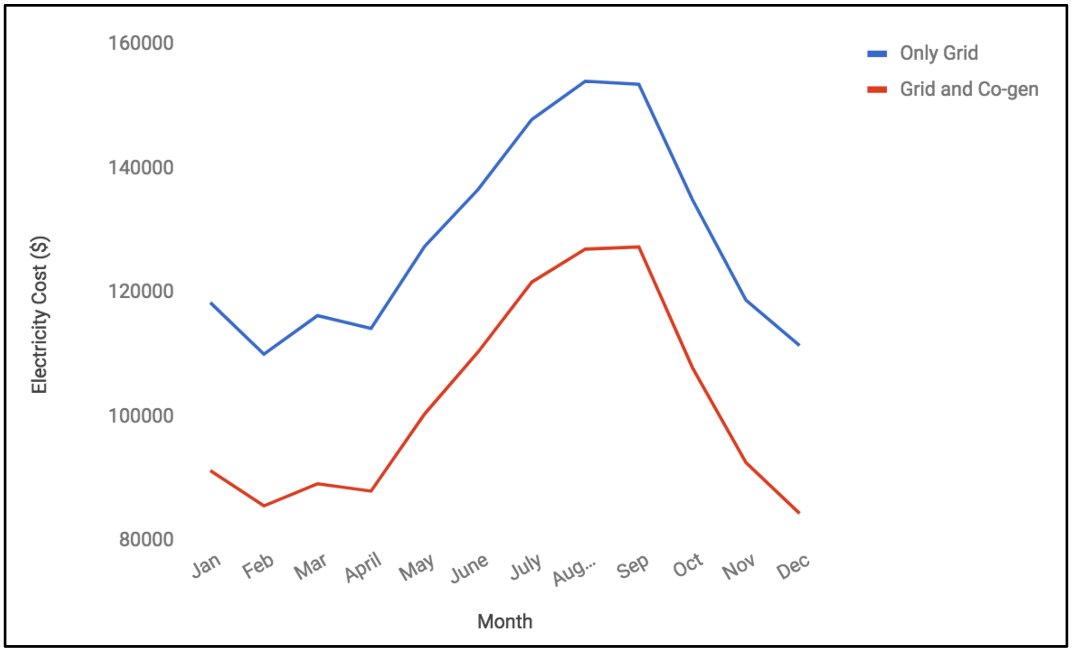

Figure 3.1. Cost Difference with Cogen.

Conclusions & Recommendations

In conclusion, the system exceed the savings necessary for a successful project. The cogeneration system would produce electricity below the cost to buy from the grid. In addition to electricity savings, the college would save on about thirty percent of heating costs. With the amount of electricity Calvin consumes, this results in substantial savings.

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Appendix 3.A: Natural Gas

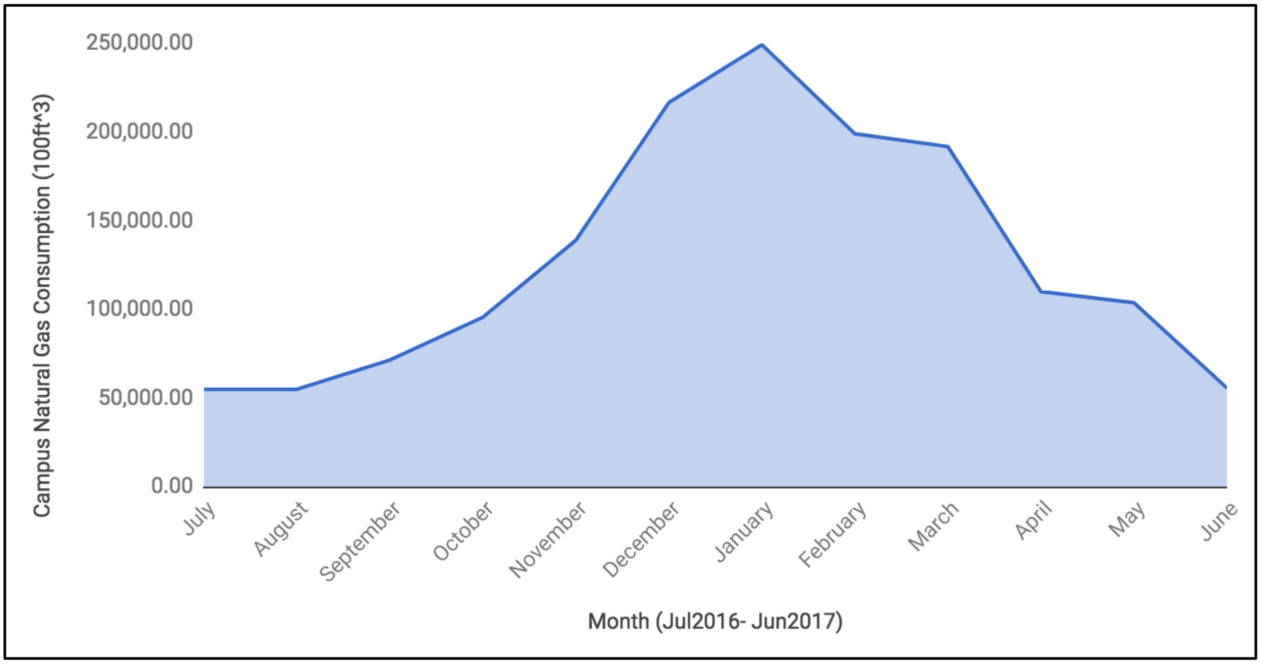
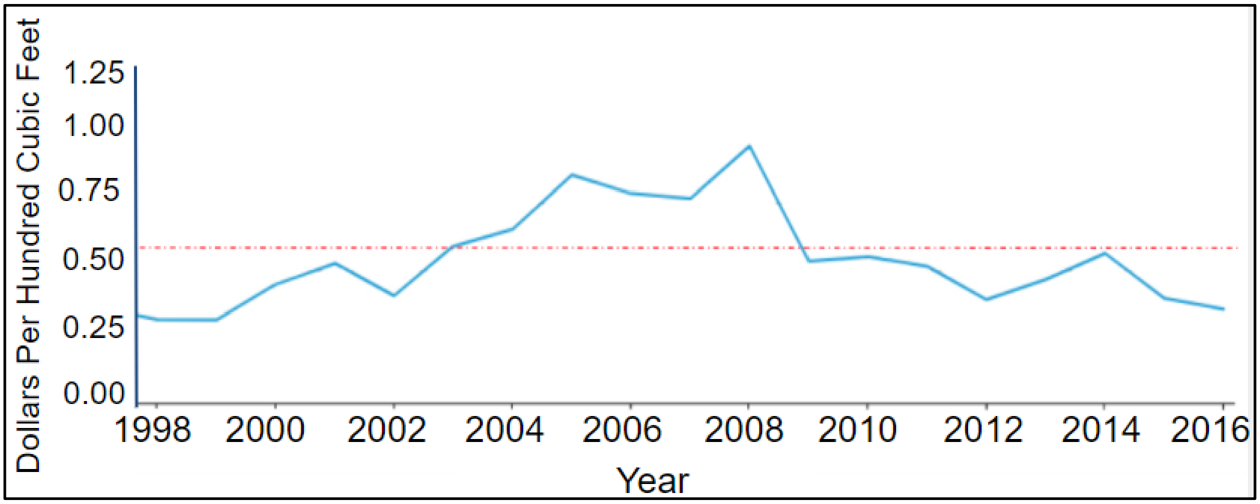


Figure 3.A.1. Natural Gas Consumption of Calvin College.



Source: eia.gov

Figure 3.A.2. Average Price of Natural Gas Throughout History.

Table 3.A.1: Total Heat Produced by Main Power Loop

	PowerPlants (ccf/month)	Natural Gas purchased (includes inefficiency of boilers) (ccf/month)	Cost of Purchasing NG from Grid ($/month)	Amount needed with cogen (ccf/month)	Cost of purchasing NG with Cogen ($/month)	Savings from running Cogen ($/month)	% of heat saved from running cogen
July 2016	40344.02181	57634.31687	$ 30,546.19	27601.16704	$ 14,628.62	$ 15,917.57	52.11%
August 2016	46024.02488	65748.60697	$ 34,846.76	35715.45714	$ 18,929.19	$ 15,917.57	45.68%
September 2016	48305.52611	69007.89444	$ 36,574.18	39943.5559	$ 21,170.08	$ 15,404.10	42.12%
October 2016	55757.03014	79652.9002	$ 42,216.04	49619.75037	$ 26,298.47	$ 15,917.57	37.71%
November 2016	71939.03888	102770.0555	$ 54,468.13	73705.71701	$ 39,064.03	$ 15,404.10	28.28%
December 2016	115188.0623	164554.3747	$ 87,213.82	134521.2248	$ 71,296.25	$ 15,917.57	18.25%
January 2017	133165.572	190236.5314	$ 100,825.36	160203.3816	$ 84,907.79	$ 15,917.57	15.79%
February 2017	104211.0563	148872.9376	$ 78,902.66	121746.2216	$ 64,525.50	$ 14,377.16	18.22%
March 2017	100946.3046	144209.0065	$ 76,430.77	114175.8567	$ 60,513.20	$ 15,917.57	20.83%
April 2017	55630.03007	79471.47153	$ 42,119.88	50407.13299	$ 26,715.78	$ 15,404.10	36.57%
May 2017	55323.0299	79032.89986	$ 41,887.44	48999.75004	$ 25,969.87	$ 15,917.57	38.00%
June 2017	41029.97218	58614.24597	$ 31,065.55	29549.90743	$ 15,661.45	$ 15,404.10	49.59%
Total:	867863.6691	1239805.242	$ 657,096.78	886189.1227	$ 469,680.24	$ 187,416.54	33.59%

Appendix 3.B: Electricity

Table 3.B.1. Total Heat Produced by Main Power Loop.

	Total Monthly Total Calvin Gas usage (Gal)	Main Boiler Loop Power Plants
July 2016	39349031.30	30179409.89
August 2016	43670527.71	34428345.25
September 2016	49499722.92	36135025.89
October 2016	61134549.70	41709135.36
November 2016	86324452.75	53814112.83
December 2016	131325016.91	86166613.78
January 2017	151746462.49	99614718.61
February 2017	122024486.40	77955246.97
March 2017	118108247.16	75513044.21
April 2017	68127788.63	41614132.76
May 2017	63973407.04	41384480.80
June 2017	39320642.73	30692536.16

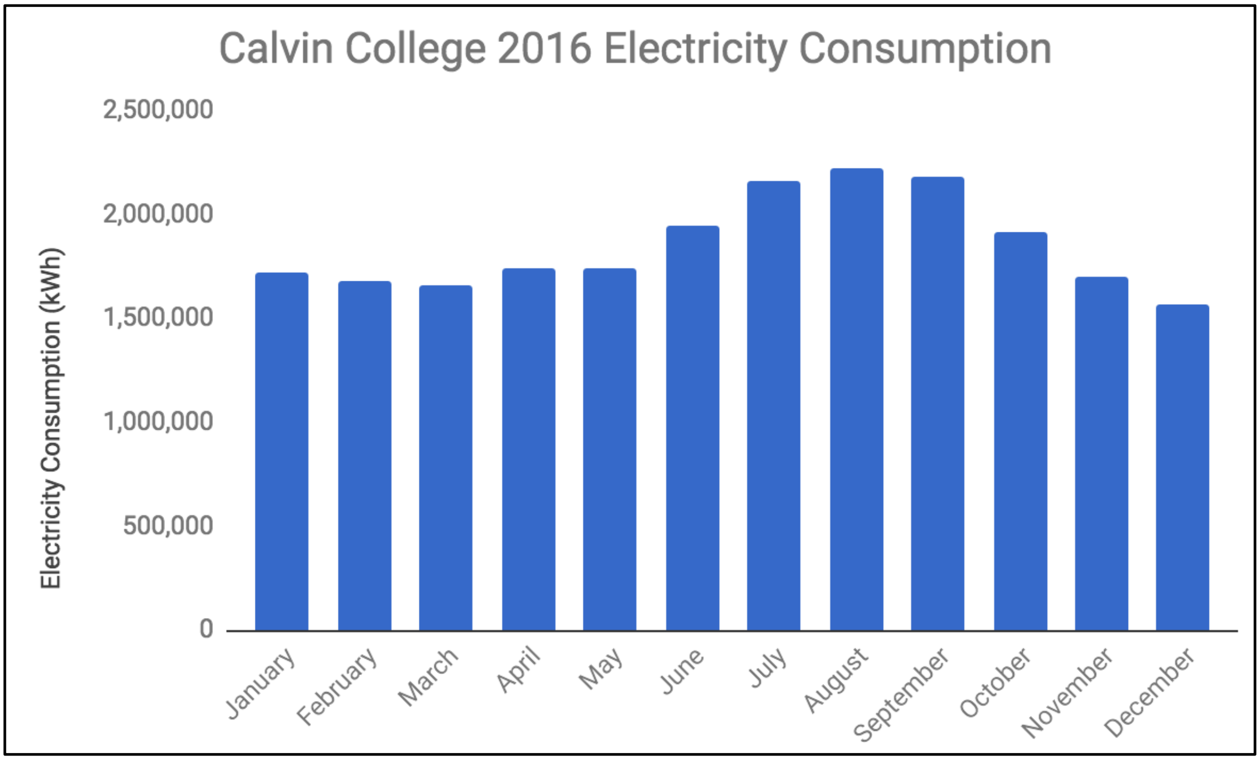


Figure 3.B.1. Raw Data of Calvin College Electricity Consumption.

Energy Saving Project: On-site Cogeneration Plant

Appendix 4 - CO_2 Savings

https://www.google.com/search?q=

Richmond Amoh
Matthew Boelens
Tyson Butler
Laura Van Winkle

Objective

The objective of the CO_2 savings group was to calculate the potential amount of CO_2 emissions that can be saved with the purchase of the selected engine as compared to purchasing electricity from the grid. To realize the CO_2 savings, an analysis was performed on both primary emissions from the co-gen plant and secondary emissions from the manufacturing of the engine as well as accompanying infrastructure. The CO_2 savings group was further tasked with considering the Presidents Climate Commitment and its implications on the Calvin community.

Research

Primary Emissions

At the beginning of this project, Calvin College purchased 100% of its electricity from Consumers Energy. As a reference and comparison for determining the CO_2 emission savings associated with utilizing a co-gen, the rate of Calvin's emissions was 0.76 kg-CO_2/kWh, the emissions rate published on Consumers Energy's website. The quantity of CO_2 released into the atmosphere from the combustion of fuel is defined as primary emissions. Each of the cogeneration engines considered throughout the project used natural gas as its fuel source for combustion. Therefore, in order to calculate the primary emissions from the co-gen plant, the process of combusting natural gas was studied in depth. Since it was unclear precisely which composition of natural gas would be used in each engine, the assumption was made for all primary emission calculations that the natural gas used was 100% methane. The combustion of methane follows the reaction equation shown below in Equation 4.A.1.

$$CH_4 + A \cdot 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + B \cdot O_2 + C \cdot N_2 \qquad [4.1]$$

Additionally, the specific volume of methane was determined to be 1.4 Sm^3-methane/kg-methane from the Santa Barbara Air Pollution Control District. The units of Sm^3 simply indicate that the utilized volume of methane is measured at standard atmospheric conditions. Data was also obtained from GE regarding the fuel consumption and energy output of the selected GE Jenbacher engine. It was determined that the engine consumed natural gas at a rate of 289 Sm^3-methane/hr to produce an output of 1189kW. In addition to studying the emissions of CO_2 produced from the combustion of methane, the team researched emissions rates for other greenhouse gases including nitrous oxide and unreacted methane. Data gathered from the Environmental Protection Agency revealed emissions rates of 0.000035 kg-NO_2/Sm^3-methane and 0.000037 kg-methane/Sm^3-methane. The EPA also included CO_2 equivalence rates of 298 kg-CO_2/kg-NO_2 and 25 kg-CO_2/kg-methane.

Secondary Emissions

Secondary emissions are defined as the sum of all the indirect emissions associated with manufacturing and running the system. To calculate the secondary emissions from the co-gen plant specifically the team had to make an initial decision on how far removed from the machine they should pursue. They decided that they would calculate the emissions associated with the harvesting of natural gas for both the co-gen engine and the boilers, the production of the steel for the co-gen engine and the emissions associated with the infrastructure around the machine. To find the rate of emissions associated with the harvesting of natural gas the team found that Calvin receives most of its natural gas from ExxonMobil and researched their rate of emissions. It was found that in the year 2016 ExxonMobil contributed 125 million metric tons of CO_2 equivalent emissions and boasted a production rate of 10.5 billion cubic feet per day. Through research the team also found the rate of CO_2 emissions for steel production to be 2.9 ton CO_2 per ton of steel, this number includes the raw material preparation, Iron making, and steel manufacture. To calculate the emissions from the construction of the building around the engine the team was reliant on the infrastructure team to determine what and how much materials would be needed. Once they had determined what it would take, the CO_2 savings team was able to calculate the CO_2 equivalent emissions of the major parts of the structure.

Post Processing of Emissions

In considering potential methods of further increasing CO_2 savings, the group researched ways by which the carbon emissions could be processed. Three main methods of capturing and reducing CO_2 emissions were found. The different processes are namely post combustion, pre-combustion, or oxy fuel combustion. In post combustion, the CO_2 is separated from the flue gas that is produced during combustion. The method can be carried out in three diverse ways including chemical absorption with the help of specific solvents, gas separation membranes or low temperature distillation. In pre-combustion, the method of capturing CO_2 is achieved by the process of partial oxidation whereby the fuel is reacted with the oxygen or air. The process guarantees the production of high amounts of CO_2 and H_2. The H_2 attained can further be used as fuel in gas turbines. Finally, the oxy fuel combustion is similar to the pre-combustion process in the sense that the fuel is combusted in almost pure oxygen to increase the output of CO_2 for simplified separation.

Methods & Analysis

Primary Emissions

The team decided it would be best to calculate the mass rate of CO_2 produced by the co-gen engine per kWh of electricity in order to best compare alternative engines. First, the fuel consumption rate from GE (289 Sm^3-methane/hr) was converted to a mass flow rate using the obtained specific volume of methane (1.4 Sm^3-methane/kg-methane). This mass flow rate, 206.5 kg-methane/hr, was then converted to a molar flow rate, 12.9 kmol-methane/hr, using a molar mass of methane of 16.04 kg/kmol. From the combustion reaction, Equation 1, the molar flow rate in of methane is equal to the molar flow rate out of CO_2, therefore the molar flow rate of CO_2 is also 12.9 kmol-CO_2/hr. Using the molar mass of CO_2 (44.01 kg/kmol), a mass flow rate of 566.5 kg-CO_2/hr was calculated. Finally, the mass flow rate was divided by the rate of energy output, 1189kW, in order to yield a primary emissions rate of 0.48 kg-CO_2,kWh. Additionally, through unit conversion and researched data, the equivalent CO_2 emissions rates for NO_2 and methane were calculated to be 0.018 kg-CO_2/kWh and 0.00022 kg-CO_2/kWh respectively.

Yielding a final primary emissions rate of 0.48 kg-CO_2/kWh. The primary emission rate of the GE Jenbacher co-gen plant is compared to Calvin College's current emission rate (Consumers Energy) in Figure 4.A.1.

Secondary Emissions

Having found the emission rates for the three areas that the team is considering for secondary emissions, harvesting natural gas, engine production and construction materials, an analysis was performed to calculate the emissions associated for one kilowatt hour [kWh]. The emissions attributed to the production of the steel in the machine and the construction of the building were both up front emissions that the team decided to spread out over a 20-year period based on the expected life of the co-gen engine. Calvin College's average annual energy consumption was given by Phil Beezhold as 23440926 kWh/year. The results from the secondary emissions can be seen in Table 4.A.1.

Table 4.1: Direct Secondary Emissions of the Co-gen

Emissions Source	Emissions Rate [kg-CO_2/kWh]	Percent of total emissions of co-gen [%]
Engine Production	0.0019	0.02
Natural Gas Harvesting	0.28	35.42
Construction Materials	0.015	1.87

Table 4.A.1 covers the secondary emissions released from the co-gen to produce 1137 kW electricity, but because a co-gen produces both electricity and heat, the emission savings from the ability to turn off a few of the boilers should also be attributed to the co-gen. To perform this savings calculation monthly natural gas consumption data was gathered from ENGR 333 section A's boiler group, the consumption was in 100 cubic feet [ccf] per month. A conversion was done from ccf/month to GJ/hr due to the fact that 1 ccf of natural gas (assumed 100% methane) is equivalent to 100000 BTU. From the infrastructure team, the co-gen would be contributing heat at a rate of 4.26 GJ/hr to only the main loop which has three power plants on it: Commons power plant located in the basement of Commons, Library power plant in the basement of Hekman Library, and the Science Building power plant located to the south of the Engineering Building. It was found that even though the co-gen does not produce heat as efficiently as the boilers Calvin College still saw a decrease in emissions.

Post Processing of Emissions

With the selection of the GE Jenbacher engine, the team concluded that, a post-combustion process will be well suited for the cogen system. The Econamine FG Plus Process, an amine based post combustion Carbon Capture system was therefore proposed. The system will have a 90% CO2 capture rate and will have a total cost of about 600$/kW of engine output. However, with the installation of such a system, the overall power plant efficiency will drop by 11% since capturing the CO2 will consume some of the power generated by the plant.

Results

Primary Emissions

The primary CO_2 emissions rate of the co-gen was calculated to be 0.48 kg-CO_2/kWh, much less than Consumers Energy's emissions rate of 0.76 kg-CO_2/kWh. However, the GE Jenbacher co-gen only produces 1137kW of electricity, not enough to meet all of Calvin's demand on campus. As a result, a significant amount of electricity still needed to be purchased from Consumers Energy. To calculate a new overall CO_2 emissions rate for campus, a weighted average emissions rate was determined. The total electricity the could be produced by the new co-gen in each month was subtracted from Calvin's electricity usage in that month during 2016. The remainder represented electricity that still had to be purchased from Consumers Energy. The weighted CO_2 emissions rate for each month was calculated by multiplying the source of electricity (co-gen or Consumers Energy) by the CO_2 emissions rate of that source. The value for each month was averaged over the course of a year to yield a final campus emissions rate of 0.63 kg-CO_2/kWh. The monthly values can be seen in Table 4.A.2.

Secondary Emissions

In the President's Carbon Commitment that President Leroy signed on December 7th, 2017 the secondary emissions of the campus are not considered. But it is important to realize that everything that we do contributes to the CO_2 equivalent emissions. In the cogen system, when not considering the boilers, secondary emissions made up 37% of the emissions associated with 1 kWh. Then, using an electricity usage estimate for 2024 of 19750573 kWh/yr, campus emissions were calculated both before and after co-gen installation, including the emissions associated with the boilers, seen in Table 4.A.3.

Table 4.2: Total Calvin Emissions with and without the Co-gen (2024)

Time	Total Emissions [million kg-CO_2/yr]
Before Co-gen	20
After Co-gen	15

Post Processing of Emissions

Installing the Econamine FG Plus process for the cogen plant will add an additional amount of about $600,000 to the total cost of the cogen plant. Considering how expensive this is, the team proposes that the College explore other avenues such as grants that may help bear the cost for the post combustion process.

Conclusions & Recommendations

The purchase and implementation of the GE Jenbacher co-gen plant would reduce Calvin College's CO_2 emissions in the central part of campus (all buildings except Physical Plant, Seminary, and Knollcrest East Apartments) by 25%, as seen in Table 4.A.3 and Figure 4.A.2. This would be a massive step forward in relation to President Leroy's recent President's Carbon Commitment signing. The researched Econamine FG Plus post-combustion scrubbing process would reduce central campus emissions even further to 11 million kg-CO_2/yr, resulting in a 45% reduction in central campus emissions. The team strongly recommends that Calvin College move forward with this proposal and purchase the GE Jenbacher co-gen plant as well as implement the Econamine FG Plus exhaust scrubber.

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Appendix 4.A: Emissions Savings

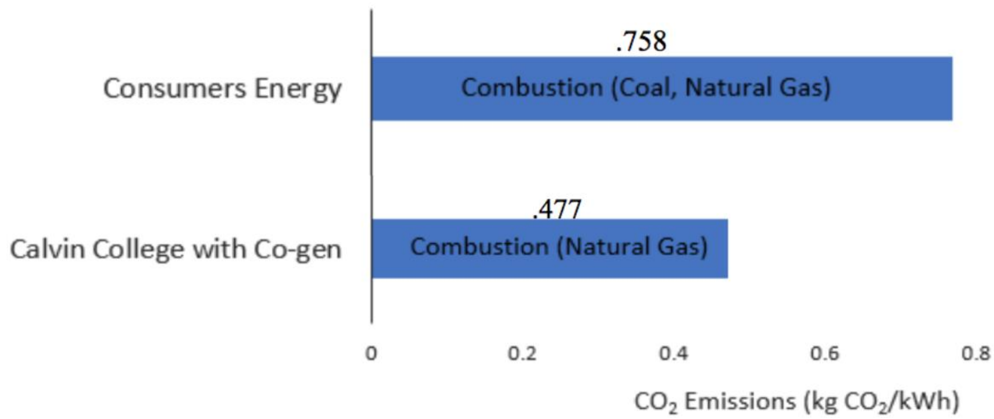

Figure 4.A.1: Co-gen Emission Reduction

Table 4.A.1: Determining Weighted CO_2 Emissions Rate

2016	Electricity Usage (2016, kWh)	Operating time (hrs/month)	co-gen max output (kWh)	Purchase from Grid (kWh)	Weighted CO2 Emissions Rate (kg CO2/kWh)
Jan	1725684	744	884616	841068	0.6137
Feb	1684175	678	806142	878033	0.6232
Mar	1660821	744	884616	776205	0.6080
Apr	1737509	720	856080	881429	0.6193
May	1877180	744	884616	992564	0.6253
Jun	1950722	720	856080	1094642	0.6344
Jul	2165302	744	884616	1280686	0.6430
Aug	2223630	744	884616	1339014	0.6460
Sep	2184119	720	856080	1328039	0.6476
Oct	1917104	744	884616	1032488	0.6281
Nov	1697480	720	856080	841400	0.6160
Dec	1570106	744	884616	685490	0.5994
Total	**22393832**	**8766**	**10422774**	**11971058**	**0.6270**

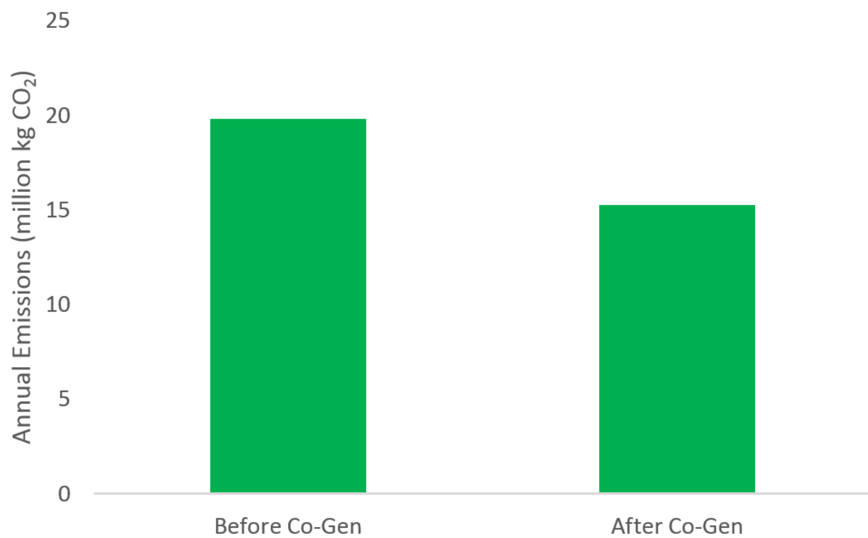

Figure 4.A.2: Total Calvin Emissions with and without the Co-gen (2024)

Energy Saving Project: On-site Cogeneration Plant

Appendix 5 - Finances

Alex Keizer
Kwame Ohemeng
Cameron Richman
Julie Van De Riet

Objective

The finance group had the task of overseeing all the finances involved in this project. This included the calculating the overall savings of the proposed system, the cost of electricity and natural gas, the cost of engine, cost of materials needed for the infrastructure, and the potential CO_2 savings should a carbon tax be implemented.

Research

Each member of the finance group worked closely with each of the four other groups. To commence our financial analysis, campus electricity and natural gas usage data was provided by Physical plant. The team looked at other schools that had implemented similar cogeneration systems and their savings. Through this power generation method, the school avoided purchasing electricity from the grid and reduced energy costs. The team also looked into the costs associated with the housing and installation of the engine. The team also investigated potential savings from carbon dioxide. There was a possibility of implementing a carbon tax and also selling carbon in the carbon market. Both options were investigated.

Methods & Analysis

The finance team required information from each of the other four teams to compute total system cost.

Engine Selection

From the Engine Selection team, Finance required the engine cost for the specified engine. After researching multiple engines, the Engine Selection team decided to select GE's Jenbacher Type 4 J416 GS-B86 cogeneration engine. There were numerous reasons involved in this selection. As mentioned previously, the output of just over 1 MW was a huge factor, but also that it was an otto-cycle engine. Speaking with GE's representative was also a tough challenge. Due to the fact that this started as an economic feasibility project, it was hard to receive information regarding the cost of the engine. After persistence on the end of the engine selection team, the rep finally gave a price estimate range per kw of energy. Taking the higher end of that estimate and knowing the power output of the engine, an initial cost estimate of $1.6 million was made. But knowing this was on the high end of the estimate along with the physical plant director saying that Calvin could install it themselves, a new estimate of $1.4 million was concluded. The one assumption with this estimate is Calvin's participation in the spare parts program that GE has to offer. This guarantees lifetime spare parts for the engine.

Interconnections

From the Interconnections team, Finance required material costs to construct the building, and any costs for utility lines such as ventilation, water, and gas lines.

CO_2 Savings

From the CO_2 Saving team, Finance required information about the amount of carbon dioxide emissions saved per year. Since there is no current economic benefit to reducing carbon emissions in the United States, the team researched policies that could be implemented in the near future. The possibilities considered were carbon tax and carbon trade systems; a carbon tax requires a fee proportional to the amount of carbon emissions, while a carbon trade puts a limit on the total amount of carbon that can be emitted, translated into credits, which can be bought and sold. The final decision was to assume a carbon trade system with a $5 per ton credit value. However, since the implementation of this system is uncertain, savings with and without the carbon trade value were calculated.

Electricity Savings

The first thing that was determined was the peak electricity values of the campus. From the Natural Gas Savings team, Finance required the savings due to reduced natural gas use for the specified engine. From the Electricity Savings team, Finance needed information on the cost of purchasing electricity from the grid for different seasons and times of day. Physical plant provided real-time natural gas usage for the college for 15-minute intervals for an entire year. With a power output of 1137 kW of the selected engine, the power needed was obtained by deducting the electricity supply from the usage. This was then used to project the costs of usage, supply and power needed.

Overall Finances

With all the information acquired, a spreadsheet was created to calculate costs and savings. Guess values were estimated and later updated after further analysis from the other groups. For savings calculations, a loan payback period of 5 years was assumed. A bank interest rate of 5% and 20 year cogen life were also assumed. The interest rate was overestimated since current bank interest rates for 15 year plans are approximately 3.15%.

Results

The following results were obtained from the financial analysis are summarized in Table 5.1. The finance team determined that the cost of the engine amounted to a total of $1,400,00. This amount includes a free spare parts and maintenance program for the entire life cycle of the engine. The cost of materials and infrastructure came up to $93,112. This includes cost of new hardware such as cinder blocks, water piping, garage door and so on. that will be installed in the existing Commons building. This location will be beneficial to the college since it already contains existing infrastructure from the old cogen that Calvin owned.

Table 5.1: Summary of Results

Total Engine Cost	$1,400,000
Carbon Trade Savings per year	$22,488
Total Interconnections Cost	$93,112
Annual savings if fully funded	$504,000
Avg savings if paying off 4-year loan	$420,000

When the additional savings associated with a carbon trade system implementation, the annual savings increases dramatically, as shown in Figure 5.1.

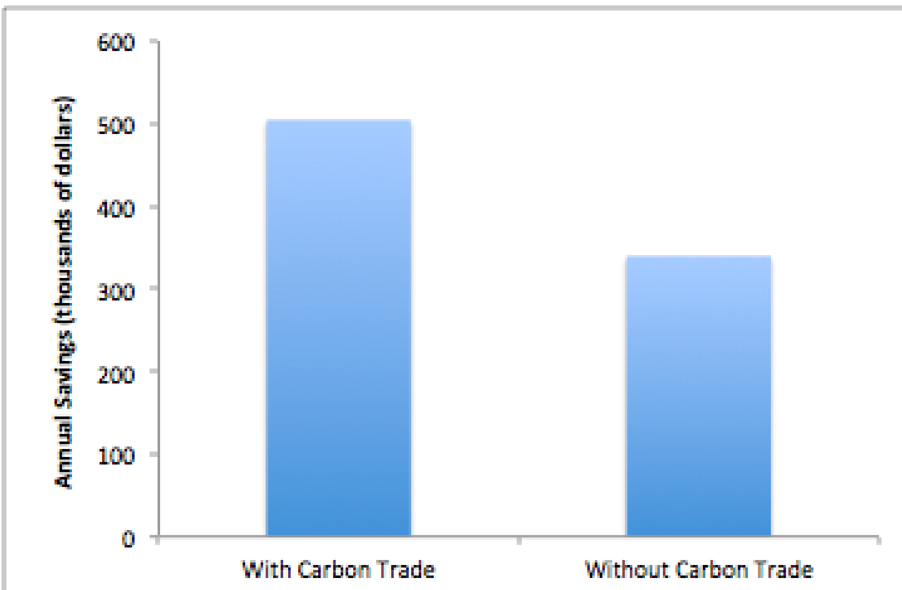

Figure 5.1. Annual Savings With and Without $5 Carbon Trade Value

Conclusions & Recommendations

It was determined that Calvin college could save up to $500,000 per year on natural gas and electricity by using a new on-site cogeneration system. The results obtained exceeded the objective of the project. Implementing this cogen plant on Calvin's campus will not only be environmental viable but also economically sensible.

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Appendix 5.A: Electricity Savings Finance

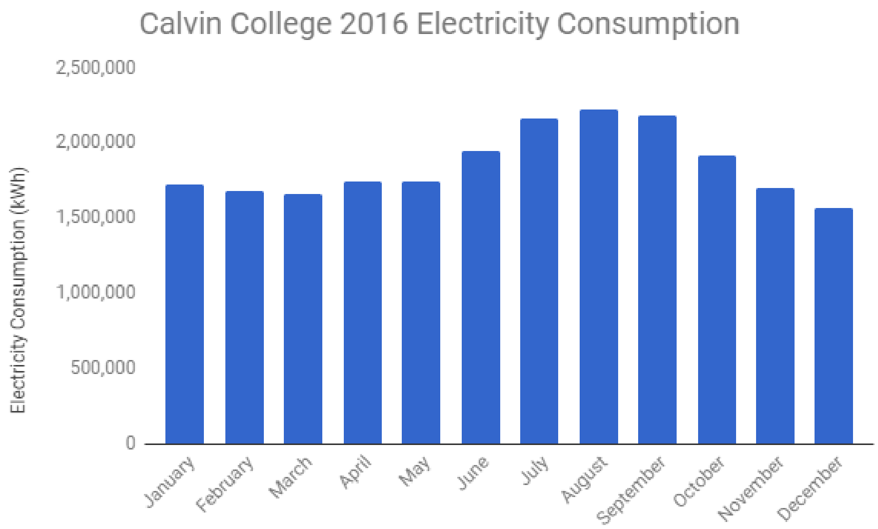

Figure 5.A.1. Campus Electricity Consumption for 2016

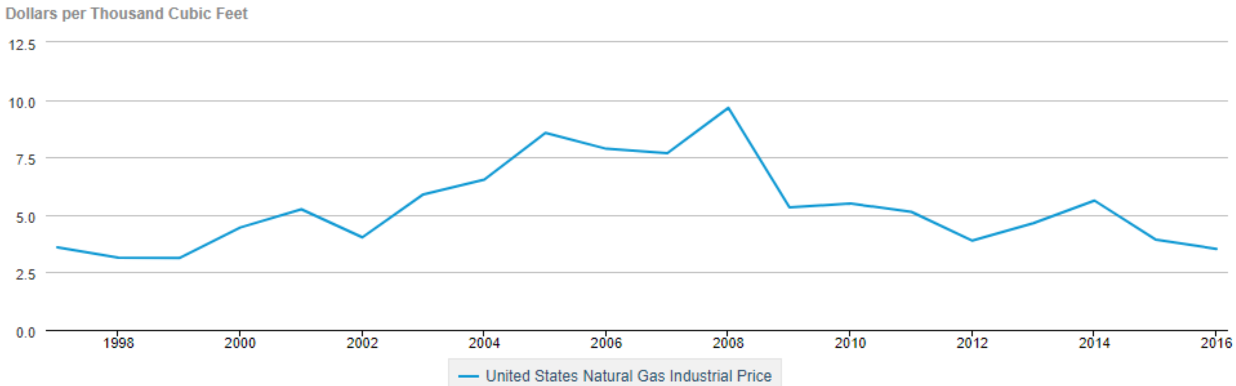

Figure 5.A.2. Gas Price Fluctuation

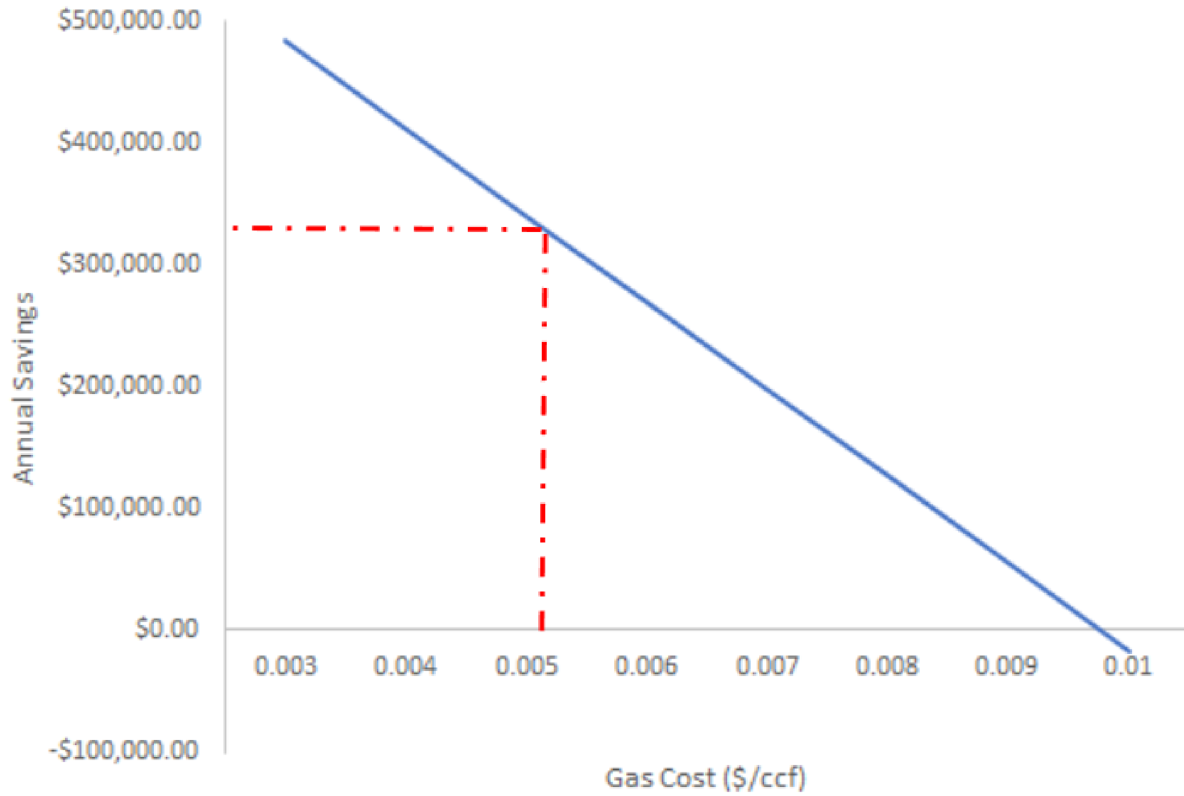

Figure 5.A.3. Sensitivity to Savings Based on Gas Cost

Appendix 5.B: CO_2 Savings Finance

Table 5.B.1: Calculation Assumptions and Conversion Factors

General Information		
GE Engine Output Energy:	1141	kW
GE Engine Energy Produced:	9995160	kWh/yr
2024 Energy Estimate:	19750573	kWh/yr
Conversions:	0.453592	kg/lb
	0.001	MW/kW
	0.00110231	tons/kg
	8760	hours/year

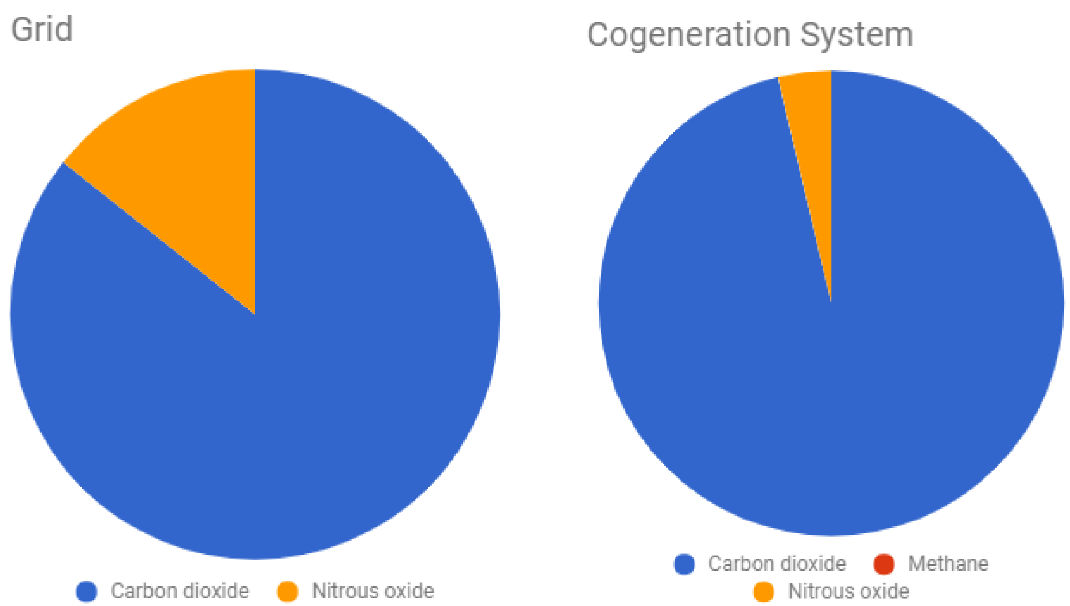

Figure 5.B.1: Emission Ratios With and Without Cogen Plant

Table 5.B.2: Cogeneration System Emissions

Proposed Cogeneration Plant		
Emission Type	Emissions [kg/kWh]	Emissions [tons/yr]
CO2 (Equivalent)	0.47646174	5250
CH4	0.00000894	0.099
N2O	0.00000233	0.026

Table 5.B.3: Consumers Energy Emissions

Consumers Energy			
		Emissions (tons/year)	
Emission Type	lb/MW*hr	tons/yr (all purchased)	tons/yr (supplemented)
Carbon Dioxide	1672.4	16515.4	8157.5
Sulfur Dioxide	2.4	23.7	11.7
Oxides of Nitrigen	0.94	9.28	4.59
High-level Nuclear Waste	0.0069	0.07	0.03
HYPERLINK "https://www.consumersenergy.com/~/media/CE/Documents/Company/Media/electric-sources.ashx?la=en" https://www.consumersenergy.com/~/media/CE/Documents/Company/Media/electric-sources.ashx?la=en			

Table 5.B.4: Total Emissions and Emissions Reduction

Substance	Formula	Carbon equivalence	Emission Amount [tons/year]		Carbon Equivalent Emissions [tons/year]	
			Current System	Proposed System	Current System	Proposed System
Carbon dioxide	CO2	1	16515.4	13407	16515	13407
Methane	CH4	25	0	0.10	0	2
Nitrous oxide	N2O	298	9.28	4.61	2766	1374
HYPERLINK "https://climatechangeconnection.org/emissions/co2-equivalents/" https://climatechangeconnection.org/emissions/co2-equivalents/				Total Equivalent Emissions [tons/year]:	19282	14783
				Equivalent CO2 Savings [tons/year]:	**4498**	

Table 5.B.5: Total Savings from Carbon Emission Reduction

			Savings ($/year)			
Carbon Tax	5	$/ton	$ 22,490.94		**Chosen System:**	**Savings ($/year)**
Carbon Trade Value	5	$/ton	$ 22,490.94		**Carbon Trade**	**$ 22,490.94**

Table 5.B.6: Cumulative Equivalent Carbon Emissions Over Time

	Equivalent Carbon Emissions			
Year	Current System	Proposed Plant	Grid	Proposed Plant
0	0	199.44	0.0	199.4
1	19282	14783	19281.7	14982.9
2	19282	14783	38563.3	29766.4
3	19282	14783	57845.0	44549.8
4	19282	14783	77126.6	59333.3
5	19282	14783	96408.3	74116.8
6	19282	14783	115689.9	88900.3
7	19282	14783	134971.6	103683.7
8	19282	14783	154253.2	118467.2
9	19282	14783	173534.9	133250.7
10	19282	14783	192816.6	148034.1
11	19282	14783	212098.2	162817.6
12	19282	14783	231379.9	177601.1
13	19282	14783	250661.5	192384.5
14	19282	14783	269943.2	207168.0
15	19282	14783	289224.8	221951.5
16	19282	14783	308506.5	236734.9
17	19282	14783	327788.1	251518.4
18	19282	14783	347069.8	266301.9
19	19282	14783	366351.5	281085.3
20	19282	14783	385633.1	295868.8

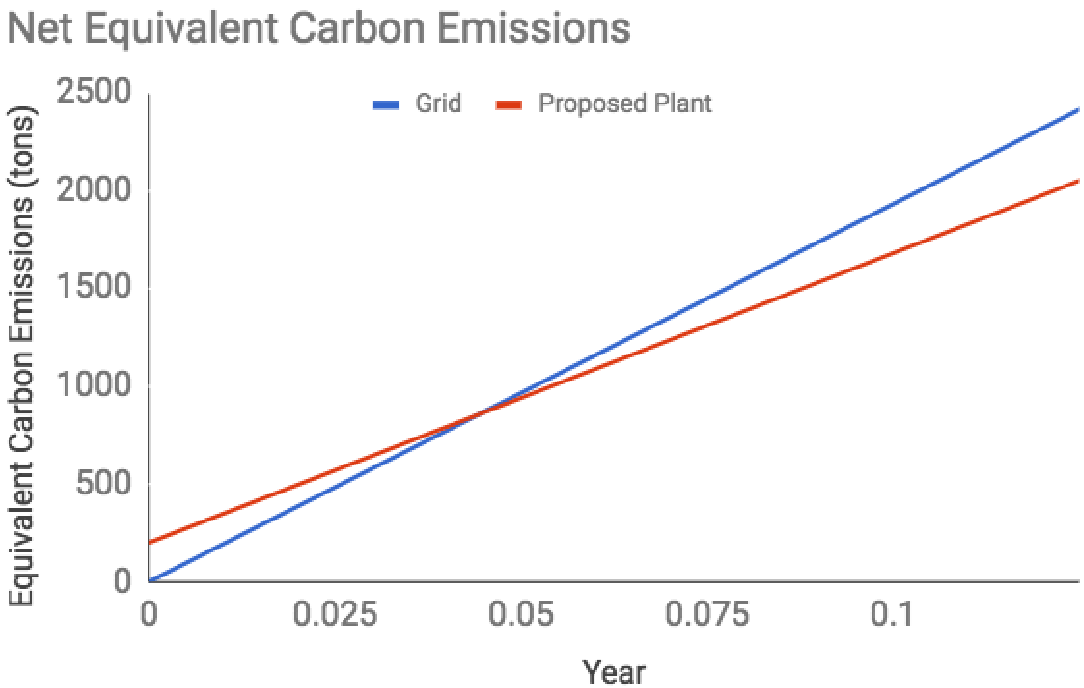

Figure 5.B.2: Cumulative Equivalent Carbon Emissions Over Time