Carbon Neutral Greenhouse Capstone Report Fall 2022

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Introduction:

For our EGRS 451 capstone project, our group was tasked with figuring out how to make LaFarms newly-constructed greenhouse carbon neutral, or minimize the carbon emissions if neutrality is not possible. This greenhouse aims to grow seedlings earlier in the colder, winter months to extend the growing season of the crops at LaFarm. This allows for increased food production and extended academic use. We discovered that there are two primary issues that need solving to properly retrofit the existing greenhouse into a carbon-neutral structure. These issues are the improvement of the greenhouse's electricity consumption and the greenhouse's current propane-powered heating system to be used during the colder winter months.

LaFarm was created as a tool to integrate Lafayette College's educational curriculum and the practice of growing food through sustainable agricultural practices. The farm has evolved into an educational, community-centric resource that impacts the lives of both students and local city residents. They provide the food grown to Lafayette's dining halls, reuse the food scraps to be composted into the soil, and contribute to community service projects to combat the local food desert issues. In addition, LaFarm allows students to transform their experiences in an educational setting and allows Lafayette classes to have tangible examples of the in-class curriculum.

LaFarm's greenhouse was introduced to extend the growing season of crops by allowing them to start seedlings earlier than traditionally possible. The space would also be used by the community enabling the community to extend its growing season. The greenhouse's season extension will increase the overlap between the academic year and the growing season, allowing for more student opportunities during the academic year.

What is a greenhouse, and why do we have it?

A greenhouse is a season extender, meaning that it is intended to lengthen the viable growing time of a farming season. It is a structure with walls and a roof made from a transparent material like plastic or glass. Greenhouses take advantage of the greenhouse effect, which refers to when the sun heats up the air inside the greenhouse and stays trapped inside the greenhouse. The transparent material allows the sun in, and limited ventilation keeps the interior warmer in the colder months, in which certain climates can be maintained to grow plants in locations they don't typically grow or extend the farming season well beyond the outside climate. The main reason we have one of these is that Easton, Pennsylvania's climate can vary from very hot in the summer to very cold in the winter. A greenhouse allows us to extend our growing season by a few months.

In this project, we concluded that carbon zero for the greenhouse would not be possible as it has already been built, and to make carbon zero, it would need to be built from the design phase up to meet the carbon zero standard. We have to aim for carbon neutrality as we plan to retrofit the greenhouse to make it carbon-neutral. Making the carbon-neutral greenhouse is one of the first steps in making LaFarm carbon-neutral, which would contribute to Lafayette's commitment to carbon-neutrality by 2035, as outlined in their Climate Action Plan 2.0.

Our project will consist of a plan to set up a commercial solar array that could create power to be put back into the grid. This would allow the solar panels to produce the energy needed to run the greenhouse during the day while also setting the excess power into the grid, crediting Lafayette for the energy they put back into the grid. They would then use these credits to counter the energy needs during low solar production days/ nights. We are also considering an alternative heating system rather than the currently installed propane air heater. Lastly, we also would like to implement a carbon buyback by planting trees to offset the carbon produced at the greenhouse.

Social Analysis:

The social context of the greenhouse project served as a big push for why the greenhouse was built in the first place, and it serves as an even bigger push for why it would be beneficial to carbon neutralize the greenhouse. Greenhouses significantly benefit the community that they produce food for, especially from a social standpoint. The Lafayette College LaFarm greenhouse puts society and the community at the forefront of their operations, and the act of carbon-neutralizing the greenhouse would only further advance the Lafayette community and the surrounding area. The social context of a carbon-neutral greenhouse is evident through the Agriculture and Farming Policy of Pennsylvania and within the United States, the college farming movement, the local food movement in Easton, and sustainable growth and energy reduction.

Agriculture and Farming Policy:

Agricultural policy is constantly evolving and mediates the relationships amongst the farming sector, the environment, and society. This policy allows governments to promote food security and the economic stability in the farming sector. In the United States, these duties fall under the jurisdiction of The Office of Agricultural Policy. This office works with other agencies to advance the United States' food security initiatives like Feed the Future and the New Alliance for Food Security and Nutrition. "The United States agricultural policy follows a 5-year legislative cycle that produces a wide-ranging "Farm Bill." Farm Bills, or Farm Acts, govern programs related to farming, food and nutrition, and rural communities, as well as aspects of bioenergy and forestry" (USDA, 2022). Lafayette College then falls under the Pennsylvania Farm Bill; this is Governor Tom Wolf's bold investment to grow opportunities and resources and to inspire future generations within the agriculture sector.

Agricultural and Farming policies essentially governs what Lafayette College, and other college farms that have sprung about in the college farming movement, is allowed to do in terms of food production. These federal, state, and local policies drastically affect a community's ability to implement farm-to-school practices. That being said, the laws put into place by Pennsylvania and Easton area legislators either promote or inhibit Lafayette College's ability to produce healthy foods that can be dispersed locally whether it be to our school dining halls or areas in the community. With the proper agriculture and farming policies in the state of Pennsylvania and in the Easton area, Lafayette's farm is able to produce the food that is needed by the community. As a season extending technology, the greenhouse expands this production and allows the farm to begin this production earlier as well as extend this production later.

College Farm Movement:

As it relates to Lafayette, the college farming movement has emerged over the past decade with small, liberal arts colleges that have begun incorporating hands-on, practical gardening and farming experiences for their students. These experiences promote student engagement within the community and allow students to learn in a real-world simulation of the agricultural sector. The college farm movement provides students a context in which disciplinary skills, manual skills, and intellectual skills are merged together in a positive environment that also serves to promote the mental health of college students. As other college's work on the progression and advancements of their farms, the social benefits of the greenhouse project become more clear.

The movement went into full force in the 1990s when schools began resisting the rising levels of processed foods in their cafeterias and dining halls. This led to more than 42% of schools in the United States introducing a "Farm-to-School" program with almost $800 million in funds put towards local food procurement (USDA, 2022). Funding for these programs is significantly backed by the USDA including the United States Secretary of Agriculture allocating $9 million in grants in 2022. Current strides would not be possible without the actions taken in the 2000s to grow the college farm movement. These actions ranged from extensive workshops to facilitate conversation between farmers and foodservice directors to the drafting of nationwide plans that allowed the National Farm to School Network, or NFSN, to increase access to local food and nutrition education. Moving forward, the NFSN is hoping to transition from creating awareness on the Farm-to-School movement to increasing the institutionalization of the program and solidifying policy across the nation.

Lafayette's LaFarm is primarily made up of student workers and volunteers; this allows for community work and educational and social opportunities for Lafayette students and community members. As previously mentioned, a greenhouse is a season extending technology which allows Lafayette's farm to begin seed starting earlier and continue growth and production through the early months of Spring. With the normal growing season in the summer, the greenhouse allows for students to be more involved in the growing process teaching them applicable skills. With goals of making the greenhouse at LaFarm a type of "modular space" with movable tables, Lafayette hopes to use the space for events, classroom activities, and alumni dinners to create a sense of community at Lafayette.

Figure S1. LaFarm Student Workers

Local Food Movement:

On top of educational and social opportunities, the greenhouse allows for the production of healthy food that can be distributed locally amongst the Lafayette community as well as the surrounding area. The West Ward community of Easton is a neighboring community of Lafayette College and the College Hill neighborhood. West Ward Easton can be classified as a food desert which refers to the difficulty within the area to buy affordable or good-quality fresh food. Food deserts are common in areas with smaller populations, higher rates of abandoned and vacant homes, and residents with lower levels of education, lower income, and higher rates of unemployment. With a median household income in West Ward Easton that is 61% of the Northampton Country median, residents have been searching for access to fresh health food for years (n.d., 2022). According to Lafayette's head farmer, Josh Parr; Lafayette College's "LaFarm" produces around 17,000 pounds of food per year; during the school year, 100% of their productions go to the dining halls at Lafayette, but during the summer, 100% of their productions go to the local community towards food pantries and community or farmers market initiatives.

In Pennsylvania, harsh winters can limit the ability of LaFarm to keep up with growth and production for around half the year; this is where a greenhouse is particularly beneficial as opposed to completely outdoor growth and production from the farm. The greenhouse will allow for the production of more healthy food with the characteristic of limitless seasonal growing. More healthy food production means more distribution to the local community allowing for purchase by residents of the West Ward Easton area who may struggle financially to acquire healthy food.

Figure S2. West Ward Easton Public Food Market

Sustainable Growth and Energy Reduction:

Carbon neutrality can be defined as having a balance between emitting carbon and absorbing carbon from the atmosphere. The benefits of carbon neutrality include less environmental pollution and improvements to the overall health of society which is an obvious positive characteristic from a social standpoint. It is the goal of many organizations, including the Intergovernmental Panel on Climate Change, to achieve carbon neutrality in their operations as carbon is the main contributor to climate change in the world. In terms of Lafayette College and its operations, their pledge to carbon neutrality by the year 2035 is a bold but necessary step to creating a more sustainable community and setting the standard for the surrounding areas. Lafayette's idea to start up their carbon neutrality pledge at the Metzgar Athletic Fields Complex puts the spotlight on the greenhouse and its emissions. Furthermore, efficient energy is the key to sustainable growth and development. There is plenty of research and work being done to create a sustainable future for the food industry in the United States.

Much of current research surrounds greenhouse growing as it works to benefit sustainability. The concept of greenhouse growing allows farmers to continue their growth during colder seasons on a smaller amount of land. Greenhouses also allow farmers to supplement aspects of farming that some may consider to be negatively impacting the environment including a reduction in water use and the ability to reuse water. As it affects the Lafayette community, the environmental aspect focused on in this project is the energy used in the greenhouse. A sustainable greenhouse leads to a sustainable Metzgar putting Lafayette College in a better position to achieve their carbon neutrality goal by the year 2035. This would allow Lafayette to be trailblazers in sustainable food growth which provides a positive model for the community as well as other colleges looking to grow their farms and implement greenhouse growth.

Review:

Social aspects of projects often determine whether they get done based on their value to the community and the opportunities it opens up. The greenhouse and the push for a carbon neutrality component of the greenhouse benefits Lafayette and the Easton community for a number of different social reasons. The four biggest social aspects of the greenhouse are the agriculture and farming policy and how it governs LaFarm's ability to produce, the college farming movement and how it has allowed farms at universities to grow and benefit their communities, the local food movement and how Lafayette's farm currently benefits the surrounding community and how the greenhouse would further impact the community positively, and lastly, sustainable growth and energy reduction and how Lafayette's goal of carbon neutrality in the near future continues to push the farm's agenda. These four components should govern Lafayette in its decision to make the farm and the greenhouse more sustainable with a main focus on carbon neutrality starting with a more sustainable source of energy to power the greenhouse.

Political Analysis:

Internal Stakeholders:

LaFarms greenhouse has many interested stakeholders, and the political context the project falls within is paramount to the successful adoption of any technologies or plans. Lafayette College is the major stakeholder in the greenhouse project, as funding and approval for any construction projects are required from them. This section will analyze the political structures within and involving the community and administration of Lafayette College.

Lafayette College's stake in the success of the carbon-neutral greenhouse project is primarily based upon their sustainability initiatives, specifically their goal for carbon neutrality by 2035 (Climate Action Plan: Executive Summary, 2019). A large part of Lafayette College's desirability to future students stems from their placement at the forefront of academic development. Lafayette College has expressed a desire to be on the forefront of the sustainability movement. This includes movements detailed in the social section above—such as the college farm and local food movements.

Lafayette College is the overarching decision-making body, but more specifically, within its structure, decision makers to be considered are Josh Parr and the faculty advisors of LaFarm, the treasurer, and the Office of Sustainability.

Josh Parr and the faculty advisors of LaFarm have decision-making power over the intended location of the project. Generally, they know the requirements and intentions of the existing greenhouse, constraints in space or environment, and approve any modifications to existing structures on LaFarm. They are knowledgeable about the details of LaFarm and the realities of the existing greenhouse and are committed to sustainability and development at LaFarm.

Josh Parr handles the day-to-day management of the surrounding LaFarm and will be overseeing the practical usage of the greenhouse once it becomes fully operational. His input on the necessary functions and total usage of the greenhouse informs the design criteria that the project team needed to navigate. Parr is also an important resource for specifications about the existing structure and surrounding areas and is the primary contact for any access to the existing structure.

The faculty advisors of LaFarm, represented primarily by Professor Cohen, present a more long-term scope of LaFarm sustainability goals. The advisory board has a larger focus on the cause of carbon neutrality in the greenhouse and LaFarm as a whole, as it falls in line with the long term goals of LaFarm. The existing solution of propane energy sourcing is not popular in this group, which allows for allyship with the project team. Professor Cohen and the faculty advisors also have valuable insight into many social and political dynamics within the project. With the variety of specialties within the board spanning Environmental Engineering to Geology (Meet the Farmers and LaFarm Advisory Board · LaFarm · Lafayette College, n.d.), they had the capabilities to assist in a large breadth of technological contexts.

There are many administrative offices that have control over the outcome of projects occurring on Lafayette's campus. The project team did not interact with all the political machinations that surround a project with a need for this level of funding within a private nonprofit university. The Office of Sustainability was the primary contact in the political navigation of this project. This office has expert knowledge on the processes required to acquire adequate funding for the greenhouse project—as well as the connections to start the acquisition processes. Sustainability is the primary objective of this remodel project, so liaising to fulfill their sustainability initiatives will be paramount in achieving success by the major stakeholders—Lafayette College as an institution—assumed metrics. It will also be critical to follow any directives given by the Office of Sustainability, as they are generally in charge of budget distributions. The Office of Sustainability will also potentially have connections through past projects—e.g. solar panels on Kirby—that may assist in the feasibility of the project—a prior relationship with reputable suppliers/contractors which could ease acquisition.

External Stakeholders:

Though the greenhouse is primarily for the members of the Lafayette community, primarily the students, it would be remiss to not analyze the potential stakeholders outside of the Lafayette community. The project, while not directly for these people, can still have profound effects and be profoundly affected by these external stakeholders through various means. To properly understand the decisions made within the solution, all relevant perspectives must be considered.

A major stakeholder for this project, which acts as a deciding factor towards design feasibility, is the local government of Fork's Township. Through paperwork such as permitting and building codes, the government of Fork's Township could impact feasibility (through permit refusal) or budget (through unknown paperwork fees). As stated in previous sections, our project team would not interface directly with this stakeholder—instead leaving this connection to be handled by Lafayette College at the time of project construction. The office of sustainability is best suited to interfacing with the local government.

The communities of Easton and Fork's Township must also be taken into consideration as active stakeholders in this project. The goals of this greenhouse do extend beyond focusing on the Lafayette community—the residents of the surrounding area are also included within the farm's longer-term goals. In 2018, 40% of crops harvested at LaFarm were used in a joint community service program called Vegetables in Communities (ViC), an initiative in tandem with other local farms to provide fresh produce to the surrounding community. Through Vegetables in Communities, LaFarm has been providing fresh vegetables to local food banks and affecting over 700 community members from the greater Easton area (Goldberg et al., n.d.). Therefore, it is important to remember that the communities surrounding Lafayette College are also engaged in the goals and purposes surrounding the greenhouse designs, however tangentially and passively it may be.

In addition to the community engagement opportunities that make the local communities stakeholders, one of the intended purposes of the greenhouse also makes their input relevant. The definition of a greenhouse as a season extender and its purpose of allowing the earlier starting of seeds make a greenhouse an important public resource for any community member who wishes to get an early start to their gardening or farming seasonal goals. The LaFarm advisory board intends for the community to have access to the greenhouse as a resource to extend their own farming season. As other local farms—such as the Easton Urban Farm—have not yet developed their own greenhouse and would benefit greatly from access to LaFarm's greenhouse.

The Easton Urban Farm and Greater Easton Development Partnership are also stakeholders, due to their involvement in Vegetables in Communities and their potential use of the greenhouse. While, similar to the non-Lafayette communities, they will not be active or vocal stakeholder, they share power over a large and important community initiative that LaFarm values, as well as potentially strongly benefitting from the functional aspects of the greenhouse.

Political Advantage:

The major advantage this project has within the political system within Lafayette College is through promises made by the office of sustainability—i.e the carbon neutrality pledge. Stakeholders, such as the office of sustainability, have publicly announced institution-wide goals which should be aligned with the goals outlined in the introduction of this project. Lafayette College has openly aligned their reputation with the issue of carbon neutrality and sustainability. It is advantageous to the project that retrofitting the greenhouse would allow for increased efforts towards carbon neutrality.

Another advantage that our project has when navigating the Lafayette College political sphere is the increasing prevalence of movements such as the above mentioned local food movement, student farm movement, and sustainability movements. The visibility that these movements bring to the issues that a carbon neutral greenhouse would combat to the center of public awareness, and they have resulted in an uptick in educational farms and sustainability technology. This increase in student farms and sustainability on University campuses places Lafayette College in a race to remain on the cutting edge of liberal arts innovation. This greenhouse project would be beneficial in the school's mission to remain a leader in both the student farming movement and sustainability.

Political Setbacks:

A major setback for our project within the political sphere is the monetary cost that has already been used in the construction of the greenhouse. With the budget that went into the construction of a state-of-the-art greenhouse at LaFarm, the acquisition of further funding may be difficult.

Financial Policy:

The financial and economic aspects of this project are intrinsically intertwined with the political aspects of the greenhouse project. Within the context of a private non-profit university, such as Lafayette College, much of the political structure is based around the acquisition and proper distribution of donations. The policy and politics surrounding non-profit identity limits acquisition and spending opportunities, which places different financial restrictions on the project. The funding of the greenhouse project is one of the most difficult aspects of hindrance to the realization of the greenhouse project. There are multiple avenues that Lafayette College can pursue in the acquisition of money for projects such as this, in this section we will discuss a few different options.

The main option to be discussed is to find a donor willing to fund this project through Lafayette's extensive alumni network. This is one of the most viable and realistic options available to the project. This is how most projects on Lafayette College's campus are approached. It is how the initial greenhouse design was funded. This would entail the office of sustainability identifying interested donors and communicating the mission and purpose of this project to 'sell' the renovation. Primarily, the project team will have no direct involvement with the potential donors but will be responsible for all supplementary documentation needed to communicate to donors the goals, needs and purposes of this project. It also affects the level of control the project team will have over the final design.

Technological Analysis:

Introduction:

After many years, LaFarm got the approval and funding to create a greenhouse. The design and technology that was implemented made it highly efficient; the temperature monitoring system with an automatic venting system optimized temperature regulation. However, a few aspects of the project did not consider renewable technologies that would make the greenhouse carbon neutral. We identified that the two major aspects of the greenhouse that were not favorable included how it was getting its electricity and what fueled the air heating system used. Does our research build off residential and farming techniques to improve the efficiency of the greenhouse? In this section, we analyze some of these techniques to find a way to reach our goal of creating a carbon-neutral greenhouse.

Greenhouse Layout and design:

The size of the newly constructed greenhouse is 30ft x 48ft. The intended space is planned to be used for seed starting for not only LaFarm, but all members of the communities. The greenhouse is located between LaFarm's current land plots and the Metzger Sports Complex (see figure #). It is located near a hill that, arguably, the greenhouse could have been built on to take advantage of some of the geothermal properties of the ground; allowing for the creation of storage. The proposed floor plan for the greenhouse is to have two rows of tables, one on each side of the greenhouse, allowing LaFarm volunteers and community members enough space to prepare and maintain seedlings. We assume that the work tables will be about four by eight feet in size to allow an adequate amount of seed starting trays to be prepared. We plan that about two rows of four tables will be placed in the greenhouse with two roughly four by four feet bins in the center of the greenhouse with potting soil storage. Each table will fit about sixteen seed starting trays (22 x 11x 2.5 inches in size). These have about 72 cells for seeds(*cell seed starter tray* (2016). This would require about 32 heating pads (48 x 20 inches in size)(*48" x 20" seedling heat mat* 2016)).

Figure T1 (Lafarm Greenhouse in final stages of construction, taken by authors)

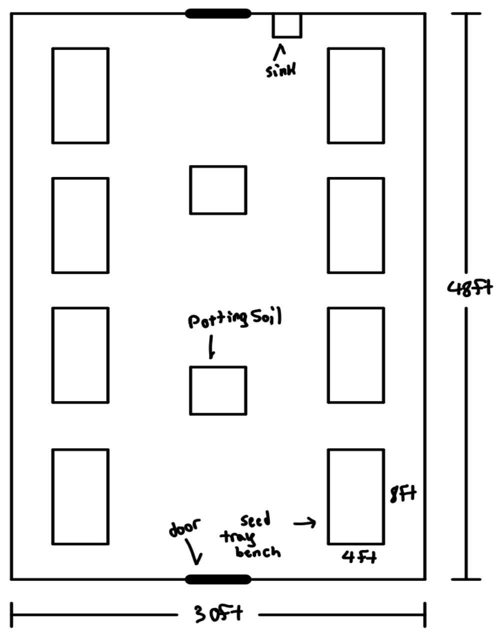


Figure T2 (This is the rough floor plan of the greenhouse, drawn by authors)

Our greenhouse plans also consider using heating pads placed right underneath the seed starting trays. This system is effective for seed starting because seedlings only need the dirt to be at the proper germination temperature. The air temperature could be much cooler, allowing us to concentrate the energy use where it would most effectively accomplish the goal. Combined with our proposed solar array, we could directly transfer the sun's free energy to the seedlings via their soil. Heating mats are affordable, simple, and require no maintenance.

Soil Temperature Conditions for Vegetable Seed Germination

Vegetable	Minimum (°F)	Optimal Range (°F)	Optimum (°F)	Maximum (°F)
Asparagus	50	60–85	75	95
Bean, lima	60	60–85	85	85
Bean, snap	60	65–85	80	95
Beet	40	50–85	85	85
Cabbage	40	45–95	85	100
Carrot	40	45–85	80	95
Cauliflower	40	45–85	80	100
Celery	40	60–70	70	85
Chard, Swiss	40	50–85	85	95
Corn	50	60–95	95	105
Cucumber	60	60–95	95	105
Eggplant	60	75–90	85	95
Lettuce	35	40–80	75	85
Muskmelon (cantaloupe)	60	75–95	90	100
Okra	60	70–95	95	105
Onion	35	50–95	75	95
Parsley	40	50–85	75	90
Parsnip	35	50–70	65	85
Pea, English	40	40–75	75	85
Pepper	60	65–95	85	95
Pumpkin	60	70–90	90	100
Radish	40	45–90	85	95
Spinach	35	45–75	70	85
Squash	60	70–95	95	100
Tomato	50	70–95	85	95
Turnip	40	60–105	85	105
Watermelon	60	70–95	95	105

Soil temperatures should be taken by inserting a soil thermometer 3 to 4 inches deep into the soil surface and noting temperature. Soil thermometers are available from garden centers, feed and seed stores, and many garden supply catalogs. Soil temperatures should be consistent for several days before seeds are sown to ensure that the seeds are being exposed to optimal temperatures for germination.

Figure T3 (Soil Temperature Conditions for Vegetable Seed Germination, Kemble & Smith, 2020)

In greenhouses, shading can be utilized as a barrier to help keep plants from experiencing extreme temperatures, helping regulate the climate inside to optimize growing the seedlings (Hesham A. Ahmed et al., 2016). One way this beneficial tactic can be used is by adding a shade that would deploy a few inches from the greenhouse ceiling, allowing optimal shading control. This allows only the air between this shade and the greenhouse ceiling panels to warm up, acting as an air buffer between warmer weather outside.

The temperatures and extreme summer heat could be unbearable during the spring, and this shading could help reduce the temperature. The new greenhouse design also utilizes two ceiling fans and vertical venting vans, along with a section of the roof being able to articulate open, allowing the hot air to escape. These methods of moving air and shading allow for an overall lower cost in regulating the greenhouse temperature at LaFarm.

Figure T4,5,6(Figures above show the ventilation and shading systems in the greenhouse, taken by authors)

Solar Technology:

How does solar work?

We are all aware that the sun produces energy and light. We can also convert the sun's energy release to create electricity. The main technology that can collect this electricity is solar photovoltaics (PV)(*Solar Energy Technologies Office*). They are widely used in residential buildings and commonly placed on roofs to help supplement houses' energy use. The demand for solar has skyrocketed in the last few years, allowing improvements in efficiency and cost to make it a more viable solution than ever. Enough sunlight reaches the Earth daily to power the world for an entire year if collected.

Sunlight is made up of tiny packets of energy called photons. These related particles reach the semiconductors on the solar panels. The semiconductors on the panels have a positive and negative layer, creating a magnetic field. When the photons hit the cell, energy releases some electrons on the semiconductor material. This creates an electric current that is harnessed from wires connected to the positive and negative sides of the cell. Each solar panel is made from dozens of these cells. Each array is made from dozens of panels. Once you add up all the voltages together, you generate enough electricity that would be meaningful to power our electronics. Solar panels produce a clean source of electricity with no emissions or moving parts. They are also fairly easy to set up anywhere it's needed. However, weather and topographical conditions can dramatically affect the solar array's output. This can limit the locations where solar would make sense.

Additionally, our solar energy production would be tied to the local power grid system. This means that during the day, whatever energy was produced in excess would be put back into the grid, and we could be credited for this excess energy. In the case of the greenhouse, we must be able to power vents, fans, water heaters, run irrigation, and power the monitoring system. To understand how many solar panels we would need to install, we first have to estimate the energy consumption of the greenhouse. Our rough estimates are shown below.

System	*Watt*	*Hr/Day*	*E/Day*	*E/Month*	*E/Y*
Fans	*120 x 2*	*18*	*4320 watts*	*129.6 kW*	*1555.2 kW*
Vents	*756 x 5*	*2*	*30,240 watts*	*907.2 kW*	*10886.4 kW*
Irrigation	*10 x 24*	*3*	*720 watts*	*21.6 kW*	*259.2 kW*
Thermostat	*100*	*24*	*2,400 watts*	*72 kW*	*864 kW*
Water Heater	*8320*	*.25*	*2,080 watts*	*62.4 kW*	*748.8 kW*
Geothermal Heating	*200*	*24*	*4,800 watts*	*144 kW*	*172.8 kW*
Only running part of the year about 3 month					
BioMass heating	*100*	*18*	*1,800 watts*	*54 kW*	*162 kW*
Heating plant beds	*32* 100*	*12*	*38,400 watts*	*115.2 kW*	*3,456 kW*
Total	*16,180 watts*		*84,760 watts*	*2,542.8 kW*	*19,659.6 kW*

Figure T7 (Energy usage per year estimated by authors)

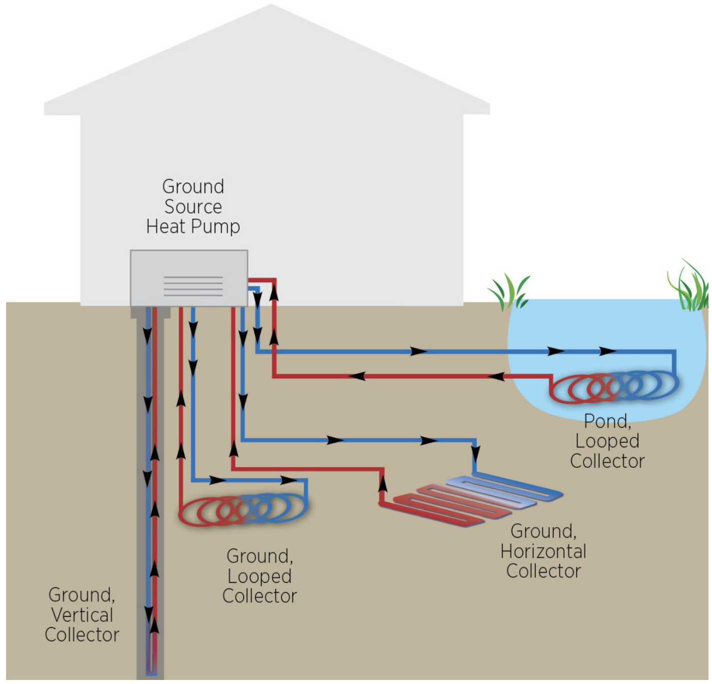
We predict that the greenhouse would require about 19,659.6 kW of energy per year. With this estimate we predict that inorder to provide enough energy. Inorder to generate this amount of energy we predicted that it we would need about 1,200 square feet. This would be about 50 feet long by 25 feet wide(*Solar calculator*). This would be a ground array similar to the Metzgar Sports Complex proposal as Lafayette has plenty of space, and it provides easy access to the arrays.

Geothermal Technology:

Geothermal heating and cooling utilize the ground's constant temperature of about 54 degrees Fahrenheit when below about 10 feet. This consent temperature can be utilized to heat air in the winter or cool air in the summer. It is achieved by burying a loop of pipes around this depth and pumping water or antifreeze fluid through it. During the winter months, the air is generally cooler than the temperature below the ground. When the solution circulates through the piping, it absorbs the heat from the earth and is pumped back to the surface, and is transferred via a heat pump. Then the heating system warms the air even more before your ventilation system distributes the air throughout the space you are heating. Taking advantage of the earth's temperature change allows less energy use to bring the temperature back to a comfortable level. During the summertime, the system works in reverse, moving the warmer fluid from the surface to below ground where the consent temperature of the ground can cool the fluid before bringing it back up to the surface. Also, saving how much is needed to spend on cooling the air.

When installing the fluid loops, there are two main methods. The first method is called a horizontal heat pump; it is closer to the surface but requires a lot of additional land. This heat pump distributes the piping horizontally in circular loops. It's ideal for smaller buildings, typically residential homes with land and minimal requirements, compared to larger commercial buildings. A vertical heat pump which puts its piping deeper into the ground, takes up less space if the land is limited as it just puts the pipes deeper into the ground. This approach is more used with larger commercial buildings as they would need a lot more land for the piping, as they have to heat and cool bigger amounts of land.

Geothermal systems can be used anywhere as they take advantage of the constant temperature of the ground below the frost line. The frost line is where the water in the soil is expected to freeze below ground. Depending on the location where the system is installed, it can vary the system efficiency, giving different amounts of cost savings. The system's efficiency makes it compelling as it's easy to maintain. Still, the additional upfront costs of the system can be a point to deter, and it should be looked at as a system to help lower costs as it can not fully replace conventional heating systems. For LaFarm’s application, there may also be a need for a shed to store all the systems that are required to run the geothermal system.



(Geothermal diagram, office of energy efficiency and renewable energy)

Biomass (pellet) Technology:

The Biomass air heater utilizes energy-dense pellets in a chemical reaction of oxygen and biomass at a high temperature that produces heat, water vapor, ash, and CO2. The heat is then used to heat air next to the combustion chamber and pumped into the air vents heating the air in the building. This heating method allows us to reach the desired temperature inside the greenhouse with minimal energy, as most power is used to start the combustion cycle. We recommend this source of heating as a supplemental source because it could reduce the amount of work the geothermal system we also recommend would do.

Additionally, we could use the resources of the engineering department to create our biomass fuel production using food scraps and other organic material from LaFarm(Ciolkosz, 2010). We could have our mechanical engineers design the system for the pellets used at LaFarm. Using a biomass pell heater would be the best supplemental air heating solution as we know that the system would only use a few months out of the year, and the geothermal system would be used year-round to cool and heat the greenhouse.

(Example of biomass heater, archiexpo.com)

Technical Analysis moving forward:

With all the research and efforts from previous capstones we believe that Lafayette College has made the steps in the right direction with building the greenhouse. We just need to keep pushing forward in our efforts to create a carbon neutral campus with making the greenhouse also carbon neutral. We laid out the technologies our group has deemed to be most effective to reach that goal. We have gained input for Farmer Josh and his experience in running other successful farms. We have given a preliminary estimation of the demands of the greenhouse as of this being written we do not have accurate energy demands of the building. Ideally the next group would be able to give a more detailed report on what the actual energy demands are of the greenhouse with it finally in operation. Given engineering studies limited knowledge in complex fields like thermodynamics it would also be helpful to seek assistance in determining a more accurate model of a geothermal system to support the greenhouse. Additionally with limited information on the greenhouses automation system, further analysis would be required to know how big of an impact it would have on the greenhouses efficiency. Hopefully this can be a model for what the future of small agricultural college farms could look like.

Economic Analysis:

The Greenhouse as it Stands

The Greenhouse as it stands today was mainly the result of donor funding. Because of the way that the school goes through the process of development the team at LaFarm found the opportunity to get their greenhouse when they could. Lafayette currently uses Tolino's Fuel Service to provide the propane for the heating system at LaFarm. Tolino's charges different rates for different volumes of delivery. The LaFarm system uses a 500 gallon tank for its fuel storage and per safety regulations can only be filled to 80% capacity meaning the maximum it can be filled is 400 gallons. This only falls within two pricing ranges offered by the company; Under 350 gallons at $3.20 per gallon and over 350 gallons at $2.90 per gallon. The output of the current system is 186750 BTUH runs on propane and given the size and temperature the system needs to produce at least 32243200 BTU per month throughout the winter to keep temperatures adequate. With one gallon of propane containing 91,452 BTU it would take roughly 352 gallons a month to operate the heater (EIA 2022). LaFarm plans to use the greenhouse to grow seedlings from late December through February. Given the types of crops that the farmers plan to grow in the green house the average temperature required is 60 degrees (Davidson 1984). Given the low factor of heat loss from the twin wall polycarbonate panels around the greenhouse, heat loss is not a major factor in the cost of any system. With the heating requirement exceeding the limit for the better of Tolino's rates with the tank being emptied the cost of operating the propane heater is $1,020.80 per month.

Propane Facts	
Gallons per Month	352
BTU Consumed/month	32243200
$/Gallon	$2.90
Monthly Cost	$1,020.80

Biomass Furnace:

Biomass furnaces can vary greatly in size but based on the temperature we need to keep and the size of the greenhouse the size we would need costs around $19,000 to purchase and install (NREL 2021). These heaters can be used to automatically regulate temperature as well as be manually operated. With the average price of the pellet fuel being $250 a ton and having a BTU content of over 8,000 per pound, that's half of the minimum heat requirement already met.

With the additional heat being provided from the geothermal supplement the cost will be around $250 a month (EIA 2022). With so little in expenses on the operation of this unit a payback analysis shows that savings will have the system paid back within 24 months. While it might take two tons of material to operate it will only cost between $250 and $500 dollars a month to operate. To further cut expenses in the unit, biomass pellets can easily be made at LaFarm. As an additional learning tool for renewable energy processes Lafayette could take steps to making its own fuel. There are also numerous ways to turn bio waste into the pellets for the system, potentially further reducing LaFarms carbon footprint and saving additional costs. As research into biomass continues fuel prices are expected to decrease further.

Geothermal Systems:

Geothermal heating systems are much more expensive than any other option to install but it has very low operating costs. The geothermal system does not require a fuel source like the other options meaning the only costs are electrical. The pump systems that these units use cost $200 a month to operate. These can live up to are expected to still be in operation after 50 years so with an average price of over $30,000 this unit is not small order but with savings of over $1,800 a month and the geothermal systems dual use as a heating and a cooling system it can pay back in around 3 years. Without any excess fuel requirements the power requirements could be easily covered by the solar panels which make up the final part of the alternative plan. The recovery from that cost comes from the constant use of the system's heating and cooling ability. Without this constant use there's no telling how long the recovery on this investment would take. Since the greenhouse is to be used as an events space when it's out of season it should be recovered quickly.

Solar Panels:

Solar expenses have been hard to predict because there is no previous consumption data. The greenhouse has never been used so without knowing how much electricity will be used makes it difficult to make the comparison. Even so, installing solar panels runs an average cost of $16,000 depending on the needs of the system and this is the size that meets the estimations of the greenhouses energy consumption. Solar panels in Pennsylvania have been shown to cost $2.38 per kilowatt. Lafayette's electric provider Met-Ed charges 10.5¢ per kWh. With the solar array generating 20000 kWh per year which is equivalent to a $2,100 electricity bill. The projected consumption would be 19500 kWh per year meaning that there is an excess of 500 kWh equal to a 52$ credit. This large gap makes the alternative attractive however there are concerns. Given that the greenhouse's main season of concern is the winter, solar devices do not always perform well. In previous years farmers at LaFarm had difficulty with the consistency of a solar powered monitoring system out in the fields. Given the harsh Pennsylvania winters with lots of snow and heavy clouds, solar is not entirely flawless. The resulting lack of reliability in this case cost the workers at LaFarm a lot of work. To work around this, we could add a solar energy storage system to collect energy during the summer and store it year round. This will allow all the excess power generated during the summer to be turned into further savings through the winter. Typically these large solar batteries will cost $5,000 and store about 12kWh equivalent to about 18 hours of continuous power. Assuming more than one might be needed to ensure electricity never runs out the additional cost would double.

Solar Analysis						
Initial Costs (Array+Batteries)	Life	Electric Rate ($/kWh)	Excess Power (kWh)	Credit	Total Savings	Payback (Years)
$ 17,000.00	20	0.105	500	$ 52.50	$ 2,152.50	7.897793264

If the greenhouse does not want to be totally removed from the grid it could still sell the solar energy back to the electric company through net metering. The standard net metering rate is 11¢ per kWh Depending on the company this could be a great deal considering the greenhouses' very limited summertime application. This solar array with its additional batteries will take the school about 8 years to pay back.

Review:

Alternative System	Initial Cost	Life	Operation costs (monthly)	expected savings (monthly)	deprec iation	Payback Per (months)	Incentives
Geothermal	$30,000	30	$200 (in electrical)	$820.80	$1,000	36.55	30% Uncapped Tax Credit ($9,000)
Biomass	$19,000	25	$250 (Pellets)	$770.80	$1,200	24.65	

The system in place now is by no means a poor economic decision given the circumstances of development. The optimal long-term system would be the biomass heater. It has a moderate upfront cost but with such low operating and maintenance costs it can pay for itself within 5 years given its limited use. Using the existing frame, we could easily install an outdoor heater. If LaFarm begins to produce its own biomass it could cut costs even further.

Geothermal is a huge forward looking technology. Having such a sustainable technology can serve as proof of feasibility for use across the campus to help with the climate action plan. The upfront cost while high is mitigated but the year round use potential of the greenhouse allows it to be economically viable as a test. Solar is very effective and has a few options to connect with the grid or make the greenhouse totally independent. The power requirements here are not expected to be great meaning that this might even be negligible unless the power is sold back to the grid.

Conclusion:

Condensed Findings:

Within the context of the community and local farm and food movements, LaFarm's greenhouse becomes an important leader for change and growth within the area. The farm's educational, nonprofit nature as a part of the college farm movement allows for more experimental forms of energy production and development. It is due to these social allowances that the project team believes that LaFarm's should be investing more heavily in the carbon neutrality and sustainability of their farm, as the freedoms that they are allowed create a space in which LaFarm can discover future methods of sustainable farming. In addition, LaFarm's continuous growth and productivity–an 11% increase between 2020 and 2021 (LaFarm Annual Report 2021 · LaFarm · Lafayette College, 2022)–demonstrates a positive trend towards LaFarm's effectiveness.

The completion of this project would affect the members of the Lafayette College community as well as the residents of surrounding areas. Primarily, the most important stakeholders are internal to Lafayette College, such as Lafayette Administration, Josh Parr, and the members of the LaFarm Advisor Board. External stakeholders, such as the local government, community members and local farms, have less control over the approval and funding of the project but still maintain strong stakes in the project success–as the greenhouse will be used in LaFarm community outreach programs and will allow for community personal usage as well.

A primary focus within the political context is optics. As a non-profit university that relies on image to attract students, Lafayette College has a greater than normal focus on how they are represented in comparison to similar universities. Universities such as Colgate University, Princeton University, and Cornell University have completed similar projects, placing them at the forefront of carbon neutrality and other topics. Lafayette College publicly states their focus on carbon neutrality in their published Climate Action Plan 2.0 (Climate Action Plan, 2022). Lafayette College has announced their plan for carbon neutrality by 2035 that starts at Lafayette's Metzgar Athletic Fields Complex.

This project's solution involves three sources of renewable energy sources: solar energy, geothermal technology and a biomass furnace. The major energy needs within the greenhouse are temperature regulation and electrical needs of the greenhouse. The temperature regulation of the greenhouse will be done through geothermal energy and a biomass furnace. The electrical usage of the greenhouse will be supplied via solar energy.

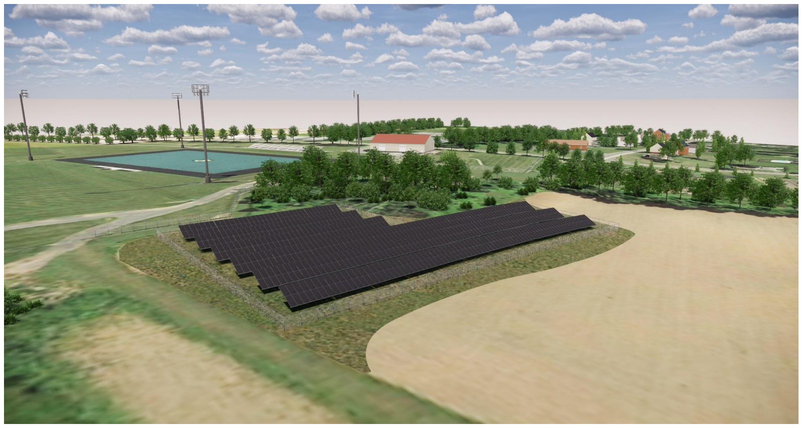


Figure C1: (Rendering of proposed Metzgar solar array)

Economically, this project will have an initial cost of approximately $65,000, with an estimated monthly saving totalling around $2820.80. With the life expectancies of biomass, geothermal and solar being 25 years, 30 years and 20 years respectively, these technologies become economically viable. The payback periods of the three technologies are much lower with biomass being repaid in 24.65 months, geothermal in 36.55 months and solar in 7 years.

Final Analysis:

The project team admits that the retrofitting of the LaFarm greenhouse with solar panels, geothermal and biofuel may seem a large correction in comparison to the rather meager comparative contribution the greenhouse has to the college's overall carbon emissions. However, Lafayette College has pledged carbon neutrality and plans to first make the Metzgar Complex (which includes LaFarms) the first step in that plan. This greenhouse, constructed after the carbon neutrality pledge was made, stands in direct opposition to this. As stated by Lafayette College's Office of Sustainability, "Achieving carbon neutrality is an ambitious goal, but Lafayette's unique identity as a small liberal arts college with a robust engineering division makes the College enormously well-situated to become a recognized leader in campus sustainability." (Climate Action Plan: Executive Summary, 2019). The project team argues that this is also true of Lafayette's position to pioneer these technologies.

The project team argues that the opportunity allowed by the college farm movement to create innovation within the small farm movement is massive, and that Lafayette College and LaFarms should be focused on pushing education and innovation–including research into sustainability. As shown in above sections, there is technical and economic background on all of the topics used in this plan, as well as educational value in the implementation of such technologies at a reachable site near Lafayette.

Challenges:

There are many challenges that this project will face within the social, political and economic contexts that exist within and around Lafayette College. These larger issues are addressed within the above plan. This section will outline the larger of these challenges and explain what can be done to minimize their detrimental effects to the construction of a carbon neutral greenhouse at LaFarm.

A large challenge this project is facing is the already existing structures that Lafayette College has heavily invested in, specifically the propane heating unit and large propane tank that the college has installed for heating the greenhouse–which is not a sustainable option. These large pieces of equipment were expensive and are relatively unused and will not be utilized (or will be barely utilized) within the plan outlined in this project. This presents a challenge within the economic context, as the school is not likely to want to immediately replace this expensive equipment after installation of it. The project team believes that the benefits of carbon neutrality in terms of productivity, sustainability and image should outweigh these concerns and suggests the acquisition of donor funding.

The greenhouse is projected to actively use energy for only three months throughout the year. This small window of use, in tandem with the surrounding non-sustainable energy on the rest of campus, creates a challenge. This creates a dichotomy of importance between this project and other larger projects that are being proposed around campus. Some stakeholders have expressed that the conversion of the greenhouse into a carbon neutral structure is not important in comparison to other potential projects. This report aims to convince Lafayette College Administrators that the greenhouse, while not a primary contributor to carbon emissions, would be a good step towards carbon neutrality. The challenge of this is due to the existing sentiment against the value of the conversion of the greenhouse. The project team aims to contradict this mindset throughout our analysis of the social and political context, in which the optics of the project are discussed. In addition, the solar panel would be functional throughout the year regardless of greenhouse use, able to counteract other carbon emissions. The project team hopes that the discussion of the values and goals of Lafayette College to be a cutting edge school will encourage administrators to use the greenhouse as a symbol of commitment to carbon neutrality, rather than judging the value based on comparisons to other potential projects on campus.

Future Plans:

After the submission of this proposal to the administration of Lafayette College, this project team would no longer be directly involved in the process going forward. This does not mean the end of this project however. The carbon neutral greenhouse will not be built or even approved by the completion of this report. Detailed here is our suggestion for who should be involved in the future steps of this process, what those future steps should be, and what the continuation and realization of this project would look like.

The culmination of this project would be the construction and completion of a carbon neutral greenhouse, with the elements detailed in the technological analysis above. The construction of solar panels to handle the air distribution and automation needs and the adoption of either biofuel or geothermal energy to supplement the necessary heating elements of the greenhouse are conditions of successful completion. These elements will take time and funding for proper construction, meaning the timeline to completion will be variable and can not currently be estimated.

This report focuses on the social, political, economic and basic technological contexts surrounding the carbon neutral greenhouse project, but is not an in depth blueprint to the construction or energy needs of the alternative renewable energy sources that are outlined above. The project team proposes that this project report is passed to a future group of Environmental Science students to continue the development of the project. These Environmental Science students can take the context study done above and refine the technical solutions to increase feasibility. The Environmental Science project team can take the project through to the approval phase–in which Lafayette College has found a donor and approved construction of the carbon neutral additions.

The administration of Lafayette College would remain engaged throughout the project until completion, especially as the need for fundraising and donor acquisition become more necessary. They would first need to decide, after review of this proposal and the subsequent Environmental Science reports, that the carbon neutral greenhouse was a worthwhile investment. Then, the administration would begin reaching out and polling potential donors to acquire the funding needed for the project. If a donor is identified, the Lafayette College administration could distribute this report to give a well rounded analysis of the social, political, economic and technological contexts. The Lafayette College administration would also handle coordination with the building and planning offices of Lafayette College.

The final phase of the project would be the construction of the additional elements. This includes the solar panels, biofuel, and geothermal construction. This phase would be primarily handled by the Facilities office at Lafayette College.

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