Renewable Energy Generation Project

Engineering 333-A

12/18/18

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1 Executive Summary

1.1 Objective:

Calvin College currently spends 2.35 million dollars on energy every year. Physical Plant is under pressure to reduce the amount of energy that Calvin purchases from the electrical grid since the college is facing many budget constraints. In addition, President Le Roy signed the President's Carbon Commitment to achieve carbon neutrality by 2057. With this need to save money on energy and reduce the college's carbon footprint, the objective of this project was to determine the largest possible reduction in Calvin's annual energy costs given a five-million-dollar investment in renewable energy.

1.2 Method and Analysis:

In order to tackle this project, the engineering 333 class split into five groups with four of them looking into different types of renewable energy types and the last team looking into finance and carbon emissions from each energy source. The four different types of energy sources are biomass, geothermal, solar, and wind. Biomass was deemed infeasible for the small amount of bio-waste that Calvin produces. For the other three renewable sources, research and energy calculations were compared to determine the main recommendation for Calvin, as well as provide alternatives for the administration in case they receive new information that could affect the decision on where to invest in renewable energy.

1.3 Conclusion:

1.3.1 Main Recommendation:

The main recommendation for reducing Calvin's annual energy costs was been determined to be 3.34 million dollars towards on-campus solar panels and 157 thousand dollars towards residential geothermal systems. The solar panels will be placed on roughly five acres of roof space on the main campus, including the new student union building. The solar system will produce 2.1 GW-hr/yr electricity and will save 225 thousand dollars per year. The residential geothermal system will be implemented into six houses including the DeWit Manor, Perkins Fellows house, two project neighborhood houses, and two other houses owned by Calvin College. The geothermal system will save a total of 15 thousand dollars per year.

1.3.2 Alternative One:

The first alternative comes with a large assumption, that Michigan will change its legislation about selling back electricity into the grid. If selling back into the grid becomes feasible and profitable, then it is recommended that Calvin spend 4.84 million dollars on solar panels to be placed on campus. The area needed for a 4.84-million-dollar investment would be 7.41 acres, which would require the use of ground solar units or parking structures in addition to the rooftops chosen in the main recommendation. This larger solar system would produce 2.97 GW-hrs each year which would result in a savings of 318 thousand dollars per year. The remaining 15 thousand dollars would be invested in the same residential geothermal systems as described in the main recommendation.

1.3.3 Alternative Two:

The second alternative suggests moving much of the solar panels to an off-site location. Due to climate and weather conditions, Michigan is not an optimal location for producing electricity with solar options, so this alternative proposes a partnership with Rehoboth Christian School in Rehoboth, New Mexico. Rehoboth has available ground space and receives one and a half times more sunlight than Michigan. If Calvin were to partner with Rehoboth, it is recommended that 3.6 million dollars be invested off-site in Rehoboth and keep 1.215 million dollars to be invested in on-campus solar panels in order to show the public about Calvin’s commitment to renewable energy. This option would provide 3.6 GW-hrs of electricity per year and save Calvin an estimated 340 thousand dollars. The remaining money would go towards the residential geothermal systems to save fifteen thousand dollars per year.

1.3.4 Alternative Three:

The third alternative comes with the assumption that wind is feasible. In order to determine that wind is feasible, a study needs to be completed over the course of one year to find out the wind speeds at 30 meters on campus. The current wind data is at 10 meters on campus and at the airport, which does not have trees like Calvin College does. If the wind speeds are high enough to say that it is worth it to invest, then it would be recommended to spend 3.34 million dollars on eight wind turbines over 55 acres. This would save 125 thousand dollars per year and have a 25-year payback.

2 Solar Appendix

2.1 Detailed Solar Alternatives

The main recommendation suggested for Calvin's investment of $5 million in renewable energy sources included a $3.34 million investment into on-campus solar panels. Investing the remaining $1.503 million would be up to the college's discretion, whether to be invested in offsetting carbon emission with carbon credits, being invested in the Calvin Renewable Energy Fund (CERF), or another option. The main recommendation utilizes seven current rooftops as well as the rooftop of the planned Student Union building. The current buildings proposed for solar include: The Prince Conference Center, the DeVos Communications Center, the CFAC, Hekman Library, Hiemenga Hall, North Hall, and the two Physical Plant buildings as shown below in Figure 1.

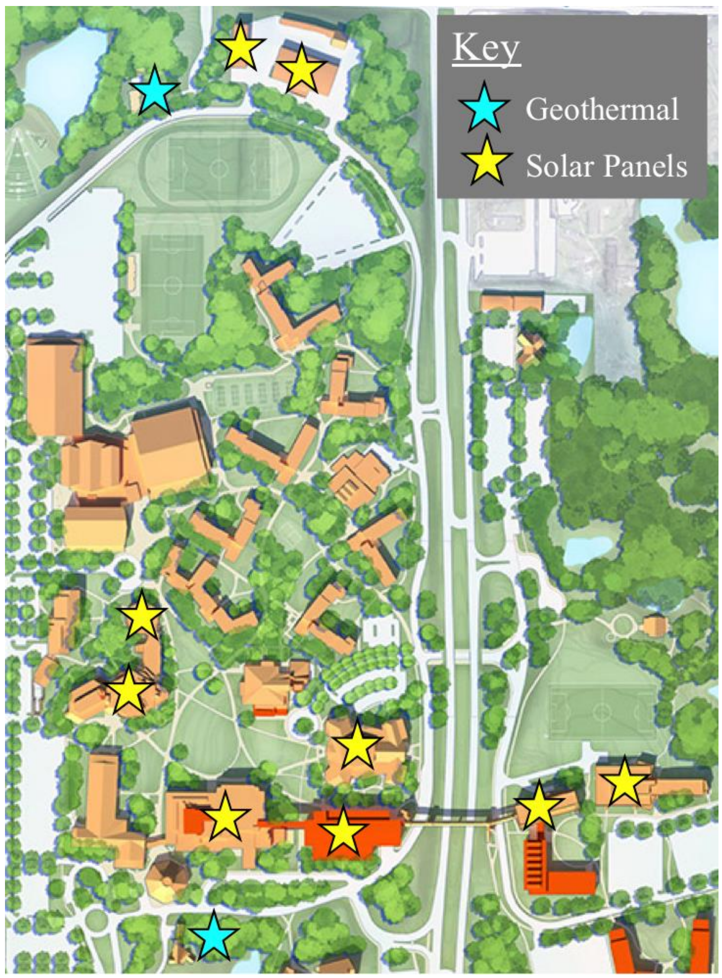

Figure 1. Proposed locations of solar panels and geothermal system for the main recommendation of Calvin's $5 million investment into renewable energy

Detailed reasoning for the selection of these locations can be found in the Locations on Campus section. This main recommendation results in $225,000 of annual purchased electricity cost savings and a corresponding payback period of 15 years. The required rooftop space totals to 5.1 acres, which includes appropriate separation distance of solar panels for maintenance and maneuvering around. The allocated budget amount for the main recommendation results from enough solar power to meet Calvin's baseline electricity usage of 1.336 MW. Details of Calvin's baseline power consumption can be found in Cost Calculations. By meeting Calvin's baseline electricity draw, or lowest level of required power, the problem of overproduction and need for energy storage is eliminated. By meeting the baseline energy need, the recommended investment produces 2.109 GW-hrs of electricity annually, or approximately 9.63% of Calvin's current annual required electricity.

The first suggested alternative for Calvin's investment takes into account a potential legislative change in electricity buy-back policy in Michigan. Currently, the state of Michigan does not allow for private electricity producers to sell electricity to the grid. However, if this policy were to change in the future, it would be beneficial for Calvin to invest the remaining amount of the $5 million budget into more renewable energy production. In terms of solar energy, the first alternative suggests investing $4.84 million into solar energy on campus. This scenario would allow for the renewable energy investment to be fully implemented, in terms of publicity and accessibility, on Calvin's campus. The produced power would go to meeting Calvin's electricity needs, and any additional production could be sold back to the electrical grid for extra cost savings when production exceeds the baseline energy use on campus. Under this alternative, Calvin could produce 2.97 GW-hrs of electricity annually, 13.55% of the current electricity needs. At the same payback period, the system would save $318,000 annually with a required area of 7.41 acres. Due to rooftop constraints, ground solar units would be required to produce the additional power in conjunction with the previously identified rooftops of the main recommendation.

Figure 2. Land identified for supplementary ground units for the first alternative.

The area suggested for the supplementary ground units is shown in Figure 2 above. This area was suggested due to its relative lack of large foliage - corresponding to a smaller amount of large clear cutting that would be required as well as a minimized amount of obstructing shade that would decrease panel efficiency. The vegetation cut down would be sent to a local composting company. The 3.8 acres of ground space identified in Figure 2 is 40% larger than the actual required area for the needed solar panels; the extra space provides a buffer zone for \ obstructions which block sunlight.

The second alternative incorporates an off-campus location for the $5 million investment. Due to climate and weather conditions, Michigan is not an optimal location for producing electricity with solar options. In areas such as the southwestern United States however, climate and weather conditions allow for even greater efficiency and greater returns on the same investment. The second alternative for Calvin's investment is to partner with Rehoboth Christian School in Rehoboth, New Mexico. Calvin already has strong ties with the school due to the current partnership between the schools on the Calvin-Rehoboth Robotic Observatory. Rehoboth has available ground space, as detailed further in Baseline Energy Use, which could be utilized for solar power with a full investment from Calvin College. The off-campus alternative boasts the ability to access 1.5 times more daily sunlight than systems in Michigan, allowing for an increased return on investment as well as an expedited payback period.

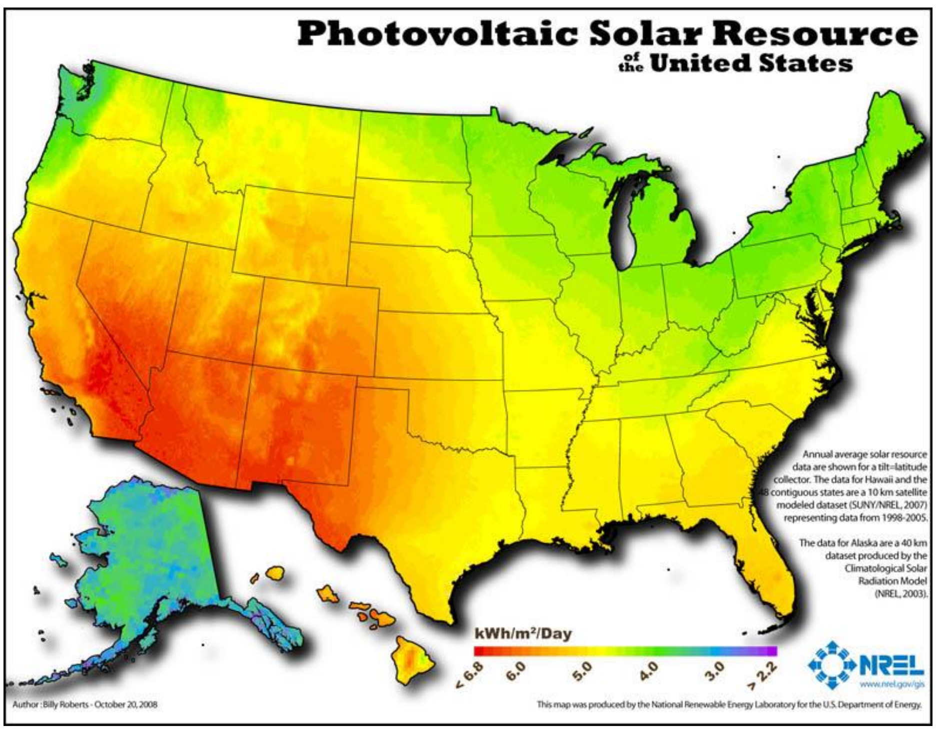

Figure 3. Average solar irradiation across the United States, highlighting the difference between Michigan and locations in the Southwestern U.S.

Contact has been made with representatives of Rehoboth, however specific details on potential partnership setups remain unknown. One of the most likely scenarios would be for Calvin to lease land from Rehoboth, and then partner directly with one of the local power companies (Tri-State, PNM, or Continental Divide Electric). These companies already use solar panels to power towns in other parts of New Mexico. This scenario is the best case for several reasons. It would allow both schools to promote sustainability and renewable energy sources while allowing Calvin to retain all of the energy credits as well as electricity profits from the setup. The third alternative details 24%, $1.215 million, of the $5 million budget be invested in solar power on-campus and the remaining amount be invested in Rehoboth. The allotted on-campus budget would be invested in solar panels to cover the proposed student union. The on-campus solar energy, although less productive than the off-campus, would be accessible to the Calvin community for research purposes, mentionable in promotional activities, and would be visual proof of Calvin's commitment to sustainability.

2.2 Feasibility

Michigan

At first glance, pursuing solar power in Michigan would seem unattractive due to the long winters and mild sunlight throughout the year. As seen in Figure 3, Michigan sits in a low intensity sun area. Although the state averages only 4.2 hours of direct sunlight per day and averages 51 inches of snowfall annually, solar power in Michigan is actually quite feasible. Grand Valley State University, whose campus is relatively close to Calvin College, implemented a solar garden in conjunction with Consumers Energy. This proved to be a profitable venture with a reasonable payback period, despite the limited sunlight available.

Another issue with solar production in Michigan is the accumulation of snow on solar panels. There are ways to combat snow accumulation with heaters or by paying for snow removal. However, the team's recommendation is to let the sun melt the snow. This self-cleaning aspect of the solar panel negates any reason to hire people to clean solar panels during the winter[1]. Additionally, Calvin's baseline electricity usage during the winter is low due to gas powered heaters and no need for electric air conditioners. During the four winter months a solar panel only generates 15% of its annual output, therefore extra snow coverage is not going to impact the total output much.

Interestingly, winter conditions can actually be beneficial to solar production. Like most electronics, solar panels work better in a cold environment[2]. Plus, snow is excellent at reflecting

[1] "Solar Panels: Lifetime Productivity and Maintenance Costs." *Boston Solar,* 8 Mar. 2016, https://www.bostonsolar.us/solar-blog-resource-center/blog/solar-panels-lifetime-productivity-and-maintenance-costs-2018/. Accessed 4 Dec. 2018.

[2] "2018 Guide to Michigan Home Solar Incentives, Rebates, and Tax Credits." *Solar Power Rocks* https://www.solarpowerrocks.com/michigan/. Accessed 13 Oct. 2018.

sunlight from the ground back up to the solar panels. On a rare day when the sun is shining and there is still some snow on the ground, the solar panels will produce more efficiently then they might during a semi-cloudy day in the summer[3].

New Mexico

New Mexico is a very attractive location for solar power. The main advantage of putting solar panels in New Mexico is the efficiency increase. On average, New Mexico generates approximately 6.7 hours of sunlight per day. A solar panel that is placed in New Mexico will generate 1.5 times more energy than the same solar panel placed in Michigan. Another benefit of solar in New Mexico is the government support. The solar incentives from the government are some of the best in America. In New Mexico many cities are already investing in solar, and many companies are helping people invest individually as well. The City of Gallup uses solar power for 10% of their electrical energy. The City of Gallup is supported by the companies Tri-state, PNM, and Continental Divide Electric.

2.3 Location of On-Campus Panels

Rooftops

On Calvin's campus there are many options for where solar panels could be placed. The most appealing locations are on the roofs of existing buildings or buildings proposed to be built as Calvin renovates its campus. Rooftops are ideal for many reasons. The first reason is that there is less of a chance for shadows from trees or other building blocking sunlight from reaching the panel when they are placed off the ground. Additionally, rooftops are visible all-around campus. This is beneficial in showing off Calvin's commitment to becoming carbon neutral to tour groups, people attending sporting events, and Calvin's own proud students. Placing solar panels on campus in such a prominent position would drastically increase the visual appeal of the school. Another added bonus is that rooftops are generally regarded as open real estate. Without needing to take up valuable on-site land or crowd existing structures, a large amount of unused area can be found on the tops of buildings.

Of Calvin's many buildings, only certain roofs are most favorable for solar panels. For optimal sunlight, solar panels should be tilted about 30 degrees from horizontal and facing South. Both of these requirements can be met by tilting the solar panels with a metal frame; however, less infrastructure means lower weight and cost. The roofs of the most viable building have been mapped out in Figure 1 and are categorized below.

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[3] "Do solar panels work in the winter?" *EnergySage,* 17 Oct. 2018, https://news.energysage.com/solar-panels-in-winter-weather-snow-affect-power-production/. Accessed 4 Dec. 2018.

Table 1. Suitable Rooftop Locations on Calvin's Campus[4]

Building	**Area (m^2)**	**Area (acres)**	**Roof Type**
Student Union	4,200	1.04	Unknown
Prince Center	3,500	0.86	Flat
Hekman Library	3,400	0.84	Flat
Hiemenga Hall	2,400	0.59	Flat
Physical Plant	2,000	0.49	Flat
DeVos CC	1,300	0.32	Flat
CFAC (Center area)	1,200	0.30	Flat
DeVries Hall	1,200	0.30	Flat
North Hall	800	0.20	Flat
Mail Services	700	0.17	Flat
Total	**20,700**	**5.12**	

Some of Calvin's larger buildings, like the Spoelhof Fieldhouse Complex, cannot be used due to their tar and gravel roof type. Most of these roofs were installed in 2009 and are only expected to last 30 years. In fact, they may need to be replaced even sooner due to an unexpectedly high rate of deterioration. Rather than installing solar panels and needing to remove them just as they begin to break even and make a profit, the team has opted to use buildings with longer lasting roof types instead. The Huizenga Tennis and Track building, despite its large size, cannot be used due to concerns with the weight of the panels being too much for the roof to support.

[4] Roof Areas were calculated using www.mapdevelopers.com/area_finder.php

Table 2. Unsuitable Rooftop Locations on Calvin's Campus

Building:	Reason Roof is Unsuitable:
Science Building	Roof is obstructed by several structures including the observatory
Huizenga T&T	Roof is unable to hold the weight of the panels
Venema Aquatic Center	Tar and Gravel Roof
Hoogenboom Center	Roof is shaded by the Aquatic Center and other buildings
Van Nord Arena	Tar and Gravel Roof
Knollcrest Dining Hall	Planned to be removed in the near future
Commons	Tar and Gravel Roof
Commons Annex	Planned to be removed in the near future
Spoelhof Center	Tar and Gravel Roof and nearby trees shade areas of the roof

Nature Preserve

Due to the cost of clearing an area for the solar panels and the possible difficulties in gaining permission to remove part of the Nature Preserve, it is not the main recommendation to clear an area of the Nature Preserve. If any area of the preserve would have to be cleared, the area just to the north of the tennis fields on the west side of Gainey Fields is recommended. This area has only a few small trees that would be easier to remove and would not reduce carbon absorption significantly.

Cost of Transmission to Campus

The cost of power transmission from the farthest point in the Gainey complex to Calvin's grid was investigated. Calvin has a power substation near the lower KE apartments. In order for the solar energy to be useful it would need to be routed to the power substation. It was found that the farthest point in Gainey complex is 0.9 miles from the substation. Consumers energy would install power transmission lines that could handle the necessary amount of power for $22,000 for one mile. The lines that would be installed by Consumers Energy would be underground.

2.4 GVSU Solar Farm

In studying the feasibility of solar power in Michigan, research was done to find if any other schools had implemented a profitable solar farm in Michigan. The study of the solar garden on Grand Valley State University, Allendale campus was studied and used as a reference for the solar team since it is in Michigan and very near geographically to Calvin campus.

GVSU's solar garden was built in April 2016 and sits on 17 acres. The solar panels are mounted on frames that sit on the ground and face south. The frames are static and do not track the sun. The land the garden is on was given to Consumers Energy by GVSU to build the solar farm in an agreement. The agreement allowed Consumers Energy to invest and build the solar garden and in return, GVSU would subscribe to buy 500 kilowatts of the garden's power for the next 25 years.

In looking at the economics of the GVSU solar garden, the initial investment that Consumers Energy made to build the solar garden was $8 million. Given that the solar garden produces 3000 Megawatt-hours of electricity per year and that electricity is sold at roughly $0.1071 per kilowatt-hour, the solar farm produces $321,300 per year. With this revenue every year, the payback period for the GVSU solar garden is calculated to be just under 25 years. Knowing this payback period for an area in Michigan, along with the fact that solar technology is always improving, the team was confident Calvin could achieve similar results if not better.

2.5 Rehoboth

Rehoboth, New Mexico is an ideal location for a potential offsite solar array. The solar array would be placed at Rehoboth Christian School (RCS). The reason for choosing this location, rather than other New Mexico locations, is the extended relationship that Calvin College has had with RCS. Calvin College performed a solar study for RCS in 2014 for their new school.[5] However, RCS did not put solar panels on the school based on a decision from the school board at the time. The report also makes the suggestion to put the solar panels on the roof, but the contact at RCS says they can be placed on the ground. The contact used from RCS was Ken Zylstra, the Director of Advancement.[6] There is more productive sunlight in New Mexico than in Michigan as seen in Figure 3. They have roughly 300 acres of land to hold solar panels as seen in Figure 4.

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[5] "Rehoboth Solar Project Final Report." *Calvin College*, Calvin College, 28 Jan. 2014, file:///C:/Engr%20333/2014_rehoboth_final_report.pdf. Accessed 2 Oct. 2018.

[6] Ken Zylstra, Director of Advancement, 505-488-3900, kzylstra@rcsnm.org

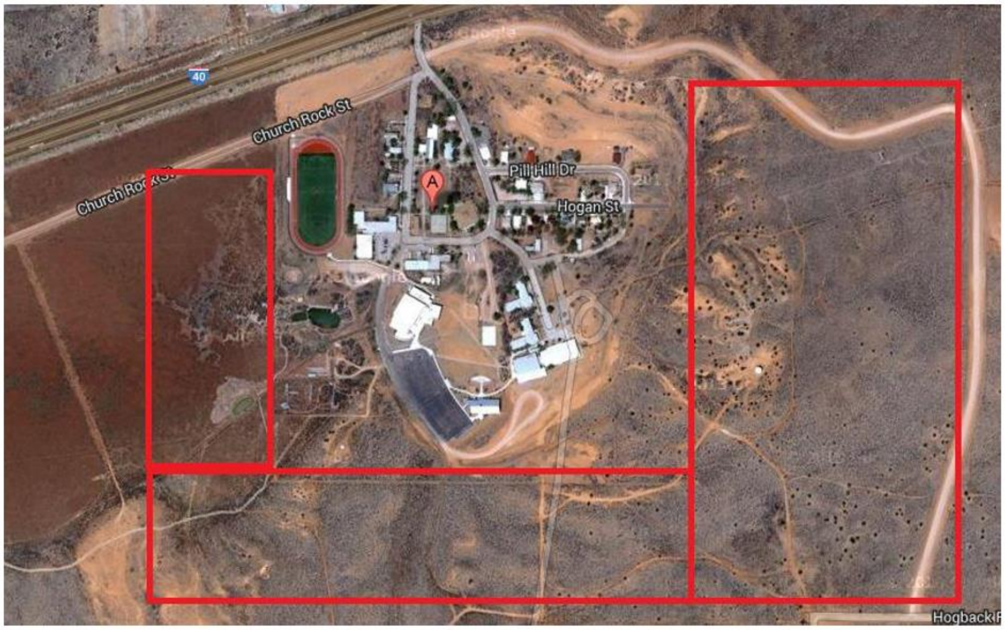

Figure 4. Land owned by Rehoboth Christian School

RCS is part of the City of Gallup, which is an extremely solar friendly city. In August 2018 the city of Gallup built a 10 MW solar farm, which powers nearly 10% of the city.[7] The city is open to adding more solar farms to their grid.

The relationship with RCS would be to reach an agreement to lease land from the school with permission to build the solar field. Then, Calvin would have to work with one of the power companies based in the region to build a solar farm. From there, Calvin would have to work out selling back the power to the grid in the city of Gallup. Lastly, Calvin would have to hire managers for the solar field because RCS could not take care of the field themselves.

2.6 Baseline Energy Use

Typically, baseline electricity usage is measured to be the minimum amount of energy required from the grid at any given point in time. Since solar panels only produce power when direct sunlight is available, the standard baseline calculation was altered to only account for daylight hours. This shortened the time frame for determining the baseline electricity usage from a 24-hour period to a 9-hour period during daylight hours. The data below in Figure 5 displays the minimum electricity draw for every day from June 2016 - May 2017. The baseline value, which became the production goal for the main recommendation, was determined based on the yearly minimum electricity draw during the daily 9:00 AM to 5:00 PM time frames.

[7] "Nearly 10-MW Solar Farm Operational in Gallup, NM." *Power Engineering*, Staff and Wire Reports, 1 Aug. 2018, www.power-eng.com/articles/2018/08/nearly-10-mw-solar-farm-operational-in-gallup-nm.html. Accessed 16 Oct. 2018.

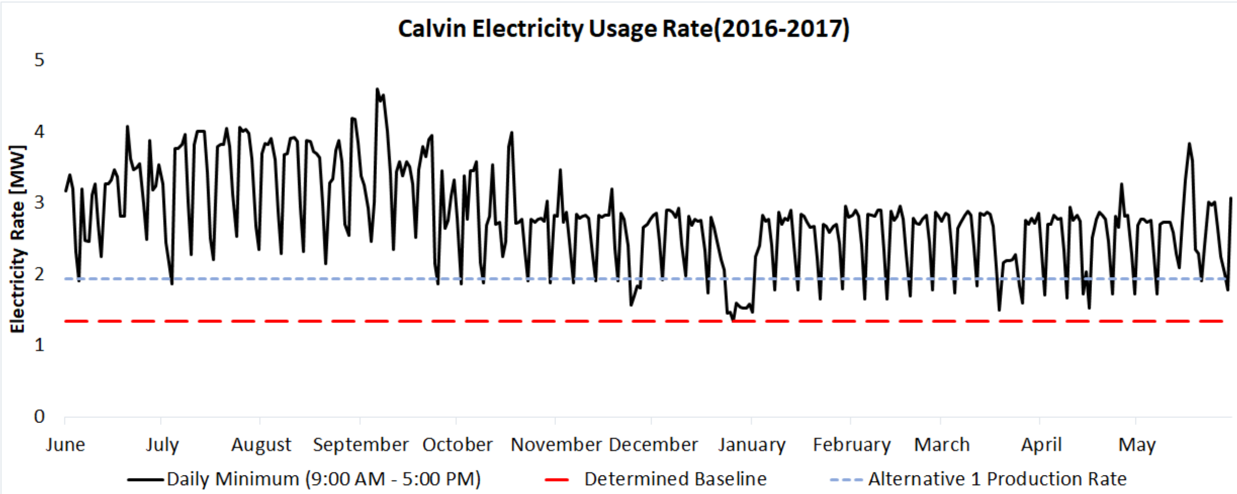

Figure 5. Recorded rate of electricity usage for Calvin during the 2016-2017 year

Because a solar power generating system is not capable of producing power outside of the specified timeframe, all minimum electricity draws values not in the production periods were ignored to allow the effective baseline to be more accurate and relevant to the renewable source.

2.7 Cost Calculations

The route taken in determining required budgets, required land space, annual cost savings, and buyback periods started with determining the effective cost of the electricity output of a typical system. Based on a report done by the National Renewable Energy Laboratory (NREL) for commercial sized systems, the effective cost of electrical output in 2017 was $2.13 per Watt of A/C power produced[8]. As displayed in Figure 6 below, the cost per Watt of D/C power is $1.85. This value was uniformly converted by the NREL report by a ratio of 1:1.15 to calculate the A/C cost. The given cost accounts for hard costs as well as soft costs and is therefore an all-inclusive value for the cost of producing usable A/C power. The value was conservatively raised to $2.50/Wac to account for minor unaccounted for costs such as rooftop racking and bracketing costs, the marginally negligible cost of annual maintenance required by the panels, and an extra contingency cushion to ensure a conservative estimate.

[8] https://www.nrel.gov/docs/fy17osti/68925.pdf

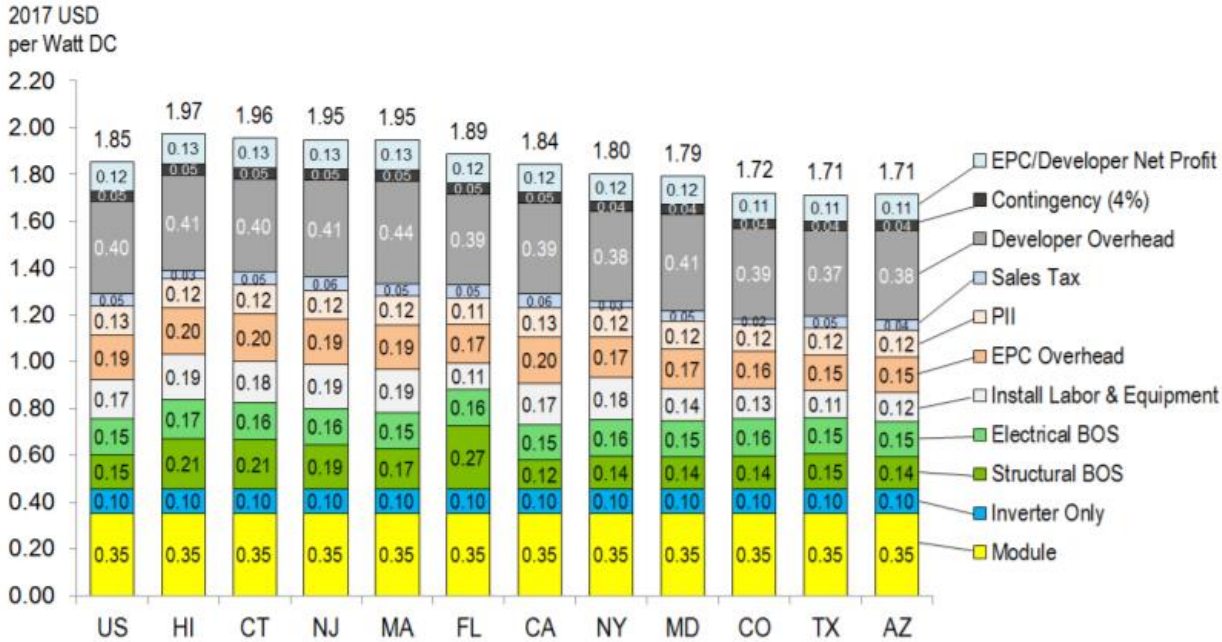

Figure 6. 2017 benchmark by location: 200-kW commercial system cost (2017 USD/Wdc)

The NREL report details the cost breakdown for residential scale, commercial scale, and utility scale systems. Each has a specified range of system capacity, and due to economies of scale, the larger the implemented system, the cheaper the overall cost, as seen below in Figure 7. The commercial scale was selected because the system implemented at Calvin would fall within the range of capacities of the commercial scale (200 kW - 2 MW).

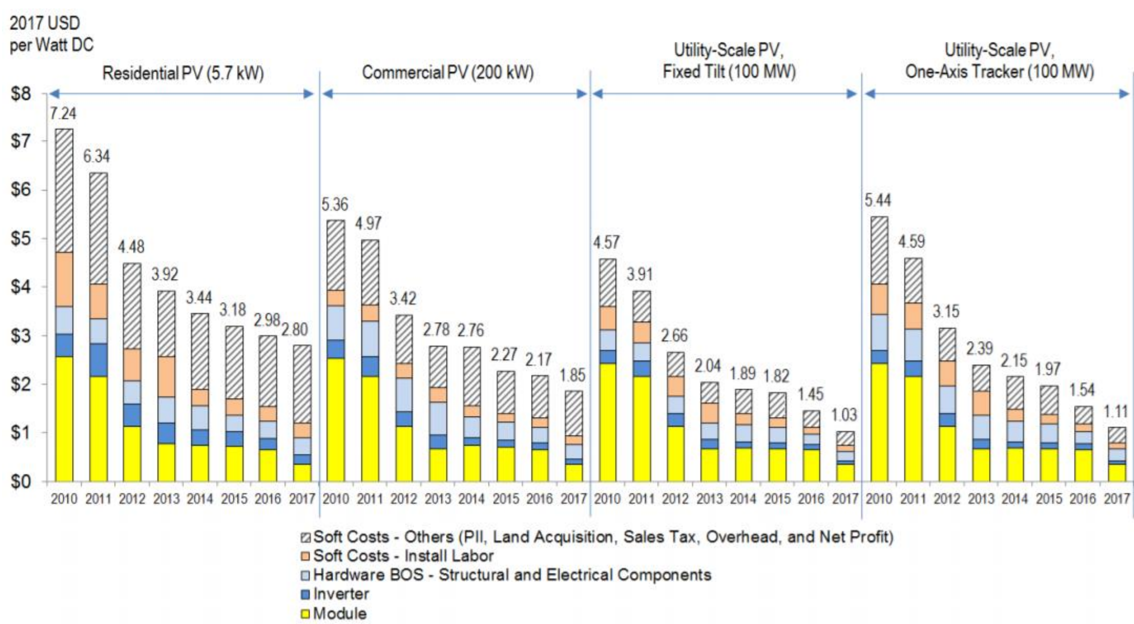

Figure 7. NREL PV system cost benchmark summary (inflation adjusted), 2010–2017.

Once the cost of electricity output was determined, equations were developed to determine the feasible output of a system that Calvin could obtain with the $5 million budget. The system capacity was determined by

Eqn. 1 $$Cap_{sys} = Capital/Cost$$

Where $Capital$ is the investment from Calvin [$], and $Cost = \$2.50/Wac$. Equation 1 provides the nameplate capacity [W] of a system that could be purchased with any given amount of money invested. Knowing the capacity of the system, the actual production [kW-hrs] can be calculated by using a capacity factor (CF).

Eqn. 2 $$Production = Cap_{sys}(CF)$$

The capacity factor determines the actual amount of the nameplate capacity that will be capable of producing usable electricity. The value used for the capacity factor was dependent on location and amount of total direct sunlight hours experienced. For the on-campus scenarios $CF = 0.175$ and for locations in New Mexico $CF = 0.2625$. These numbers were determined from the average hours of direct sunlight at each location. There are an average of 4.2 hours of direct sunlight in Michigan and 6.3 hours in New Mexico[9]. In accounting for the average amount of full-intensity solar hours at a given location, the actual production of the system can be calculated using Equation 2. Additionally, the annual savings [$/yr] of a given budget and corresponding purchased solar system was calculated using Equation 3.

Eqn. 3 $$Savings = Production(Cost_{electricity})$$

Where the cost of electricity [$/kW-hr] was also dependent on location, determined by data from the U.S. Energy Information Administration[10]. The payback period (PP) [yrs] for a given scenario could be calculated using Equation 4.

Eqn. 4 $$PP = Capital/Savings$$

The payback period was one of the key metrics used in determining the feasibility of different scenarios. Examining the required time for an initial capital investment to be paid off is a consistent and accurate measure of the financial security of an investment. Finally, the amount of required

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[9] http://www.longtermsolar.com/solar-sunlight-hours/
[10] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

space needed to house the purchased system was calculated using an estimated average amount of production per area (PPA) [W/ft^2], a space utilization factor, and the system capacity [W].

Eqn. 5 $$A = Cap_{sys}/(F_{space}PPA)$$

The production per area was determined to be 15 [W/ft^2], and the space utilization factor was set at 0.40. This value was estimated taking into account the necessary space between panels to allow for walking paths as well as adjacent panels' shadows, and the buffer space required by rooftop obstacles and edges.

2.8 Solar Panels

Type

The two types of solar panels being considered for this proposal are polycrystalline and monocrystalline. The advantages and disadvantages of these options were closely evaluated.

Monocrystalline panels are the recommended option for this project. These solar panels are the most efficient of any current solar panel with a 21.5% efficiency rating. Monocrystalline solar panels also take up the least amount of space, which is beneficial for Calvin where space is limited. Lastly, these panels tend to have a longer lifetime than the other types of solar panels. The two primary disadvantages of monocrystalline panels are their larger investment cost compared to polycrystalline panels and the effect of shade on their efficiency. Shade from trees or other objects can prevent an entire array from producing electricity.

The polycrystalline panels only have a 13-16% efficiency compared to the monocrystalline panels. They also take up more space, which is a valuable commodity on Calvin's campus. However, these panels are cheaper than the monocrystalline panels and are less sensitive to temperature.[11]

Cleaning

The output of a solar panel is most obviously linked to the amount of sunlight it receives, but there are a number of additional factors that can affect the amount of power generated. The effectiveness of a solar panel decreases if the surface gets covered in dirt or dust. Sprinkler systems and washing services can clean off solar panels, but due to Michigan's climate, there is typically enough rain to let nature clean the panels.

[11] Maehlum, Mathias A. "Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film." *Energy Informative*, Energy Informative, 16 Mar. 2018, energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/. Accessed 2 Oct. 2018.

Maintenance

Maintenance is a small cost when it comes to solar power. A solar panel has no moving parts and no fuel intake. If installed correctly, there are very few ways a solar panel could fail. If they do fail however, it will most likely be due to corrosion in the wires that connect the panels to the inverter[12]. Annual inspections are recommended to insure maximum output and cost about $250 per MegaWatt of panels[13].

2.9 Comments/Future Questions

If this project were to be continued, there are a few topics that might be researched further. First, The Venema Aquatic Center and the Van Noord Arena were not used due to the short life span of their roofs. Theoretically, these large roof spaces could be utilized, but it would involve removing and reinstalling them once the roofs needs to be replaced in about 20 years. Perhaps this process would not be that expensive and these roofs could be used. Perhaps the solar panels might even help increase the lifespan of the current tar and gravel roof by acting as a shield from the elements. Another option that could use a more in depth research would be solar roofs over some of the parking lots. Due to their large infrastructure cost over rooftop or ground panels, these were discarded as an option. However, perhaps it would be economically feasible to cover a few of the parking lots. The parking lot would have to be free from trees or building shadows, therefore the recommended lots would be 1, 7, 8, 15 or 16. Lastly, new buildings may be added to Calvin in the near future, with the Student Union as a prime example. It is much easier to install solar panels onto a new building because the roof design can be best accommodated for the panels and they can be wired directly into the building's infrastructure.

[12] Dilthey, Max. "How to Maintain Your Solar System Year Round." *Solar Power Authority,* 14 Mar. 2017, https://www.solarpowerauthority.com/maintain-solar-system-year-round/. Accessed 4 Dec. 2018.

[13] Deign, Jason. "Drones could inspect 16 hectares a day for just €1,800." *Solar Plaza,* 7 Sept. 2016, https://www.solarplaza.com/channels/asset-management/11609/drones-could-inspect-16-hectares-day-just-1800/. Accessed 4 Dec. 2018.

2.10 Works Cited

[1] "Solar Panels: Lifetime Productivity and Maintenance Costs." *Boston Solar*, 8 Mar. 2016, https://www.bostonsolar.us/solar-blog-resource-center/blog/solar-panels-lifetime-productivity-and-maintenance-costs-2018/. Accessed 4 Dec. 2018.

[2] "2018 Guide to Michigan Home Solar Incentives, Rebates, and Tax Credits." *Solar Power Rocks* https://www.solarpowerrocks.com/michigan/. Accessed 13 Oct. 2018.

[3] "Do solar panels work in the winter?" *EnergySage*, 17 Oct. 2018, https://news.energysage.com/solar-panels-in-winter-weather-snow-affect-power-production/. Accessed 4 Dec. 2018.

[4] Roof Areas were calculated using www.mapdevelopers.com/area_finder.php

[5] "Rehoboth Solar Project Final Report." *Calvin College*, Calvin College, 28 Jan. 2014, file:///C:/Engr%20333/2014_rehoboth_final_report.pdf. Accessed 2 Oct. 2018.

[6] Ken Zylstra, Director of Advancement, 505-488-3900, kzylstra@rcsnm.org

[7] "Nearly 10-MW Solar Farm Operational in Gallup, NM." *Power Engineering*, Staff and Wire Reports, 1 Aug. 2018, www.power-eng.com/articles/2018/08/nearly-10-mw-solar-farm-operational-in-gallup-nm.html. Accessed 16 Oct. 2018.

[8] https://www.nrel.gov/docs/fy17osti/68925.pdf

[9] http://www.longtermsolar.com/solar-sunlight-hours/

[10] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

[11] Maehlum, Mathias A. "Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film." *Energy Informative*, Energy Informative, 16 Mar. 2018, energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/. Accessed 2 Oct. 2018.

[12] Dilthey, Max. "How to Maintain Your Solar System Year Round." *Solar Power Authority*, 14 Mar. 2017, https://www.solarpowerauthority.com/maintain-solar-system-year-round/. Accessed 4 Dec. 2018.

[13] Deign, Jason. "Drones could inspect 16 hectares a day for just €1,800." *Solar Plaza*, 7 Sept. 2016, https://www.solarplaza.com/channels/asset-management/11609/drones-could-inspect-16-hectares-day-just-1800/. Accessed 4 Dec. 2018.

3 Wind Appendix

The wind team explored the possibility of putting another wind turbine on campus. The main focus of research was done in these sectors: requirements and laws, small turbines versus large turbines, turbine placement, and off site investments.

3.1 Requirements/Laws

Maximum turbine height is limited due to Calvin College's proximity to Grand Rapids Regional airport. The Federal Aviation Administration (FAA) set guidelines that requires any structures constructed within 20,000 feet from any point on an airport runway that are 200+ feet tall to be reviewed by the FAA for approval before construction.[14] Since this process could become very costly as well as difficult legally, our turbine design is to remain under 200 feet. This eliminates the possibility of erecting the larger wind turbines such as 2 MW capacity ones, which require towers of greater than 300 feet in height.

Another concern with wind power on campus was noise. Wind turbines produce machine noise at audible frequencies to humans and animals. Noise regulations prohibit any noise louder than 55 dB at the edge of one's property. Thus, the turbine selected must remain quiet enough to meet this law, and must be placed far enough from the property line to not disturb neighboring property owners.

3.2 Turbine Selection

Small and large turbines were looked into to determine which route would produce better results on Calvin's campus.

Small turbines were not chosen for this project because of the amount of trees and buildings on campus causing wind speeds near rooftops to the ground to be low for economic viability. Smaller turbines do not have as good of a power output as large turbines do as size tends to scale exponentially. If a bigger turbine is able to installed, then it makes sense to take advantage of that extra increase in power. The smaller turbines also had worse purchaser reviews. When putting turbines on top of buildings was studied, the real power output produced by these devices was an extremely low percentage of their total capacity. It also was discovered that for solar power, a feasible option was to put panels on the roofs. Thus, roof-mounted wind turbines were removed from the alternatives. This helped the wind team to decide to move to bigger turbines as they are more efficient for mass production of electricity.

[14]Federal Aviation Administration. *Notification of Proposed Construction or Alteration on Airport Part 77*, FAA, 24 Aug. 2017, www.faa.gov/airports/central/engineering/part77/. Accessed 9 Dec. 2018.

Large turbines choices were limited as Calvin College proximity to the Ford International Airport prevents building above 200 ft without special permission. Even under this height large turbines close to the cutoff height may need to be approved by authorities.

The optimal turbine found was a Nordtank NTK130 turbine. Using the power curve of the turbine with wind speeds of the area collected at the airport this system would have a cost of $270,000 per turbine with a payback period of 25 years producing 130 kW. Possible placement would include the open area around the cross country course where eight turbines could fit in 55 acres. This would require cutting down at least some of the trees around the cross country track. This is to create pathways to the turbines as well as having an area around the turbine cleared so no trees would grow into it or into the path of the blade. The specifications of the NTK130 turbine are shown in Table 1.

Table 1. NTK 130 turbine specifications.

Number of Blades	3
Rotor Diameter	21 m
Rotor Speed	44.5 rpm
Cut-in Wind Speed	3.5 m/s
Cut-out Wind Speed	30 m/s
Survival Wind Speed	53 m/s
Hub Height	27 m
Maximum Continuous Power Output	145 kW

The low power output from the wind reading based from Calvin's Geology department measurements by the Bunker Center(it was taken three meters off the ground and is below tree line) and the similar data from the current wind tower, it seemed that wind did not create enough power to be feasible. This data was compared to the wind data from the Grand Rapids airport which produced a enough power to be feasible. The approach to compensate for the difference was to take 80% of the airports data to provide a more accurate result on Calvin's campus. This results in a payback period just shy of 25 years. As the expected lifetime is 25 years for the turbine, the project will barely break even. This then depends on the actual wind speeds in the location of the proposed turbines. If Calvin wants to invest in wind, it would be advised to do an actual wind speed study on campus at the same height as the wind turbine to determine accurate speeds at Calvin's location. A wind data logger kit can cost anything from $300 to several thousand.[15] This extra data will allow calculations to help determine feasibility.

3.3 Wind Speed Calculations

There were three different wind speed calculations that were done based off of data from Gerald R. Ford Airport, Geology Department wind gauge by the Bunker Interpretive Center, and the wind turbine located on the edge of the Nature Preserve. The wind speed data from the airport had the highest wind speeds since the airport had the least amount of obstructions. The data gathered from Calvin's wind turbine was slightly lower than the data collected from the Geology Department Bunker Interpretive Center because it was taken during the summer opposed to the Geology Department data which was taken during the winter. Geology Department data and Calvin's wind turbine data led to total power outputs that were around 60% lower than the power output that the airport data produced. The Gerald R. Ford airport is about four miles away from Calvin so the wind speeds at the airport should be close to the wind speeds on Calvin's campus, but as mentioned earlier, it would be beneficial to take wind speed readings at the desired location of the turbine.

To find the average power output of the NTK-130 turbine, calculations had to be done using wind probability and the power curve for the turbine. The power curve for the NTK-130 turbine can be seen in Figure 1.

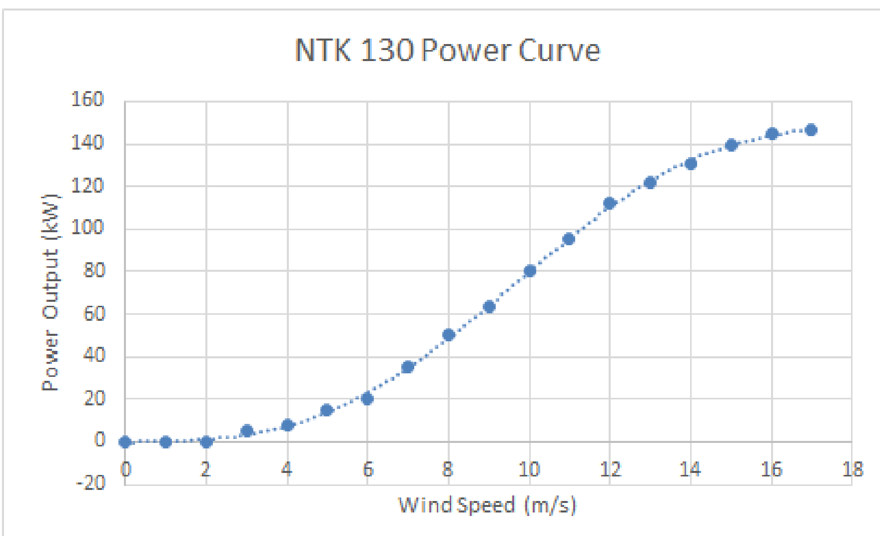

Figure 1. NTK-130 Power Curve

Wind speed probability data for the Gerald R. Ford airport was found by looking at the wind rose distribution from the data collected by the National Weather Service for the airport. The probability

[15] "Wind Speed Recording System | Measuring Wind Speed | Scientific Sales." *Barometers | Barometric Pressure Sensor* | *Brass & Aneroid Barometers*, www.scientificsales.com/ProductDetails.asp?ProductCode=110-200&gclid=EAIaIQobChMIgujw0czg3gIV1luGCh0opwcmEAkYASABEgLmjvD_BwE.

for wind speeds on Calvin's campus were estimated using the data from the Geology department and Calvin's on campus turbine. For both of these data sets the probability for each wind speed was found by counting the number of occurrences of wind speeds within a range for the entire set of data for a given month which were then summed for the year. The number of occurrences of a specific wind speed for the entire year was then divided by the total number of wind speed data taken for the entire year. A table of these calculations can be seen in Table 2.

Table 2. Wind Speed Probability Table for Geology Wind Speed Data

Wind Speed (mph)	Jan (count)	Feb (count)	Apr (count)	Aug (count)	Dec (count)	Year total	Wind probability	Power Probability (kW)	Total Power Output (kW)
0-2.36	179	359	301	449	182	1470	0.191	0	7.61
2.36-4.47	231	350	224	223	214	1242	0.162	0	
4.47 - 6.71	315	304	303	404	339	1665	0.223	1.11	
6.71 - 8.95	343	217	222	224	291	1297	0.174	1.39	
8.95 - 11.18	244	144	172	111	213	884	0.118	1.78	
11.2 - 13.4	136	76	123	62	156	553	0.0743	1.48	
13.42-15.6	37	36	81	15	74	243	0.0326	1.14	
15.65-17.8	0	0	39	0	16	55	0.00798	0.443	
17.89-20.1	0	0	15	0	3	18	0.00242	0.169	
20.13-22.3	0	0	7	0	0	7	0.000941	0.075	

The weighted average for the power output of the turbine for each wind speed could then be found by multiplying the probability for each wind speed by the corresponding power output at that wind speed on the NTK-130 power curve. The average output of the NTK-130 was then found by summing all of the weighted average power outputs together. The same method of calculating the average power output was performed for all three data sets.

Eqn. 1 $$Wind_{prob} = \frac{w_{count}}{w_{sum,count}}.$$

Where the wind w_{count} is the number of occurrences of a specific wind speed in a specific month and $w_{sum,count}$ is the total number of wind speed data taken for every wind speed range.

Eqn. 2 $$P_{prob} = Wind_{prob} * P_{wind}$$

Where the $P_{prob}$is the weighted average of the power output for each wind speed and P_{wind} is the power output of the turbine at the same wind speed that the $Wind_{prob}$is using Equation 3.

Eqn. 3 $$P_{avg} = \Sigma P_{prob,i}$$

Where the power output average of the turbine is the sum of the all of the weighted power outputs at each of the wind speeds.

After the calculation for the power output based on the probability, the amount of savings per day was calculated using Equation 4.

Eqn. 4 $$\frac{Savings(\$)}{Year} = Output(kW) * \frac{24\ hours}{day} * \frac{365\ days}{year} * Electricity(\$/kWh)$$

This allowed a value to be given to how much the turbine will save Calvin each day. Then the Return of Investment(ROI) was calculated through Equation 5.

Eqn. 5 $$ROI(years) = \frac{Cost(\$)}{Savings(\$)/Year}$$

The cost in Equation 5 is the total cost: this includes maintenance, installation, and the cost of the turbine itself. The maintenance cost was found by assuming a 3% cost per year based on the purchase price.[16] Installation costs for wind turbines are typically between 20% and 30% of the cost of the turbine. This project assumes an installation cost of approximately 25% of the turbine cost. These calculations allow for a direct cost savings that Calvin would receive by investing in wind turbines.

3.4 Wind turbine spacing

The general rules for optimum performance of wind turbines, are that they have to be installed within 4-10 times rotor diameter away from another turbine. It must be installed twice the turbine height from the closest property, roads and buildings. The turbine height should be 10 meters higher from obstacles below it such as buildings or trees. Turbines at least 24 meters tall are appropriate in areas where the land is flat or elevated and there are no obstacles within 150 meters. So according to selected turbine, the wind turbine spacing is at least 100 meters away from each other. Since the highest point of the selected turbine is 38 meter than Turbines should be installed at least 76 meters radius from the closest property. See the Figure 2 below.

[16] Zhang, Lu, et al. "Deterministic Optimization and Cost Analysis of Hybrid PV/Wind/Battery/Diesel Power System." *International Journal of Renewable Energy Research*, vol. 2, no. 4, 2012, dergipark.gov.tr/download/article-file/148418. Accessed 5 Dec. 2018.

Figure 2. Shows the turbine spacing.

From the spacing criteria mentioned earlier, the required area of wind turbine farm will be 55 acres. For the best results, this whole area would be free of trees and buildings. If trees are above a certain height, which is based on each turbine, those trees will need to be cut down as to maintain laminar layer of wind hitting the turbine. However, if it is desired to keep as many trees as possible, then a smaller diameter around the turbine would need to be cleared around the turbine.

3.5 Summary of Off-Campus Wind Options

When examining the feasibility of wind as source of renewable energy for Calvin College, it was worth-while to look at the feasibility of investments outside of Calvin's Grand Rapids Campus. After studying the potential on Calvin's campus, research was done to investigate if there was a more worthwhile investment opportunity in wind energy elsewhere. In order to make a more meaningful investment off campus options. Options looked at include: a co-sponsored project with Consumers or DTE energy similar to the Grand Valley Solar Farm, an offshore project in Lake Michigan, and capital investments in larger non-local projects.

One option that was looked at was to invest in a something similar to what Grand Valley State University had done with their Allendale campus solar farm. It was determined that Calvin would not be able to participate in a project like this. That project required Grand Valley to supply the large amount of land needed for the solar field while Consumers Energy owns and operates the farm and sells the electricity to Grand Valley at a discounted rate.[17]Since Calvin does not have a large parcel of land, this is not an option.

The other option with Consumers and DTE that was looked at was purchasing into their "Green Bonds" program. This money would be invested by the company into green energy options throughout the state of Michigan. However, this investment acts more like a bond and the only benefit to the College would be financial, Calvin would not be able to claim the credit for carbon reduction. Thus, this was not deemed a feasible option either.

In researching local wind speeds, it was noticed that just a few miles offshore of Lake Michigan the average wind speed increases significantly. This makes offshore turbines more feasible. Unfortunately, there are many other obstacles to building turbines in the Great Lakes. The closest case study available was a proposal for offshore turbines in Muskegon.[18] The community pushback was so fierce, the project was quickly scrapped. There is a project that has a large backing in Ohio, offshore in Lake Erie. But this project was independently funded from a Finnish company and there would be no way to buy into it. Also, similar to the Muskegon project there is major community pushback as well is pushback from "big coal". Like in Muskegon opposition to this project sites aesthetics and environmental concerns.[19]

It was determined that at this point, Great Lakes wind power does not have the infrastructure, market, or community backing to be a feasible option to invest in. It should be noted that there is a lot of potential for the Great Lakes as a source power in the future.

Lastly, research was done to see if there were any other possible options to invest in clean wind energy. The main takeaway was that currently, a market does not exist to invest in wind energy. The majority of projects tend to be independently funded. Since wind scales exponentially the projects tend to be large with investments in the ballpark of $100 to $200 million. With the allocated $5 million, the budget for the project would be too small to make a significant investment into wind energy.

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[17]"Grand Valley State University." *Grand Valley State University*, www.gvsu.edu/ens/solargarden/benefits-8.htm.

[18] Solis, Ben. "Proposed Wind Farm East of Muskegon Sparks Anger from Residents." *MLive.com*, MLive.com, 22 Aug. 2018, www.mlive.com/news/muskegon/index.ssf/2018/08/proposed_wind_farm_east_of_mus.html.

[19]McCarty, James F. "Icebreaker Lake Erie Wind Project Praised, Criticized at Hearing before State Board." *Cleveland.com*, Cleveland.com, 21 July 2018, www.cleveland.com/metro/index.ssf/2018/07/icebreaker_lake_erie_wind_proj.html.

3.6 Works Cited

"Another Round of Snow Tonight and Thursday Morning May Create Slick Roads." *National Weather Service*, NOAA's National Weather Service, 20 Apr. 2015, www.weather.gov/grr/grrinfo.

Federal Aviation Administration. *Notification of Proposed Construction or Alteration on Airport Part 77*, FAA, 24 Aug. 2017, www.faa.gov/airports/central/engineering/part77/. Accessed 9 Dec. 2018.

"Grand Valley State University." *Grand Valley State University*, www.gvsu.edu/ens/solargarden/benefits-8.htm.

Industrial Wind Turbine Nordtank NTK 130. *Industrial Wind Turbine Nordtank NTK 130*, Nordtank, www.mwps.world/wp-content/uploads/2016/08/NORDTANK-NTK130-Techical-specifications-low-res.pdf.

McCarty, James F. "Icebreaker Lake Erie Wind Project Praised, Criticized at Hearing before State Board." *Cleveland.com*, Cleveland.com, 21 July 2018, www.cleveland.com/metro/index.ssf/2018/07/icebreaker_lake_erie_wind_proj.html.

Solis, Ben. "Proposed Wind Farm East of Muskegon Sparks Anger from Residents." *MLive.com*, MLive.com, 22 Aug. 2018, www.mlive.com/news/muskegon/index.ssf/2018/08/proposed_wind_farm_east_of_mus.html.

"Wind Speed Recording System | Measuring Wind Speed | Scientific Sales." *Barometers | Barometric Pressure Sensor | Brass & Aneroid Barometers*, www.scientificsales.com/ProductDetails.asp?ProductCode=110-200&gclid=EAIaIQobChMIgujw0czg3gIV1luGCh0opwcmEAkYASABEgLmjvD_BwE.

Zhang, Lu, et al. "Deterministic Optimization and Cost Analysis of Hybrid PV/Wind/Battery/Diesel Power System." *International Journal of Renewable Energy Research*, vol. 2, no. 4, 2012, dergipark.gov.tr/download/article-file/148418. Accessed 5 Dec. 2018.

4 Biomass Appendix

The Biomass group explored several options. The two main projects were conversion of a diesel lawn mower to run on waste vegetable oil and an anaerobic digester.

4.1 Waste Vegetable Oil

In 2013, an Engineering 333 group evaluated the feasibility of modifying several campus vehicles in order to operate on Waste Vegetable Oil (WVO)[20]. Any diesel engine can be operated on waste vegetable oil, provided that the oil is heated to increase viscosity. However, for the project discussed above, this option was eliminated due to the small relative returns, and the potential for regulatory problems.

The 2013 team then conducted an analysis into filtering and storing the used oil in the physical plant building, and converting one of the campus lawnmowers and a transportation van to use WVO. They found that the up-front costs of the entire system were $6680, and $3000 annually to maintain. The system, once set up, would save Calvin approximately $4000 per year. See Figure A.1.

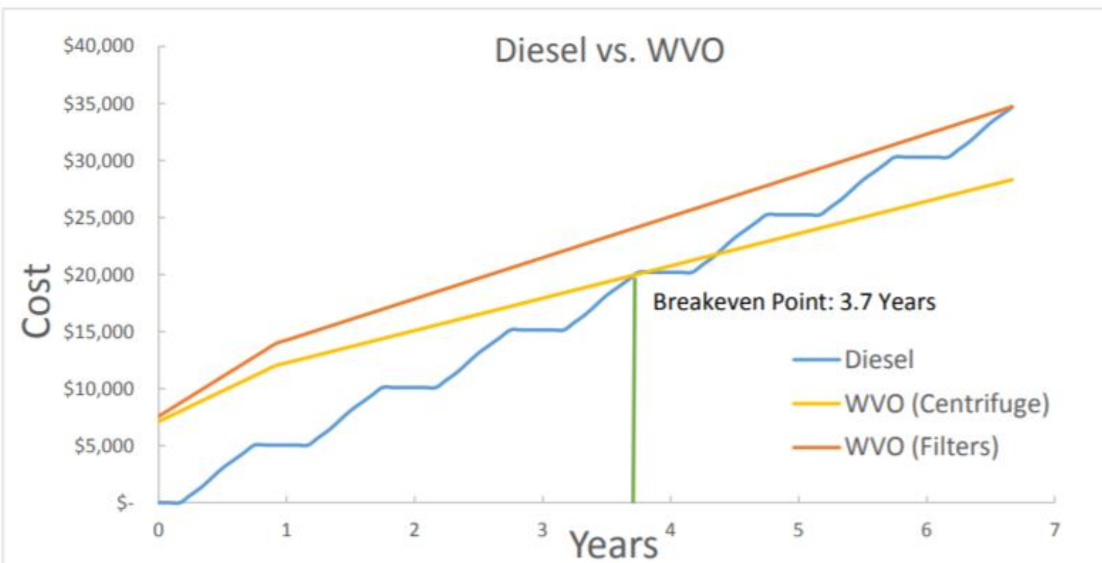

Figure 1: Cost Analysis of Waste Vegetable Oil use for lawn mowers and sprinter vans, from 2013 analysis.

For the current analysis, the costs were updated based on present day technology, and were found to be roughly equal (±10%). However, some regulatory hurdles were encountered in using WVO for fuel in vehicles, as the law is not clear on the legality of the process. For example, using waste

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[20] http://www.calvin.edu/~mkh2/thermal-fluid_systems_desig/2013_biofuel_vehicle_projec.pdf

vegetable oil as fuel without paying fuel taxes is considered tax evasion[21]. In addition, longer term studies have found that WVO can cause damage to engine components (such as fuel pumps) and shorten the life of the vehicle, resulting in higher costs over time[22]. Also, studies have found that burning waste vegetable oil can result in 10 - 20% higher emissions of NO_x than traditional diesel fuel[23]. Finally, it was decided that the $4000 payback, although significant in terms of the total investment, was not significant enough in terms of the scope of the overall investment in renewable energy, as it composed only 0.08% of the $5 million investment.

In conclusion, the small payback (less than 0.1% of the total $5 million investment), coupled with potential regulatory hurdles and engine damage make the conversion of diesel vehicles on Calvin's campus impractical for the scope of the project.

4.2 Anaerobic Digester

Calvin College produces between 300 and 500 tons of compostable material annually. This material is currently composted by NewSoil, a subsidiary of Arrowaste. As it composts, it emits methane, which can be harvested and burned as a fuel using an Anaerobic Digester. Small scale (1000-2000 ton per year) anaerobic digesters generally cost around $1.2 million[24].

An anaerobic digester would convert waste food on campus into methane that could be used in power generation, water heating, or winter sidewalk heating, rather than sending that food to be composted. As an added benefit, the methane that would have otherwise been released into the atmosphere would be burned for fuel into carbon dioxide (a much less potent greenhouse gas) effectively saving Calvin over 100 tons of Carbon Dioxide emissions per year.

Other college campuses like UC Davis, Purdue, and University of Michigan have used biodigesters for converting dining hall food into energy, but these proved much more economically practical. For instance, UC Davis' FEAD digester cost $ 8.5 million and converts 50 tons of organic waste to 12,000 kWh of renewable electricity each day. This system is nearly fifty times larger than Calvin would be able to supply.

On its own, Calvin cannot feed a digester of practical size. A partnership was explored with NewSoil, but conversations with Mr. Henry Kingma, Calvin College recycling coordinator,

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[21] Wacker, Tim. "Run a Diesel Vehicle on Vegetable Oil." *Mother Earth News*, Dec. 2007. Accessed 17 Oct. 2018.
[22] Hönig, Vladimír, et al. "Biobutanol Standardizing Waste Cooking Oil as a Biofuel." *Polish Journal of Environmental Studies* 26.1 (2017).
[23] D'Alessandro, Bruno, et al. "Straight and waste vegetable oil in engines: review and experimental measurement of emissions, fuel consumption and injector fouling on a turbocharged commercial engine." *Fuel* 182 (2016): 198-209.
[24] See the EUCOlino by BIOFerm

indicated that the investment required and small overall return meant that this project was not an attractive investment for Calvin College. The amount of compostable material that Calvin produces does not justify the costs associated with building an appropriately sized digester, despite the fact that this would reduce the costs. Even if Calvin did find a anaerobic digester, the payback period is similar to the other projects assuming Calvin got all the revenue from the project during the payback period.

4.3 Conclusion

At this time Biomass is not a viable source of renewable energy for Calvin College. Current regulations make using vegetable oil as fuel in Grounds lawn mowers impractical. The cost of building and maintaining a Bio-digester, on or off site, does not yield enough energy to be economically feasible.

5 Geothermal Appendix

The main recommendation for reducing Calvin's annual energy cost includes $157,000 towards residential geothermal systems. It was decided that the investment would be best spent on residential systems instead of commercial systems because residential systems often have a shorter payback period and are a more feasible method for Calvin to implement than the very large commercial systems that would be needed for many of the larger on-campus buildings. A more in-depth investigation into each type of geothermal system, its implementation, its cost, and its feasibility for Calvin College can be seen below.

5.1 Types of Systems

The three categories of geothermal systems include closed loop systems, open systems, and special systems. A closed system exchanges heat with the ground through pipes with circulating fluid within the system. An open system exchanges heat and water within the ground typically in the form of a well. Special systems include hybrid systems which is a combination of exchanging heat within the ground and by using natural resources for the remainder of the heating or cooling capacity. Another type of special system would be a pond system where the piping would exchange heat with the water of a pond rather than with the ground.

A horizontal loop also known as a horizontal trench loop is a closed system are typically the most cost effective when the land area is available. The general layout of this system can be seen in Figure 1. The trenches the pipes are placed into are typically around six feet deep or below the frost line in areas where freezing could occur. In order to produce a one-ton capacity a typical pipe length is around 300 feet.

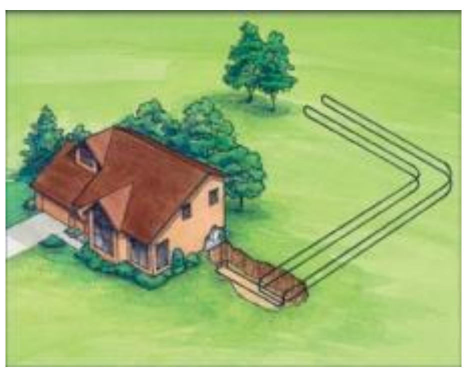

Figure 1: Horizontal Loop System

A vertical loop also known as a vertical bore loop system is a closed system that requires significantly less land than horizontal loop systems and can be seen in Figure 2. These systems cost significantly more than other systems because they require bore holes that are 150 to 450 feet deep. The cost of making bore holes increases the deeper the hole needs to be.

Figure 2: Vertical Loop System

The pond loop is a closed loop system that requires the proximity of a pond nearby. A potential layout of this system can be seen in Figure 3. This system is the most cost effective of the geothermal systems if the pond already exists and meets the volume, depth, and area requirements. A pond system needs to be maintained at a minimum of 12 to 15 feet minimum and have to have an area of an acre to be feasible. However, the capacity of a pond loop system is much greater than a horizontal or vertical loop system.

Figure 3: Pond Loop System

5.2 False Starts

5.2.1 Heating and Cooling vs. Electricity

Geothermal systems can be used to produce electricity or to heat and cool a building. In geothermal power plants, a large bore hole, about a mile long, is drilled into the earth where underground reservoirs are found. The systems are called Deep Enhanced Geothermal Systems. These reservoirs contain extremely hot water or steam. The water and steam are pumped aboveground and turn turbines that are linked to generators which produce electricity. In the United States, there are areas more favorable for geothermal power plants. These areas that are favorable for geothermal power plants are shown in Figure 4.

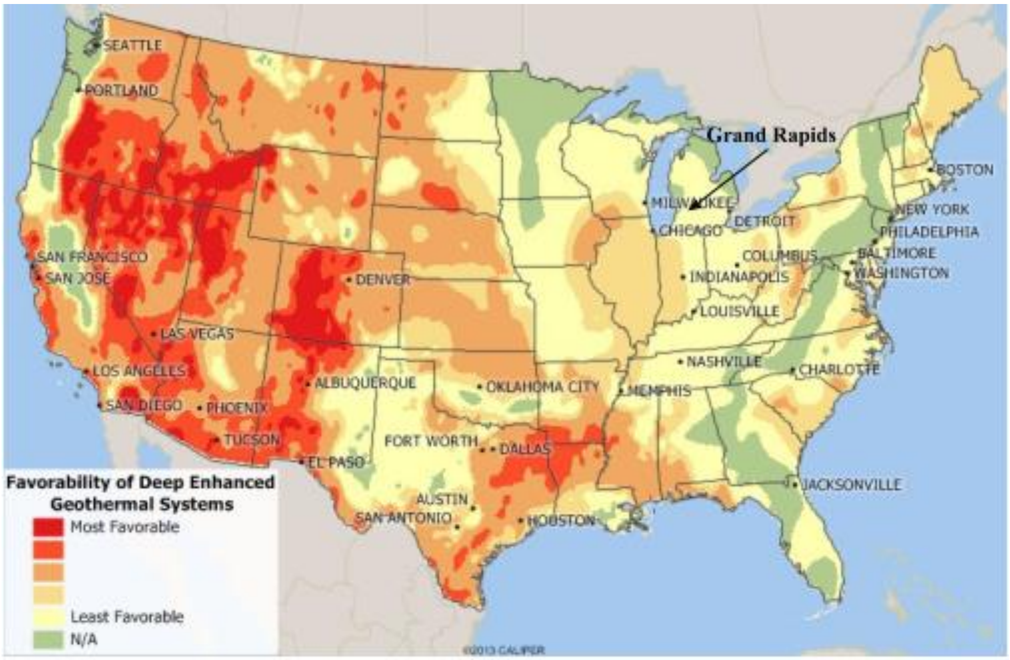

Figure 4: Locations that are favorable for Deep Enhanced Geothermal Systems

As seen on the map above, Grand Rapids, Michigan is one of the least favorable locations to have a geothermal power plant. Geothermal power plants perform better in “high temperature” locations such as around geysers and volcanoes which are located near tectonic plates. A map of tectonic plates is in Figure 5.

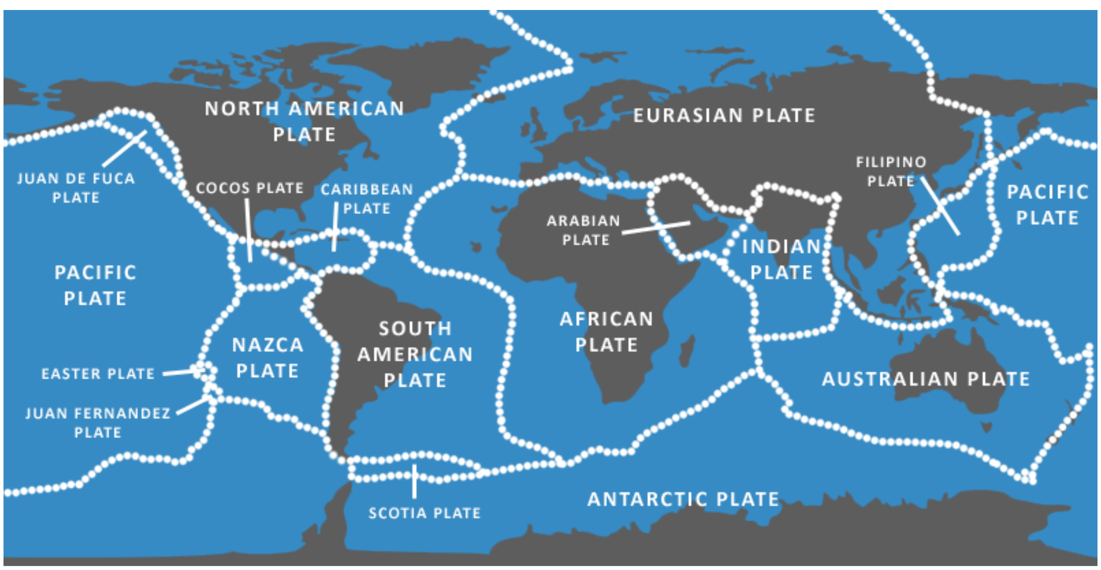

Figure 5: The Tectonic Plates of the World

As seen in Figure 5, Michigan is not near any tectonic plates. Additionally, geothermal power plant systems have an efficiency of around 12%. As such, it was determined that electricity generation was not feasible at Calvin College. Further research was done on using geothermal systems purely for heating and cooling buildings.

5.2.2 Residential vs. Commercial

There was also considerations between commercial and residential geothermal systems. It was determined that commercial systems were not feasible for Calvin College. Due to higher ventilation standards, commercial geothermal systems are required pull in a certain percentage of outside air. Thus, in the wintertime, cold outside air would be pulled into the house. The geothermal system would then have to heat the incoming cold air in addition to the cold air already inside the house. The same is true during the summertime, except hot outside air is pulled into the house which needs to be cooled. The pulling in of outside air lowers the overall system efficiency which would make the system cost more. Thus, it was determined that commercial applications would be not feasible at Calvin College.

5.3 Rod Boreman

During this project the geothermal team had meetings with Rod Boreman. Rod Boreman was a previous employee for a local geothermal company called Greensleeves LLC. Rod suggested hybrid geothermal systems if the team was to implement a geothermal system for any of Calvin's commercial buildings. This is because a commercial geothermal system has to take on a much larger heating load and consequently are much larger and expensive. This is due to the ventilation systems bringing in outside air and the system having to heat this air. To offset the large upfront costs of a pure commercial geothermal system, Rod suggested a hybrid geothermal system. The hybrid geothermal system reduces upfront costs by reducing the size of the well field. This is accomplished by the geothermal system utilizing a cooling tower or a boiler to provide additional heating or cooling to the ground loop water under peak conditions. Ultimately the Geothermal team decided against implementing these systems due the low CO_2 emissions decrease that these systems provide.

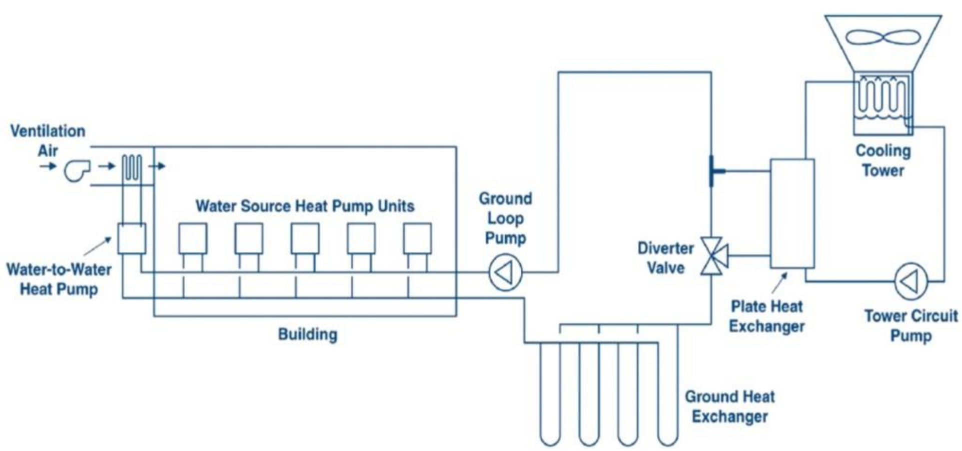

Figure 6: Hybrid Geothermal System

5.4 Other Schools with Geothermal

Geothermal systems are not uncommon on college campuses. Throughout the research phases of this project, several other college campuses were looked at to determine the feasibility of implementing a similar system on Calvin's campus. These campuses include the University of Michigan, Missouri University of Science and Technology, and a previous Calvin 333 class that looked at adding a geothermal system to the Spoelhof center in 2012.

Of these three campus systems, both Missouri University of Science and Technology and Calvin's Spoelhof project return similar values of around $37 per square foot of building space when the values were scaled to the present value of money. The system installed on the University of Michigan's campus came out to a value of $753 per square foot of building space. This outlier is likely due to a different type of system. Deep well systems are significantly more expensive as they often require 150-450 foot bores holes, which increase in cost significantly the deeper they get. Installing horizontal loops and pond loops, which would be proposed for Calvin's campus, are the less expensive option. Table 1 shows a breakdown of each of these three systems.

Table 1. Breakdown of three alternate campus setups

Campus	Initial Cost (millions)	Initial Size (sqft)	Scaled Cost ($/sqft)	$1.25 million potential	$5 million potential
University of Michigan	$2.5	4,000	753	1,660 sqft	6,640 sqft
Missouri S&T	$32	1,000,000	37.55	33,290 sqft	133,170 sqft
Calvin Spoelhof Project	$1.78	56,150	36.32	34,420 sqft	137,680 sqft

5.5 Cost

5.5.1 Base Case Evaluations - Sample Systems

Table 2. Breakdown of three researched residential setups

Campus	Initial Cost ($)	Initial Size (sqft)	Scaled Cost ($/sqft)
Sample 1	$22,500	4,400	5.11
Sample 2	$19,000	2,000	9.50
Sample 3	$23,000	3,500	6.57

Using the data from the three-sample residential geothermal systems, an average scaled cost of 7.06 $/sqft for installation cost was calculated. This constant was used to calculate the installation cost for potential residential buildings considered in the main recommendation. Given the utility costs for each sample, both before and after the geothermal system install, we were able to calculate the average effect that the systems had on the utility costs of the sample. Using the sample data, it was calculated that the geothermal systems reduced natural gas usage by roughly 85% and increased electricity usage from 5% to 10%.

5.5.2 Final Calculations - Walk throughs

Using the data calculated during the base case calculations, individual system install costs and utility savings were calculated for six residential homes listed in the following section. The average install cost for each home was calculated by multiplying the derived constant of 7.06 $/sqft by the square footage of each potential home. The original utility costs for each of the six homes were provided by Russell Bray. Using the sample utility savings, an estimate of each houses new utility cost was also calculated. The difference between the estimated new utility and actual utility costs was used to calculate the total annual savings of the geothermal systems. This annual savings was then used to calculate the estimated payback period for the total geothermal investment, by dividing the installation cost by the annual savings. Costs can be seen below in Table 3.

Table 3. Final Geothermal Recommendation Data

Total Install Cost ($)	Annual Cost Savings ($)	Total Payback Period (yr)
$156,500	$14,500	11

5.5.3 Potential Houses

1. On Campus
   a. 3215 Burton (Manor House):

Table 4. Cost breakdown of 3215 Burton

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$61,506.72	$8,199.99	7.50

The pond system is not recommended for the Manor House because the seminary pond is too shallow and has an uneven bottom that would need to be dredged in order for this system to work. The cost of updating the pond to fit the requirements for a geothermal pond system would be almost double the cost for a horizontal loop system.

b. 1453 Knollcrest (Perkins Fellows House):

Table 5. Cost breakdown of 1453 Knollcrest

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$15,532.00	$2,649.10	5.86

2. Off Campus

a. 3151 Hampshire:

Table 6. Cost breakdown of 3151 Hampshire

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$14,232.96	$717.53	19.84

b. 1807 Observatory

Table 7. Cost breakdown of 1807 Observatory

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$11,691.36	$626.75	18.65

c. 1230 Lake Dr (Project Neighborhood)

Table 8. Cost breakdown of 1230 Lake Drive

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$35,963.64	$1,217.97	29.53

d. 232 Travis (Project Neighborhood)

Table 9. Cost breakdown of 232 Travis

Estimated Geothermal Install Cost ($)	Estimated Monthly Cost Savings ($)	Estimated Payback Period (yr)
$17,544.10	$1,103.94	15.89

3. On/Off Campus Totals

Table 10. Total Cost Breakdown

Total Estimated Install Cost ($)	Total Estimated Annual Utility Cost Savings ($)	Average Payback Period (yr)
$156,470.78	$14,515.28	10.78

These proposed values, again, are all estimates and concrete values. They are based on the square footage of each house along with the estimated install cost to implement a horizontal loop geothermal heating system. If Calvin does decide to go with this option, actual values will be calculated by a company like GMB Architecture who will install the system and figure out what the actual cost will be.

5.6 Works Cited

[1] https://www.michigan.gov/documents/CIS_EO_KC-MAY06-Workshop_159640_7.pdf

[2,3] http://www.heatpump-reviews.com/Geothermal-Heat-Pump.html

[4] https://www.michigan.gov/documents/CIS_EO_KC-MAY06-Workshop_159640_7.pdf

[5] https://www.nationalgeographic.com/environment/global-warming/geothermal-energy/

[6] https://www.caliper.com/maptitude/solutions/geothermal-energy-mapping.htm

[7] https://getech.com/plate-tectonics-50/

[8] https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2012/46654final00097.pdf

[9] https://energynews.us/2012/04/13/midwest/biomass-geothermal-replacing-coal-on-campuses/

[10] http://sustainability.umich.edu/news/first-geothermal-facility-opening-campus