A Lighthouse Model for Sustainable Food Production: Dartmouth Big Green Energy House

Environmental Studies 50, Spring 2021

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Chapter One: Introduction

1.1 Greenhouse Sustainability Goals

To facilitate sustainable transitions in greenhouse crop production, it is important to clarify what is meant by sustainability. The definition of sustainability, even within agriculture, can change given the context and goals it seeks to achieve (Ong & Liao, 2020). For this project, sustainability requires forming a balance between environmental and economic challenges and considerations. From an environmental perspective, sustainability goals for greenhouses may be reducing energy usage and the carbon footprint of agricultural processes. This is congruent with the definition of sustainability proposed by the Food and Agriculture Organization in centering climate resiliency and response to climate change (Foley et al., 2011). The energy efficiency of a greenhouse largely depends on the design and its compatibility with the outdoor environment. Using recycled building materials, incorporating renewable energy systems, and taking advantage of light and temperature of the local environment can all be ways to improve the environmental sustainability of a greenhouse. Energy efficiency targets can only be met on the basis of economic viability. Greenhouse designs for remodeling are limited by financial budgets and funding. Design planning also has to consider the ability for the greenhouse to sustain itself economically through profits and funding after reconstruction. This would require analyzing the economic tradeoffs and benefits of energy efficient infrastructures and systems. Ultimately, sustainability requires a holistic approach to addressing ecological and economic concerns.

An additional sustainability goal that is specific to our project is to propose a design and engage a community that will sustain the goals and intentions of an energy-efficient greenhouse in the future. Since the primary aim of our project is to be a lighthouse model (as outlined in Chapter 3 by the Farmer Relations Team) for sustainable greenhouse transitions in the Upper Valley, the longevity of our project's impact both in its physical design and public discourse is a primary concern.

1.2 Introduction to the O-Farm Greenhouse Design

The design of the current and future Big Green Energy House must meet a diverse set of needs and specific goals stemming from the diverse set of stakeholders who may presently and hope to use the greenhouse in the future. Importantly, the design of the green house must also reflect the energy efficiency aspirations outlined within the Irving grant proposal and depend as little as possible on fossil fuels in its operation.

The most obvious need is temperature control during the shoulder seasons to extend growing time for food production and experimental space. As part of this task, the green house must also be able to successfully cool itself during the peak growing season to a desirable temperature. To do this in accordance with the Irving Institute goals, the design will incorporate a Ground to Air Heat Transfer (GAHT system) that is detailed below as well as the passive solar energy design detailed below in the Design Chapter of this report. Aside from this constant, the design team has proposed several varying designs that range from renovating the current greenhouse and building upon the present footprint to moving the entire structure altogether. These options will provide the Greenhouse Committee with a selection of choices that they may choose from as a better understanding of legal limitations and additional funding may arise.

1.3 Goals of the project

The mission of this project is to plan, design, build, and advocate for the Dartmouth Big Green Energy House, a new sustainable greenhouse on the Dartmouth Organic Farm. The Big Green Energy House aims to extend four-season crop production without the use of conventional climate control mechanisms which rely heavily on fossil fuels for regulation of internal temperature and lighting to optimize crop growth. Instead, the

Big Green Energy House will rely on passive solar design and geothermal energy harnessed through a GAHT system to regulate the interior climate. Students enrolled in ENVS50, the culminating experience class for Dartmouth Environmental Studies majors, intended to use the class as an opportunity to instigate the project and create concrete recommendations for completion of the Big Green Energy House by our project's client, the Greenhouse Committee.

The Big Green Energy House is intended as a lighthouse model for farmers and community members interested in transitioning to or learning more about sustainable food production. As such, project partners must assess the energetics, sustainability, economics, and ecology of our passive solar greenhouse project to determine its feasible adoption by agricultural professionals for crop production. The project aims to evaluate these criteria through research on cost, models, and effects of the GAHT system installed in the Big Green Energy House on seasonal crop production.

As a lighthouse model, a primary goal of the Big Green Energy House is to make our sustainable greenhouse design accessible to the Dartmouth community and area farmers. This goal requires extensive research into infrastructural barriers to actualizing the greenhouse. Students identified and began navigating the zoning regulations, conservation easements, building codes, and permitting and planning processes posed by the Town of Hanover and Dartmouth College which will guide construction of the Big Green Energy House. They also generated a list of officials to contact throughout the future permitting and construction processes and crafted a construction and permitting roadmap which accounts for several different sizes and locations for the greenhouse project.

Our project also demands research and attention to local farmer and community needs and interests both to ensure the design is relevant to existing capacities and to learn from existing greenhouse systems. Student partners acquired farmer knowledge and gauged farmer requirements for greenhouse crop production in addition to advertising the Big Green Energy House project as a research opportunity which intends to prove the feasibility and profitability of sustainable, geothermal crop production. ENVS50 students focusing on the construction of the Big Green Energy House created a preliminary blueprint for the passive solar greenhouse design that incorporates diverse stakeholder objectives including appropriate labor management, research needs, and teaching goals. Students tackled Big Green Energy House climate regulation through the preliminary design of a GAHT system that is appropriate for the anticipated size of the project greenhouse and can be modified to satisfy the requirements of other sustainable greenhouse projects.

Furthermore, this project hopes to highlight the financial accessibility of sustainable greenhouse design through identification of sources of upkeep and construction funding available to the Greenhouse Committee and area farmers. ENVS50 students accounted for the projected cost of the project by compiling a list of funding opportunities within and outside of Dartmouth College which may be pursued in the event that the Big Green Energy Project requires resources beyond the Irving Grant. Additionally, they researched grant opportunities for farmers interested in replicating the Big Green Energy House model.

The Big Green energy House project aims to encourage sustainable energy transitions in agriculture through outreach and education.This goal is accomplished through community-building and avenues of communication among local sustainable agriculture stakeholders including the Greenhouse Committee, local farmers, and Dartmouth students, faculty, and staff. Students opened avenues for community communication using social media, a website, educational literature, and planning for a high-visibility in-person educational and networking event centered around GAHT systems. The community formed through project outreach is intended to provide a safe and educational space for members to share ideas, problem-solve, and support one another through resource-, knowledge-, and labor-sharing.

Finally, the ENVS50 class report and presentation on the Big Green Energy House are an opportunity to share student progress on the project and provide concrete recommendations to the Greenhouse Committee for completion of the Big Green Energy House project. The goal of the student-led presentation is to provide community stakeholders, such as Dartmouth Environmental Studies faculty, Dartmouth facilities staff, the Town of Hanover, and area farmers, with project information. The goal of this report is to provide detailed information covered in our final presentation including: methods for maintaining and establishing communication with farmers about their visions and requirements for sustainable crop production; auxiliary sources of project funding; a pathway for navigating infrastructural barriers for greenhouse construction; greenhouse and GAHT system design plans for energy efficiency and year-round crop optimization; balancing research and teaching desires with labor and financial constraints; long term communication tools for a wide range of stakeholders; and plans for the GAHT system educational event.

1.4 Client identities

ENVS50's client for the Big Green Energy House is the Greenhouse Committee, composed of the Dartmouth faculty and staff whose roles and work are detailed below.

Professor Theresa Ong is an assistant professor in Dartmouth's Environmental Studies Department. She taught ENVS50 in the Spring 2021 Term and worked closely with the students throughout the project. Professor Ong's work focuses on the ways that ecosystems and food production are influenced by interactions between the environment, organisms, and people.

Professor Caitlin Hicks Pries is an assistant professor in Dartmouth's Biological Sciences Department. She offered students valuable insights on the biological function of a greenhouse as we designed an effective model for the Big Green Energy House. Professor Pries's work explores terrestrial carbon cycles and carbon within ecosystems.

Laura Braasch is the Dartmouth Organic Farm (O-Farm) Program Manager. Molly McBride is a Sustainability Fellow with the O-Farm. The students consulted Laura and Molly about O-Farm labor constraints, current O-Farm infrastructure, ongoing or prospective renovations at the farm, and organic agriculture.

Alana Danieu is the project research assistant for the Big Green Energy House. She was available to answer student questions throughout the term.

1.5 Group Member Identity

Our ENVS50 class is made up of a wide variety of learning styles, academic backgrounds, and technical experience. Though we share a common academic major of Environmental Studies, our varied skills and areas of expertise provided a broad base of knowledge to draw on throughout this project. From the outset of this project, we sought to create an environment which included all perspectives, backgrounds, and personalities. More than this, the various teams were specifically created with these diverse backgrounds in mind. Each team was assembled by incorporating different learning styles and personality types, which were assessed in the first week of this class.Therefore, our group seeks not simply to include, but embrace, our differences. We aim to use them to our advantage, cultivating an environment where no member is alone or overwhelmed in completing a task.

We are a group united by our common passion to furthering Dartmouth's sustainability goals and making its campus a shining example of environmental stewardship and progress. Many project members are active members of Dartmouth's sustainability and energy communities, contributing to our school's advancement and innovation in these respective fields. It is our hope that this project, which continues to bring together such strong community voices, will provide an opportunity for all Dartmouth students and Upper Valley residents to engage with energy transitions and sustainability.

1.6 Overview of Individual Team Goals

Our class is divided into 5 teams who are responsible for various goals relating to the project: facilitating farmer relations, infrastructure, creating a barn-raising event, designing the greenhouse itself, and synthesizing all of the teams so that they act as a cohesive whole.

The first team, farmer relations, is responsible for establishing relationships with farmers in the Upper Valley in hopes that we learn about how the Dartmouth Big Green Energy House can become a lighthouse for local greenhouses. The farmer relations team also supports these farmers by relaying all of the information that we have acquired through this project. This team is an integral part of the project as they acquire first-hand knowledge from farmers who have been cultivating land in the Upper Valley for generations.

The infrastructure team is responsible for navigating infrastructural barriers to renovations and building on conservation easements, Dartmouth properties, and organic farm land. They also identify funding opportunities for construction and maintenance of the Big Green Energy House. This team's role is incredibly important as they allow us to plan for long-term sustainability for greenhouse maintenance and operations by following all of the infrastructure protocol involved in producing a new greenhouse at the Organic Farm.

The barn-raising team is responsible for planning a barn-raising event with high visibility in order to create a larger audience for our project and establish more connections with Dartmouth students, staff, and locals. They are also in charge of ensuring feasibility and successful implementation of the project within a reasonable timeframe and budget. This is incredibly important as it allows us to see this project through and create lasting followers who want to become involved in the project as well.

The design team is responsible for designing the Big Green Energy House to maximize 4-season energy efficiency while balancing the needs of local farmer partners that may adopt the design with the research and teaching needs of Dartmouth faculty, staff and students. This is an integral part of the group as they are in charge of the whole creation of the greenhouse itself.

Lastly, the synthesis team is responsible for facilitating cross-group collaborations and understanding in a remote environment throughout the project. The team is in charge of the synthesis and review of the final report and associated products that include any outward facing communication and publicity including a social media campaign. This team is incredibly important for establishing connections between all of the different groups in this project and maintaining that everyone stays on the same timeline. They are also responsible for facilitating a public voice for the project and incentivizing others outside the project to follow along and get involved in the work after ENVS50 is done.

Chapter Two: Synthesis

Jack Jacobs, Steven Jump, Sophia Ludwig, Avery Saklad, Serena Nanji-Totani

2.1 Overview of PR implemented

Being responsible for establishing a strong public presence, the synthesis team created a website as well as an Instagram account and a Facebook page. The website provides an in-depth view of the project through weekly blog posts that provides updates for our followers on our progress. The website is also a major educational tool that can inform farmers who are curious about embarking on a similar project themselves. The Instagram account is a more summarized and easily digestible outlet for information on the project. It contains small, easy to read updates on the project, as well as a few educational tools on the subject. We have used this platform to reach out to the younger generations who actively use Instagram, such as Dartmouth students, in hopes that they continue their interest in the project after this class is over. We also managed to grow the following substantially (to over 80 followers to date) after we contacted the owner of the Organic Farm Instagram who agreed to share our content. The Facebook page provides the same content as the Instagram account, however, it is known that Facebook is primarily used by older generations and could potentially be a platform for farmers who have not yet made the leap to Instagram.

2.2 Synthesis Process

Our team was responsible for various modes of stakeholder communication and synthesis of student team information for the Big Green Energy House project. The following is an in-depth look at our external and internal communication methods as well as our successes and areas for improvement for the benefit of future ENVS50 Synthesis Teams.

2.2.1 Outreach Goals

We began the project by identifying our outreach goals. Our primary objective was to transfer relevant knowledge among student groups and to keep intragroup progress reports up-to-date. We found that timely information sharing was essential to meeting compounded project goals. For example, communicating the Infrastructure Team's knowledge about zoning and conservation easement restrictions on the O-Farm was necessary for the Design Team to orient and create dimensions for their greenhouse design. Furthermore, we believed that communicating progress details among groups would give students a concrete idea of the project's overall progression. This would help them to feel as though they were making progress toward a final goal, which would in turn boost student morale and productivity.

2.2.2 Internal Communication

To accomplish our internal communication tasks, the Synthesis Team assigned one or two representatives within our group to each student team. These representatives had access to all Google Drives, group chats, and other relevant project communication channels and materials within other student groups. The representatives consistently reviewed these materials in addition to sitting in on weekly meetings with their assigned groups. The representative then acted as a liaison among student groups and the Greenhouse Committee. They shared relevant information from their assigned teams with other students, asked other groups for necessary information or to complete tasks relevant to their assigned team's project goals, and clarified deliverable criteria and project questions with the Greenhouse Committee. The Synthesis Team encouraged their groups to virtually meet on the class Gathertown link, a collaborative online platform with multiple chat rooms, so that representatives could easily travel between virtual student groups. The Synthesis Team met twice weekly to debrief on other student groups' progress and support requirements.

The Synthesis Team encouraged their student groups to post accomplished and future tasks on a class Trello Board. The Trello Board allowed students to collaborate with other groups working toward similar goals and reduced stakeholder meeting and research redundancies. Additionally, the Trello Board informed the progress reports included in the Synthesis Team's weekly blog post. Blog posts provided an expanded source of information on the project for students to review. These posts were also aimed at communicating project goals, student progress, and educational materials on GAHT systems to interested community members and the Greenhouse Committee.

As the term progressed and student groups began to accumulate relevant materials for project completion, the Synthesis Team created and shared a class Google Drive for resource sharing. The class and professors contributed materials to this Drive for the benefit of all groups including progress report presentations and media materials. Additionally, the class Drive facilitated group collaboration on the compiled final report and presentation. Synthesis Team members reviewed and edited all stages of the final report -- outlines, chapter drafts, and final chapters -- as to eliminate informational redundancies, identify gaps in information, and create natural transitions and stylistic uniformity among each group's contributions. Finally, the Synthesis Team created a final presentation template and reorganized all groups' final presentation contributions to ensure the cogence of this deliverable.

2.2.3 External Communication on Behalf of Student Groups

Synthesis Team members also facilitated external communications among student groups and project stakeholders. We accomplished this task by asking other student groups to identify specific areas of communication support. We typically asked each Synthesis Team representative to accomplish the external communication tasks correlated to their groups, but in cases where teams required extensive communication support, we shared external communication responsibilities among Synthesis Team members. In support of the Infrastructure and Design Teams, Synthesis Team representatives spoke with Dartmouth Faculty about project objectives and areas for institutional support. For example, a Synthesis Team representative opened a line of communication with the manager of Dartmouth Life Sciences Greenhouse so the Infrastructure Team could gather information about costs and labor requirements for research greenhouse upkeep. The Synthesis Team also created deliverables, such as a project fact-sheet (see Appendix A), to facilitate communication in funding and planning meetings.

A Synthesis Team representative accompanied the Farmer Relations Team in meetings with local farmers to assist in the communication of student group questions about infrastructural, communication, and educational farmer needs. This representative also communicated farmer knowledge about sustainable food production to relevant student groups. Additionally, the Synthesis Team reached out to sustainability-oriented Dartmouth student organizations and local nonprofit organizations focused on sustainable food production. These connections provided labor and knowledge support as well as intel on community enthusiasm for the Barn Raising Team's educational event on GAHT systems.

2.2.4 Community-Centered Communication

The Synthesis Team also accomplished external communications for the Big Green Energy House project independent of other student groups. We met this objective by first identifying our desired external outreach communities as Dartmouth students, Dartmouth staff and faculty, area farmers, Upper Valley community members interested in sustainable food production, and the Greenhouse Committee. We then catered specific forms of communication to our target audiences and anticipated obstacles to communication.

As a preliminary measure for sharing information about the Big Green Energy House and project partners, the Synthesis Team researched the Family Education Rights and Privacy Act (FERPA) and distributed a Media Release Form to ensure the legality of posting pictures, videos, and audio clips of ENVS50 students and the Greenhouse Committee through our various form of media.

The Synthesis Team tackled student outreach by creating social media accounts on Facebook and Instagram that were easily accessible to established social media users. We created an audience by asking the managers of popular student organization accounts to promote our pages through their stories or by reposting our social media materials. For example, we asked the account manager for the Dartmouth Organic Farm and Dartmouth Sustainability Instagram accounts, both of which have substantial student followings, to repost some of the Synthesis Team's Instagram posts. This quadrupled our Instagram following, successfully making more members of the Dartmouth student community aware of the Big Green Energy House project.

The Synthesis Team targeted our student audience as well as Dartmouth faculty and staff by promoting our website and social media accounts in the campus-wide VOX newsletter and the Environmental Studies listserv. We accessed these avenues for communication by reaching out to Kim Wind, the Dartmouth Environmental Studies program administrator. VOX and listserv communications garnered a wider project audience by advertising project outreach materials to Dartmouth community members not active on social media or not previously exposed to the sustainability and farming communities at Dartmouth.

Our team determined that our external communication materials needed to extend beyond social media accounts to make project information accessible to stakeholders such as the Greenhouse Committee, Dartmouth faculty and staff, and farmers who are completely inactive or spend less time than students on social media. For this purpose, we created a blog with in-depth information on student progress and project goals. The link to this blog was distributed by VOX and the Environmental Studies listserv as well as through our social media accounts. We asked the Farmer Relations team to communicate the link to the blog to farmers interested in learning more about our project. We encouraged farmers active on social media to follow our accounts and created a reciprocal relationship by offering to advertise other farming operations through our social media accounts. We also communicated the blog link to the Greenhouse Committee through email and communication with Professor Ong. We encouraged the Committee to review the weekly posts and remain up-to-date on their student partners' efforts and directions for the project.

Finally, the Synthesis Team reached out to project stakeholders including Dartmouth Environmental Studies faculty, Dartmouth facilities staff, the Town of Hanover, and area farmers and asked them to attend our final presentation. We intended for this virtual presentation to offer the audience a real-time opportunity to learn about the project, ask questions, and establish connections with the Greenhouse Committee, who will carry on project progress following the conclusion of the ENVS50 class.

2.3 Assessment of Communication Strategies

2.3.1 Effective Communication

The Synthesis Team found many of our internal and external communication methods highly successful. Specifically, our social media collaboration with popular student-run sustainability and farming accounts greatly expanded our student audience. Our social media and blog advertisements through the Environmental Studies listserv and VOX newsletter generated a broader project audience and specifically increased project awareness among Dartmouth community members not active on social media. The Synthesis Team representatives that worked closely with other student groups allowed our team to effectively manage, synthesize, and communicate project progress and knowledge among students. This information facilitated intragroup communication and informed external communication of student progress and goals. Finally, the class Google Drive, Trello Board, and blog function as central modes of information and resource sharing that kept all project stakeholders up-to-date on progress, reduced stakeholder communication redundancies, and increased resource accessibility among ENVS50 class members.

2.3.2 Areas for Growth

The Synthesis Team identified several areas for improvement in our external and internal communication methods. We struggled to encourage other student groups to post regularly to the Trello Board and to fill out the Media Release Forms. The Synthesis Team representatives regularly reminded their groups to complete these tasks with limited success. In the future, we suggest setting aside several minutes of class time to fill out Media Release Forms and assigning student representatives from each group to update the Trello Board weekly.

Our team found it difficult to expand our audience beyond people already affiliated with Dartmouth's sustainability communities. Outreach methods such as advertising our informational materials through other student organizations, the Environmental Studies listserv, and VOX were successful in reaching a wider range of Dartmouth community members but did not effectively relay project information to Dartmouth community members not already subscribed to various environment-focused communication platforms or to people outside of the Dartmouth community. To ameliorate this shortcoming in the future, we suggest promoting project materials through local NGO communication platforms, emphasizing project platforms in all external communications, and advertising the project in areas with diverse through-traffic. For example, it may be beneficial to distribute a newsletter with project information and references to virtual project communication platforms at local farmer's markets.

2.4 Effective scientific communication

Recent literature argues for more research on the integration of public relations tools into science communication strategies (Su et al., 2017). Social media tools, such as twitter, allow for new ways to encourage participation and interaction with stakeholders that extends beyond conventional information sharing models (2017). The use of hashtags, hyperlinks, mentions, and reposts allow stakeholders to engage more in scientific topics and build relationships. We utilized these tools in our Instagram by working with other student organizations such as the Farm Club to mention and repost our content in order to reach a wider audience. Instagram's private messaging tool also allowed for student stakeholders to interact with us directly, offering their expertise and sharing interest in our project.

On top of taking advantage of the participation tools of social media, we also had to account for the diversity in our audience and tailor our public messages accordingly. In Roser-Renouf et al.'s work on messaging strategies for global warming, we can see how important it is to recognize the types of audience members we are engaging with (2014). Following a similar format to Roser-Renouf et al, we divided up our audience into four main categories: informed & engaged, interested, disengaged, dismissive.

The first category of 'informed & engaged' could refer to local farmers and greenhouse experts who have a scientific background and knowledge of greenhouses and either are already participating in the project or would like to be involved. This audience is similar to the ‘Alarmed’ group that Roser-Renouf et al identified as being receptive to messages with a great deal of information and complexity, including relatively high-level science and policy content (Roser-Renouf et al., 2014). The ‘interested’ group mostly comprises local clubs, student clubs, and faculty that are involved in environmentally-focused projects in general and would be curious to learn more about solar greenhouses in particular. The ‘disengaged’ group comprises individuals who have limited background in greenhouse systems and are not interested in learning more.The ‘dismissive’ group actively disagrees with the objectives of our project and do not want to involve themselves. We figured that our blog page, consisting of detailed scientific descriptions and elaborate progress reports would be most suited for the ‘informed & engaged’ group and the ‘interested’ group. Meanwhile, our Instagram and Facebook group, which consists of simplified scientific jargon and heuristical graphics, would be most suited for ‘interested’ and ‘disengaged’. We did not focus any of our PR materials on the ‘disengaged’ group.

2.5 Social Media as an Educational Tool

While literature on the use of social media to engage stakeholders in greenhouse design and sustainable agriculture generally is limited, one notable study which aided our approach surveyed extension professionals working within sustainable agriculture in California and their use of information and communication technologies including social media. The study suggested that the use of email and social media was successful in quickly reaching larger and diverse audiences, but that challenges emerged from a potential for misinformation and the technological expertise needed to successfully use these tools (Lubell & McRoberts, 2018). These results alerted us to some of the potential downfalls of differing social media platforms and post types throughout our project.

Current literature from other fields also suggests that social media and other PR methods are effective in education of the general public on a variety of issues. While there is a lack of research addressing the use of social media to convey greenhouse sustainability particularly, the impact of social media use by health organizations is especially well documented and uniquely quantifiable through measurable health outcomes (Courtney, 2013). This efficacy extends even to niche and sometimes inaccessible topics such as clinical radiology in which it was found to be effective at connecting groups of teachers and learners better than traditional methods (Ranginwala & Towbin, 2018). Perhaps one of the most promising takeaways from the health field was the demonstrated effectiveness social media presented in establishing two-way communication on topics of nutrition and food safety (Shan et al., 2015). This conclusion suggests that social media presents the possibility of fostering learning communities that hold the potential to benefit all parties engaged.

Although these studies cover the use of social media in communicating different material, many of the methods of engagement are similar to those undertaken by our team throughout the term and have informed our approaches. The particular use of Instagram and blog-style websites were present in each of these studies and speak to the adaptability of these two platforms for engagement.

While this body of literature was useful insofar as providing pointers to how we may work towards engaging a broad audience with the project, we hope that our own endeavors may eventually serve in adding to the study of social media use in sustainability education and work to fill in some of the gaps we encountered.

2.6 References

Courtney, K. (2013). The use of social media in healthcare: Organizational, clinical, and patient perspectives. *Enabling Health and Healthcare through ICT: Available, Tailored and Closer*, *183*, 244.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337–342. https://doi.org/10.1038/nature10452

Lubell, M., & McRoberts, N. (2018). Closing the extension gap: Information and communication technology in sustainable agriculture. *California Agriculture*, *72*(4), 236–242. https://doi.org/10.3733/ca.2018a0025

Ong, T. W. Y., & Liao, W. (2020). Agroecological Transitions: A Mathematical Perspective on a Transdisciplinary Problem. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.00091

Ranginwala, S., & Towbin, A. J. (2018). Use of Social Media in Radiology Education. *Journal of the American College of Radiology*, *15*(1, Part B), 190–200. https://doi.org/10.1016/j.jacr.2017.09.010

Roser-Renouf, C., Stenhouse, N., Rolfe-Redding, J., Maibach, E. W., & Leiserowitz, A. (2014). Engaging Diverse Audiences with Climate Change: Message Strategies for Global Warming's Six Americas. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2410650

Shan, L. C., Panagiotopoulos, P., Regan, Á., De Brún, A., Barnett, J., Wall, P., & McConnon, Á. (2015). Interactive Communication With the Public: Qualitative Exploration of the Use of Social Media by Food and Health Organizations. *Journal of Nutrition Education and Behavior*, *47*(1), 104–108. https://doi.org/10.1016/j.jneb.2014.09.004

Su, L. Y.-F., Scheufele, D. A., Bell, L., Brossard, D., & Xenos, M. A. (2017). Information-sharing and community-building: Exploring the use of Twitter in science public relations. *Science Communication*, *39*(5), 569–597.

Chapter Three: Farmer Relations

Abby Chamberlin, Sasha Gilmore, Catherine Good, Wes Gordon, Nick Krause

3.1 Introduction

The goal of the Farmer Relations team has been to connect with local farmers in and around the Upper Valley to establish meaningful, reciprocal relationships among farmers and Dartmouth's Greenhouse Committee. Creating networks among farmers and non-farmers in the Upper Valley is central to developing the new 4-season greenhouse at the Dartmouth Organic Farm that will be a "community repository of knowledge" (Silka & Renault-Caragianes, 2006). The Greenhouse Committee intends the Dartmouth Big Green-Energy House to be a "lighthouse model," meaning that the greenhouse will serve as a site of community collaboration and knowledge sharing, while also working toward sustainability goals (Nicholls & Altieri, 2018, p. 1). More specifically, a lighthouse model creates space for the voices of local partners as well as physical spaces for experiments, participation, and applying knowledge to the practices of food production (Montenegro de Wit, 2014, p. 9). Strong, diverse networks are key components of "lighthouse models." To assist the Greenhouse Committee in constructing a greenhouse that serves as a model for sustainable food production and quality research, over the past 10 weeks, the Farmer Relations team has explored literature on farmer/non-farmer relationships, studied farms in the Upper Valley through website review and individual interviews, and facilitated meetings with farmers, the Greenhouse Committee, and the ENVS 50 via Zoom (due to the ongoing COVID-19 pandemic).

First, we researched local farms and identified those which currently utilize greenhouses and those which have climate batteries, in addition to those that have neither a greenhouse nor use climate batteries but may be interested in building a greenhouse with a climate battery in the future. During the initial stages of our work, we were aware of the risk of "extractiveness," meaning that we became cognizant of the importance of balancing knowledge and know-how of both farmers and non-farmer stakeholders by ensuring that reciprocity and productive communication be achieved. That being said, in order to be effective in establishing enduring, reciprocal relationships with local farmers and maintain said relationships for the Greenhouse Committee following the end of the term, it was imperative that we were transparent with farmers in our exchange about the mission of the project, the goals of the Greenhouse Committee and Dartmouth Organic Farm, and the objectives of the Farmer Relations group.

Second, we developed a plan to ensure that COVID-19 safety measures and protocols were followed. While changing the nature of our interactions, distance communication due to the ongoing COVID-19 pandemic enabled larger-class discussions with farmers, which may not have been as possible in a traditional academic year. However, we were able to visit one farm in the beginning of the term, Long Wind Farm, while following guidelines set by both Dartmouth College and the state of Vermont. During this visit, all group members present, as well as the farmers, were masked, socially distanced in an outside and ventilated area, and cognizant about sanitizing any surfaces when possible. However, after this visit, we transitioned to a fully remote environment when reaching out to other farmers and farms, communicating solely via email, phone, and/or Zoom to fully ensure full COVID-19 safety for both parties.

Finally, we connected with local farmers, providing them with information about the Dartmouth Big Green Energy House Project, its mission, and its goals, followed by inquiry regarding their interest in the project and whether or not they would be interested in creating a relationship with the Greenhouse Committee in the future. The goal of these conversations was not only to learn about greenhouse design and technologies and practices used at different farms in the Upper Valley, but to initiate an enduring and meaningful relationship between local farmers and the Greenhouse Committee. Following preliminary conversations, we facilitated meetings between farmers, the Greenhouse Committee, and the ENVS 50 class in order to provide opportunities for knowledge sharing. Going forward, it is important that each of these stakeholders recognize their role in the development of this project and that all voices and concerns are heard, evaluated, and implemented in a respectful way. As we developed these goals and began interacting with farmers, one of the main questions we sought to answer, and one that the Greenhouse Committee will need to consider, is how to effectively and ethically interact with local farmers and those beyond the Dartmouth community. This was rather crucial to the Farmer Relations group given our role as a liaison between farmers, the Greenhouse Committee, and the ENVS 50 class. Examining the question of how to effectively and ethically interact with farmers required in-depth research about reciprocity in research between researchers and non-researchers, ethical forms of communication and collaboration, and how to create genuine and productive interactions.

3.2 Objectives

Our objective has been to build collaborative relationships with local farms and farmers and inform these valuable members of the community about the Dartmouth Big-Green Energy House project's 4-season greenhouse and climate battery. In addition, we wanted to ensure that everyone understands the project's intention to serve as an agroecological "lighthouse model" functioning to foster knowledge sharing within and around the Dartmouth community, while creating improved mechanisms for sustainable food production and farming practices. This requires collaboration and willingness from both sides, with the Farmer Relations group working with both local farmers and the Greenhouse Committee to ensure that this transition and sharing of knowledge progresses beyond the 10-week term. With the use of a climate battery system and upgraded infrastructure and design, the hope is that the Dartmouth Organic Farm's new 4-season greenhouse will provide a civic space for learning about successful local ecological initiatives throughout the Upper Valley. Furthermore, it is crucial to learn from farmers about their experiences with greenhouses, any obstacles they may have faced, and how an updated 4-season greenhouse at the Dartmouth Organic Farm could be a key resource for the Upper Valley's agricultural sector.

3.3 Research Questions

Our first research question explores how to interact with farmers in an effective and ethical manner. Through an extensive literature review, we have found that reaching out to farmers in a respectful and engaging way is crucial to creating enduring connections among Dartmouth students, the Dartmouth Organic Farm, the Greenhouse Committee, and local farmers in the Upper Valley. It is important to ensure that we are respectful of the farmer's time and work that they carry out throughout the growing season, and similarly, that it may not always be easy to schedule meetings given that their work and personal lives take precedence over the project. By creating a system of knowledge sharing between the farmers and the Greenhouse Committee, findings and research conducted in a 4-season greenhouse can be used by all parties. In sum, through ethical, respectful, and intentional interactions with farmers, we hope to have created a foundation for the Greenhouse Committee to carry on this work after the academic term ends.

Our second research question analyzed how to create an agroecological "lighthouse model" at the Dartmouth Organic Farm and how this goal can be best communicated to local farmers. Implementing the concept of a lighthouse model into the new greenhouse and at the Dartmouth Organic Farm must be a concept that is effectively translated to farmers and made a reality once construction/renovation is completed and research begins. The goal of the lighthouse model at the Dartmouth Organic Farm would serve the community as a research facility to broaden the knowledge of different greenhouse and growing techniques. To this end, a few sub-questions we have considered include: Are farmers willing to disclose information about their current greenhouses, and share aspects of their infrastructure that they were not able to incorporate due to budget concerns or other constraints? Are farmers interested in participating in a reciprocal partnership for the benefit of the community? How can we form relationships with surrounding local farmers to make the Dartmouth Big Green Energy House a reality?

3.4 Background Research

Conducting research and gaining background knowledge was a critical part of our workflow process and helped inform many of the protocols, questions, and plans that we designed over the course of this project. Our research led us to a number of key insights that helped ground our work and establish a strong knowledge base for the Greenhouse Committee to review and effectively proceed in cultivating relationships with local farmers. Our research began with an exploration on agroecological lighthouse models. After establishing an understanding about this specific type of model, we sought research and literature focused more heavily on interactions between farmers and researchers and other non-farmer participants. The scholarly work we discovered on this topic helped us identify a number of key principles and practices implemented into our process and methods, including the importance of reciprocity and cooperation, balancing stakeholder goals, creating inclusive and enduring connections, and ensuring safe and cautious behaviors in regard to the ongoing COVID-19 pandemic. For a complete and detailed list of articles that heavily influenced our approach, please see Appendix D.

3.4.1 Agroecological Lighthouse Models

One major goal that the Greenhouse Committee expressed at the outset of the term was for the Dartmouth Big Green Energy House to serve as a lighthouse model. Through our research, we discovered that serving as an agroecological lighthouse model means that the space is part of the community, radiates knowledge and collaboration, and helps the community to “build the basis of an agricultural strategy that promotes efficiency, diversity, synergy, and resiliency” (Nicholls & Altieri, 2018, p. 1). A lighthouse model creates space for the voices of local partners as well as physical spaces for experiments, participation and applying knowledge to the practices of food production (Montenegro de Wit, 2014, p. 9). Critically, the success of the lighthouse model framework has been heavily researched and has proven to be effective in spreading impactful agroecological initiatives from the lighthouse to surrounding areas (Nicholls & Altieri, 2018, p. 19). Additional research has also shown that the model “opens up potential for new researcher-farmer partnerships as well as a means for expanding what we consider legitimate knowledge-making communities" (Montenegro de Wit, 2014, p. 9). Given that Dartmouth is situated within the Upper Valley community, students and faculty of the college are provided with unique opportunities to interact with locals and collaborate on projects such as the Big Green Energy House project. For this reason, the lighthouse model has the potential to foster even stronger bonds between the College, the Organic Farm, and Upper Valley community members, especially farmers.

3.4.2 Reciprocity

Establishing reciprocity is extremely important in conducting community-based participatory action research. Reciprocity requires addressing differences and variation in participating groups as well as creating space and mobility for all voices to be heard, included, and valued. The result is a more cooperative and fair partnership functioning to maximize benefits for all actors involved. A crucial first step in creating reciprocal relationships is the commitment of time. By effectively using time, clear paths of communication can be created, goals and motivations can be clarified, and important “power differentials" and “environments where meaningful exchanges can occur" can fabricated, each of which are key factors in effective relationship development (Maiter et al., 2008, p. 319). In terms of the Big Green Energy House project, motivations and power differentials should be paid particular attention to. Given that the Dartmouth Organic Farm does not rely on its yield and production to function given its access to Dartmouth-related funding opportunities and resources that local farmers may not have access to, it is imperative that the Greenhouse Committee and those involved at the Organic Farm take local farmers' economic and profit constraints into consideration when engaging in and conducting research. Additionally, it is worth noting that researchers and academics have different experiences and backgrounds compared to local farmers when it comes to farming and agricultural practices; local farmers have significantly more knowledge and experience than non-farmers. By being aware of various power dynamics created by differences in knowledge and expertise, building enduring relationships and allowing all partners to be open to working together to address different goals is crucial for the success of this project. Noting research conducted by Silka and Renault-Caragianes, community members and non-researchers often face challenges in using their voice in research when these types of power differentials exist (Silka & Renault-Caragianes, 2006, p. 172). In addition, another limiting factor to successful reciprocal relationships is that researchers too often "arrive at these communities with research plans already fixed and stay only as long as it takes to collect data to test their preconceived hypotheses" (Silka & Renault-Caragianes, 2006, p. 172). Given this, researchers should be open to adapting their research to meet farmers' needs and incorporate their knowledge as much as possible. Similarly, power differentials can be categorized, as described in research we discovered by Maiter et al. One category typifies these differentials as structural and relates to the distribution and allocation of resources (Maiter et al., 2008, p. 321). A second category is organizational. Here, academic incentives can sometimes overshadow advocacy work, and "turn-over and other personnel changes in community agencies or groups," disrupting reciprocal relationships and commitments that were previously established (Maiter et al., 2008, p. 321). In sum, establishing reciprocal relationships is imperative to ethical research and community partnerships. With this in mind, being a cooperative and ethical partner requires balancing the goals of all stakeholders, and not merely extracting information for the sake of a research paper or publication.

3.4.3 Balancing Stakeholder Goals

As we briefly mentioned in the discussion of reciprocal relationships, different partners have different ways in which they will benefit from a collaborative project between researchers and community members or non-researchers. Balancing the goals and methods of stakeholders and partners is a challenging yet necessary part of the Dartmouth Big Green Energy House project. A model discussed by Silka & Renault-Caragianes aims to provide a framework for achieving the goals of all partners involved. The authors write that in community-university research collaborations, the goal is to complete a research publication, while the partners from the community aim to solve a problem. The goal of the model presented is to "bring the two [goals] together… to reframe the hypothesis so that the findings satisfy the requirements of both 'good science' and 'good problem solving'. By tying together an analysis of a problem with its possible solution, the model suggests how to reframe difficult issues" (Silka & Renault-Caragianes, 2006, p. 175). One key element of this model that we found productive is to think in terms of "research cycles" rather than "one-shot studies" in order to create what is referred to as the previously noted "community repository of knowledge" (Silka & Renault-Caragianes, 2006, p. 178). By developing an enduring relationship and space for collaboration and knowledge collection, this will not only help to foster additional research, but will simultaneously allow community members to access beneficial information and utilize it for years to come.

3.4.4 Establishing Inclusive & Enduring Relationships

Creating lasting and inclusive relationships with our community partners is also key to the success of the Dartmouth Big Green Energy House and the lighthouse model objective. A stated goal of the Greenhouse

Committee is to have the new greenhouse be a space where local farmers can collaborate, network, and participate in projects at the Organic Farm. For this to occur, inclusivity and accessibility must be at the forefront of interactions with local farmers and community members. Creating a welcoming environment of collaboration will also help to support these relationships in the long run. Per our research, Maiter et al. note that the strength of a “community-university research project” and its potential for success, “lies in the relationships that are being created, tested, and deepened with each new stage of the project” (Maiter et al., 2008, p. 310). Therefore, it is important that relationships are continually assessed and supported through all stages of research, planning, design implementation, construction, etc.

3.5 Initial Research on Local Farms

Beyond our academic literature research, our team conducted preliminary research on the farms with which we planned to interact. Through a deep dive on farm websites, we gathered general background information about various types of farms in the area, their systems and practices, and their goals and obstacles.

In particular, we found a series of nuances between farms that we felt were important to recognize. Here, we learned that some farms in the Upper Valley are certified organic farms, while others are not. Per its name, the Dartmouth Organic Farm is an organic farm, meaning that it possesses certification proving that it follows guidelines and standards as outlined by the USDA to be “organic.” However, this certification is expensive, and is not wholly indicative of a farm’s commitment to sustainability. Many of the farms we interacted with have strong sustainability goals and efforts, yet they are not all certified organic. Additionally, some local farms are part of a Community Supported Agriculture, or CSA, where consumers buy shares of a farm’s harvest in advance, with produce being shared among these shareholders as the growing season continues. Many of the farms we have reached out to fall into this category.

A more significant distinction between the Dartmouth Organic Farm and the farms we made connections with is that, as mentioned previously, the Dartmouth Organic Farm is not a for-profit farm and does not rely on yield and consumers to be sustained, which provides it with substantial financial flexibility. However, balancing sustainability and profitability is a challenge many of our farmer collaborators face; it can be difficult for small scale farmers to focus exclusively on sustainability. For these reasons, it is imperative that consideration be given to the constraints and goals of farmers when it comes to farming practices and sustainability, as well as how these might differ from those of researchers due to different financial and infrastructural constraints.

Finally, information and knowledge obtained in our research and literature review helped us to develop a strong interview protocol and begin the process of connecting with farmers while keeping our mission of ethics, reciprocity, cooperation, and the balancing of stakeholder goals in mind.

3.6 Farm Visits

3.6.1 Long Wind Farm

The first farmer we contacted was Dave Chapman of Long Wind Farm located in Thetford, VT, who is a familiar face to most of our group’s members who had previously met him while taking Ecological Agriculture (ENVS 25) over our sophomore summer. Dave has a strong interest in working with Dartmouth, has demonstrated this interest over several years, stands out as incredibly knowledgeable about farming practices, and is heavily focused on fine-tuning his operational practices. Long Wind Farm has a well-developed greenhouse system for growing tomatoes year-round and Dave’s in-depth knowledge of greenhouses, their design, their construction, and their use would be of great benefit to the Big Green Energy House project and Greenhouse Committee.

After communicating over email, five members of the Farmer Relations group visited Long Wind Farms on April 8th. Dave took us on a 90-minute masked tour of the farm and walked us through everything from the original greenhouse construction process to the growing dynamics in his most recent $1.8 million Dutch-designed greenhouse configuration. We came equipped with a comprehensive set of questions, which he was able to answer, but of course, many other questions arose. The questions we asked can be found in Appendix C. After the visit we followed up via email and thanked him for his time and sharing of knowledge.

Despite our pleasant and informative interactions with Dave, this visit complicated our understanding of the greenhouse building process. First, we realized that the demands of our space would be dramatically different than other farmers without the burden to produce vegetables and earn money. Partly as a result of this and because of the space constraints of the Dartmouth Organic Farm, the new greenhouse would be sized very differently than any existing models, and especially compared to the greenhouse at Long Wind. Following our discussion with Dave about climate batteries, we learned that maintaining ideal growing conditions in a greenhouse can often become challenging depending on the chosen energy system and source. Similarly, outfitting a space often requires an understanding of what specifically will be grown inside which changes the internal infrastructure of the greenhouse. With this in mind, in-depth consideration of the greenhouse's physicality, energy systems to be used, and climate risks (specifically flood risks), would be very important for the Greenhouse Committee to consider.

3.6.2 Hip Peas Farm

Our group also reached out to Hip Peas Farm, a 5.5 acre farm, agritourism destination and wedding venue located in Hooksett, NH. Of the 5.5 acres, two-thirds of an acre is used for farming, while another acre is rented as a satellite farm nearby. Hip Peas Farm specializes in gourmet foods for a high end market, with a focus on fresh cut greens. Hip Peas Farm was listed in the Irving Grant proposal, given its use of a functioning climate battery similar to the one the Greenhouse Committee intends to install at the Dartmouth Organic Farm. The Director of Agricultural Operations, Dan Birnstihl, is an expert in sustainable agriculture.

After sending the initial email with background on our project and asking about an interview, Dan agreed to speak on the phone with me to answer some questions and talk more about Hip Peas Farm. The interview was very informative. Dan expressed excitement about our project and was more than happy to share his experience with designing, building, and utilizing a 4-season greenhouse powered via climate battery. He also agreed to meet with the Greenhouse Committee and any members of the class who could attend the meeting. Detailed notes from the phone call can be found in the Appendix section under "Resources & Deliverables."

Finally, a key takeaway from this meeting was Dan's description of the construction and design of the climate battery used at Hip Peas. Dan also provided many valuable contacts, such as the horticulture and greenhouse director at UNH and Rimbol, the company Hip Peas used to build their greenhouse. Finally, Dan imparted knowledge about certain obstacles and challenges he and his team has faced at Hip Peas.

3.6.3 Cedar Circle Farm

Our group was also able to solidify a relationship with Cedar Circle Farm and Education Center. Cedar Circle is a 50-acre organic vegetable and berry farm located on the banks of the Connecticut River on the

Vermont side, about 8 miles north of the Dartmouth campus. Cedar Circle is dedicated to agricultural scientific research that serves public interest, while also providing agricultural education and training to children, parents, educators, farmers, students, and other members of the Upper Valley community. This is achieved by promoting organic, regenerative farming techniques and transitioning to a localized food economy, which includes the production of healthy, organic food for the Upper Valley and enhances resources for future generations.

Our main point of contact, Michelle Shane, the Greenhouse Manager, joined Cedar Circle in 2011. We were able to schedule a meeting with Michelle where she spoke with the ENVS 50 class over Zoom, which proved beneficial for other groups in the class in regard to their own goals and objectives. The Farmer Relations team feels that Michelle and Cedar Circle can be very impactful partners for the Greenhouse Committee moving forward.

Michelle and the Cedar Circle team are looking to upgrade/update their existing greenhouse infrastructure in the next 1-2 years. Cedar Circle has three retail greenhouses, two large greenhouses that have annual production, and one smaller seasonal greenhouse. She was not aware of who designed their current greenhouses, but expressed how they have been beginning to age over the past few years. In particular, ventilation issues have arisen, specifically that the greenhouses are no longer efficient enough to run throughout the winter. In their main greenhouse, they have large circulation fans that run one direction up one side and then the other direction on the other side. The third greenhouse has one large fan that runs one direction. When upgrading, Cedar Circle is looking to switch from a north-south ventilation to an east-west orientation. However, their larger goal is to upgrade the heating system, which is currently run with aging furnaces. As with many other local farms, Cedar Circle is looking to increase its efficiency and sustainability, while keeping the retail aspect in mind. Michelle explained that they spend roughly $10,000 in fuel per year for their three retail greenhouses.

Michelle recommended reaching out to their education director, Meredith (meredith@cedarcirclefarm.org), and Cedar Circle's founder, Will Allen (will@cedarcircle.com). Cedar Circle has also partnered with a farm in Nebraska (www.greenhouseinthesnow.com) to design a new greenhouse that utilizes geothermal infrastructure.

3.6.4 Red Shirt Farm

We also connected with Red Shirt Farm, an organic vegetable farm in Lanesborough, MA. We spoke with Jim Schultz, the farm's founder and lead farmer. During this interaction, it was useful to get insight into his experiences when first building Red Shirt's greenhouses, as well as hardships and obstacles he ran into that the Greenhouse Committee may need to consider. Jim provided us with a connection to a company in Colorado that he used to build his greenhouse, in addition to technical and structural tips relevant to the Design team.

Some important information about Red Shirt we gathered included the physicality of the greenhouse, including size, materials, location, and what is grown inside. Jim discussed Red Shirt's financial constraints upon starting the farm after receiving a grant to build the greenhouse itself, stating that they would not have been able to afford starting the farm without this financial assistance. However, he noted that constructing the greenhouse, despite the length of time, energy, and financial resources required, has benefited their farm tremendously. Red Shirt's main motivation behind the construction of their greenhouse was for season extension, sustainability, and being able to grow greens without the use of propane. Jim also provided a few ideas for potential research experiments that he would be interested in coordinating with the Greenhouse

Committee on given that Red Shirt is already space and time constrained. Overall, we believe that a relationship between Red Shirt Farm and the Greenhouse Committee would be incredibly beneficial to both parties.

3.6.5 Edgewater Farm

We also connected with Pooh Sprague at Edgewater Farm in Plainfield, NH. He seemed interested in the idea of working with us and the Greenhouse Committee. However, we encountered various scheduling and communication difficulties due to the busy growing season. From this experience we learned that communication accessibility and scheduling dynamics are a critical piece of working with farmers. Despite this, we stayed firm in our commitment to not compromise the integrity of our messaging or mission in our efforts to reach out to farmers by ensuring that the farmers we interacted with were still provided with adequate contact information for the Greenhouse Committee for the sake of future communication.

3.6.6 Sunrise Farm

Finally, we connected with Chuck Wooster '89 of Sunrise Farm in White River Junction, VT via email. He seemed rather interested in the project and becoming involved, and provided us with a bit of information about Sunrise's hoophouses, which are used year-round. However, similar to our interactions with Pooh at Edgewater, communication and interview scheduling difficulties arose due to the busy growing season. From this experience we learned about the importance of effectively and accurately communicating objectives and time constraints early on in our outreach to farmers, but were also reminded that the Farmer Relations team and the Greenhouse Committee have operated on different timelines compared to other stakeholders over the course of the term. This is to be expected and largely relates back to our initial research questions and objectives surrounding the importance of effective, ethical, and respectful communication between farmer and non-farmer actors.

3.7 Recommendations

In order for the Greenhouse Committee to best interact with farmers and be able to establish new relationships or continue existing relationships beyond the 10-week term, the Farmer Relations group has the following set of recommendations.

3.7.1 Utilize the Interview Protocol & Questions

Over the course of the term, our group has worked hard to develop a comprehensive interview protocol that includes interview questions both broad and specific to each farm. We hope this will serve as a resource for the Greenhouse Committee in guiding future interactions that they continue to build with local farmers. We recommend using this interview protocol and these questions in laying a foundation for ethical and meaningful relationships with local farmers while also making the transfer of responsibilities from the Farmer Relations group to the Greenhouse Committee easy and straightforward.

Additionally, our team carried out extensive research on how to ethically conduct interviews between researchers and non-researchers in a way that promotes reciprocity. We utilized this literature review to guide our interview structure and protocol. This research will also serve as a resource for the Greenhouse Committee as they create a community around the lighthouse model greenhouse – an important aspect of our project's goals, and one that we hope remains a strong component of the Greenhouse Committee's mission going forward.

3.7.2 Orient Actions Around Reciprocity

First, it was important to ensure that all our interactions with the farmers were ethical, which we cemented through our literature review in addition to discussions we held with the Greenhouse Committee. As a result, we have been able to promise that our interactions and interviews with the farmers were conducted in an ethical manner and reflected positively on our team, the ENVS 50 class, and Dartmouth as a whole. We also wanted to make certain that we relayed to the farmers that a reciprocal relationship was the end goal. As mentioned previously, it is important that all stakeholders understand that this is a reciprocal relationship where both sides are supposed to benefit from the construction of the Dartmouth Organic Farm greenhouse and the research to be conducted there. Finally, it is important that technical information regarding the greenhouse and climate batteries from farms who already have them installed be relayed between farmers and the Greenhouse Committee.

3.7.3 Provide Scheduling Flexibility & Consider Conflicting Time Horizons

Upon handing off our connections with the farmers to the Greenhouse Committee, we recommend that the Greenhouse Committee be flexible when working with the local farmers in accommodating their schedules. Most of these farms are working day after day for profit while the Dartmouth Organic Farm is in a position where it is not required to sustain itself by making profits. Instead, the Dartmouth Organic Farm serves as a space for learning and growing. With this comes understanding individual identities, connections, and experiences of both farmers and non-farmers. Furthermore, it has been pertinent, but also at times rather difficult to coordinate with numerous groups of people such as our Farmer Relations team, the Greenhouse Committee, the ENVS 50 class, and the local farmers, especially when working towards our goal of facilitating conversations among all stakeholders. Farmers work long days and have unique schedules that often makes getting in touch with them challenging, especially during the spring season. This is important to note in order to maintain healthy relationships between those associated with the College and farmers by ensuring that farmers do not feel pressured or form a negative view of Dartmouth and the Greenhouse Committee. We hope that connections made between the groups this term will lead to lasting relationships and navigation of the lighthouse model.

3.8 References

Bridgnell, Haley, and By. “10 Do's and Don'ts for Designing a Ground to Air Heat Transfer System.” Ceres Greenhouse, April 18, 2021. https://ceresgs.com/10-dos-and-donts-for-designing-a-ground-to-air-heat-transfer-system/.

Davies, B., Blackstock K., Brown K., Shannon, P. (2004). “Challenges in Creating Local Agri-environmental Cooperation Action Amongst Farmers and Other Stakeholders.” *The Macaulay Institute*, 1-87. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.459.6600&rep=rep1&type=pdf.

“GAHT® SYSTEM: A GEOTHERMAL OPTION.” Ceres Greenhouse. Accessed May 10, 2021. https://ceresgs.com/environmental-controls/gaht/#1470854812211-c5fedf5.

Lacombe, C., Couix, N., and Hazard, L. (2018). “Designing agroecological farming systems with farmers: A review.” *Agricultural Systems, 165*, 208-220. https://doi.org/10.1016/j.agsy.2018.06.014. (https://www.sciencedirect.com/science/article/pii/S0308521X1830060X)

Maiter, S., Simich, L., Jacobson, N., and Wise, J. (2008). “Reciprocity: An ethic for community-based participatory action research.” *Action Research, 6*, 305. doi: 10.1177/1476750307083720.

Schiller, L., & Plinke, M. (2016). “The year-round solar greenhouse: how to design and build a net-zero energy greenhouse*”. New Society Publishers*.

Sharp, J., and Smith, M. (2003). “Social capital and farming at the rural-urban interface: the importance of nonfarmer and farmer relations.” *Agricultural Systems 76*(3), 913-927. https://doi.org/10.1016/S0883-2927(02)00083-5.

Silka, L., Renault-Caragianes, P. (2006). “Community-University Research Partnerships: Devising a Model for Ethical Engagement.” *Journal of Higher Education Outreach and Engagement, 11*(2), 171.

Volker, H., Probst, K., and Christinck, A. (2007). “Farmers and researchers: How can collaborative advantages be created in participatory research and technology development?” *Agriculture and Human Values, 24*, 355-368. https://doi.org/10.1007/s10460-007-9072-2.

Wilmoth, Tyree. “Sustainable Technology and the Built Environment.” Greenhouse Comparative Research Study Underway at Appalachian State's Farm, November 2, 2020. https://stbe.appstate.edu/news/greenhouse-comparative-research-study-underway-appalachian-state%E2%80%99s-farm.

Wiskerke, J. S. C., & van der Ploeg, J. D. (Eds.) (2004). *Seeds of Transition. Essays on novelty production, niches and regimes in agriculture*. (European perspectives on rural development). Van Gorcum. https://edepot.wur.nl/359042.

Chapter Four: Infrastructure & Funding

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4.1 Introduction

As the Infrastructure and Funding team, we aim to identify infrastructural barriers to building The Big Green Energy House and outline how to address and overcome these obstacles. The main area of our investigation will fall within the scope of zoning and planning restrictions, overseen primarily by Dartmouth College and the Town of Hanover. In addition, we aim to identify alternative funding sources for the structure and long-term maintenance of the greenhouse. The main questions we seek to answer for our clients, the Greenhouse Committee, are: what aspects of regulation apply to our project, and who are the relevant authorities to contact when following these regulations?

In order to answer these questions, our group focused its research on interviewing the relevant authorities and collecting the documents which detail the applicable building codes and regulations. The following chapter includes a summary of the interviews we conducted over the course of this term. The interviewees fall into three categories: the Greenhouse Committee, Institutional Dartmouth, and the Town of Hanover. This chapter also includes a discussion of both potential internal and external funding sources for the project. These sources will supplement the amount awarded to the Greenhouse Committee from the Irving Institute Grant to cover the planning, construction, and future operating endowment of the new greenhouse. As a final product, this chapter contains (1) a flow chart for navigating organizational barriers and (2) a table identifying funding opportunities.

4.2 Background

4.2.1 Basic Facts about the Dartmouth Organic Farm Property:

A. Zoning

- The Dartmouth Organic Farm is located on a state highway and thus is governed by a state highway right of way zoning setback of 50 ft (Town of Hanover 2020 Zoning Ordinances Article IV §405.9).
- The Dartmouth Organic Farm is zoned Rural Residential ("RR"), meaning it must adhere to a 50 ft front, rear, and side yard setback (Town of Hanover 2020 Zoning Ordinances Article IV §405.9).
  - The corner of the Hoop House closest to the private lot is likely located at the 50 ft side setback point (see Figure 4.6).
- Although it is within the state highway setback line, the existing greenhouse is grandfathered into the zoning code giving Dartmouth use of this land for a greenhouse structure. If the greenhouse is torn down or the use changes, as defined by Article VI of the Town of Hanover 2020 Zoning Ordinances, Dartmouth will never again be able to use the land. The College has received a special exception written into the Town of Hanover Zoning Ordinances Article VI on Principal Uses for structures to allow for environmental and agricultural research on this property (Article VI §612; Article IV §405.9; T. McNamara, personal communication, 27 April, 2021).
    - It should be noted that the Town of Hanover operates under inclusionary zoning laws, rather than exclusionary zoning. Only uses given explicit permission are allowed which makes most projects more complicated to build.
  - If the use of the greenhouse changes from §612 Agriculture, Forestry, and Environmental Research and Education, the building will no longer be grandfathered into Hanover zoning code.
- Town of Hanover Zoning Ordinances allow for a 35 ft maximum building height (Town of Hanover 2020 Zoning Ordinances Article IV §405.9).

    - If one wanted to alter the shape of the existing greenhouse, one could only raise the back wall without needing a permit. Raising the front wall changes the frontage (road facing profile of the building) which would require a variance. This would most likely not be issued considering the building is grandfathered in on non-buildable land (McNamara, T. April, 2021).
- A greenhouse design would not have to meet the Town of Hanover's energy codes (which requires certain amounts of insulation, etc.) (T. McNamara, personal communication, 27 April, 2021).
- If repairs of an existing structure exceed 50% of the College's assessed value of the structure, the project must comply with current building, life safety, and Americans with Disabilities (ADA) codes and regulations (Town of Hanover 2020 Zoning Ordinances Article XI §1101, *see definition of "substantial improvement"*).
    - Regardless of regulation, efforts to integrate ADA accessibility should be made to make the space as inclusive as possible (ramp access, turn-around space, lighting, etc.).
- The snow load capacity of the existing greenhouse most likely does not meet the 60 lb per square foot requirement meaning repairs will be necessary to be in compliance (T. McNamara, personal communication, 27 April, 2021).

B. Buildings

- A septic project is underway at the farm to increase the Dartmouth Organic Farm's capacity to host events.
    - The septic and leach field will be located on the west side of the Hoop House on the ridge to supplement the current compost toilet structure (T. McNamara, personal communication, 27 April, 2021).
- The skylights of the existing greenhouse do not open well and glass panels fall out from the structure (T. McNamara, personal communication, 27 April, 2021).
- The existing greenhouse is attached to the old milk house (See Figures 4.5 and 4.6).
- The old barn will ultimately come down because it is structurally unsound (T. McNamara, personal communication, 27 April, 2021).
    - Taking down the old barn and milk house will likely be expensive and time consuming because it has hazardous materials such as lead and asbestos in the interior (T. McNamara, personal communication, 27 April, 2021).
- The daycare building is rented by a tenant on the Dartmouth-owned land. It is predicted that the daycare will leave the space within the next year, after which the College will likely take the building down and use the building pad for operations at the Dartmouth Organic Farm (T. McNamara, personal communication, 27 April, 2021).

4.3 Project Stakeholders

By conducting interviews, we aim to accomplish two goals: (1) to identify and understand the process for building a greenhouse at the Dartmouth Organic Farm, and (2) to identify the needs and desires of each stakeholder involved in the project (see Table 4.1). We aim to seek out the people in relevant positions of authority who can help to make this project a reality. We hope to ensure that each stakeholder's needs are equally considered and breach neither zoning regulations nor college policies.

Table 4.1: Overview of Project Stakeholder Positions and Roles

Stakeholders	**Position**	**Contact Information**	**Interest or Role**
Theresa Ong	*Greenhouse Committee,* *Assistant Professor of Environmental Studies*	Theresa.W.Ong@Dartmouth.edu	Building a new research-grade greenhouse larger than the current solar greenhouse with two climate batteries on the current footprint
Caitlin Hicks Pries	*Greenhouse Committee,* *Assistant Professor Biological Sciences*	Caitlin.Hicks.Pries@Dartmouth.edu	Building a research-grade greenhouse with two climate batteries Creating an outdoor working area for potting Adding storage space for tools and materials
Laura Braasch	*Greenhouse Committee,* *Head of the Dartmouth Organic Farm,* *Sustainability Office Program Manager*	laura.m.braasch@dartmouth.edu	Renovating the current greenhouse to house both research experiments and Dartmouth Organic Farm seedlings Educating Dartmouth students about food systems using the greenhouse Implementing the Master Plan at the Dartmouth Organic Farm by building a kitchen and multipurpose space Maintaining the recently renovated Hoop House

Rosi Kerr	*Director of the Sustainability Office*	rosalie.e.kerr@dartmouth.edu	Implementing the Master Plan for the Dartmouth Organic Farm by building a kitchen and multipurpose space, both of which can be used as an educational space in conjunction with the new greenhouse Keeping and continuing to maintain the recently renovated Hoop House because it plays a vital role in raising seedlings for the Dartmouth Organic Farm
Tim McNamara	*Prospective Project Manager,* *Associate Director of FO&M*	timothy.j.mcnamara@dartmouth.edu	Making sure the new greenhouse is built so as to conform to Dartmouth's cohesive vision of facilities Ensuring the project follows College procedures on planning and meets College standards
Bernard Haskell	*Assistant Director of Residential Operations*	bernard.w.haskell@dartmouth.edu	Supporting student education at the Dartmouth Organic Farm in any way possible Using recycled materials to renovate or build a new greenhouse at the Dartmouth Organic Farm Ensuring future maintenance
Patrick O'Hern	*Director of Project Management Services*	patrick.r.ohern@dartmouth.edu	Furthering the educational mission of Dartmouth College and supporting faculty research through project planning and management
Jennifer Casey and Katherine Norton	*Office of Development and Advancement*	jennifer.e.casey@dartmouth.edu	Advancing Dartmouth College's mission by raising money for specific College-approved initiatives

		Katherine.R.Norton@Dartmouth.edu	
Theresa Berry	*Greenhouse Manager at Life Sciences Center*	theresa.d.barry@dartmouth.edu	Managing the research-grade greenhouse located on the top floor of the Life Sciences Center
Robert Houseman	*Planning and Zoning Director for the Town of Hanover*	robert.houseman@hanovernh.org	Overseeing planning and zoning within the Town of Hanover office Ensuring the project complies with Town of Hanover rules and procedures
Irving Institute	*Grant Providers*	irving.institute@dartmouth.edu	Funding interdisciplinary approaches to overcoming transitions to a sustainable, resilient, and equitable energy system Engaging local farmers to create a “lighthouse model” greenhouse Engaging students from project conception through implementation and maintenance
Dennis Washburn & Dean Madden	*Dean of Interdisciplinary Studies & Vice Provost of Research*	dennis.washburn@dartmouth.edu dean.madden@dartmouth.edu	Building a new research-grade greenhouse to highlight Dartmouth’s sustainability as an institution Highlighting Dartmouth’s cutting edge research for the local community and peer institutions

4.3.1 Greenhouse Committee Stakeholder Interviews

A. Theresa Ong, Ph.D, Assistant Professor of Environmental Studies at Dartmouth College

As a member of the Greenhouse Committee, Assistant Professor Theresa Ong, Ph.D. wishes to test the efficacy of using climate batteries to extend the Organic Farm Greenhouse to a four-season research-grade greenhouse. Professor Ong wants the greenhouse to have two separate climate battery systems that can be controlled independently. Although Professor Ong estimates a 100 x 30 foot greenhouse space would best meet each researcher's needs, she is willing to use the existing greenhouse footprint if the existing frame is replaced. She foresees challenges with the existing greenhouse's attachment to the milk house, an adjacent building that will be demolished in the near future due to lead and asbestos contamination (see Figure 4.1). Finally, Professor Ong would like a storage area within the greenhouse for her research supplies and believes the corridor connecting the milk house to the existing greenhouse could be a viable option for such a space.

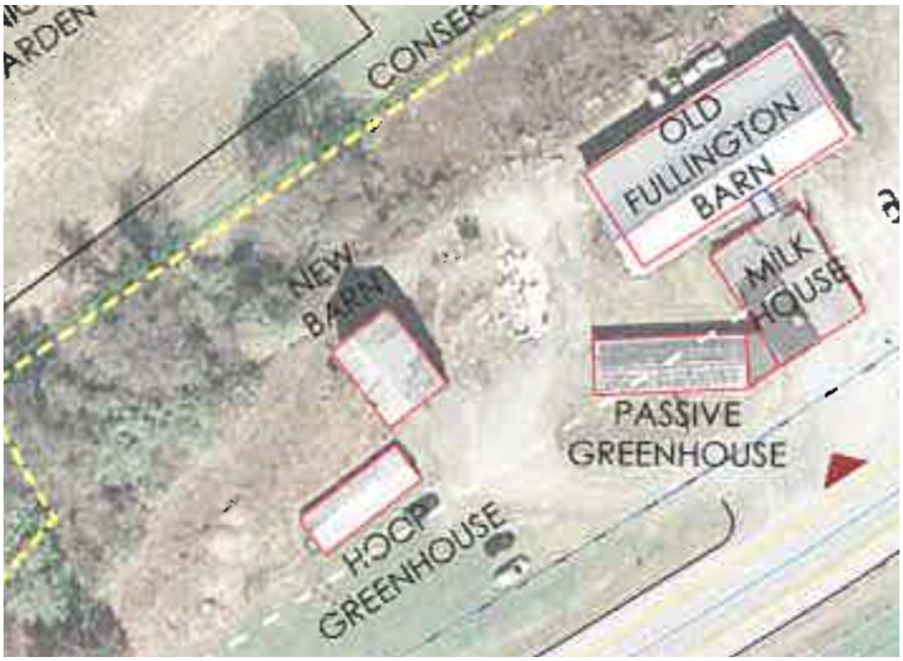


Figure 4.1: Current footprint of the greenhouse on the organic farm, the milk house and the old barn. ("Dartmouth College Fullington Farm Concept Master Plan," 2013).

B. Caitlin Hicks Pries, Ph.D, Assistant Professor of Biological Sciences at Dartmouth College

Greenhouse Committee member Caitlin Hicks Pries, Ph.D. hopes to build a research-grade greenhouse at the Dartmouth Organic Farm with reliable temperature control. Professor Hicks Pries has experience conducting experiments with plants in Dartmouth's Biology Greenhouse in the Life Sciences Center (LSC). Unfortunately, the LSC's greenhouse overheats in warm seasons due to design barriers preventing adequate internal temperature control (see Theresa Barry's interview). Professor Hicks Pries's top priorities for the Big Green Energy House project include an outside work area to pot and organize labs, a storage shed for dirt, compost, and tools, and land for undergraduates to pose their own research questions and run their own experiments.

C. Laura Braasch, Sustainability Office Program Manager and Head of the Organic Farm at Dartmouth College

As a Greenhouse Committee member and Head of the Dartmouth Organic Farm, Laura Braasch hopes the new greenhouse will further her goal of continuing to educate Dartmouth students about food systems and sustainable agriculture methods. Braasch prefers keeping the new greenhouse the same size and location as the existing greenhouse footprint, citing the number of employees as the biggest limiting factor. The current greenhouse dimensions are 63.5’ x 21.9’ x 16.6’. Braasch believes reliable temperature control is the most pressing need in the new greenhouse. Braasch hopes to remove the fish tanks occupying the north wall of the existing greenhouse in order to free up more space for production and experimentation.

Braasch highlighted that there are other needs not currently being met by current infrastructure at the Dartmouth Organic Farm. Some of these needs included a kitchen space and a four-season teaching and learning area. Additionally, the lack of a septic system limits the number of individuals that can visit the Dartmouth Organic Farm at one time. However, Dartmouth College is currently working on adding a septic system and leach field on the western side of the Hoop House. Addressing all of these needs is part of the larger Master Plan for the future development of the Dartmouth Organic Farm.

Braasch stressed that the existing greenhouse is in a state of disrepair and in dire need of renovation. Based on her personal conversations with contractors, Braasch knows that depending on the materials used, it will take between $40,000 and $60,000 to simply reglaze the existing structure. Braasch would prefer that the current greenhouse is renovated, rather than building a new structure, in order to maintain the current footprint. Due to the fact that the current greenhouse structure protrudes into the legal setback limit for the road, its footprint cannot be altered without triggering new zoning standards. The structure is currently grandfathered into the zoning law, meaning that it is exempt from the legal setback limit for the road, but once the footprint is changed, the structure must be moved farther back from the road in compliance with Town of Hanover standards (see section 3.2). Braasch hopes the project will maximize buildable space on the farm by using the existing footprint because, “if we don’t use it, we will lose it” (L. Braasch, personal communication, May 6, 2021).

Finally, Braasch informed us that much of the Dartmouth Organic Farm is located on a conservation easement which limits the potential locations for a new greenhouse (see Figure 4.2). According to the Town of Hanover’s 2020 Zoning Ordinance, Article V, §508:

> The lot is protected permanently through the grant of a conservation easement to a governmental agency or a conservation organization approved by the Planning Board in consultation with the Conservation Commission. Such conservation easement will restrict the uses of the lot to silviculture, agriculture, and non- commercial outdoor recreation conducted in accordance with recognized conservation practices and will otherwise be in form and substance satisfactory to the Planning Board in consultation with the Conservation Commission (p. 55).

Figure 4.2: Green highlighted area illustrates the land protected by conservation easement on the Dartmouth Organic Farm. ("Town of Hanover Protected Open Space," 2003).

The yellow dashed line in Figure 4.3 denotes the area of the Dartmouth Organic Farm that is not a part of the conservation easement. Essentially, this is the only buildable area of land at the Dartmouth Organic Farm due to the building protections granted to conservation easements. Braasch also informed us that the Zoning Board and Town of Hanover are very aware of any changes or new structures added to the farm. As such, any temporary and permanent changes must be well-documented and communicated well in advance and throughout the process to the Town of Hanover.

Figure 4.3: Yellow dashed line denotes edges of the conservation easement. ("Dartmouth College Fullington Farm Concept Master Plan," 2013).

Braasch also noted that much of the Dartmouth Organic Farm falls within the floodplain of the Connecticut River (see Figure 4.4). This reality further limits the potential building locations at the farm. Fortunately, most of the conservation easement and the floodplain overlap. After considering the Town of Hanover's setbacks within the buildable lot, no potential location for new or current infrastructure is in an area at risk of flooding (see section 4.2).

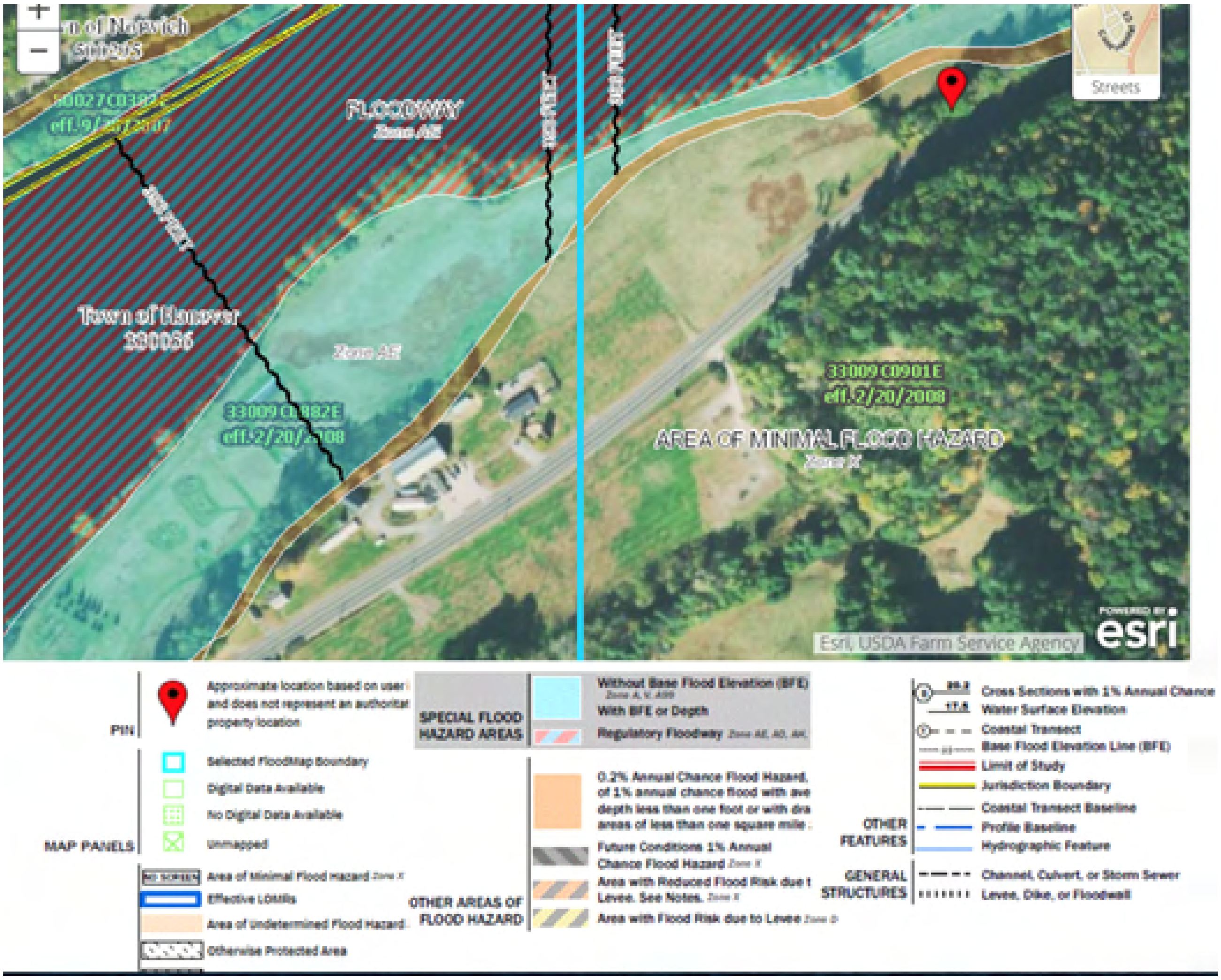


Figure 4.4: Areas of the Dartmouth Organic Farm subject to flooding. ("FEMA Flood Map of Hanover, NH," 2008).

4.3.2 Dartmouth College Stakeholder Interviews

A. Rosi Kerr '98, Director of Sustainability at Dartmouth College

Rosi Kerr '98 is the Director of Sustainability at Dartmouth College. As the director, one of her main goals is seeing the Master Plan for the Dartmouth Organic Farm implemented. Kerr sees building a new greenhouse or renovating the existing structure as a key piece of the Master Plan. Other aspects of the Master Plan include building a new multipurpose structure with a kitchen, bathroom, classroom, and lounge area which would require demolishing the existing milk house and old barn. Kerr supports using the existing footprint of the greenhouse for our project because she does not want the College to lose the right to use the grandfathered land. The current greenhouse structure protrudes into the legal setback limit for US Highway 10 enacted after its construction. Given the limited land area for building at the Dartmouth Organic Farm, the competing conservation easement, and existing Master Plan, Kerr believes using the existing structure is the Greenhouse Committee's best option. She further states that building a new structure on a different location would require a longer, more complex permitting process and would necessitate navigating the Town of Hanover's unique exclusionary zoning laws.

Kerr anticipates the Greenhouse Committee will face a number of fundraising hurdles going forward. Namely, this Greenhouse Project falls under Dartmouth's "capital project" designation as it exceeds $50,000. Capital projects at Dartmouth require project proponents to not only acquire 70 to 80 percent of the project's funding prior to launch but also to put money away into an operating endowment to cover future costs of renovation. Furthermore, capital projects and development campaigns are subject to Dartmouth's administrative priorities and thus compete with all other large campus initiatives, such as Dartmouth Hall's multimillion dollar renovation, for any given year. Dartmouth considers all capital project proposals in late October and submits suggestions to the Board of Trustees for consideration in January and February.

Given these financial hurdles, Kerr discussed the current finances for the Dartmouth Organic Farm. Currently, the farm is allotted an approximate $100,000 operating budget within the Sustainability Office. While the Sustainability Office occasionally receives gifts from donors, these gifts are typically $5,000 t0 $10,000 with $50,000 being the largest gift ever received. However, the Sustainability Office will not use donor gifts for capital projects or building renovations. It is instead saved for a rainy day or used to fund student fellowships.

Moving forward, Kerr outlined a number of paths the Greenhouse Committee can take to fund the Big Green Energy House project. First, the Committee may establish the project as an institutional priority for the Development Office. The Development Office creates campaigns for capital projects of high importance to the College, such as the "Call to Lead" campaign that was founded in 2018 to advance the undergraduate experience at Dartmouth to make a lasting impact on the world. Second, students may speak with alumni in hopes they will make small donations for this specific project rather than one of the Development Office's leading initiatives. Third, if neither of these options work, the Greenhouse Committee may work with Dartmouth's Facilities Operations & Management team (FO&M) to find reserve funds internal to the College. Finally, the President of the College has a discretionary budget of roughly a few million dollars. If the Committee develops the Greenhouse Project as a priority for President Hanlon, he may use his discretionary budget to fund the project.

B. Tim McNamara, Associate Director of FO&M

Tim McNamara is not a stakeholder in the operation of the greenhouse, but he is the best representative of Dartmouth College as an institutional stakeholder. The College controls building on its property and will take charge of guiding the Greenhouse Committee through the construction and permitting processes for the Big Green Energy House. Understanding these processes ahead of time allows for conceptual design and functional requirements to be adjusted in order to create a unified vision of what can be built and what the project will ultimately look like.

Projects costing more than or equal to $50,000 are classified by the College as "capital projects" (T. McNamara, personal communication, 27 April, 2021). With this designation, receiving approval for the project from College officials is next (see section 4.5). Additionally, Director of Project Management Services, Patrick O'Hern needs to be heavily involved in any capital project. Tim McNamara also stressed the importance of getting Director of Sustainability Rosi Kerr, Patrick O'Hern, and himself "all into one room" to discuss the project many times throughout the process (T. McNamara, personal communication, April 27, 2021).

From interviews with Tim McNamara, our group has come away with a number of his recommendations for the completion of a greenhouse upgrade or renovation at the Dartmouth Organic Farm. McNamara's main recommendation is that the Greenhouse Committee work within the footprint of the current Organic Farm greenhouse, renovate the structure down to the existing foundation and concrete, and rebuild from there. He proposes keeping the concrete walls of the existing greenhouse due to the embedded carbon within them. He also recommends that the existing greenhouse's metal frame be recycled, if possible.

For the purpose of obtaining the highest appraisal possible of the current greenhouse structure, McNamara recommends stakeholders push for the Town of Hanover to consider the greenhouse, milkhouse, and old barn (if possible) as one structure. This is due to the fact that projects costing more than 50% of the appraised value of a structure must have additional design features and equipment included to meet current building, life safety, and ADA codes and regulations

To address concerns regarding the state of disrepair of the attached milkhouse and old barn, McNamara recommends that during construction of a new greenhouse, designs take into account closing off the greenhouse from the rest of the structure. In this way, the newly renovated greenhouse will be unaffected by the future removal of the milkhouse and barn.

To address concerns regarding the limited space of the existing greenhouse footprint, McNamara recommends raising the back roof line (the side with a tall concrete wall) by 4'-6' and designing the interior with 3D planning in mind to maximise the utility of the vertical space within (i.e. hanging hydroponics or vertical tomato plants growing). Only the back wall can be raised because raising the front wall changes the frontage of the building. Changing the frontage requires a variance, which would most likely not be issued considering the building is grandfathered in on non-buildable land.

For the construction of the renovated greenhouse, McNamara recommends using a metal frame to avoid the rot that happens in wood materials. He also recommends laying a concrete pathway down the middle of the greenhouse, between two plant beds, for wheelchair accessibility.

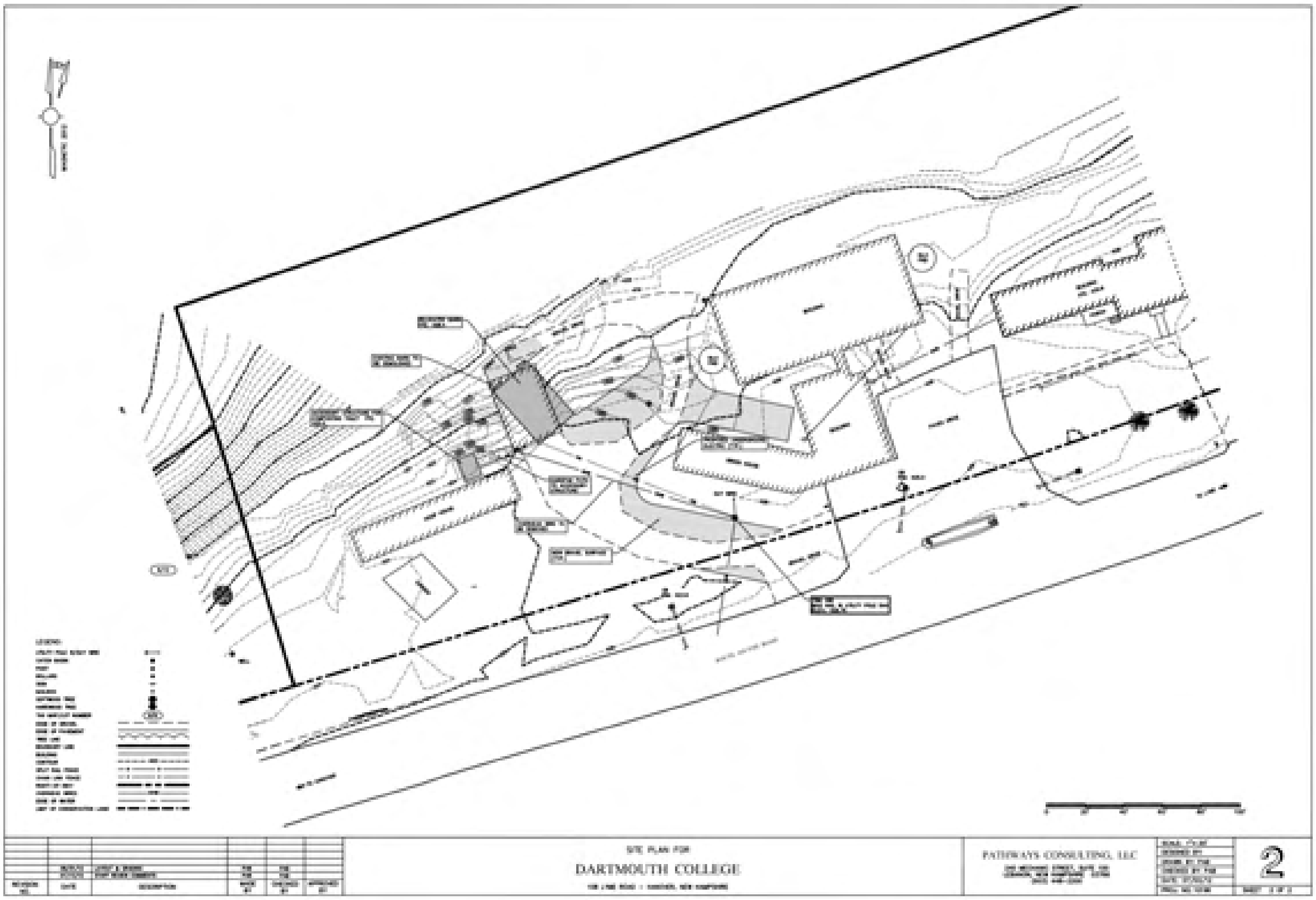


Figure 4.5: Site plan from 2013 for installing the farm sign (1" = 20′). ("Overall site plan for Dartmouth College," 2012).

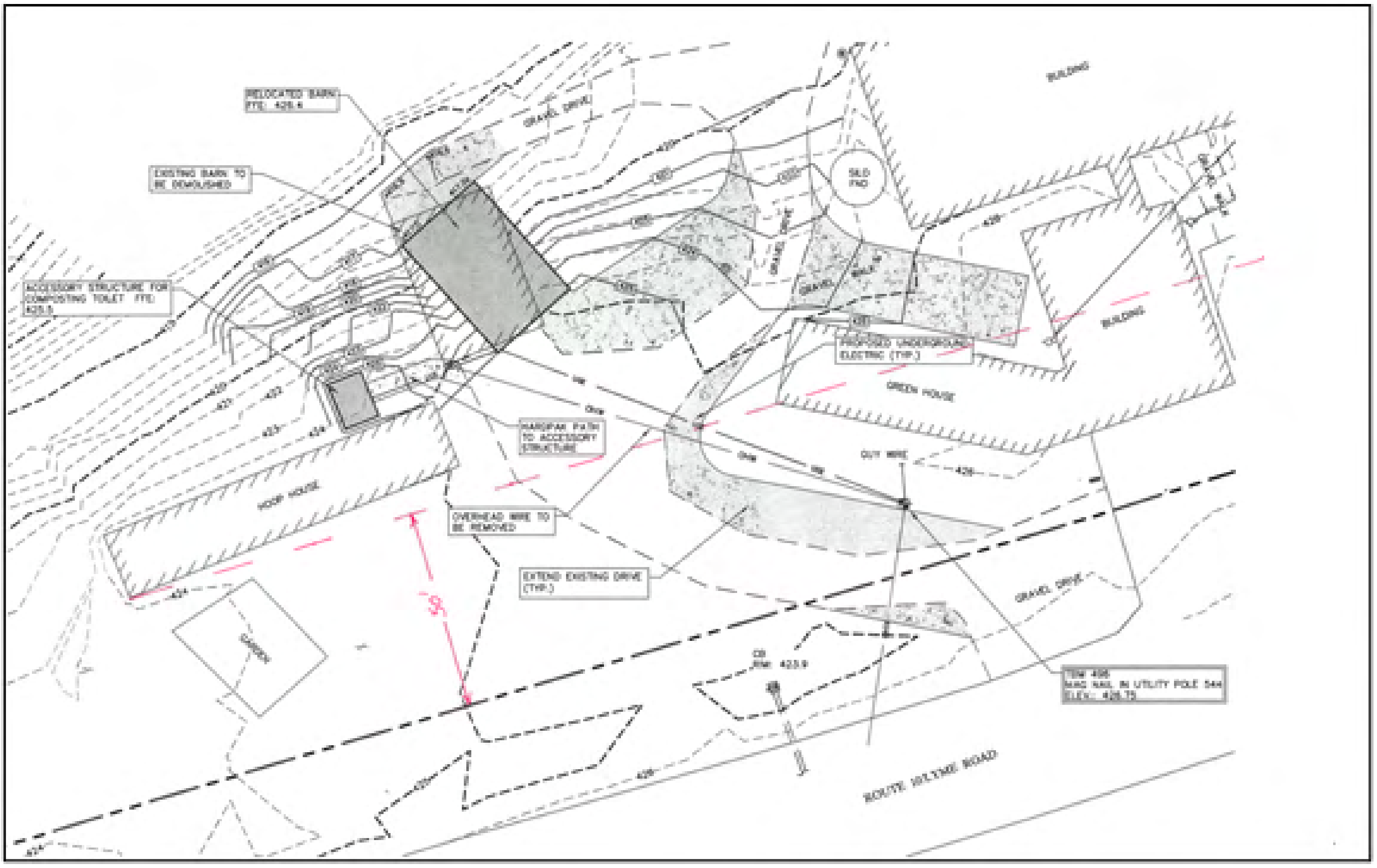


Figure 4.6: Enlarged version of above site plan from 2013 for installing the O-Farm sign. Depicts the Organic Farm Front Yard Setback (in red) with 1" = 20. ("Overall site plan for Dartmouth College," 2012).

C. Bernard Haskell, Assistant Director of Residential Operations at Dartmouth College

Bernard Haskell, Assistant Director of Residential Operations at Dartmouth College, provided valuable information on several aspects of the Big Green Energy House project. First, the Town of Hanover uses the International Building Code ("IBC"), which is more stringent than other New Hampshire building codes. Second, he recommends the Greenhouse Committee cast a wide net when looking for volunteers or advice because many people outside of the Sustainability Office are interested in Dartmouth's Organic Farm. Third, he recommends the Committee recycle and reuse existing on-site materials as much as possible to reduce waste. Finally, Haskell mentioned it may be possible to incorporate the new greenhouse's building maintenance into the Residential Operations plan, though Residential Operations does not regularly maintain the Organic Farm infrastructure and their involvement is more reactionary than proactive maintenance at the moment. Therefore, the Greenhouse Committee will have to communicate with Residential Operations to discuss maintenance plans going forward.

Bernard also recommended using Dartmouth's practice of proposing several alternative design plans simultaneously. He clarified that the Greenhouse Committee must submit plans to Dartmouth, and the College will then interface with the Town of Hanover. The Committee should not directly submit plans to the Town of Hanover unless asked to do so by the College.

In terms of timeline, Haskell mentioned the review process with the Town of Hanover may take 6-12 months. We are currently looking into this suggestion for more information on what is and is not required for the Town's review.

D. Patrick O'Hern, Director of Project Management Services at Dartmouth College

Patrick O'Hern contributed invaluable information on the College's infrastructural processes for capital projects (projects costing greater than $50,000) all the way from planning to construction. O'Hern also importantly noted that the project management services team is usually involved early on in a project expected to exceed $50,000.

Dartmouth Capital Projects often takes on much of the initial financial risk in launching a project. If a project has future funding sources, but only has the initial planning cost of the project covered at the start, Capital Projects is able to take on the cost of the project, within reason, as a bridge loan. However, a bridge loan is an unlikely resource for the Big Green Energy House due to the small cost of the greenhouse relative to other Dartmouth College projects such as the approximately $150 million Thayer project.

O'Hern conservatively estimates a project such as the Big Green Energy House would take about a year from start to finish. However, he noted several obstacles to the launch of this project. The Project Management Services team feels resource-constrained at the moment in terms of staffing. As a result, the office may need to hire someone externally to manage the project. O'Hern also sees both funding and the effects of COVID-19 on the construction industry as one of this project's primary obstacles. It is difficult for Capital Projects to proceed with a project with limited committed funding. Additionally, COVID-19 is having drastic impacts on the construction industry. O'Hern cited that his project managers are having difficulties getting at least one bid in the bidding process with contractors when three bids is the usual baseline. Moreover, the cost of many building materials are rising, taking a prolonged amount of time to ship, or are in short supply. O'Hern mentioned that two of his projects the week of our interview were stalled at the bidding process due to unaffordable contractor bids from the rising cost of construction. As a result, O'Hern sees a fall project launch as an aggressive, perhaps improbable, goal.

Please see below for a detailed description of the Dartmouth College capital project planning and approval process:

I. Planning Phase

To begin, a rough idea or careful plan for the Big Green Energy House including a relative financial commitment (at least enough to cover the cost of the planning portion of the project) is brought to Capital Projects. While the office meets annually in the fall to review plans from departments all across Dartmouth to develop their capital budget for the following year, project plans are continuously being accepted for review by the office. It's important to note that projects with more concrete details about funding sources are more easily accepted and propelled to completion.

II. Site Assessment

Project management services, FO&M, and potentially a structural engineer and/or other specialists will be brought out to the Dartmouth Organic Farm to assess the existing greenhouse structure and other potential project locations. Structural, electrical, historical, life safety, soil, and accessibility assessments may be conducted at the site to determine the project scope and feasibility. The assessment of the site is supplemented by the latest available facility condition index (FCI). FCIs are conducted every 5 years at Dartmouth where architects and engineers assess the "remaining life of systems" in every campus building. The FCI is then used by project management services to prioritize certain campus projects and create a map of the condition of campus buildings.

III. Design Phase

An architect or design specialist will be brought on board to create schematics or designs. Based on these designs, a rough in-house cost estimate will be made. If the cost estimate is greater than $300,000 the project must then be approved by both the Executive Vice President and Chief Financial Officer of Dartmouth. If the project estimate falls below $300,000, project approval is only required from the Vice President of Campus Services.

IV. Contractor Bidding

Following project approval, the designs are used in a contractor bidding process using a Construction Management At-Risk contract (CMAR). In this form of agreement, the contractor is committing to completing a project within a guaranteed maximum price prior to bidding. In the bidding process, the project manager will share designs with contractors with the aim of getting at least three contractors to provide bids. Contractors provide bids by reviewing the project designs and creating or searching for price estimates of materials, labor, and any additional fees. This is to ensure the feasibility of the project and that the contractor is providing a confident cost estimate for the project that is supported by present market conditions for labor and materials. Once a bid is selected, the construction manager is bound by the CMAR to provide the cost breakdown of all materials, labor, subcontractors, contingency funds and their own fees, thus allowing Dartmouth to regain any future money leftover. In other agreements contractors are only required to provide a final cost, which limits cost control.

E. Jennifer Casey, Executive Director of Campaign Initiatives and Academic Coordination in Dartmouth College Advancement Division & Katherine (Kate) Norton, Director of Corporate and Foundation Relations at Dartmouth College

Jennifer Casey currently works as the liaison between Dartmouth’s Director of Sustainability Rosi Kerr and the Office of the Provost. She has bi-weekly meetings with the Office of the Provost and has been in this position for fourteen years. At the moment, Casey is aware of two potential projects related to Dartmouth’s Organic Farm: the educational living-learning building and the Big Green Energy House. She believes these projects are exciting because they have a low price tag as well as a broad impact on Dartmouth students and faculty, Dartmouth’s research curriculum, and social opportunities. At the same time, she hopes the Greenhouse Committee remains realistic about passing such an initiative. The Provost, the Greenhouse Committee, and other college stakeholders may need to sit with this proposal and consider the optics and priorities of the College. Furthermore, this greenhouse project may be more complicated because it is a facility. Finally, in terms of timeline, Casey is presenting the Greenhouse Proposal and Fact Sheet to the Provost on May 19, 2021. Casey requests that the Greenhouse Committee always keep Rosi Kerr updated with the latest Greenhouse Proposal and updates and that she be the liaison between the Greenhouse Committee and the Office of Advancement.

Katherine (Kate) Norton helps faculty find and apply to appropriate grants and foundation funding opportunities to meet their needs. She has worked with Professor Ong and Professor Pries in the past on proposals and suggests that the Foundation for Food and Agricultural Research may be a good funding source to look into for this project. She stated two challenges for working with foundations. First, foundation grant application deadlines only happen once or twice a year. Second, it usually takes 9-12 months for a grant to come through. One advantage of foundations is that faculty applicants do not need Provost or Dean of Faculty support before submitting proposals to companies or foundations.

Going forward, Casey and Norton suggest that the Greenhouse Committee continues sharing new iterations of the proposal as the project moves along and ensures Rosi Kerr has the most up-to-date proposal at all times because she is Advancement's point person.

F. Theresa Barry, Life Sciences Center Greenhouse Manager

Theresa Barry, the Greenhouse Manager at the Life Sciences Center ("LSC") Biology Greenhouse, spoke about the designs and technologies that have worked best for her. She recommends prioritizing airflow, ventilation, humidity control, shade cloths, computer temperature control systems, and ensuring the greenhouse has the correct fan sizes for its dimensions. Barry finds well-designed roof ventilation, roll up side shades, and fans important for the greenhouse's functionality. Finally, she recommends elevating plants to reduce disease, especially for research-focused greenhouses. Keeping plants in the ground exposes them to pests, humidity problems, and uncleanliness and ultimately leads to more plant diseases.

Barry expressed excitement about a new greenhouse at the O-Farm because there is more demand for greenhouse space than is available at the LSC. She believes research that cannot be conducted at the LSC greenhouse may be conducted at a research-grade O-Farm greenhouse. Looking forward, Barry recommended reconnecting with Long Wind Farm to discuss four-season greenhouse design and upkeep in New England.

4.3.3 Town of Hanover Stakeholder Interviews

A. Robert Houseman, Planning and Zoning Director for the Town of Hanover

Robert Houseman explained that renovating an existing O-Farm greenhouse structure is the simplest option for the Greenhouse Committee. He clarified that while the Town of Hanover Planning & Zoning Department's permit turnaround time may take up to 45 days, most small project permits take up to two weeks. This Big Green Energy House is what he would consider a small project. For context, the brand new Thayer School Computer Science Building took 45 days to receive permit feedback.

Houseman reminds the Greenhouse Committee that only designs stamped by a structural engineer may be considered by the Town of Hanover. Additionally, only renovations expanding external lights, external walkways and parking need to be re-approved by the Town's Zoning Board. Finally, Houseman recommends consulting Section 803.2 and Section 405.9 of Hanover's Zoning Ordinance to ensure renovations comply with the Town.

4.4 Summary of Interviewee Recommendations

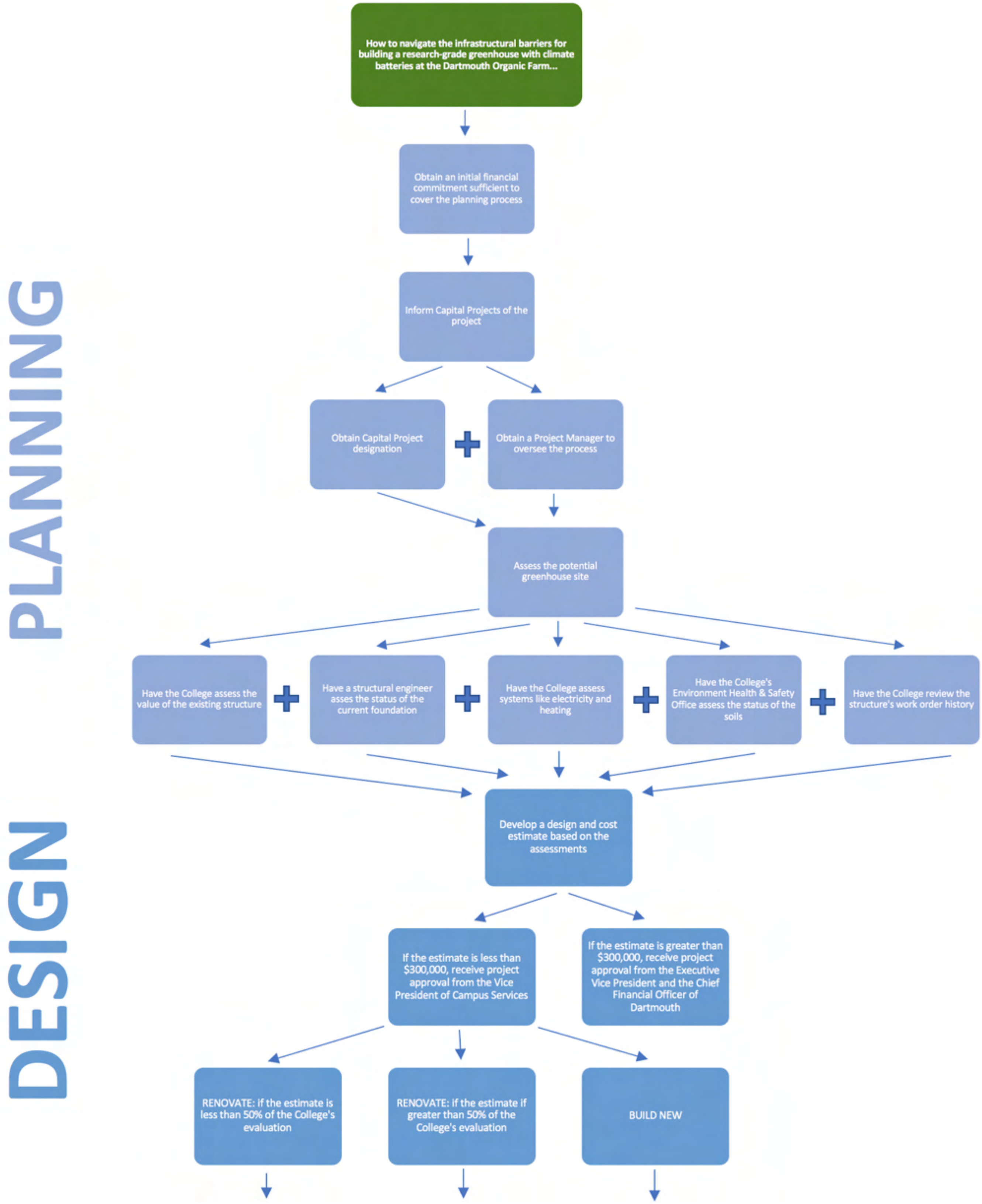
Table 4.2: Summary of Interviewee Recommendations

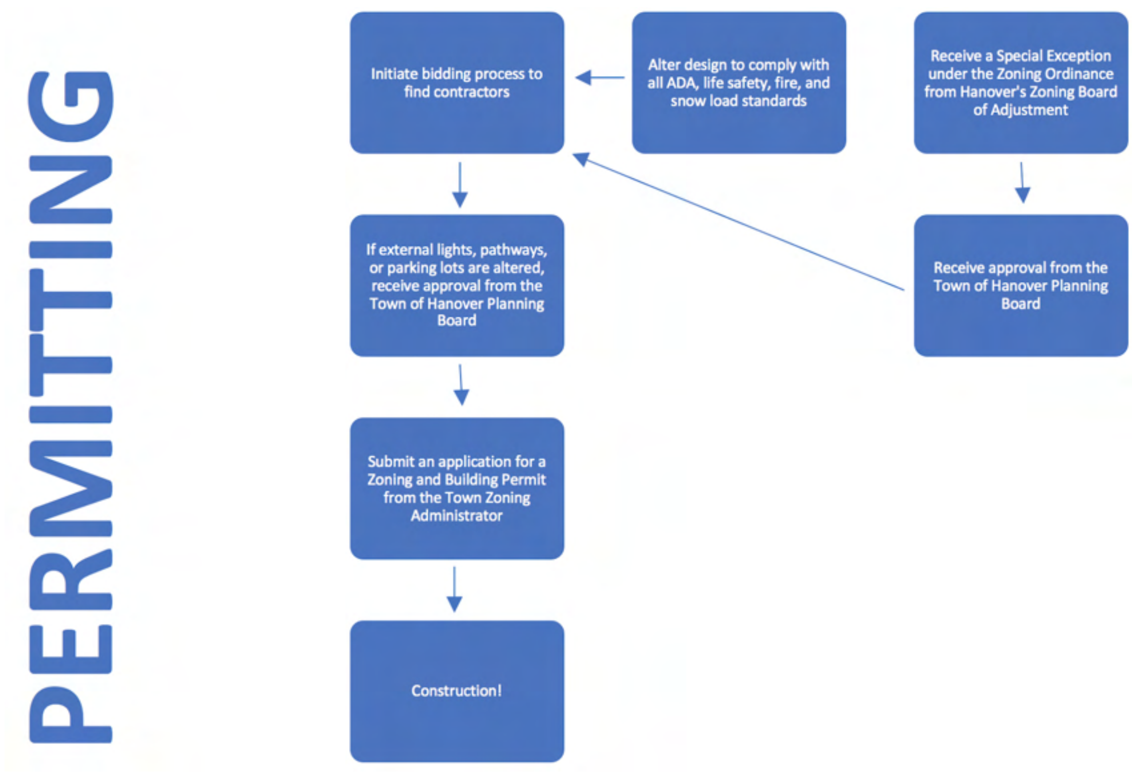
Interviewee	**Position**	**Recommendation**
Theresa Ong	*Greenhouse Committee, Assistant Professor of*	Create a research-grade greenhouse with two climate batteries that has a storage area for research supplies. If

	Environmental Studies	the footprint of the existing greenhouse is used, ensure that the new structure is not attached to the milkhouse.
Caitlin Hicks Pries	*Greenhouse Committee, Assistant Professor of Biological Sciences*	Create a research-grade greenhouse with two climate batteries. Incorporate outside potting areas and a shed for storing tools into the design considerations.
Laura Braasch	*Greenhouse Committee, Head of the Dartmouth Organic Farm,* *Sustainability Office Program Manager*	Utilize the footprint of the existing greenhouse for the new structure. Create a research-grade greenhouse that allows for both teaching and experimenting. Replace the entire frame of the existing greenhouse. Remove the large fish tanks on the north side of the existing structure. Keep the recently renovated Hoop House.
Rosi Kerr	*Director of the Sustainability Office*	Utilize the footprint of the existing greenhouse for the new structure. Consider how this new greenhouse will fit into the Master Plan for the Dartmouth Organic Farm. Keep the recently renovated Hoop House.
Tim McNamara	*Associate Director of Campus Planning and Facilities*	Work within the existing footprint of the current greenhouse, renovate the structure down to the existing foundation and concrete, and rebuild from there while maximizing the vertical space. Designs should take into account closing off the greenhouse from the attached milkhouse structure, should use a metal frame to avoid the rot that happens in wood materials, and should include laying a concrete pathway down for wheelchair accessibility. Stakeholders should push for the Town of Hanover to consider the greenhouse, milkhouse, and old barn (if possible) as one structure to get the highest appraisal possible and avoid triggering new zoning and building code updates (see section 3.2).
Bernard Haskell	*Assistant Director of Residential Operations*	Propose several alternative design plans simultaneously to Dartmouth. Involve a variety of advisors and volunteers outside of the Sustainability Office to engage others interested in Dartmouth's Organic Farm. Allow Dartmouth to interface with the Town of Hanover

		with design plans and proposals. Communicate with Residential Operations to discuss maintenance plans going forward. Recycle and reuse existing on-site material as much as possible to reduce waste. Adhere to the International Building Code.
Patrick O'Hern	*Director of Project Management Services at Dartmouth College*	Connect with Capital Projects as early as possible once the Greenhouse Committee has a concrete funding plan or at least has enough available funds to cover the initial cost of the planning phase. Aiming for a fall 2021 project launch is an aggressive, perhaps improbable goal.
Jennifer Casey, Katherine Norton	*Office of Development and Advancement*	The Greenhouse Committee should establish a liaison with the Development Office so that the Big Green Energy House may be included as a candidate for funding from the general alumni fundraising pool.
Theresa Barry	*Greenhouse Manager at Life Sciences Center*	Prioritize a well-designed ventilation system, constant airflow, correctly-sized fans, and humidity control. Elevate plant beds from ground to mitigate risk of disease. Consider including roll-up shade cloths and computerized temperature control systems. Connect with Long Wind Farm on design and upkeep of four-season greenhouses in New England.
Robert Houseman	*Town of Hanover Planning Department* *Planning and Zoning Director*	Ensure designs submitted to Town are stamped by a structural engineer. Consult Town of Hanover Zoning Ordinance Sections 803.2 and 405.9 to ensure renovations comply with the Town.

4.5 Flowchart for Navigating Infrastructural Barriers





4.6 Funding Opportunities

Table 4.3: Potential Project Funding Sources

Internal Funding Sources	External Funding Sources
President's discretionary fund	Irving Grant *Applied*
Direct solicitation of alumni donations	Northeast Sustainable Agriculture and Research and Education (SARE) Program *Proposal Deadline: August 3rd* *Full Proposal Deadline: October 26th*

Alumni donations through development office	Organic Farming Research Foundation Grant *Grant proposals temporarily suspended*

4.6.1 External Funding Opportunities

A. Irving Institute Grant

The Irving Institute grant has already been applied for and is anticipated to provide a maximum of $100,000 of funding towards building the Big Green Energy House. Potential issues with the grant are the fact that the amount will likely not cover the full cost of rebuilding the greenhouse. Furthermore, the initial grant money will not cover long term operating and maintenance expenses.

B. Northeast Sustainable Agriculture and Research and Education (SARE) Program

The SARE Program provides grants from $30,000 to $200,000 for research and education as well as research for novel approaches. The latter is likely the best fit for the scope of the Big Green Energy House as it is intended for "proof of concept projects intended to confirm the benefit and feasibility of new practices and approaches that have high potential for adoption by farmers" (Sustainable Agriculture Research and Education [SARE], 2021). This description fits closely into the lighthouse model envisioned for the greenhouse and therefore is a good option to pursue. The grant application requires submitting a pre-proposal which outlines the concept and its merits.

C. Organic Farming Research Foundation Grant

The Organic Farming Research Foundation funds research project design and implementation on certified organic land with a strong education component. The grant provides $20,000 for only the first year of a project. The grant can be applied for by submitting a letter of intent outlining the project and must also heavily involve local farmers in the process. The grant application is currently closed but is worth keeping in mind for coming years as its requirements closely match the intended lighthouse model for the Big Green Energy House.

4.6.2 Internal College Funding Opportunities

A. President’s Discretionary Fund

Money from the president's discretionary fund can be obtained through direct appeal to the Office of the President by presenting the academic merits of the Big Green Energy House. The president's discretionary fund has $5,000,000 available for projects, but it is in high demand due to being open to many groups on campus.

B. Alumni Donations

Alumni donations cannot be solicited directly by the Sustainability Office. Coordinated student outreach to alumni previously involved in the Dartmouth Organic Farm or Sustainability Office asking for specific funding is the best avenue. The highest donation received in the past by the Sustainability Office was $50,000. Direct alumni donations are likely smaller and a one-time source of funding.

Funds from alumni donations can also be obtained directly through Dartmouth's Development Office. Higher amounts of funding are available through the Development Office as they are from the general pool of alumni donations or are solicited from foundations or corporate donors. One such foundation is the Food and Agriculture Foundation. Any application for funding through the development office requires the assignment of a principal investigator for oversight. Projects requiring funding through the Development Office are usually proposed to donors in the fall and take 9-12 months to complete the process of approval. The low price tag of the Big Green Energy House project relative to other projects makes it a good contender for receiving funding via alumni donations. The connections between students and the community at large, being student run, and the experiential learning aspect are all merits in addition to the research and sustainability aspects which can be emphasized to broaden the support base for the project among donors.

4.7 References

Braasch, L (April, 2021) Personal communication [Personal Interview]

Dartmouth College Fullington Farm Concept Master Plan [Two-dimension map illustrating the layout of buildings]. (2013).

Flood Map of Hanover, NH [Map]. (2008). In *FEMA Flood Map Service Center* (33009C0883E). Hanover, NH: Federal Emergency Management Agency.

Hanover, NH, Zoning Ordinance (2020).

Haskell, B (April, 2021) Personal communication [Personal Interview]

Hicks-Pries, C (April, 2021) Personal communication [Personal Interview]

Kerr, R (May, 2021) Personal communication [Personal Interview]

McNamara, T (April, 2021) Personal communication [Personal Interview]

O'Hern, P (May, 2021) Personal communication [Personal Interview]

Ong, T (April, 2021) Personal communication [Personal Interview]

Overall site plan for Dartmouth College [Map]. (2012). Hanover, NH: Pathways Consulting.

Sustainable Agriculture Research and Education. (2021, May 12). *Research for Novel Approaches in Sustainable Agriculture Grant Program*. SARE Northeast. https://northeast.sare.org/grants/get-a-grant/research-for-novel-approaches/.

Town of Hanover Protected Open Space [Map]. (2003). In *Town of Hanover Master Plan* (Vol. 5-1). Hanover, NH: Town of Hanover.

Chapter Five: Design

Ella Dobson, Bee Hollyer, Ed Johnson, Devin Quinlin, Rebecca Rorabaugh

5.1 Introduction

As the design team, our goal with this project is to find a feasible design solution that meets the needs of all stakeholders, while keeping sustainability and efficient energy systems our top priority. This is a priority because Dartmouth College is undertaking sustainability initiatives, including upgrading the inefficient steam-based central heating system, and we aim to build on this momentum. The Irving Grant is also meant specifically to support innovative sustainable energy projects, so it's important for our potential funding. Lastly, as ENVS students, we're interested in taking steps towards a more sustainable future, and hope to enable this project as a space for sharing energy-efficient technology and information.

Some of the questions we addressed were how to heat and cool the greenhouse to a research-dictated temperature range, minimize energy consumption and optimize the opportunity to work with the Irving Institute to advance energy efficiency concerns. Our key considerations were efficiency, cost, sustainability, accessibility, materials, timeframe, and greenhouse size. The greenhouse interior climate parameters involve keeping the temperature above freezing in the winter, preferably at 40ºF, and below 90ºF in the summer for our research stakeholders. In order to achieve this we investigated sealing and insulating the greenhouse, better glazing orientation, and a climate battery system, as well as electric heating. Other questions addressed include programming needs for research, teaching, and Organic Farm operations, as well as feasibility with the site, budget, existing greenhouse status, and building code requirements. Perhaps most importantly, we thought deeply about what it means for this building to act as a lighthouse model, and how it would best serve local farmers and the broader community as a place to share and learn new information.

Our team researched literature and local examples of climate batteries and similar technologies, we met with stakeholders and experts, and devoted significant time to assessing feasibility at the Dartmouth Organic Farm site. Our main emphasis in deliverables has been to make a realistic recommendation. We want this report to usefully assist the greenhouse committee as they move forward with a building project, so we have tried to be very sure that our design options fit with practical, infrastructural, and stakeholder requirements. We ensured that our plan fits well with the existing greenhouse structure, the climate battery control experiment specified in the Irving grant proposal, our stakeholder expectations, and we aimed to fit within the Irving grant budget. The budget and cost estimates turned out to be a particularly difficult part of our process, and our most basic option is estimated to cost just under $300,000.

5.2 Methods

Our approach to designing the Big Green Energy House started with extensive background research to better understand the overall scope of our assignment. We first looked at climate batteries and other greenhouse examples, specifically those in similar climates to Hanover, to get a sense of existing technology in the field. We consulted peer-reviewed literature, news articles, and other sources. We then interviewed some experts in the field including current O Farm greenhouse designer Dr Chris Polashenski, Facilities, Operations & Management (FO&M) Associate Director Tim McNamara, Ceres Greenhouse Solutions, Rimol Greenhouses, and Life Science Centre (LSC) greenhouse manager Theresa Barry. These interviews were key to our understanding of the current greenhouse at the organic farm, institutional barriers to construction, greenhouse fabrication and customisation, and lessons learned from the research grade greenhouse at the LSC at Dartmouth. Through our conversation with Dr Chris Polashenski, we were able to understand the footprint we would soon be working with and the status of the current greenhouse. In addition to speaking with the current greenhouse designer, two representatives from the Design Team conducted a site visit and documented extensively with photography. This was instrumental in understanding the limitations and possibilities involved with a renovation of the existing greenhouse. We learned dimensions, materials, foundation layout, condition of the existing greenhouse, and the roof geometry of the milkhouse connection.

During the design process we were constantly adapting to new information. Initially we focused on understanding how a climate battery would practically work with the existing greenhouse foundation, then learned of institutional interest in new construction, but then began to understand the costs involved and refocused on a renovation. Design iterations were drawn in Adobe Illustrator in architectural section, plan, and elevation drawings (Figures 5.4, 5.12, 5.14, 5.15), and were modeled in Sketch Up (Figure 5.13) to better understand the spatial dynamics and how the connection to the milkhouse would affect the design. Feedback from experts and stakeholders influenced our designs: for example the Ceres Greenhouse Systems representative helped inform the roof angle of our final shed roof option. Basic heat calculations and cost estimates also helped inform our decisions, ruling out the taller shed roof due to heat loss and ruling out custom offset roof trusses due to cost.

Finally, as a team of multidisciplinary students, we distributed tasks to best suit team member's specific areas of expertise. Some team members focused on creating specific designs, while others continued to research materials and costs, and to organize interviews and meetings to keep the team on the same page.

5.3 Stakeholder needs

In addition to our methods outlined above, we remained highly cognizant of the stakeholder parameters when researching and designing the greenhouse and climate battery. The stakeholder needs we took into consideration include teaching, research, general farm use, and a lighthouse example for local farmers. The teaching needs of the Greenhouse Committee and future professors is currently difficult to implement as the amount of space in the greenhouse is suboptimal due to the current large water barrels for passive solar heating. With the climate battery, these will be removed and more space for teaching benches and bare soil will be created. Next, for research purposes, we have tried to make recommendations in order to have two separately controlled climate batteries. The two separately controlled batteries, in conjunction with a divider implemented above ground in the greenhouse can ensure optimised control of the two systems. This is primarily to evaluate the efficacy of the climate battery through control and experimental sides. However, these two systems and/or the divider, could be used in the longer term to meet the needs of different research projects. The underground divider between the two climate batteries is intended to be removed to make a more efficient climate battery after the experimental year is over. In addition, we have tried to meet the needs of the O Farm, mainly by providing enough space for growth of produce year round, which is presently not possible with the leaky greenhouse, or hoop house with high energy demands. Finally, to serve as a lighthouse model for local farmers, we have opted for a climate battery system with easily available materials, and a simple design that could easily be adopted for each farmer's own greenhouse needs. We mainly compared the current passive solar heating system with a climate battery (detailed in Current Greenhouse section below). We concluded that due to the heating and cooling benefits of the climate battery, along with approximately 1.33 times the heating capacity of the soil over the water barrels [Appendix F], the climate battery would be beneficial for four season greenhouse functioning with increased space, and decreased additional heating demand. We believe this may be an adoptable system for local farmers looking to extend their growing seasons, and the climate battery dimensions and materials can be slightly altered to fit the needs of each farmer. We will provide details of areas which can lower costs, and provide material properties and longevity at length in the Materials appendix [Appendix G]. Our team did background research in multiple different areas in order to come to the recommendations that will be outlined at the end of this chapter.

5.4 Hanover Climate and the Organic Farm Setting

The town of Hanover, New Hampshire totals 49 square miles in area, situated in the Connecticut River Watershed (Britannica). As with much of New England, Hanover is classified as a Dfb climate under the Koppen Climate Classification system, which means that it has a warm continental climate. Warm continental climates have four distinct seasons, marked by cold, snowy winters and warm, humid summers. July is the hottest month of the year in Hanover, with an average high temperature of 77.7°F, while January is the coldest, with an average low temperature of 12.6°F (Weather Atlas). Hanover also receives 4.4 inches of precipitation in October, compared to only 2.8 inches in February (Weather Atlas). Because of the low temperature and high precipitation during the fall and winter months, agriculture is difficult to practice in Hanover, thus the need for a four season greenhouse at the Dartmouth Organic Farm.

First ideated in the 1980's by a group of students involved in a class project, the Dartmouth Organic Farm became a fledgling organic garden in the 1990's before flourishing into its first harvest in 1996. Since then, the farm has blossomed into a hub for interdisciplinary and hands-on learning; supporting an educational working garden; labs and classes; faculty and student research; and a variety of social activities. Every year, the farm and its 3-season greenhouse produce more than 4000 pounds of diverse organic produce that span over 60 varieties of grains, flowers, and vegetables (*FARM: Dartmouth Sustainability* n.d.).

5.5 Current Greenhouse

The O-Farm's current greenhouse was designed and built by a group of students in 2007, led by Dr. Chris Polashenski (C. Polashenski, personal communication, 27 April 2021). Dr. Chris Polashenski was a Thayer School of Engineering student and is now a geophysicist working at the Cold Regions Research and Engineering Laboratory in Hanover, NH, and is an adjunct engineering professor at Dartmouth ([Christopher Polashenski's faculty page], n.d.). In 2007, Polashenski along with a team of students repurposed a greenhouse steel frame, laid a perimeter foundation, added polycarbonate panels, a concrete north wall, and built a connector to the milkhouse that is located on the eastern side of the greenhouse as seen in Figure 5.1 (C. Polashenski, personal communication, 27 April 2021). The greenhouse dimensions are shown in Figure 5.2. This current greenhouse was designed with the intention of including the passive solar heating water barrels that can be seen in Figure 3. There are 11 barrels, each with 750 gallons of water, that line the north side of the greenhouse The water barrels are approximately 1103 cubic feet of mass. Water has a high specific heat capacity of 4.18 J/cm^{3}K, compared to 1.28J/cm^{3}K for wet soil and 0.88J/cm^{3}K for dry soil (Ogden Publications, n.d.). However, this passive heating system has some significant drawbacks, which is why we have recommended removing them from the greenhouse. One major downside to this passive heating system is they have no cooling potential (Schiller & Pinke, 2016, p. 211). A study in the Hubbard Brook experimental forest found significant increases in seasonal temperatures across a 50 year period ending in the early 21st century, and these seasonal, and annual increases are expected to continue to increase with climate change throughout this century (Hamburg et al., 2012). Therefore, we think it is important to consider a system such as a climate battery in order to improve summertime cooling (Appendix A). A further downside to this system is the amount of space the barrels take up. With the implementation of our recommendations, the removal of these barrels will create more space for use by various stakeholders, as well as improve the cooling capacity of the greenhouse. Ghosal et al. (2004) modelled the heating and cooling capacity of a climate battery and found that the greenhouse was 3-4 degrees celsius cooler in the summer than in a greenhouse without a climate battery. The climate battery coupled with ample ventilation or misting systems would increase the cooling capacity of the O-Farm greenhouse significantly.

Figure 5.1. Southside of Greenhouse with milkhouse connector to the right.

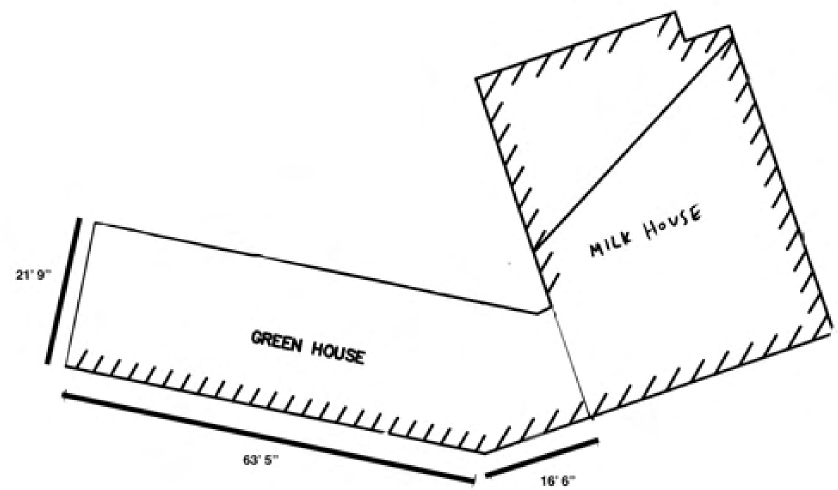


Figure 5.2. Greenhouse external dimensions.

Figure 5.3. Passive solar heating system along the internal side of the north wall.

The aluminum frame was salvaged from the Cold Regions Research and Engineering Laboratory, and was originally built in 1972. The foundation is a 4' in ground insulated, perimeter foundation, reinforced with metal rebar and has a standard 3' footing and 10" inboard footing as pictured in Figure 5.4. Dr. Polashenski estimated that the foundation has an R-value of ~40 (C. Polashenski, personal communication, 27 April 2021). The R-value refers to the ability of a material to resist heat flow, and is more commonly thought of as the insulation value of most building materials (Aldawi & Alam, 2016). The high R-value of the foundation will aid the climate battery in storing hot and cold air through its ability to resist heat exchange through the sides of the soil thermal mass. The north wall on the greenhouse is insulated concrete forms (poured concrete wall surrounded by an insulating material, usually polystyrene) finished with stucco and painted white (Figure 5). Insulated concrete forms have been studied for their potential for short term thermal storage, therefore, are likely to aid the thermal capacity of the climate battery, which is why we recommend keeping this structure in our design options (Ekrami, et al., 2015). The light colour of the north wall was chosen over a darker colour to optimise light reflection into the greenhouse, over the absorption of heat of a darker wall (Polashenski & Watcher, 2007).

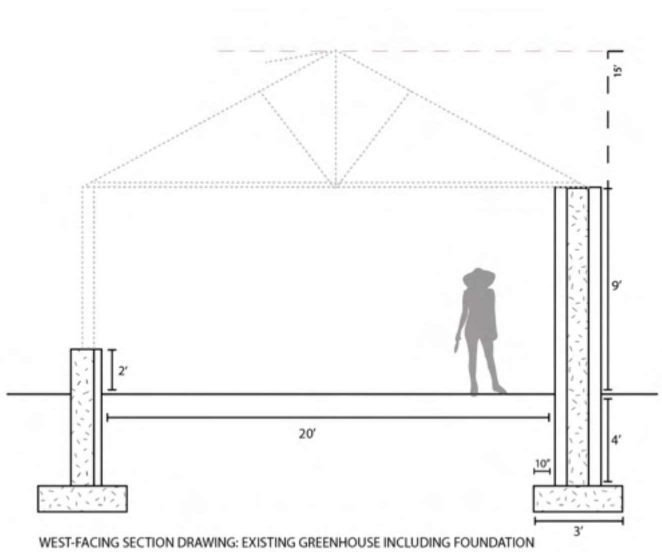


Figure 5.4. Reference image of 3' footing and 10" inboard footing.

Figure 5.5. North wall of the greenhouse.

The three remaining walls and roof are insulated with polycarbonate panels (Figure 5.6). Polycarbonate panels are listed in Appendix G, along with detailed material properties information and longevity. The existing polycarbonate panels are twinwall, and are at the end of their expected lifetime. As seen in Figure 5.6, there are significant gaps between the panelling and the frame. This is consistent in the roofing too, which is leading to a leaky structure allowing hot or cold air to move in and out, as well as letting in precipitation.

Figure 5.6. Polycarbonate panels.

Finally, the greenhouse is connected to the milkhouse as seen on the outside from Figure 5.7, and inside, Figure 5.8. The connection to the milkhouse was crucial for building the greenhouse in this location due to zoning regulations. Due to its classification as a renovation, it did not have to abide by the legal setback of 50' from the road.

Figure 5.7. Outside attachment to the milkhouse.

Figure 5.8. Inside of the attachment to the milkhouse.

5.5.1 Structural Analysis

We worked with Tim McNamara of the Facility Operations and Management (FO&M) to have the foundation assessed by the College's contracted structural engineer, and this was conducted the week of May 10th, 2021. We are currently awaiting the as-built drawings of the foundation to ensure that the foundation is up to code. In terms of the aluminum frame, since it was built in 1972, and was a reused structure when the 2007 team built this greenhouse (Polashenski, personal communication, 27th April 2021), we are unsure of the long term feasibility of reusing and renovating the structure. Due to the necessity of a snow load capacity of 60lbs/sqft, an assessment of the frame and glazing would be beneficial to make sure it is up to code. Finally, the college is planning to demolish the attached milkhouse structure in the near future, so we must take this into consideration when designing our new greenhouse.

5.5.2 Regulation considerations

The zoning regulations detailed in the Infrastructure chapter require a legal setback of 50' if we were to build a new greenhouse with a new foundation. However, if we maintain the footprint and foundation of the current greenhouse, we can build a new greenhouse on this same plot of land. In addition to zoning, we took into consideration the ADA compliance of the new design as mentioned in the previous chapter.

5.6 Climate battery research

A climate battery, also known as Ground-to-Air-Heat Transfer (GAHT), is a simple system which circulates air around four feet below the ground, and is a low-emissions system for heating and cooling of buildings (Schiller & Pinke, 2016, pp. 191-192). Simply, it uses buried perforated drain pipes to both cool and heat the air and the soil as seen in Figure 5.9 (Schiller & Pinke, 2016, p.193). During the warmer months of the year, the intake fan will pump warm, humid air into the pipe system and heat the soil while additionally cooling the air primarily through condensation (Schiller & Pinke, 2016, p.192). The condensed water is drained out of the perforated pipes into the soil, which can be then absorbed through the roots (Schiller & Pinke, 2016, p.192). During the colder periods, both at night and in the winter months, a second fan can be turned on to extract heat from the heated soil and from some deeper geothermal energy, therefore, pumping warmer air into the greenhouse (Schiller & Pinke, 2016, pp. 193-194). Geothermal energy is primarily how the climate battery can provide warmer air during the harsher, cold months of winter when the soil returns to a natural temperature state, which is higher than the air temperature (Schiller & Pinke, 2016, p. 195). In instances of extreme cold periods, backup heaters could be used to assist the climate battery, but the demand for alternative heating is much lower in a greenhouse with a climate battery (Schiller & Pinke, 2016, p. 207). We investigated greenhouses in similar climates to Hanover that have climate batteries in place and outline two examples in more detail below.

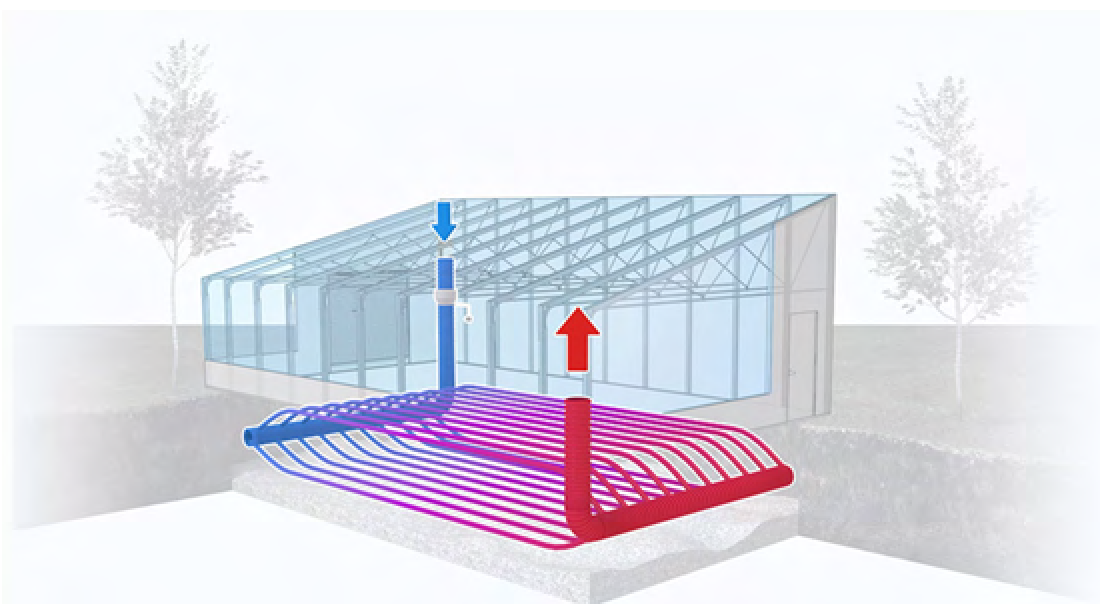


Figure 5.9. Model of a climate battery. Blue arrow indicates air in through the intake pipe into the pipe system and the red arrow indicates the air out of the exhaust pipe. Source: Ceres Greenhouse Solutions (n.d.)

4.6.1 Examples of climate battery systems in similar climates

1. Greenhause Inc: Almonte, Ontario, Canada - 30’x70’ HighYield™ Ceres Kit Greenhouse - GAHT - Lettuce

A 30’x70’ HighYield Ceres Kit Greenhouse was built in Almonte, Ontario, Canada in August 2019. This geography of the greenhouse is characterized by winters nearly as cold as the Upper Valley - New Hampshire’s cold season lasts approximately 3.3 months with an average daily high temperature below 39ºF and with season lows of 10ºF while Almonte’s cold season lasts 6 months with lows down to 22ºF. Despite the cold outdoors, Greenhaus Inc stays consistently above 55ºF and derives heat from the GAHT system only. The farm grows lettuce (Schaffer et al., n.d.).

2. The Gray House: Mechanicsburg, PA, US - 30’ x 96’ - Climate Battery - Fruit Trees

A 30’x96’ greenhouse with a climate battery was built in Mechanicsburg, PA in 2017. The geography of the greenhouse is characterized by winters nearly as cold as the Upper Valley - New Hampshire’s cold season lasts approximately 3.3 months with an average daily high temperature below 39°F and with season lows of 10°F while Mechanicsburg’s cold season lasts 3.1 months with lows down to 23°F. The Gray House design includes three climate batteries. Tubing is buried starting at 4-feet below grade with climate batteries installed lower, ideally 6’ - 8’, to capture latent heat from the earth on the coldest nights. The R-value is a universal metric of a material’s ability to insulate. Different greenhouse structures necessitate a different R-value depending on their utility. Higher R-values indicate a greater insulating quality. The Gray House’s perimeter is insulated with R-5, 1” foam board. With a higher budget, the farm would utilize heavier insulation such as 2” foam board. The Gray House insulates around the perimeter of the greenhouse as opposed to beneath the climate battery for two reasons. First, lining the perimeter insulates the indoor soil from the top soil that reduces heat loss and keeps that soil warmer throughout the four seasons. Second, the greenhouse can harness the stabilizing temperatures of the deep underground soil (Threefold Farm, n.d.; Schiller & Plinke, 2016, pp. 79).

5.6.2 Climate Battery Materials

Here we list the materials needed for the construction of two climate batteries in our 20’ x 60’ (1200SQft) greenhouse along with descriptions of why these materials. A full list of material qualities is outlined in the table (#). We utilised both Schiller & Pinke (2016) and a resource from Eco systems Design Inc. to aid our conception of the climate battery materials needed for the O Farm greenhouse (*Climate Battery Calculator,* n.d.).

- 1500’ of 4-inch socked corrugated perforated drain pipes
    - Perforated drain pipes are necessary for condensed water to flow out of the pipes when hot, humid air is pumped into the pipe system
    - The pipe material does not impact the heat performance of the climate battery (Peretti et al., 2013).
    - The diameter of the pipes also has an impact on the efficiency of heat transfer in the pipes through convective heat transfer. If the pipes are too wide in diameter, with insufficient air flow considerations and changes, there is a risk that there will be a drop in contact heat transfer (Maoz et al., 2019). This would lead to an overall decrease in the heating capacity of the battery. The optimal pipe diameter has been quantified as between ~4-12 inches (Maoz et al., 2019).
- 8x 5” diameter manifolds, max. 17-foot long

- 4x intake pipes
    - Intake pipes should reach the peak of the greenhouse to maximise hot air intake, and can be made out of PVC or HDPE drain pipe
    - The material of the intake and exhaust pipes have little impact on the efficiency.
    - As discussed further in our chapter, we have recommended two climate batteries, each with two layers that function independently from one another; each layer requires an intake fan, exhaust pipe and fan.
- 4x exhaust pipes
    - These should reach plant level inside the greenhouse to distribute air close to the plants.
- 4x thermostats
    - One for heating, one for cooling
- 4x 200” 1/3HP HAF fans, capable of pushing 5,000+ CFM
    - Fans for each climate battery layer.
- Rigid foam board, either polystyrene or polyiso
    - Insulate the perimeter of the climate battery.
- Expanded sheet metal and insulating material (like rigid foam board or polystyrene pellets)
    - For the divider between the two climate batteries
- Miscellaneous hardware for joining pipes at each end of the climate battery

5.6.3 Installation of the climate battery

Here we outline some of the steps necessary for installing the climate battery and reasonings behind some of the methods necessary. To begin installation of the climate battery, the ground must be excavated to the appropriate depth, around 4’, using a skid steer or hydraulic excavator. One thing to be aware of is the water table depth at your greenhouse location, and ensure the climate battery sits above this to not flood the system (Schiller & Plinke, 2016, p.200). Once the ground is excavated, the pipes should be laid out with enough space between each pipe to maximise heat exchange with the soil; 2’ spacing is optimal with the 4” pipes in our materials list to promote the greatest thermal interaction (Schiller & Plinke, 2016, p.200, Peretti et al., 2013). For maximised heat exchange, the soil radius around the pipe should be at least double that of the pipe radius (Maoz et al., 2019).

The length of the pipes is also a major consideration, and is one of the more valuable parameters affecting heat transfer. At a certain pipe length, the thermal capacity of the pipes plateaus, therefore, there is no benefit for increasing the pipe length above 60m (Figure, 9; Maoz et al, 2019). This is not a particular consideration for our climate battery as we have two systems each of just under 30’ (9.14m), but would be for larger greenhouses. Figure 5.10 shows the impact of the length of the pipes on temperature drop, which is the difference in the temperature of the air from the intake pipe to the exhaust pipe; it shows that the shorter the pipes, the smaller the drop in temperature between the intake and exhaust pipes, with a plateau around 60m. While a longer pipe system may be beneficial for cooling of the greenhouse, it would significantly impact the heating capacity of the climate battery (Maoz et al., 2019). Furthermore, it is also important to note the equal length of the parallel pipes, as shorter pipes have lower resistance, therefore, air is more likely to travel the shorter path. This can have a negative impact on the even distribution of air through the pipe system, which in turn will reduce the efficiency of the climate battery.

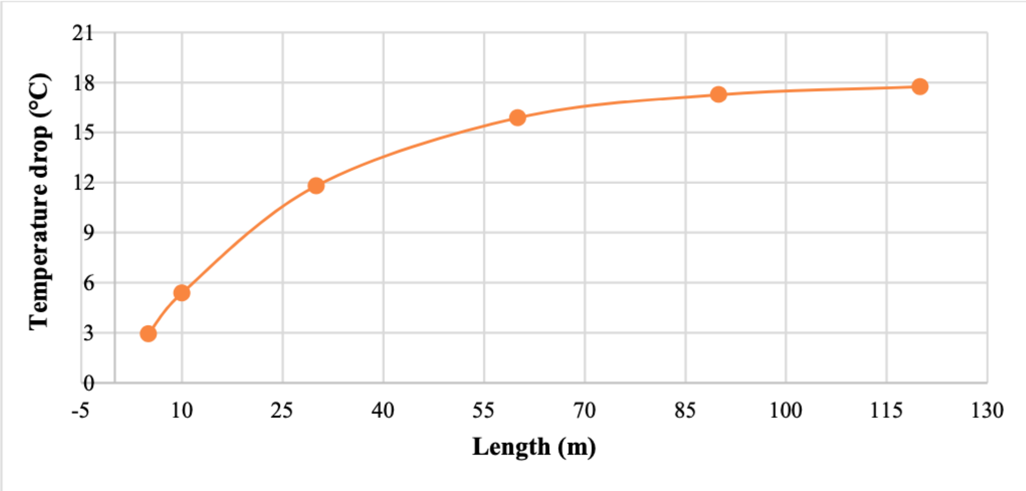


Figure 5.10. Pipe length impact on temperature drop (Maoz et al., 2019)

A multi-layer climate battery is recommended, with enough soil surrounding each layer to again maximise heat exchange with the soil (Schiller & Plinke, 2016, pp. 200-201). There are multiple ways to utilise these layered pipes. They can be operated separately with individual fans and intake/exhaust pipes which can be a less expensive option as you do not have to source larger, more expensive pipes (Schiller & Plinke, 2016, p.202), but must consider the cost of double the number of fans and intake/exhaust pipes. Alternatively, the longitudinal drain pipes could all be connected to larger end pipes to create a single system in which both of the layers are connected. Once each layer is laid, backfill the removed soil, making sure nothing is crushing the pipes in the process and that there is even distribution of the soil (Schiller & Plinke, 2016, p.203). Finally, when the last layer has been covered, the soil should be allowed to settle, or can be manually compacted to the desired grade using a compactor (Schiller & Plinke, 2016, p. 205). The compaction or settling of the soil should be carefully considered as Hip Peas Farm manager, Dan Birnstihl noted that if this is not done properly, there may be further complications of instability when building the greenhouse (D. Birnstihl, personal communication, 11 May 2021).

Once the greenhouse has been built, the intake pipes and fans should be installed. The intake pipes should reach the peak of the greenhouse (Schiller & Plinke, 2016, p.205). Inline fans can be installed into the intake pipes so that air can be pushed through (Schiller & Plinke, 2016, p. 205). For the exhaust pipes, these should reach about plant level in order to distribute the air most effectively to the plants (Schiller & Plinke, 2016, p. 205). Finally, the two thermostats should be installed to control for heat and for cooling. These automatic thermostats should be set to turn the fans on when needed i.e. if the greenhouse is too hot, or too cold, as to not put too much pressure on the system when it is unnecessary. As previously mentioned, to aid the system on extremely cold nights, a backup heater should be installed. Similarly, to aid cooling, a form of ventilation should be considered such as peak or end wall ventilation in the greenhouse structure. Cooling effects could be amplified by misting systems to cool the greenhouse through plant evapotranspiration.

5.7 Design Recommendations

We have suggested two design options that balance stakeholder needs, legal and financial limitations, with incorporation of the research outlined in the section above. Briefly, our first design option is a renovation on the existing footprint with a new steel frame, and our second design is a bigger greenhouse on a completely different footprint (outlined in Design option section below).

For the first design, we have opted for a renovation on the same footprint over a relocation of the greenhouse due to a range of factors. Firstly, a legal setback of 50’ from Lyme Road would cause zoning issues with relocating the greenhouse to a location where the greenhouse can feasibly be south facing. The Infrastructure chapter of this report elaborates on relevant zoning limitations. Next, for sustainability and cost reduction, we have opted to keep the concrete perimeter foundation as the embedded carbon is significant. We estimate it to be 7.8 tons of CO_2, calculated by multiplying the volume of the concrete in yards with the 400lbs of CO_2/yd emissions multiplier (Appendix A, Portland Cement Association, n.d.). Additionally, pouring a new foundation would add further costs to the project. In addition, we have opted to recommend a new above ground structure with a new frame and glazing. This is due to the age of the current frame and lack of efficiency of the panelling.

Our second design option would hopefully fuel a longer term project wherein a larger greenhouse could provide more space for all of the needs mentioned above. However, the Irving Grant we have for this project would likely not cover such a big project. Therefore, we highly recommend design option 1. Ultimately, we hope for a long term, efficient and low-emissions solution for the Dartmouth Big Green-Energy House.

5.7.1 Design Option 1: Renovation

Our first design option is the most cost-effective and material efficient, making use of the existing foundation and north wall. Reusing the concrete wall and foundation is significant because the embodied emissions for this material are particularly high. Since the structural assessment of our existing foundation had a positive outcome, we can likely use the aforementioned emissions that are embodied in the existing concrete for another 30 years, rather than incurring new emissions by pouring a new foundation. We decided to investigate two different renovation strategies in order to ensure feasibility: one uses a Rimol Greenhouse Systems Matterhorn greenhouse that will fit onto the existing foundation, the other uses a custom frame design and insulated panels to better respond to our geographical location. The Rimol modular renovation is the simplest and least-costly option. On the other hand our custom renovation better optimizes the angle of the glazing for our northern latitude and insulates more of the building. Both renovations introduce a climate battery to a maximum depth of 4’ as determined by the existing depth of the footers. We have estimated both renovation options to cost more than the $100,000 Irving grant budget in our rough estimates, but the Rimol renovation option is going to be less expensive at just under $300,000. The custom option with steel fabrication and engineering design fees is estimated at just under $475,000.

A Rimol renovation would entail replacing the existing aluminum frame with a new galvanized steel one of a very similar shape. The new frame would ensure further longevity of the greenhouse, and help enable much tighter glazing. We would have the option of triple polycarbonate glazing on the north pitch of the roof for extra insulation, and might have the option of introducing a night curtain for added nighttime insulation, or temporary insulation curtains on the end walls during the winter. Rimol’s Matterhorn Greenhouse comes in a 20’ width and 12’ modules, so will possibly fit on the existing footprint and foundation. The price for the greenhouse structure at that size is $50,000, and installation of that frame with glazing would cost between $25,000 and $40,000. Rimol is a good option because they’re based in Hooksett, NH, source all their steel inside the US, and come recommended by Hip Peas farm (D. Birnstihl, personal communication, 11 May 2021). They’re also somewhat rare in offering a 20’ width that fits our foundation, and have expressed a strong interest in working with us on this unorthodox installation.

A custom renovation means a new design and fabrication suited specifically to the existing greenhouse foundation and location. Our group used a basic architectural design process to come up with a specific recommendation. The first step in designing this option was to decide on the geometry of the new greenhouse frame. It was clear that we wanted to improve the insulation in the roof and the solar gains through the glazing, but we also needed to keep constraints in mind. The factors we considered included the solar elevation angle during colder months, avoiding a tall or high-volume building with higher heating demands, reasonable head height inside the greenhouse, and height of the existing north wall and milkhouse connection of 9'.

In order to understand the insolation, or solar energy received per surface area, we did a site analysis. To learn about available daylight during the winter months we considered the solar angle relative to the surrounding topography. The top of Oak Hill, a large terrain feature located directly to the south, is approximately 3,462ft from the greenhouse and around 420ft higher (Google). This means that the angle of the average slope between the greenhouse and the high point is ~9º.

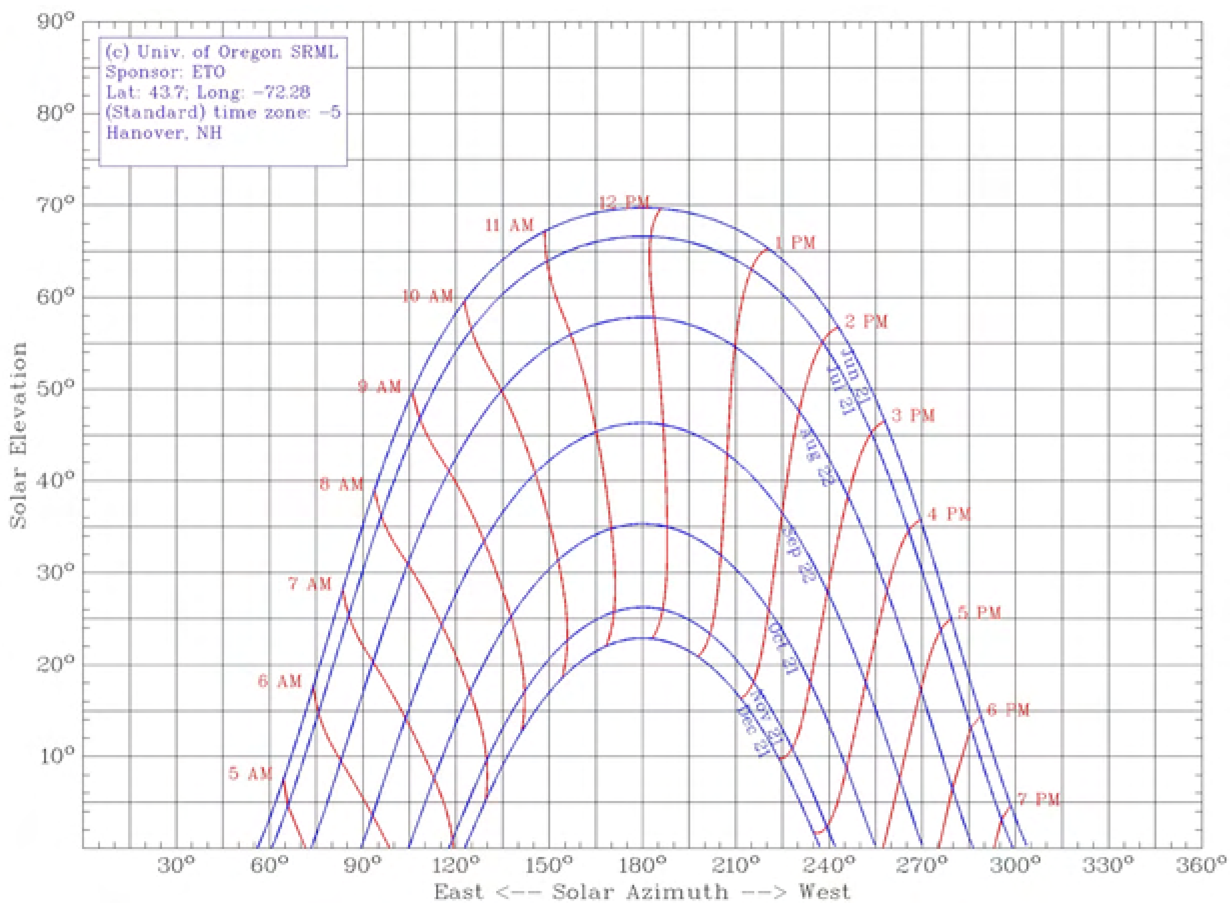


Figure 5.11. Solar Elevation chart for Hanover, NH. Source: University of Oregon Solar Radiation Monitoring Laboratory online calculator. (http://solardat.uoregon.edu/SunChartProgram.html)

Given a solar elevation angle of 23º on the winter solstice, the greenhouse will still receive some direct sunlight. The greenhouse will be directly lit from approximately 8:30AM to 3:00PM on December 21st when the solar angle is above 10º, as Figure 5.11 demonstrates. Since sunrise is at around 7am and sunset is around 4:00PM on December 21st, Oak Hill is not a very large barrier to insolation at the Organic Farm, resulting in 2.5

hours less direct sunlight on winter solstice. Calculating the height of Oak Hill helped us rule out any limitations to insolation at low solar elevations.

The greatest solar elevation on winter solstice occurs at 11:45am and is approximately 23º. In order to most efficiently capture light at midwinter, we would specify a sloping wall or roof angle of 68º, perfectly perpendicular to the angle of solar elevation. However, because solstice is only one day of the year, it's better to design for a more general winter sun elevation angle to maximize solar gain when the sun has more strength (Schiller and Plinke, 2016, p. 59). The average winter solar elevation between the equinoxes (September 22 to March 22) is closer to 30º, so in order to optimize solar gains we would theoretically specify an angle of 60º. Unfortunately, a roof with such a steep pitch is impractical to construct given the need for a vertical south wall of 6ft for reasonable head height, while keeping a reasonable building height.

The current greenhouse has a traditional gabled roof with a slope of 30º, which is not optimized for the climate in Hanover. Having a large uninsulated north side, the roof will be losing at least 46,137.6 BTU/hr on a -20ºF night, or 24,136.2 BTU/hr on a 10ºF winter day at expected research temperatures, while receiving almost no solar gain. The formulas for these calculations can be found in Appendix F, but consist of the surface area multiplied by the U value of the material, multiplied by the temperature difference from outdoors to indoors in degrees Fahrenheit. This quantifies the heat transfer from indoors to outdoors in BTU/hr. The importance of the U value in this calculation shows that by insulating more parts of the greenhouse we can reduce the heat loss. Shifting the peak to the north will also increase solar gain through the south pitch. U values and material properties are listed in Appendix G.

When using a translucent glazing material like 8mm double Polycarbonate panels or double-layered Ethylene Tetrafluoroethylene (ETFE) film, the solar angle of incidence matters less than when using transparent materials like glass. We decided to use a shallower roof angle because the additional south-facing roof area will be more helpful than an ideal angle of incidence. As long as the angle of incidence is less than 45º from perpendicular, the light transmittance for polycarbonate changes less than 7% (Schiller and Plinke, 2016, p. 59). Compared to glass these translucent materials distribute diffuse light more evenly throughout the greenhouse, have a more insulative R value, are lighter in weight, and are more cost-effective than glass. As noted in Appendix G, single pane glass has an R value of .9, twin wall polycarbonate glazing is closer to R=1.6, double layer ETFE is R=2, and a 8" thick wood-framed wall with fiberglass insulation has an R value of 20 [Appendix G]. Polycarbonate is easier to source and has the advantage of being a comfortable material for local contractors to work with, and is cheaper than ETFE. ETFE however, is a state of the art greenhouse glazing material and is becoming increasingly popular in greenhouse and architectural design. This will make it easier to source over time. It has a better R-value than polycarbonate, lasts longer without UV degradation, is fully recyclable, and is better self-cleaning, so is an attractive option. Snow load might seem like a potential problem for a film material like ETFE, but it's been demonstrated to hold up to 130lb per square foot at a car park in Munich, Germany (Plastic News). ETFE also allows 85%-90% light transmission, which is better than twin wall polycarbonate's 80%-85% [Appendix G]. Material properties and longevity are addressed in more depth in Appendix G.

Given the translucent material, we initially chose a roof angle of 40º, with a 20º angle of incidence, and 7ft of head height on the south wall (Figure 5.12). This allowed us to insulate 34% of the roof, reducing heat loss by an estimated 2,248 BTU/hr. The roof geometry would have an offset peak, giving a first impression of being thoughtfully designed, obviously visible on the side of Route 10.

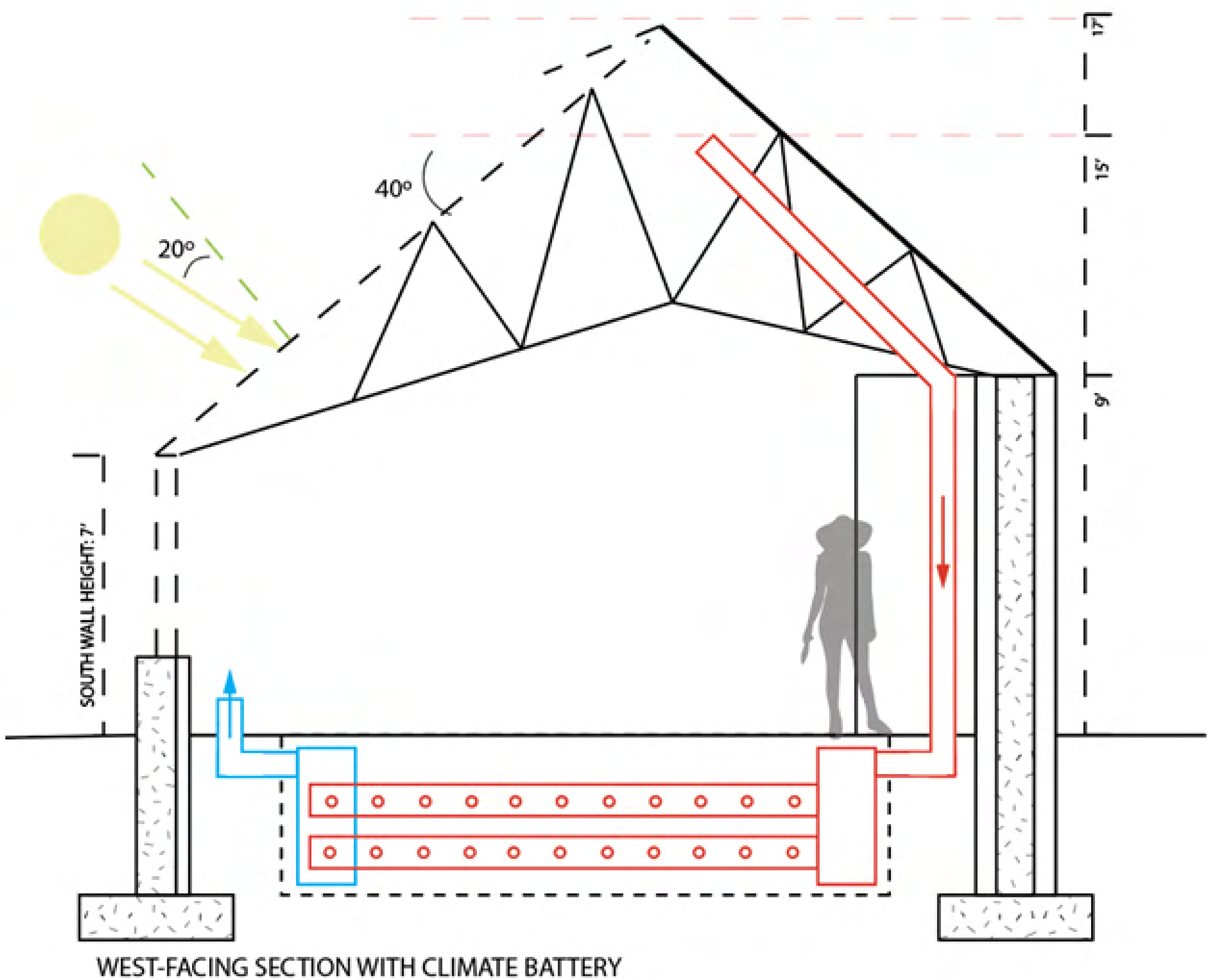


Figure 5.12. West-facing section drawing illustrating roof angles, wall heights, and climate battery depth.

However, as our design process progressed, we began to see how expensive and impractical a custom offset roof could be. With a normal prefabricated gabled roof structure we can expect to spend $50,000 on the steel and glazing alone, and a custom one could likely cost twice as much (T. McNamara, Personal Communication, 20 May 2021). We explored the option of using a Ceres greenhouse with an offset roof on our footprint, but none of their prefabricated designs come in a 20 foot width. Communication with Ceres is ongoing at the time of this report, their custom options may be a possibility. Ceres custom greenhouses are designed in a shed roof configuration, not offset peak like their modular options (J. Jorgensen, personal communication, 1 June 2021). We recommend following up with Ceres as it might be cost effective to use them as a vendor for a shed roof option.

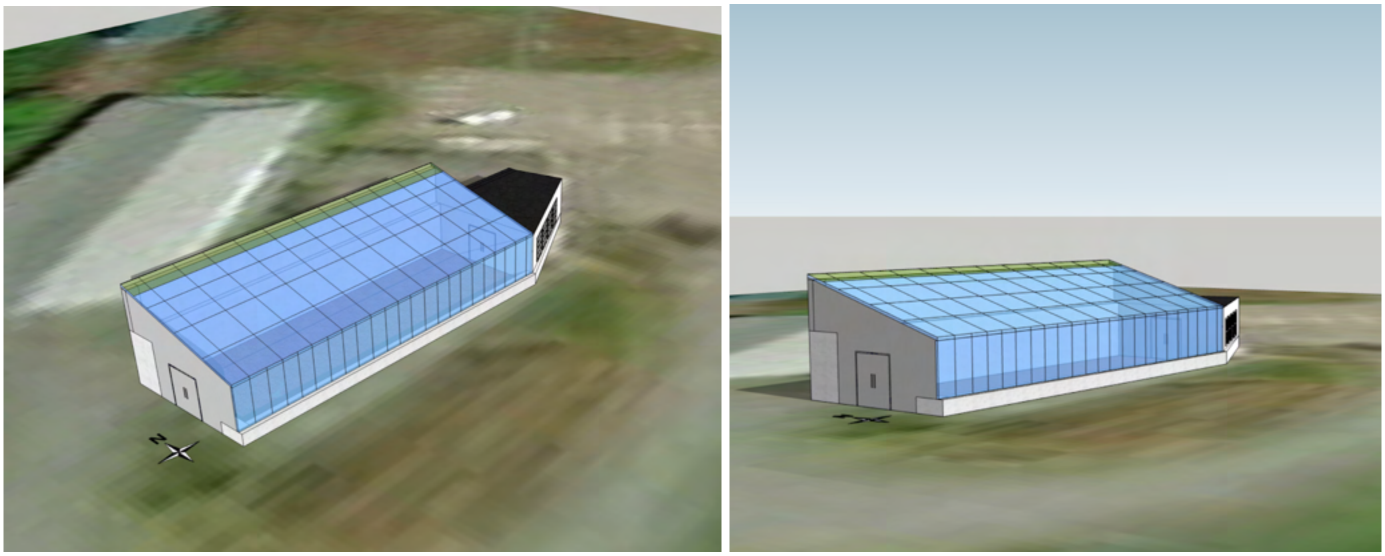


Figure 5.13. 3D image of the shed roof option with the milkhouse connector included.

A shed roof is one with a single sloping pitch from a taller wall to a shorter wall, pictured in Figure 5.13. This has the obvious advantage of capturing more light from the south, greatly simplifies the steel trusses and engineering involved in a custom structure, and allows us to insulate all north-facing parts of the structure more easily. An insulated vertical wall would be added atop the existing concrete north wall. We are recommending stick-frame construction for the north wall extension as it is lightweight, inexpensive, and can be designed to handle the weight of the roof, snow load, and anything suspended from the roof. This wall will also need to have a moisture-hardy cladding on both sides, as greenhouses are notoriously humid environments. As you can see in Figure 5.13, the roof angle is fairly shallow at 16.5º. However, as discussed earlier, the angle of incidence needs only be within 45º of the solar elevation when using translucent glazing materials in order to effectively capture 93% of the maximum insolation (Schiller and Plinke, 2016, p. 59). A taller north wall would give a steeper roof angle and more insolation, and originally we had designed a 21' north wall with a 30º roof pitch, but discovered that the solar gain was likely not worth the tradeoff in heating requirements. The greater surface area on the roof would increase heat loss during cold nights, and the larger building volume would require more energy to heat.

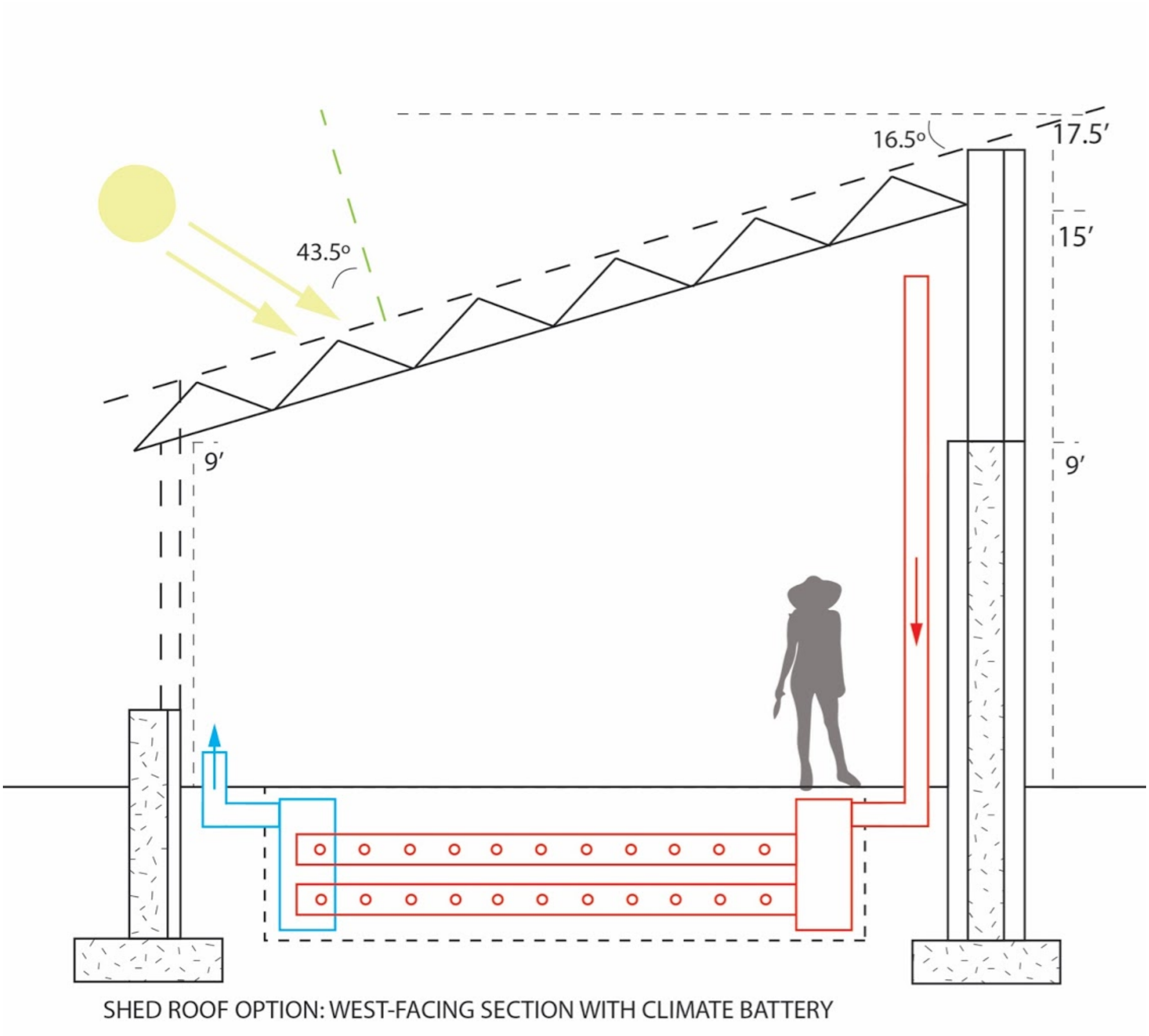


Figure 5.14. West-facing section illustrating shed-roof angle with climate battery.

The heat loss from a building can be estimated using heat transfer equations for each wall and the roof. Given our climate battery's use as a heat source we have decided to omit the heat transfer equation for the ground and use the heat loss to differentiate between the two renovation options. A building's heating efficiency relative to its size, is largely dependent on its volume to surface area ratio (Lim and Kim, 2018) A smaller building will require less energy to heat, and a building with relatively less surface area will also be more efficient than one with the same volume. This is because heat is lost on every surface in contact with the outdoors, and heat loss, or energy transfer, is a function of surface area.

The offset peak option has a total building volume of 14893.8 cubic feet, while the shed roof option has a total building volume of 16564.8 cubic feet. This is only a 1.2% difference, but they have different surface area to volume ratios: the offset peak is .217, while the shed roof is .209. This indicates that the shed roof is a more efficient shape, likely due to the reduced height of the structure, compared to the Offset Peak option Figure 5.14. The gable roof is actually an efficient shape to heat, the inefficiencies of the current greenhouse and the Rimol retrofit result largely from the cladding materials.

Table 5.1. Building Volume and Surface Area Data.

Option	Total Surface Area (Square Feet)	Total Volume (Cubic Feet)	Surface Area/Volume Ratio
Shed Roof	3465.76	16,564.8	.209
Offset Peak Roof	3242.06	14893.8	.217
Gable Roof	2959.2	14400	.206

Building materials and their U value or heat transfer resistance value are the more important questions when considering heat loss from a building. The U values for each material can be found in Appendix G. Heat loss calculations require the surface area for each material, the U value, and the temperature difference between indoors and outdoors. These formulas can be found in Appendix 5.1, note that roof calculations include an additional multiplier to account for the earth's radiation to space. Using the surface area information from Table 5.1 and the material U value of each area, each area's heat loss is calculated separately then aggregated to estimate the heat loss from the entire building on a cold winter night (Table 5.1). 10.1ºF is the average low temperature in January in Hanover, NH, and we decided to use it because we thought it representative of a consistent cold snap (data.org, n.d.). Consistent cold weather will challenge the design the most, and differentiate best between two designs. -20ºF is some of the coldest weather Hanover experiences, so the final calculation is intended to demonstrate the maximum energy requirement to avoid freezing. The glazing material used was twin wall polycarbonate, with a U value of .6. This material is easy to source and cost effective, so we used it in calculations because we thought it was the most likely to be implemented.

Table 5.2. Surface Area Value Table for Shed Roof and Rimol Retrofit options.

Option	Roof Surface Area (SF)	South Wall Surface Area (SF)	North Wall Surface Area (Existing) (SF)	North Wall Surface Area (New) (SF)	Insulated Panel End Wall Surface Area (SF)	Polycarbonate End Wall Surface Area (SF)
Material	Twinwall Polycarb-onate	Twinwall Polycarb-onate	Concrete in Insulated Foam Forms	8" Depth Stick Frame with Insulation	Insulated Metal Panel	Polycarbonate

Shed Roof	1281.6	636	540	456	522.16	0
Rimol Gable Roof	1399.2	540	540	0	0	480

Table 5.3. Heat Loss Value Table for Shed Roof and Rimol Retrofit Options.

Option	Rate of Heat Loss at 10.1ºF, 40ºF Interior (BTU/hr)	Heating Requirement for 24h at 10.1ºF (BTU)	Rate of Energy Use for Electric Heat at 10.1ºF (kWh)	Rate of Heat Loss at -20ºF, 32ºF Interior (BTU/hr)
Shed Roof	35,800.4	859,210.5	10.49	62,054.10
Rimol Gable Roof	43,273.8	1,038,571.2	12.68	75,007.92

Ultimately, regardless of how tight and insulated the envelope is, the most important design features of either renovation option will be inside. Using the climate battery we will help offset heating and cooling energy use inside the greenhouse. Because we are designing for a climate battery experiment per the Irving Grant proposal, we kept in mind that we need to be able to separate climate battery experimental and control sides of the greenhouse

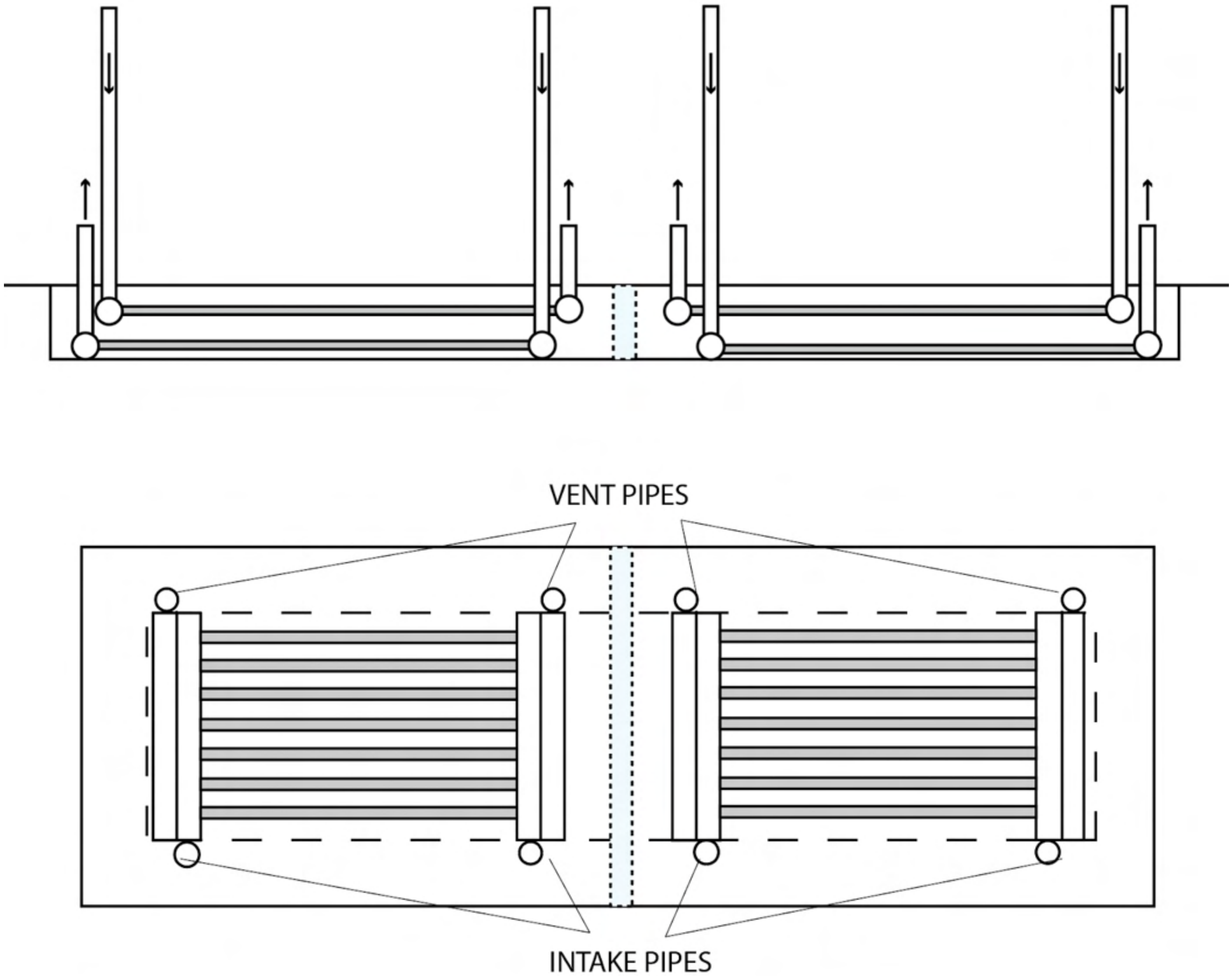


Figure 5.15. South Facing Elevation View and Plan View of the climate batteries with divider.

Figure 5.15 demonstrates how we have divided the area into two halves and plan to install flexible dividers to keep each half of the airspace thermally separate. These dividers could see future use as a way to keep insect experiments isolated during its use as a research greenhouse. One option is to attach double sheets of polyethylene film, reaching up to the roof peak during the one year experiment. Because the air temperature on both sides of the experiment is supposed to be similar, this shouldn't cause too much heat transfer. Underground we plan to use two expanded metal sheets, a permeable and durable option to bury as a divider between the two climate batteries. Polystyrene insulation pellets or rigid board insulation can fill the gap between metal sheets during the one-year experimental period, and then should be replaced with gravel or soil when we no longer need the two halves thermally separated. It's important to be able to rejoin the two halves of the sub-grade thermal mass because a climate battery is more efficient when it's larger.

We chose to use two independent layers of piping in each battery so that we can pipe heat in opposing directions. This will help avoid hot and cool areas on the greenhouse floor. It will also double the number of fans we use, increasing the air exchanges per hour and increasing the climate battery efficiency. It is important to note that we have not recommended insulating the north, west, and south sides of the climate battery excavation because of the heavily insulated concrete foundation. We do however recommend 2" foam board insulation along the east side of the excavation to prevent heat loss to the milkhouse foundation.

We have laid out a flexible floor plan that works with either renovation option, keeping in mind requirements from the climate battery experiment, research space, organic farm needs, and ADA accessibility, shown in Figure 5.16. Professor Ong and Professor Hicks-Preis each asked to have one or two benches, and pointed out the need for a potting bench for common use. We chose bench dimensions of 4'x8', as this is an industry standard. Professor Hicks-Pries also pointed out that floor space is required for the autochambers for CO_2 measurement during the climate battery experiment. There will be space for four autochambers in 3'x3' areas on the soil floor. Molly McBride and Laura Braasch at the Organic Farm mentioned that half of the greenhouse space was enough for their needs, so after the climate battery experiment we've planned for them using half of the greenhouse with some in-floor planting and some on benches.

ADA requirements that we were sure to meet include 6' of floor space inside each door, and a wide aisle for access. Floor surface requirements are unclear for greenhouses in ADA guidelines, but in the interest of keeping the soil usable we suggest using a grated system laid on top of the soil. Tuf-Tite Grate, a durable plastic grate with openings of ½" is ADA compliant, for example. Compacted D1 gravel might be another option, it is considered ADA compliant for nature paths for example, but would make reclamation of the underlying soil difficult if the use of space changed in the future. This is an area where we recommend further research, as cost will play a role making this decision.

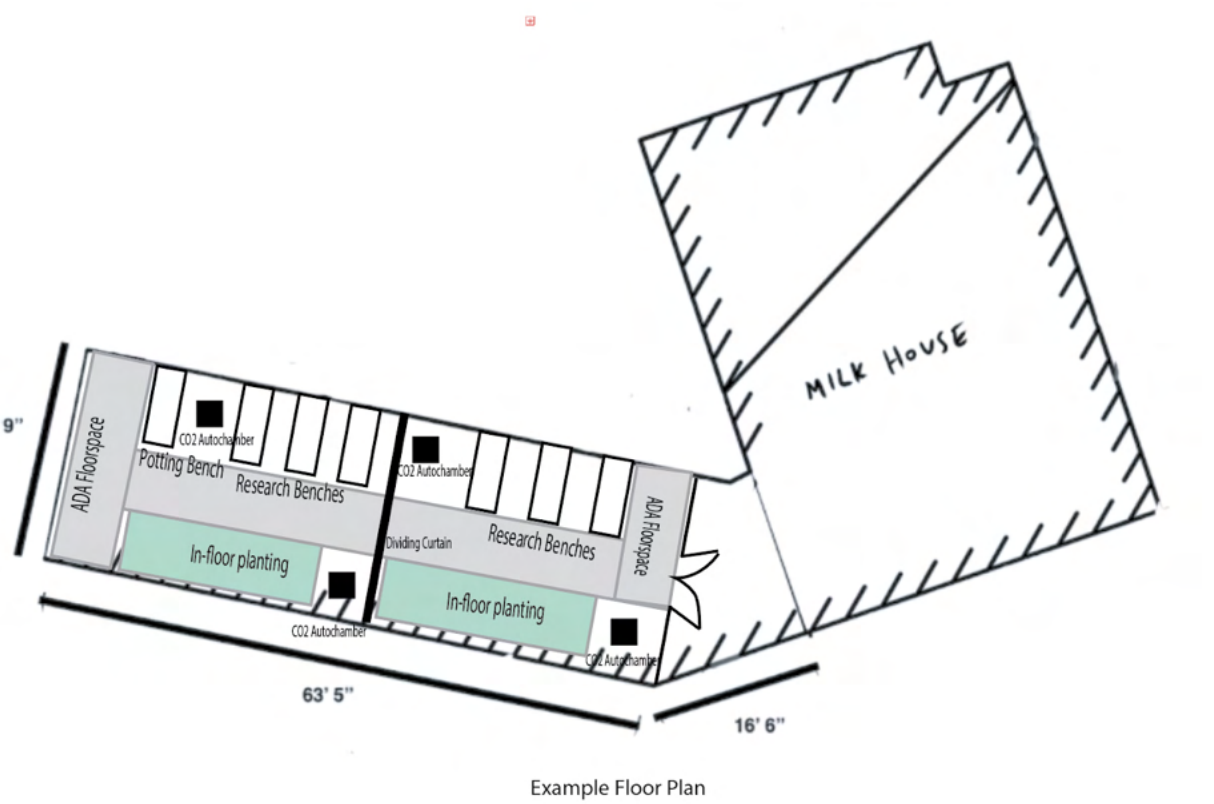


Figure 5.16. Example Floor Plan.

The materials required for this project include galvanized trusses and structure, polycarbonate or ETFE glazing, attachment hardware, intake and exhaust piping, fans, manifolds and underground pipes, fine gravel, thermostats, vent motors and thermostats, vent fans, insulation pellets, expanded metal sheets, and miscellaneous hardware. It seems unlikely that we will find any of these materials for reuse, and have been discouraged in this pursuit by building code admonitions against it. A conversation with FO&M Associate Director Tim McNamara, a likely project manager for any greenhouse renovation in the future, made reuse sound like an unlikely prospect because of uncertainties about whether it would be allowable (T. McNamara, personal communication, 27 April 2021). In our estimation, expanded metal and insulation pellets for below-grade use are the most likely for us to be able to find as surplus at Dartmouth and implement because we need so little of them and temporary below-grade use is less limited by building codes.

Because we will not be reusing the existing aluminum frame due to glazing inefficiencies, thermal bridging problems, and longevity, demolition will be the first order of business in construction. Removing and disposing of the frame, the polycarbonate panels, and the tanks and hydronic tubing inside will cost time and disposal fees. Digging the hole for the climate battery will likely be done with an excavator and take one person only one day, but installing the climate battery will require more labor and at least one day of work. Our estimate is that this whole project will take a contractor a month or more to complete because of timing with demolition, gravel delivery, steel frame delivery.

Our timeline in this class was to have a well-developed design ready for feedback at our final presentations. We were also ready to share it in a design charrette or other community event, and have productive conversations with members of the wider farm community. The timeline for construction is very uncertain right now. There is a chance that building materials may be backordered due to high demand, and prices may have increased as we reemerge from the pandemic. In order to learn more about this situation we reached out to greenhouse suppliers and learned from Rimol Greenhouse Systems' Mike Bisogno that they increased their prices in January, March, and will likely have to do so again in July (M. Bisogno, personal communication, 16 May 2021). They've also had to diversify their fabricators, and their lead times are now up to three months instead of a few weeks. These changes have all been made because of the pandemic-caused issues in the supply chain. It is our recommendation that either we move quickly to make this greenhouse plan happen before prices change more, or wait until the worst of these price inflations pass. As mentioned in the Infrastructure chapter, timing with the Irving grant and additional funding also ought to be considered.

Our cost estimates can be found in Tables 5.4 and 5.5. One of our largest obstacles has been learning how to make useful cost estimates, as there is a large amount of uncertainty in this stage of the design and in the construction market today. Our conversations with Tim McNamara helped us understand how to best go about it, and we've used a bottom-up approach with a cost breakdown structure (Elmousalami, 2020). A cost breakdown estimate is based on material costs plus rough estimates of contractor fees. Design-stage cost estimates like this are usually within 20% of the final cost, but design team experience is a limiting factor so we estimate this figure to have 25% accuracy (Liu and Zhu, 2007). Table 5.4 shows the cost estimate for the Rimol renovation option which totals just under $300,000. This figure is contingent on the $50,000 cost for frame and glazing, as well as the 75% installation cost mentioned by Mike Bisogno of Rimol, which are extremely rough estimates (M. Bisogno, Personal Communication, 16 May 2021). Bisogno expressed interest in a site visit with a contractor in order to produce a more accurate quote. Table 5.5 shows the custom shed roof cost estimate: custom steel fabrication and additional structural engineering design fees make this option much more expensive at just under $475,000. The custom design cost estimate is likely less accurate than the Rimol because we were unable to get a quote response from a custom fabricator. After speaking with Tim McNamara we simply doubled the estimated cost for the Rimol frame and glazing, reflecting the additional cost of fabrication.

Table 5.4. Itemized Cost Estimate for Rimol Renovation Option.

Item	Quantity	Price	Total Cost
Climate Battery:			
Fans	4	$210.00	$840.00
4" ADS tubing	20	$97.98	$1,959.60
Manifold and Intake Tubing	12	$309.00	$3,708.00
Risers	1	$399.00	$399.00
Excavation	1	$15,000.00	$15,000.00
Hardware	estimate	$500	$500
Washed Rock	50 tons	$2,500	$2,500
Greenhouse Structure			
Demolition	1	$10,000	$10,000
Frame and glazing	1	$50,000	$50,000

Installation	75%	$37,500	$37,500
Mechanical			
Greenhouse climate controller	1	$1,500	$1,500
Vent motors	estimate	$4,000	$4,000
Irrigation/plumbing	estimate	$7,500	$7,500
LED Lighting	30	$900	$27,000
Electric Heaters	2	$1,000.00	$2,000.00
Circulation/vent fans	4	$700	$2,800
Mechanical Installation	estimate	$15,000.00	$15,000.00
Electrical Installation	estimate	$20,000.00	$20,000.00
Mechanical Engineering	estimate	$7,500	$7,500
Electrical Engineering	estimate	$7,500	$7,500
Freight			
	estimate	$10,000	$10,000
Contingency			
General Contingency	20%	$45,441.32	$45,441.32
Pandemic-Related Price Escalation	10%	$22,720.66	$22,720.66
Project Management			
Dartmouth Project Manager Fee	10%	$29,536.86	$29,536.86
Permitting			
Town Zoning and Building Permit		$1,782	$1,782
		Total=	$295,368.58

Table 5.5. Itemized Cost Estimate for the Shed Roof Custom Renovation Option.

Item	Quantity	Price	Total Cost
Climate Battery:			
Fans	4	$210.00	$840.00
4" ADS tubing	20	$97.98	$1,959.60
Manifold and Intake Tubing	12	$309.00	$3,708.00
Risers	1	$399.00	$399.00
Excavation	1	$15,000.00	$15,000.00
Hardware	estimate	$500	$500

Washed Rock	50 tons	$2,500	$2,500
Greenhouse Structure			
Demolition	1	$10,000	$10,000
Design	1	$15,000	$15,000
Frame and glazing	1	$100,000	$100,000
Installation	75%	$75,000	$75,000
Mechanical			
Greenhouse climate controller	1	$1,500	$1,500
Vent motors	estimate	$4,000	$4,000
Irrigation/plumbing	estimate	$7,500	$7,500
LED Lighting	30	$900	$27,000
Electric Heaters	2	$1,000.00	$2,000.00
Circulation/vent fans	4	$700	$2,800
Mechanical Installation	estimate	$15,000.00	$15,000.00
Electrical Installation	estimate	$20,000.00	$20,000.00
Mechanical Engineering	estimate	$7,500	$7,500
Electrical Engineering	estimate	$7,500	$7,500
Freight			
	estimate	$10,000	$10,000
Contingency			
General Contingency	20%	$65,941.32	$65,941.32
Pandemic-Related Price Escalation	10%	$32,970.66	$32,970.66
Project Management			
Dartmouth Project Manager Fee	10%	$42,861.86	
Permitting			
Town Zoning and Building Permit		$2,582	$2,582
		Total=	$471,480.44

5.72 Design Option 2: New Greenhouse Structure

Our second design option is to build an entirely new structure. While this option would be significantly more expensive, it is a longer term solution and would allow for the complete customization of the structure. While our overall project recommendation is to pursue the first option, renovating the structure, we hope that constructing a new structure in a new location will be an option considered in future years. Outlined below are some of the key considerations in regards to the benefits and drawbacks of this option.

The major benefit of this option is that the Organic Farm would have a brand new, top of the line greenhouse and climate battery. The greenhouse would be an entirely new system, have modern technology, and adhere to current zoning and building regulations. This new structure would be customizable in regards to all specifications. Higher end options like temperature/humidity control, irrigation, grow lights, etc. could easily be added to the new design. Double doors could be added to both sides, new glazing would increase efficiency, and customization would allow the tailoring of the structure to the specific needs of Dartmouth Organic Farm staff and Dartmouth faculty. Our group also discussed the possibility of increasing the greenhouse to a 30’x100’ footprint, increasing the planting space by 2.5x. The new greenhouse would likely have a significantly longer lifespan than renovating the existing greenhouse. A top-of-the-line greenhouse of this size would completely change the output capabilities of the organic farm.

This design option does, however, have drawbacks which we have outlined below. The major downside to this option is that the structure could not be built on the current site of the greenhouse. This new, larger structure would have to be moved farther away from the road to adhere to zoning laws. Our team identified two new potential locations for this new structure. The first location would be on top of the current hoop house footprint (in orange Figure 5.17) , and the second location (in yellow Figure 5.17) would be a location behind the current barn. The hoophouse option would require the removal of the hoophouse, a crucial farming structure with a recent $5,000 renovation. The footprint of the hoophouse is also not south-facing, meaning we would need to rotate the footprint or accept the lower efficiency of the current footprint angle. The second location option is definitely viable, but the location is further away from the center of the Organic Farm and would require more time and effort to access. For the entire lifetime of the greenhouse, organic farm staff would have to exert more energy to use this structure. Another key consideration is the sustainability of the project. Building a completely new structure would likely have significantly more environmental impact than renovating. Importantly, this option would also likely cost much more than option 1 - pricing will be outlined below.

Figure 5.17. Map of Dartmouth Organic Farm from: "Hanover, New Hampshire." Map, Google Maps. Accessed 18 May. 2021.

Within this second design option, our group decided to find a greenhouse design group to discuss possibilities for how to design, source, and construct the new greenhouse. We found Ceres Greenhouse Solutions, the owners of the GAHT system, to be a great option for a greenhouse design firm to work with. Through communicating with Ceres we identified the Commercial Designs HighYield ™ Kit as the best option. The 30x option has a base width of 30' and allows for customization of length, peak height, and south wall height. Wind and snow load calculations are important to consider in choosing these dimensions. Ceres has constructed many greenhouses across NH and VT, proving that their greenhouses are a strong option in our climates.

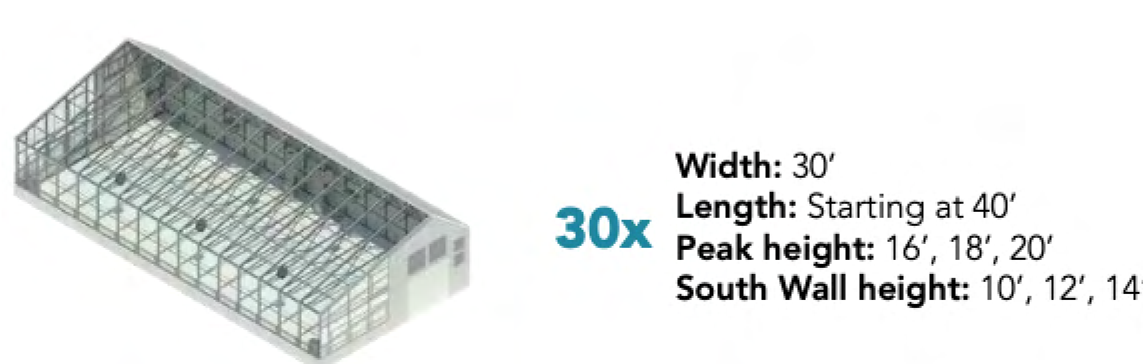


Figure 5.18. HighYield ™ Greenhouse Kits. Ceres Greenhouse. https://ceresgs.com/greenhouses/highyield-kits/.

This option is the HighYield ™ base model -- we would need to upgrade to a Vented System to gain access to Ceres GAHT technology.

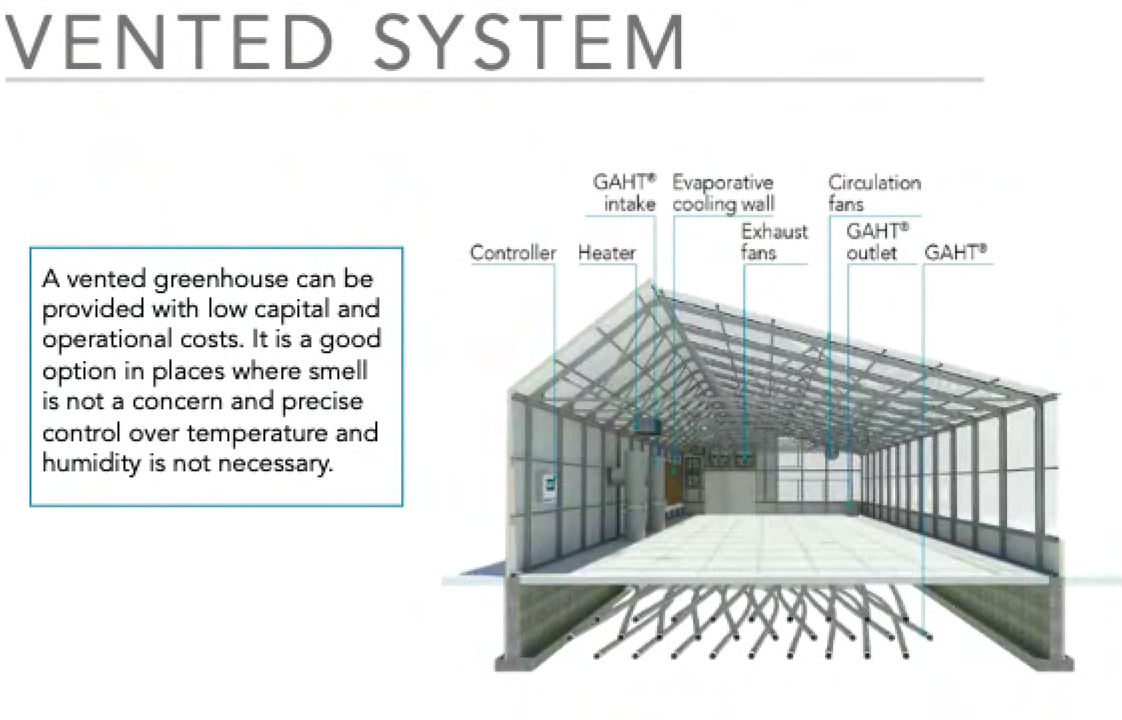


Figure 5.19. HighYield ™ Greenhouse Kits. Ceres Greenhouse. https://ceresgs.com/greenhouses/highyield-kits/.

Understandably, pricing between the base and vented structure vary greatly. For a 3,000 square foot modular greenhouse, Ceres estimates a cost of $35-$45/sqft. This includes the base material kit, steel frame, insulated metal panels, and glazing. Total design and materials cost of this structure would be $105,000 - $135,000. Importantly, these costs do not include construction and labour costs. These costs can vary greatly by geographic location and require further calculation. Estimates for construction labor and for a greenhouse contractor would likely be similar to our design option 1 and are outlined in the table below.

Table 5.6. Itemized Cost Estimate for Ceres HighYield ™ Base Model.

Ceres HighYield ™ base model	
Greenhouse Structure	
HighYield Base Model	$135,000
Installation	$101,250
Contingency	
General Contingency	$47,250.00

Pandemic-Related Price Escalation	$23,625.00
Project Management	
Dartmouth Project Manager Fee	$30,712.50
Permitting	
Town Zoning and Building Permit	$1,943
Total	$307,125.00

For a 3,000 square foot complete vented greenhouse, Ceres estimates a cost of $85-$120/sqft. This price includes the complete structure discussed above, as well as evaporative cooling, GAHT®, heaters, dehumidifiers, SunSense™ controller, LED grow lights, irrigation, fertigation, complete engineering, and construction documentation. Total design and materials cost of this structure would be $255,000 - $360,000. Total cost has been estimated below using the same estimates for construction, contingency, and other fees.

Table 5.7. Itemized Cost Estimate for Ceres HighYield ™ Vented Upgrade Model.

Ceres HighYield ™ Vented Upgrade	
Greenhouse Structure	
HighYield Base Model	$360,000
Installation	$101,250
Contingency	
General Contingency	$92,250.00
Pandemic-Related Price Escalation	$46,125.00
Project Management	
Dartmouth Project Manager Fee	$59,962.50
Permitting	
Town Zoning and Building Permit	$3,698
Total	$599,625.00

While we understand that pursuing these options may not be realistic in the short term, we do hope that the Ceres models discussed above will be considered in the future development of the Organic Farm. Constructing a greenhouse like the HighYield ™ Vented System would completely change the capabilities of the Organic Farm.

5.8 Recommendations for future research

Our final recommendations come in the form of places for future research. Firstly, we recommend speaking at length with Hip Peas Farm, a farm located close to the O Farm. Collaborating with farms that have already implemented climate batteries in the local area may help the refinement of the O farm climate battery design. Secondly, we recommend researching a night curtain option for roof insulation. This will help with the insulation of the greenhouse, preventing heat loss at night (particularly in the winter). However, the greenhouse structure chosen will determine whether this will be possible, as our team had concerns whether the night curtain would impact the temperature of the air coming in through the intake pipe at the peak of a greenhouse with a gable roof geometry. Thirdly, as multidisciplinary environmental studies students we were unable to explore the option of modelling the energy dynamics of a climate battery system this term, since we focused more broadly in our investigation. Modelling would be an excellent opportunity to learn about the potential contribution to heating and cooling. Academic investigations like the modelling paper of a similar greenhouse by Ghosal et al. provide a thorough description of calculations and modelling required to investigate this further using tools like MatLab (2004). Finally, the greenhouse committee may consider partnerships with other faculty members, such as Professor Vitor Vasconcelos for future modelling of the climate battery system in the short and long term future.

5.9 Conclusion

To design a sustainable, climate-battery-powered 4-season greenhouse providing a lighthouse model for local farmers and a productive site for academic endeavors, our design's conception considered a wide array of stakeholder needs in tandem with budgetary constraints. Situated in the Upper Valley of New Hampshire, our greenhouse design options incorporate features and materials specific to the region's characteristically substantial seasonal temperature variation and weather change. In addition to considering the greenhouse's energy needs, our design reflects consideration for the spatial academic research and teaching opportunities, a rigorous enquiry into the spatial features necessary to support academic research and teaching. Informed by stakeholder needs and constrained by legal and financial parameters, our team presents two design options. The first and preferable option is a renovation of the current greenhouse on the existing footprint with a new steel frame. The second option is an entirely new structure with a larger frame. Although a renovation of the current greenhouse procures some cost-efficiency and material-efficiency, its expense is still considerable, at an estimated cost of $295,369.

5.10 References

Aldawi, F., Alam, F. (2015). Residential Building Wall Systems: Energy Efficiency and Carbon Footprint. In Hassan, N. M. S. Editor & Khan, M. M. K. Editor. *Thermodynamic Modelling in Energy Efficiency Applications (pp. 167 - 196).* Academic Press.

Akhtar, S., Reza, B., Hewage, K., Shahriar, A., Zargar, A., & Sadiq, R. (2015). Life cycle sustainability assessment (LCSA) for selection of sewer pipe materials. Clean Technologies and Environmental Policy, 17(4), 973–992. doi.org/10.1007/s10098-014-0849-x

Asif, M., Muneer, T., & Kubie, J. (2005). Sustainability analysis of window frames.*Building Services Engineering Research & Technology, 26*(1), 71-87. doi:http://dx.doi.org.dartmouth.idm.oclc.org/10.1191/0143624405bt118tn

Bisogno, Mike. Rimol Greenhouse Solutions Sales Associate. Personal Interview May 16 2021

"Hanover." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., www.britannica.com/place/Hanover-New-Hampshire.

Ceres Greenhouse Solutions. (n.d.). GAHT System: A Geothermal Option. Retrieved May 9, 2021, from https://ceresgs.com/environmental-controls/gaht/#

Clear 8mm Triple Wall THERMOCLEAR™ 15 Polycarbonate Panel. (2021, April 26). Retrieved from https://www.duralightplastics.com/8mm-triple-wall-thermoclear-15-with-uv-clear.html

Climate Battery Greenhouse. Threefold Farm. (n.d.). https://threefold.farm/climate-battery-greenhouse.

Climate Battery Calculator. eco systems design, inc. (n.d.). http://www.ecosystems-design.com/climate-battery-calculator.html.

Data.org. Climate. (n.d.). https://en.climate-data.org/north-america/united-states-of-america/new-hampshire/hanover-25696/#climate-table.

Ekrami, N., Garat, A., & Fung, A. S. (2015). Thermal Analysis of Insulated Concrete Form (ICF) Walls. *Energy Procedia*, *75*, 2150–2156. https://doi.org/10.1016/j.egypro.2015.07.353

Elmousaslami, H. H. (2020) Artificial Intelligence and Parametric Construction Cost Estimate Modeling: State-of-the-Art Review. *Journal of Construction Engineering and Management*. 146(1): 03119008

ETFE Cushion. (2016, July 07). Retrieved from https://www.architen.com/products/etfe-cushions/

ETW: Wall - 2x6 Advanced Frame Wall Construction. (2014, November 15). Retrieved from https://www.buildingscience.com/documents/enclosures-that-work/high-r-value-wall-assemblies/advanced-frame-wall-construction

Evans, M. (n.d.). Unit 03: Glazing. https://greenhouse.hosted.uark.edu/Unit03/Printer_Friendly.html.

FARM: Dartmouth Sustainability. (n.d.). Retrieved from https://www.sustainability.dartmouth.edu/organic-farm

Ghosal, M. K., Tiwari, G. N., & Srivastava, N. S. L. (2004). Thermal modeling of a greenhouse with an integrated earth to air heat exchanger: an experimental validation. *Energy and Buildings*, *36*(3), 219–227. https://doi.org/10.1016/j.enbuild.2003.10.006

Google. (n.d.) [Elevation data of Oak Hill and the Dartmouth Organic Farm in Hanover, NH] Retrieved May 15, 2021, from https://goo.gl/maps/gVxgodGcFpdefRCN6.

Greenhouse Covering Insulation Comparison. The Greenhouse Catalog. (n.d.). https://www.greenhousecatalog.com/greenhouse-insulation.

Greenhouse Glazing System. (2021, February 19). Retrieved from https://www.bcgreenhouses.com/greenhouse-buying-tips/glazing-systems/

Hamburg, S. P., Vadeboncoeur, M. A., Richardson, A. D., & Bailey, A. S. (2012). Climate change at the ecosystem scale: a 50-year record in New Hampshire. *Climatic Change*, *116*(3-4), 457–477. doi.org/10.1007/s10584-012-0517-2

HighYield ™ Greenhouse Kits. Ceres Greenhouse. (n.d.). https://ceresgs.com/greenhouses/highyield-kits/.

Inc, Building Media. “Architecture Extraordinaire: A Primer on Fabric Structures.” *CE Center* -, continuingeducation.bnpmedia.com/article_print.php?L=407&C=1238#:~:text=ETFE pricing can average between $125 and $185 per square foot.

INGAL Specifiers Manual, Australian Steel Institute.

J&D 20 Inch Green Breeze HAF Fan With Cord VBG20 1/3 HP 3650 CFM. (n.d.). Retrieved from https://www.globalindustrial.com/p/20-green-breeze-with-cord

Kalayci, E., Yavas, A., & Avinc, O. (2016). Ethylene Tetrafluoroethylene (ETFE) Materials for Building Textiles. Retrieved from https://www.researchgate.net/publication/309410559_Ethylene_Tetrafluoroethylene_ETFE_Materials_for_Building_Textiles

Life-Cycle Assessment. (2021, June 02). Retrieved from https://galvanizeit.org/hot-dip-galvanized-steel-for-parking-structures/environmental-advantages/life-cycle-assessment

Liu, L., & Zhu, K. (2007). Improving Cost Estimates of Construction Projects Using Phased Cost Factors. *Journal of Construction Engineering and Management*, *133*(1), 91–95. doi.org/10.1061/(ASCE)0733-9364(2007)133:1(91)

Lim, H. S. & Kim, G. (2018). Analysis of Energy Performance on Envelope Ratio Exposed to the Outdoor. Advances in Civil Engineering. 2018. 1-10. 10.1155/2018/7483619.

Maraveas, C. (2019). Environmental Sustainability of Greenhouse Covering Materials. Sustainability (Basel, Switzerland), 11(21), 6129–. https://doi.org/10.3390/su11216129

Maoz, M., Ali, S., Muhammad, N., Amin, A., Sohaib, M., Basit, A., & Ahmad, T. (2019). Parametric Optimization of Earth to Air Heat Exchanger Using Response Surface Method. *Sustainability*, *11*(11), 3186. doi.org/10.3390/su11113186

Material Specifications - Metl-Span, Insulated Wall Panels, Roof Panels, Architectural Wall Pane, Insulated Foam Panels. (n.d.). Retrieved from

Mempouo, B., Cooper, E., & Riffat, S. (2010). Novel window technologies and the Code for Sustainable Homes in the UK. International Journal of Low Carbon Technologies, 5(4), 167–174. https://doi.org/10.1093/ijlct/ctq013

Miller, S. (2020). The role of cement service-life on the efficient use of resources. *Environmental Research Letters*, 15(2), 24004–. doi.org/10.1088/1748-9326/ab639d

Naik, T. (2008). Sustainability of Concrete Construction. Practice Periodical on Structural Design and Construction, 13(2), 98–103. https://doi.org/10.1061/(ASCE)1084-0680(2008)13:2(98)

New Hampshire, USA - Climate data and average monthly weather. Weather Atlas. (n.d.). https://www.weather-atlas.com/en/new-hampshire-usa-climate.

Ogden Publications, I. (n.d.). 3 Methods for Heating Greenhouses for Free. Mother Earth News. https://www.motherearthnews.com/homesteading-and-livestock/heating-greenhouses-for-free-zb0z1411zmat.

Opal 25mm 5 Wall X Structure THERMOCLEAR™ 15 Polycarbonate Panel with 2 Sided UV. (2021, February 12). Retrieved from https://www.duralightplastics.com/25mm-5-wall-x-structure-thermoclear-15-opal.html

Parvez, J. (2018). Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials. *Proceedings of the Water Environment Federation, 2018*(7), 5493-5518. doi:10.2175/193864718825138925

Peretti, C., Zarrella, A., De Carli, M., & Zecchin, R. (2013). The design and environmental evaluation of earth-to-air heat exchangers (EAHE). A literature review. *Renewable and Sustainable Energy Reviews*, *28*, 107–116. https://doi.org/10.1016/j.rser.2013.07.057

Plastics News. (N.D.) *ETFE Fluorothermoplastic roof supports 50 t of snow, and generates electricity.* Retrieved May 17, 2021 from https://www.plastics.gl/construction/etfe-fluorothermoplastic-roof-supports-50-t-of-snow-and-generates-electricity/.

Polashenski, C., Watcher, L. (2007). *Engineering Sciences 190, Final Report.* [Unpublished manuscript]. Thayer School of Engineering, Dartmouth College.

Portland Cement Association. (N.D) *Carbon Footprint.* [online pamphlet]. https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf?sfvrsn=2&sfvrsn=2

Schaffer, M., & By. (n.d.). A Greenhouse for Cold Climates, Eh? Retrieved from https://ceresgs.com/greenhouse-for-cold-climates/

Schiller, L., Plinke., M. (2016). The Year-Round Solar Greenhouse: How to Design and Build a Net-Zero Energy Greenhouse. New Society Publishers.

Single Layer ETFE by Architen Landrell. (n.d.). Retrieved from https://www.specifiedby.com/architen-landrell/single-layer-etfe

Suntuf 26 in. x 6 ft. Polycarbonate Roof Panel in Clear-155030. (n.d.). Retrieved from https://www.homedepot.com/p/Suntuf-26-in-x-6-ft-Polycarbonate-Roof-Panel-in-Clear-155030/206166246

The Online Materials Information Resource. (n.d.). Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=501acbb63cbc4f748faa7490884cdbca&ckck=1

The Online Materials Information Resource. (n.d.). Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=5c9aca1a960945aa8d9129f8a618b007

The Online Materials Information Resource. (n.d.). Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=edce30af0a9c4b72876c5bd2b5aa8cb6

The Online Materials Information Resource. (n.d.). Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=632572aeef2a4224b5ac8fbd4f1b6f77

Washington State Energy Code Builders Field Guide. (2004). Olympia, WA.: Washington State University, Extension Energy Program.

Chapter Six: Barn Raising

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6.1 Barn-raising Event Planning

Dartmouth's Greenhouse Committee has a mission to prioritize hands-on sustainability learning and collaboration amongst diverse, interdisciplinary groups of students, faculty, and staff to generate effective solutions to environmental issues that are just, equitable, and accessible to all people. The raising of Dartmouth's Big Green-Energy House, as a lighthouse example of energy efficiency and sustainable agriculture, offers the institution a strong path to contributing to this mission. Even before the climate battery and greenhouse are up and running, the Big Green-Energy House presents us with a unique opportunity to host an event that not only celebrates a project that will pioneer a path towards adoption of energy efficient 4 season greenhouses in New England, but also brings together a diverse group of people to have shared conversations about green energy, sustainable agriculture, and community resilience. In planning such an event, community engagement is at the forefront of our priorities. In order to have a meaningful, informative, and memorable event that values the voices of local farmers, Dartmouth students and faculty, and other parties who are interested in learning about the rewarding technology of climate batteries, we propose that the event utilize a collaborative scheme. We suggest a design charrette, where event participants can talk through, collaborate on, sketch, share, and explore a broad variety of design ideas for climate battery-powered greenhouses. This event will also allow participants to have an interactive experience with the physical materials that will be used in the lighthouse model greenhouse. To make this event a success, disseminating relevant information to our attendees is critical. In order to do so, we provide participants with documents that will ease their understanding of climate batteries and discussion facilitators with guiding questions and in-depth knowledge of the project and discussion topics. We intend for this event to foster collaboration between our diverse participants and open a dialogue about significant topics like green energy and sustainable agriculture. Through this event, the greenhouse committee has the unique opportunity to showcase a lasting use-inspired project with potential to catalyze sustainable energy alternatives both locally and beyond.

6.2 Sustainable Energy Transitions and Community Engagement

It is important that the Greenhouse Committee challenges our institution and its students to engage with the intersectional human and environmental problems of a rapidly changing planet and utilize the strength we have in the realms of research, innovations, teaching models, and human capital in order to tackle global sustainability challenges. Utilizing a Ground to Air Heat Transfer System, or climate battery, the "Dartmouth Big Green-Energy House" will serve as a lighthouse model of sustainable food production that provides research, education, and outreach opportunities while encouraging sustainable energy transitions in agriculture. Geothermal energy systems that provide heating and cooling using the ground represent a simple technology that supports sustainable use of energy. The barn-raising event, by showcasing this alternative to non-renewable energy, will not only introduce this technology to the Dartmouth community and farmers in the Upper Valley, but open a dialogue between these groups that has the potential to inspire sustainable agricultural transitions and lasting connections between these groups.

In addition to acting as an example of energy efficient design, the "Dartmouth Big Green-Energy House" will be an excellent hub for community engagement and empowerment. Dartmouth College's sustainability office actively seeks to create an environment where everyone feels welcome and valued, prioritizes individual well-being and happiness, embraces challenging conversations, opportunities for growth, and diverse experiences and perspectives. Further, the Big Green-Energy House project prioritizes hands-on sustainability learning and collaboration amongst diverse, interdisciplinary groups of students, faculty and staff to generate effective solutions that are just, equitable, and accessible to all people by framing the greenhouse as comparable to a community garden.

Community gardens are plots of land used for growing food by people from different groups/communities to collaboratively grow food. Whether cultivated through a stable system of farm managers, or tended by a student and volunteers, community gardens involve the leadership and active participation to plan and care for these socio-ecological spaces (Okvat and Zoutra, 2011). Because community gardening involves connecting with others, participation in decision-making, targeting local issues, and resisting globalization (of food production), it has potential to contribute to empowerment outcomes that enhance connections, health, and well-being (Perkins, 1995). Koay and Dillon (2020) examined the relationship between community gardening and a number of mental health benefits, in the forms of subjective well-being, stress, resilience potentials, and resilience factors (self-esteem, optimism, and openness). Their results indicate that, after controlling for age and levels of connection to nature, community gardeners reported significantly higher levels of subjective well-being than individual/home gardeners and non-gardeners, indicating that engagement in community gardening may be superior to individual/home gardening or non-gardening outdoor activities. Further, community gardeners reported higher levels of resilience and optimism than the non-gardening control group. Many studies propose that, when individuals experience stressful life events, their positive assets such as trait resilience and self-efficacy can be activated to support them for successful adaptations and active coping. The construct of resilience can be employed to illustrate the ability to bounce back from stress to optimal levels of well-being.

Alternatively, resilience refers to the ability to enable individuals to adapt to hardships or the ability to enable individuals to adapt well to stressful situations and the ability to deal with shocks and unexpected changes. In our current social, political, and environmental climates, which are wrought with global health, social inequity, and climate crises, we are in need of effective strategies to build resilience within our communities. Climate change, a threshold that is both a consequence and cause of global environmental collapse, economic meltdown, and increasing social inequity, exacerbates a range of global problems related to the environment and human health, but also offers an opportunity for humanity to awaken as an interconnected, global community. The “barn-raising” ceremony celebrating Dartmouth’s Big Green-Energy House offers the opportunity to motivate the execution of other collaborative efforts in education, research, and transitions in sustainability that are necessary in mitigating climate crises.

6.3 Maximizing the Barn-Raising Event’s Impact

With such strong potential for meaningful impact, the “barn-raising” event requires careful planning and consideration to maximize its reach as a bright example of Dartmouth’s leadership in sustainability challenges in food and energy production and community engagement. There is growing concern about declining opportunities for outdoor learning and low levels of understanding about food, farming and sustainability issues amongst young people in this country (Dillon, 2005). Outdoor educational opportunities, like the “barn-raising” event we are providing recommendations for, can involve many positive benefits such as working with others, developing new skills, undertaking practical conservation and influencing society. Because of this great potential, we implore the greenhouse committee to invite a wide-reaching audience of local farmers, Dartmouth students, staff and faculty, as well as other interested parties in the Upper Valley, so that many can benefit from the information we share and conversations we start.

Taking place in a relaxed, informal environment, such experiences can encompass knowledge and understanding, attitudes and feelings, values and beliefs, activities or behaviors, personal development, and social development. In a 2005 study conducted by the National Foundation for Educational Research in England and Wales, researchers identified a typology designed to contribute to the process of making value judgements about the worthwhileness of particular activities and programs, which includes the experience, the outdoor context, pedagogy, an integrating idea, and learning. The typology also highlights four important features for supporting learning in the outdoor classroom: contextualization (acknowledging the realities of the educational setting; promoting good learning design (supporting well-informed approaches to the use of outdoor classroom); promoting professional learning (enabling individuals or groups to do something new or differently by learning from experience); working with communities of learners and practitioners (supporting learning and change) (Dillon, 2005). This typology can make important and distinctive contributions to the totality of the learning experience, and our recommendations for the "barn-raising" event will take them into consideration. In order to have a successful event, we hope to build and strengthen a community with meaningful conversations about green energy production and sustainable agriculture, and encourage this community to engage with the "Big Green-Energy House" in the future.

6.3.1 Community Involvement

Gauging the interest of the Dartmouth community and beyond in involvement with a future barn-raising event includes sourcing educators, who will present content relating to the ENVS 50 Spring 2021 Big Green Energy House project, sustainable agriculture, climate batteries and green energy, and community resilience, and sourcing event participants who want to learn about the aforementioned topics. Note: the synthesis team is engaged in outreach and establishing connections with the Dartmouth community and beyond for both the event and general project.

Potential event volunteers and participants:

- Farmers who can be invited can be found here (courtesy of farmer-relations team):https://docs.google.com/spreadsheets/d/11JyONks8XwzO7bISkF0gsjjCaS-9Olo_0bQQ0vLwBIM/edit#gid=0
- Dartmouth community: Dartmouth Organic Farm, Farm Club, Dartmouth Sustainability Office, Department of Environmental Studies, Wellness at Dartmouth, general student body.
- Upper Valley community: Willing Hands, Vital Communities, Lebanon Farmer's Market, Hanover Farmer's Market, Norwich Farmer's Market.
- Community members who have shown interest in taking on the role of facilitator at the event: Department of Outdoor Affairs, Farm Club, Dartmouth Organic Farm staff/volunteers, Environmental Studies department faculty and students. Farm Club members have shown high interest in taking on the role of facilitator at this event and are interested in planning activities. We recommend that facilitators include a mix of students and faculty who have a greater extent of expertise on climate batteries like Theresa Ong and Kaitlin McDonald, for example.

Especially in light of the greenhouse committee's concerns and perspectives, we have summarized the findings of our research as they relate to the climate battery (Climate Battery Brochure) and educational aspects of the event (Event Education Factsheet) [See Appendix H and Appendix I].

6.4 Recommendations

6.4.1 Pre-Event Considerations

There are many considerations to take into account when planning the event further into the future. In particular, in order to reach the greatest number of people, careful consideration of timeline, dates, and transportation should be implemented.

A. Timing

First, the timing for the event must be carefully considered. Ideally, the event would occur in Fall, Spring, or Summer, because these times are more ideal for working outside and less snow needs to be cleared to establish the foundation for the greenhouse. Because there are more students available to volunteer for the Barn Raising event in the Fall and Spring terms than in the summer, these terms may be better suited for the event. In order to allow for an extra season of growing time in the Winter, the ideal time to do this event would probably be the Fall.

Because of Dartmouth's tight ten-week schedule, it may be easier to source volunteers during weeks 1 to week 3, before students are hit with a great deal of coursework. Furthemore, an effort should be made to work around the hectic schedules of farmers, so it may be wise to avoid busier times like peak harvest. It may be useful to communicate with farmers to determine availability closer to the event date. Finally, it will be easier to source volunteers to build the greenhouse when the weather is nice, and it will also likely take less effort to construct the greenhouse. For these reasons, we recommend that the event take place sometime in between week 1 and week 3, when the academic term is not rigorous. We also recommend looking ahead and making sure that the weather is nice when building is planned. In order to maximize engagement, a weekend date for the main educational component may be best in order to accommodate the most schedules.

B. Excavation

Prior to the event, excavation of the site must be conducted. Because this requires a deep and large hole, we recommend this is done by a professional excavator or construction crew. The event space should also be set up, with a station for water and snacks for volunteers, as well as a place where the materials and instructions can be accessed.

C. Transportation

Finally, prior to the event, transportation considerations should be taken into account. If COVID-19 is still a concern, the Greenhouse Committee should take into consideration the limited capacity of the buses required to transport people to and from the Greenhouse. Personal protective equipment should also be provided and required, and a schedule for the bus should be considered to allow for consistency in the schedule.

D. Agenda

We are recommending that there be a tentative start time of noon. This will allow for ample time to have introductions made to the group. It will also give us the time to run a successful, engaging event through the early afternoon.

12:00 PM - Arrival: Arrive and meet at the Dartmouth Organic Farm.

12:05 - Greetings and Introductions: MC volunteer provides a welcome to everyone attending the event. Following introductions of the general flow of the event and key volunteers who will be running discussion groups, the Dartmouth Big Green-Energy House project, its mission, goals, and plans for the future should be introduced. After introductions, attendees should be split into small groups for discussion

- General introductory message to be delivered before folks split into groups about the significance of this project by MC volunteer(s): "Today's planet remains plagued with food insecurity and anthropogenically induced climate change, two issues that must be addressed for both human and environmental success around the world. The Environmental Studies capstone class of Spring 2021 aims to bring light to both of these issues by promoting green energy design and sustainable agriculture through their greenhouse project. The education of the greater Dartmouth community on the importance of sustainable agricultural practices, passive heating systems, and the general principles of green energy design as it pertains to greenhouses and beyond remain at the forefront of the capstone class's goal. We hope to inspire and ultimately instill change in the realm of promoting the economic and environmental significance of green energy design and sustainable agriculture in the Upper Valley and beyond. The following activity will be centered around educating local farmers and the greater Dartmouth community about "pioneering a path towards adoption of energy efficient 4 season greenhouses not only in New England but throughout cold winter regions generally, further strengthening local food networks and improving access to fresh, locally sourced, nutritional produce year-round" (Ong 2021). Such an approach will be made possible by community engagement from a diverse set of voices and the opportunity for ample audience participation. In this barn raising event, we hope to encourage the greater community to follow suit and develop more projects like the Big Green Energy House. We look forward to your participation in a safe, memorable, and impactful barn raising event. We are glad you are here. Welcome."

12:20 - Small Groups across the O-Farm, First station: Just conversations in groups of 5+. Each group will follow the same schedule and topics for conversation, and we recommend small groups because it will provide an opportunity to hear the voices and contributions of as many invitees as possible. Our recommendation is to have several small groups and have engaging conversations about the suggested designs for the new Greenhouse and topics related to green energy and sustainable agriculture. Using the provided materials, facilitators will be able to answer questions pertaining to climate batteries in addition to guiding small group discussions. The factsheets (Dartmouth Big Green-Energy Greenhouse Factsheet & Event Education Factsheet) and other supplementary materials should be emailed to the facilitation volunteers as soon as those spots fill.

12:50 - Water and snack break

1:05 - Meet Back with Small Groups. Meet back in small groups, this time have physical materials to look and talk about in groups. Participants can look at materials for building a climate battery based greenhouse.

1:35 - 1:45-Meet back as a full group. Meet back together, have symbolic "ground breaking" of the event. This is dependent on what stage the construction of the greenhouse is in. If its development is still very early, a classic spade and ribbon event may be preferable. If the hole is dug significantly enough (4 ft) then this could allow lowering one of the climate batteries tubing into the pit. Event photographer(s) should be present to document the group together, and especially document the groundbreaking event.

1:50 - (this could fluctuate depending on what happens in "ground breaking". Thank everyone for coming out, offering snacks and water etc.

6.4.2 Educational Engagement

At the barn-raising event, we hope to share information about the Dartmouth Big Green-Energy House and its plans going forward, climate batteries, sustainable agriculture, and the potential for the Energy House's function as a collaborative hub for the Dartmouth Community and beyond. In order to promote collaboration and build connections between our diverse invitees, we hope to open a dialogue about the aforementioned information through discussion, as opposed to a lecture format. The National Foundation for Educational

Research in England and Wales (2005) highlights four important features for supporting learning in the outdoor classroom: contextualization (acknowledging the realities of the educational setting; promoting good learning design (supporting well-informed approaches to the use of outdoor classroom); promoting professional learning (enabling individuals or groups to do something new or differently by learning from experience); working with communities of learners and practitioners (supporting learning and change). With these in mind, we propose that the event utilize a collaborative scheme—in the form of a design charrette—to not only celebrate the Dartmouth Big Green-Energy House project and its potential as a lighthouse model, but to share key concepts relating to green energy, sustainable food production, and community resilience.

A design charrette is a collaborative meeting during which representatives of the Dartmouth Big Green-Energy House can share their work with the event goers: local farmers, Dartmouth students, staff, and faculty, and other interested participants. In this setting, invitees can talk through, collaborate, and sketch designs to explore and share a broad diversity of design ideas for both the Big Green-Energy House and their own climate battery-powered greenhouses. Every participant has a unique perspective informed by their lived experience, which means every participant has valuable insight and can engage with the topics of green energy, sustainability, community resilience in meaningful ways.

A. Design Charrette Plan
    a. The design team has formulated two design options, which we recommend are printed for the event as hand-outs or in poster format so that discussion facilitators and participants can reference them.
    b. In order to foster intimate discussion through a design charrette scheme, we recommend that the event participants are split up into 3-5 groups (or more depending on how many people are in attendance). Each group should be seated in a circle so that participants can hear each other speak clearly and see each other's faces. For each group, we recommend that at least one discussion facilitator is present, that the facilitator has the requisite materials for distribution (brochure, design hand-outs) and reference (Event Education Factsheet, Irving Proposal), and that they are prepared to guide conversation.
    c. Within each group, we recommend that the following topics and concepts are explored and discussed, and that their exploration is guided by at least one facilitator. We have provided guiding questions for the facilitators, and we recommend that they ask the questions of the entire group and allow every participant the opportunity to answer *and* reply to or comment on other people's answers. This is a conversation, so replies to guiding questions should not necessarily be directed to the facilitators.
        i. The Dartmouth Big Green-Energy House
            1. Starting the conversation with an overview of the Dartmouth Big Green-Energy House project and its mission, its goals, the plans for its construction, and how the Greenhouse Committee will measure its progress in the future. All of this information can be found in the Irving Proposal [see Appendix A].
        ii. Green energy, climate battery basics, sustainable agriculture, and community resilience.
            1. A general discussion of these topics will be useful before we dive into their relation to the designs for the Big Green-Energy House. In this part of the conversation, we hope to gauge participants' prior knowledge on the subjects and the extent to which these concepts are important to them personally, and in their communities. Information about these subjects can be found in the Event Education Factsheet [see Appendix I]. We recommend gathering physical materials for the groups' reference (e.g. options for temperature control hardware, tubing, paneling, insulation, etc.).

2. Guiding questions:
    a. Do you use any green energy strategies / non-renewable alternatives at your farm or in your life? Give us an example.
    b. What does sustainability mean to you? Is it important to you? Why or why not?
    c. What does resilience mean to you? What about community resilience?
    d. Do you have community strengthening strategies? What are they?
    e. Do you know the farmers in your area? Would you like to know more of them, or know them better?
    f. What are the strengths of your community? Weaknesses?

iii. Dartmouth Big Green-Energy House Designs (there are two).
1. Facilitators should walk through both potential designs for the Big Green-Energy House, one at a time, pausing for questions and comments from participants [see Design Chapter for recommended designs]. After walking through each design, the facilitator should ask questions pertaining to participants' general thoughts on the designs, strengths and weaknesses, advice and suggestions for improvements, and how the design may be applicable to local farmers' greenhouses.
2. Guiding questions
    a. Which design would be more relevant to your farm?
    b. Which design do you think would fit better for the Dartmouth Organic farm specifically?
    c. Do you think this would be feasible for your own farm? Why or why not.
    d. What aspects of this design would work well for you? What wouldn't work?
    e. Are there any weaknesses that jump out at you? Strengths?
    f. How would you improve this design?
    g. Are there any aspects of this design that you would want to implement in your own?

iv. Climate Battery Application in the Upper Valley
1. We hope that after working through two potential design options for the Big Green-Energy House, this will inspire local farmers to consider the feasibility of a ground to air heat transfer system in their operations. This part of the conversation should resemble a brainstorming session, and facilitators should take care to enable the discussion to ultimately help farmers see the potential of implementing their own climate battery system.
2. Guiding questions:
    a. Do you have a greenhouse? What temperature control/regulation system do you use? Is it effective? Can it be improved?
    b. How long has your greenhouse been running, when was it built?
    c. Is it feasible for you to manage a four season greenhouse, as opposed to a three season?
    d. How might growing in the Winter improve or hinder your business?
    e. Do you have any dream renovations for your greenhouse?
    f. Have you done anything similar (to the designs reviewed) with your greenhouse? What has worked and what hasn't?

g. What barriers do you expect to face at your farm? How can you overcome them?
h. What kind of support would you need to make the changes you want to make to your greenhouse?

6.4.3 Event Documentation

To successfully document the information of the event, we recommend capturing photographs and video of the event. The Dartmouth campus's Media Production Group is available to document public activities and performances. In addition, they provide video overflow to increase the capacity of public events, as well as live online streaming to YouTube, Facebook, and LiveStream. The Event Management System must be used to plan all activities. The Media Production Group is available to any member of the Dartmouth Community. The rates for the MPG are $95 per hour (recording and editing), $95 overflow setup, $250 live webstream. It is important to note that their service is contingent on resource availability. Also, the MPG has to be notified about the event at least 48 hours prior. They can be reached by email and phone: media.production.group@dartmouth.edu and (603)-646-3832.

6.4.4 Special Considerations

If this event is hosted at a time where COVID-19 precautions need to be taken, please refer to the COVID-19 Restrictions & Policies for Student Events [Appendix J]

6.5 References

Climate Battery FAQ. *Eco Systems Design, Inc.*, http://www.ecosystems-design.com/faq.html.

Climate Battery Greenhouse. *Threefold Farm*. https://threefold.farm/climate-battery-greenhouse.

DIY Greenhouse Plans. (2018). *Ceres Greenhouse*. https://ceresgs.com/greenhouses/diy/.

Ogden Publications. *How to Design a Year-Round Solar Greenhouse*. Mother Earth News. https://www.motherearthnews.com/organic-gardening/how-to-design-a-year-round-solar-greenhouse-zbcz1502.

Environmental Protection Agency. (2018). Local Energy Efficiency Benefits and Opportunities. *EPA*.

Farm-Energy. (2019). Introduction to Energy Efficiency and Conservation on the Farm. *Farm Energy*.https://farm-energy.extension.org/introduction-to-energy-efficiency-and-conservation-on-the-farm/.

GAHT Systems: A Geothermal Option. *Ceres Greenhouse.* https://ceresgs.com/environmental-controls/gaht/.

How Climate Batteries Work. *Atmos Greenhouse Systems*. https://atmosgreenhouse.com/how-climate-batteries-work.

Koay, W. I., & Dillon, D. (2020). Community Gardening: Stress, Well-Being, and Resilience Potentials. *International Journal of Environmental Research and Public Health*, 17(18), 6740.

Li, Guozhen & Tang, Llewellyn & Zhang, Xingxing & Dong, Jie & Xiao, M. (2018). Factors affecting greenhouse microclimate and its regulating techniques: A review. *IOP Conference Series: Earth and Environmental Science.* 167. 012019. 10.1088/1755-1315/167/1/012019.

National Foundation for Educational Research in England and Wales, & Dillon, J. (2005). Engaging and learning with the outdoors: The final report of the outdoor classroom in a rural context action research project.

Okvat, H. A., & Zautra, A. J. (2011). Community gardening: A parsimonious path to individual, community, and environmental resilience. *American journal of community psychology*, 47(3-4), 374-387.

Ong, T., Hicks Pries, C., Braasch, L., McBride, M., and Danieu, A. (2021). The Dartmouth Big Green-Energy House: impacts of geothermal energy technology for agriculture. Proposal: *Irving Institute for Energy and Society*.

Perkins, D. D., & Zimmerman, M. A. (1995). Empowerment theory, research, and application. *American journal of community psychology,* 23(5), 569-579.

Schultz, J. Climate Battery Greenhouse: Energy Efficient and Sustainable Winter Growing. *Northeast Organic Farming Association of Massachusetts*. https://www.nofamass.org/wp-content/uploads/2020/07/Fact-Sheet-6-8-5x11-1.pdf.

YouTube. (2019). How to Build a Greenhouse. YouTube. https://www.youtube.com/watch?v=Bbibe0yuiew.

Climate Batteries. Eco systems design, inc. http://www.ecosystems-design.com/climate-batteries.html.

YouTube. (2020). How To Build a Climate Battery - Day 3 - Construction In Passive Solar Greenhouse. YouTube. https://www.youtube.com/watch?v=5g92Smw2Hic&list=RDCMUChqxlr587JCD5I9veE62s1w&start_radio=1&rv=5g92Smw2Hic&t=648.

Zhang, Chong & Wang, Jinbo & Li, Liao & Wang, Feifei & Gang, Wenjie. (2020). Utilization of Earth-to-Air Heat Exchanger to Pre-Cool/Heat Ventilation Air and Its Annual Energy Performance Evaluation: A Case Study. *Sustainability*. 12. 8330. 10.3390/su12208330.

Chapter 7: Conclusion & Summary of Recommendations and Results

7.1 Summary of Individual Team's Results in Respect to Overall Project Goal

7.1.1 Design Team Results

The Design Team undertook the project with the goal of providing design options for the Big Green Energy House. They met this goal by creating two design alternatives for the Big Green Energy House. The design options were informed by interviews with GAHT system and greenhouse engineers, Dartmouth College faculty, and other project stakeholders familiar with the engineering component of greenhouse design. Based on their interviews and extensive research into geothermal energy and crop production, their designs include preliminary GAHT system designs for each option..

The team created one design option which would reuse the current Dartmouth Organic Farm greenhouse foundation and cement wall. Their second design option is for an entirely new, larger greenhouse structure on an alternative plot of O-Farm land, identified within the design chapter of this report. The Design Team drew up approximate cost estimates and construction timelines for each of these options. These designs, cost estimates, and timelines provide the Greenhouse Committee with information on the feasibility of greenhouse size and location options as they move forward with the project.

7.1.2 Infrastructure Team Results

The Infrastructure Team began the project with the goal of creating a roadmap in the form of a decision tree for navigating construction obstacles in multiple scenarios. The decision tree will be a resource for the Greenhouse Committee to reference as they continue implementing the greenhouse project. They met their goal by reviewing and compiling documents which detail the conservation easements, zoning ordinances, local building codes, and ADA compliance requirements as well as contact information for Hanover officials involved in local construction and permitting processes. This information informs the spatial limitations of the project and the timeline of the permitting process, which must be taken into account as the Greenhouse Committee finalizes design plans and makes final placement decisions for the greenhouse. These documents identify renovations on top of the existing O-Farm greenhouse foundation as the most realistic avenue for greenhouse construction due to the existing exceptions in zoning ordinances which apply singularly to the current structure. The team's compilation of Hanover-specific building and permitting information can also inform local Hanover farmers on the local obstacles for replicating the Big Green Energy House lighthouse model.

The Infrastructure Team defined the timelines and institutional requirements for Dartmouth College's bidding, permitting, planning, and project management processes through multiple conversations with Dartmouth's Associate Director of Facilities Operations & Management. They compiled a list of the Dartmouth administrators and personnel responsible for the oversight of infrastructural projects. The Infrastructure Team's identification of these processes and contacts will guide the Greenhouse Committee through institutional regulations on the future construction of the greenhouse.

Lastly, the Infrastructure Team identified and compiled auxiliary sources of funding through local, regional, and national nonprofits for the construction and maintenance of the Big Green Energy House and other sustainable greenhouses. These resources were identified through extensive literature review on sustainable food production funding sources and financial obstacles to implementation of these systems. Compiling these funding sources and understanding the financial barriers to transition to sustainable food systems meets the team's goal of highlighting the financial accessibility of sustainable food production for Dartmouth and area farmers.

7.1.3 Farmer Relations Team Results

The Farmer Relations Team identified community-building among ENVS50 students, the Greenhouse Committee, and area farmers for the purpose of facilitating resource-, knowledge, and labor-sharing as the primary goal of their project contribution. The team accomplished this goal by performing a literature review on ethical practices to engage with farmers when conducting interviews. They used this literature review as the basis of their recorded ethical guidelines and exhaustive interview protocol for ensuring that farmer interactions are mutually agreed upon and secure. The guidelines and protocol place particular emphasis on ensuring the health and safety of interactions between farmers and interviewers during the COVID-19 pandemic.

The Farmer Relations Team met the project goal of defining a 'Lighthouse Model' through a literature review which focused on the best way to establish lighthouse models in a local context. They identified the key elements of a lighthouse as building collaborative and reciprocal relationships which are responsive to locality-specific stakeholder needs. To achieve the lighthouse goal for the Big Green Energy House, the Farmer Relations Team interviewed Dave Chapman of Long Wind Farm, Jim Schultz of Red Shirt Farm, and Michelle Shade of Cedar Circle Farm. In these interviews they sought to build long term relationships with the farmers, to glean the farmers' knowledge about farm construction and expansion, and to gauge their interest in receiving materials and updates from the Big Green Energy House team. The Farmer Relations Team's defined interview protocols and ethical guidelines for farmer interactions can assist the Greenhouse Committee in building reciprocal relationships and gleaning information from farmers in future interactions.

7.1.4 Barn Raising Team Results

The Barn Raising Team began plans and created documents to facilitate the Greenhouse Committee's future implementation of a high-visibility educational event on GHAT systems hosted at the O-Farm. This event will help the Greenhouse Committee, the Dartmouth sustainability community, local agricultural nonprofit organizations, and other interested parties to make in-person connections, share relevant knowledge-sharing, and build a broader community with a variety of stakeholders.

The team has crafted a rough timeline for the barn-raising event which can be implemented in the Summer, Fall, or Spring Terms. They have reached out to nonprofits, Dartmouth students, Dartmouth sustainability faculty, the Upper Valley agricultural community, and other community members connected to the Big Green Energy House project to participate in the barn-raising event as educators and volunteers. They put together a fact sheet on GAHT systems to distribute to attendees, event volunteers, and educators as well as a brochure that the Greenhouse Committee can use to get the word out about the project and the event.

7.1.5 Synthesis Team Results

The Synthesis Team identified dispersion of knowledge about the project and sustainable greenhouses as well as establishment of a diverse community committed to sustainable food production as the goals of their project contributions. They accomplished this goal by creating and advertising several informational platforms over social media, online, and through email. These various forms of communication are accessible to diverse stakeholders with different preferences for obtaining information and project updates. The establishment of avenues for communication will benefit the Greenhouse Committee as they continue to relay information on the Big Green Energy House project.

The Synthesis Team also identified intragroup communication facilitation as an essential element of their project contribution. They met this challenge by creating the Google Drive and Trello class resources for sharing resources and information. The website also functioned as an in-depth informational resource for students, the Greenhouse Committee, and interested community-members to remain on the same page about project progress, goals, and relevant educational materials on GAHT systems. The accessibility of the website met the team's goal of facilitating student communication with external stakeholders. External outreach by Synthesis Team representatives on behalf of other student groups helped the students to create and maintain communication with potential stakeholders including Dartmouth faculty and staff, students outside of the class, and local nonprofits with agricultural missions. These connections may be drawn upon by the Greenhouse Committee in the future of the project as sources of agricultural knowledge, infrastructural knowledge, volunteer labor, and community advertisement.

7.2 Final Assessments and Recommendations

ENVS 50 recommends the Greenhouse Committee select one of the two presented options based on consultation with relevant stakeholders and the availability of funding. We propose reusing the concrete wall and foundation and maintaining the current footprint of the greenhouse as a cost-effective option that meets many of the intended goals of the Big Green Energy House while also accounting for the installation of a divided GAHT system and decreased energy consumption as a result of this climate battery and a new glazing and frame. Additionally, conservation easements on the O-Farm, the 50foot setback line from Lyme Road, and funding opportunities all limit the size and placement of the new greenhouse. Building atop the current O-Farm greenhouse foundation allows the Greenhouse Committee to circumnavigate restrictive conservation easement and zoning ordinances by grandfathering the new greenhouse into exceptions already in place for the old structure.

Students recommend referencing the Infrastructure Team's list of national, regional, and local grants for additional project funding. If funding becomes available, we propose the complete relocation of the greenhouse to one of two suitable new sites and the outsourcing of materials from an experienced industry leader -- Ceres Greenhouse Solutions. This option presents a significantly higher cost than the first but provides the hope of extending the usable growing space by 2.5 times and better accommodating the diverse needs and goals of the stakeholders.

Regardless of the design option that the Greenhouse Committee decides to implement, the ENVS50 student groups recommend specifically delineating and diversifying upkeep and management responsibilities among the O-Farm staff, Dartmouth FO&M staff, and research faculty. ENVS50 also recommends that the Greenhouse Committee frequently consult Laura Braasch and Molly McBride about the state of ADA accessibility and septic tank construction on the O-Farm. A septic tank and ADA accessibility are essential infrastructure for obtaining Town of Hanover building permits for the Big Green Energy House.

In future communications with farmers, ENVS50 recommends that the Greenhouse Committee consult the recorded ethics and interviewing protocols established by the Farm Relations Team to build a foundation of trust and security. We also recommend demonstrating particular attentiveness to health and safety in all stakeholder interactions during the COVID-19 pandemic and demonstrating receptivity to farmer's needs and time constraints, especially during harvesting times. The Greenhouse Committee should also review the Farmer Relations Team's guidelines and suggestions for effective communication and the creation of mutual partnerships with farmers. The Committee should also share the Farmer Relations Team's funding resources document with all farmers interested in replicating the lighthouse model. In all stakeholder communications, project partners should use ENVS50's concretized definition of a 'Lighthouse Model' as a basis for community outreach to ensure the successful creation of collaborative and reciprocal relationships and integrate locality-specific stakeholder needs into the outcome of the Big Green Energy House project.

ENVS50 recommends maintaining frequent communication with farmers and other members of the Dartmouth and Upper Valley communities through the project's established social media platforms and website. We encourage the Greenhouse Committee to continue to draw on Kim Wind, the Dartmouth Sustainability Office, and the student-led Farm Club and Sustainability Club as valuable resources for information dispersal, project advertisement, and volunteer sources. We encourage project partners to broaden the project audience by developing additional outreach materials such as a newsletter which may be distributed to individuals outside of the Dartmouth community. Hard-copy materials may be distributed at local farmers markets and other high-traffic areas which cater to people who are likely to be interested in sustainable food production. They may also be distributed to local nonprofits who can distribute information to their established audiences. The Greenhouse Committee should provide status updates and maintain contact with established partners throughout the entirety of the project to ensure that they stay engaged and connected to the project.

Student-made connections with area nonprofits, Dartmouth students, Dartmouth sustainability faculty, Upper Valley agricultural community members, and other community members connected to the Big Green Energy House project should be drawn upon for auxiliary leadership, volunteer, and education resources during the barn raising event. ENVS50 recommends considering weather, duration, the academic calendar, the growing season calendar, and transportation when planning for an in-person barn-raising event in the Summer, Fall, or Spring terms. The Greenhouse Committee should also pay special consideration to the COVID-19 safety protocols outlined by the Barn Raising Team when hosting this event. The agenda for the event should include the installation of one GAHT system in a pit dug prior to the event as well as refreshments and educational activities on GAHT systems and four-season greenhouses in accordance with the Barn Raising Team's event schedule. A photographer should be hired to document activities so that the event can be shared on the Big Green Energy House social media and web platforms.

Event volunteers should distribute the how-to guide for climate battery installation and the fact sheet developed by the Barn Raising Team. Attendees should be made aware of social media and online materials developed by the Synthesis Team to receive updates on the Big Green Energy House. Success of the project may also be shared at the Dartmouth Social Impact Practicum (SIP). Finally, the grant sources compiled by the Farmer Outreach Team should be distributed to attendees interested in pursuing sustainable food production.

7.3 Acknowledgements

This project is the culmination of efforts contributed by a diverse group of stakeholders, advocates, and educators. The class of Environmental Studies 50 would like to thank several people and organizations for their support, passion, and advocacy throughout the process of constructing this report. With their help, the large task of developing the Big Green Energy House became far more manageable. It resulted in a wealth of knowledge which we hope will serve as the foundation to an incredible addition to the Dartmouth Organic Farm.

We are extremely grateful to the Greenhouse Committee, who made our term project possible. Professor Theresa Ong instructed us throughout the term and offered her agriculture expertise and connections to project stakeholders. Professor Caitlin Hicks Pries provided indispensable knowledge on the biological function of a greenhouse. The class liaisons from the Dartmouth Organic Farm, Laura Braasch and Molly McBride, were instrumental in providing our class with the background necessary to tackle the challenges of this project. Their early encouragement and instruction, as well as their wisdom from past experiences, created a sound learning environment right from the start. Finally, Alana Danieu was heavily involved in class support and research.

We're also grateful for the educators who helped every group in this class reach their fullest potential. Dr. Karen Bieluch was indispensable in providing assistance at every turn taken by this project. Her insightful advice on group dynamics and maximizing each student's potential created an environment which encouraged new ideas and more efficient decision-making processes. Kaitlin McDonald, the Spring 2021 ENVS50 teaching assistant, guided students throughout the project and supported the class instructors to make this class possible.

We are of course thankful for the knowledge gained through discussions with New England farmers. Thank you to Dave Chapman of Long Wind Farm, Michelle Shane of Cedar Circle Farm, Dan Birnsihl of Hip Peas Farm, Jim Schultz of Red Shirt Farm, Pooh Sprague of Edgewater Farm, and Chuck Wooster of Sunrise Farm.

We are also thankful for the Dartmouth faculty and staff whose expertise and insights helped students to move forward in the Big Green Energy House project. Thank you to Patrick O'Hern, Jennifer Casey, Kate Norton, Bernard Haskell, Rosi Kerr, Theresa Barry, Chris Polashenski, and Tim McNamara.

A special thanks to Rob Houseman for communicating Town of Hanover zoning and permitting processes. We would also like to thank Mike Bisogno of Rimol Greenhouse Systems for sharing his expertise on climate batteries.

Finally, our team also thanks the Dartmouth Farm Club, Dartmouth Sustainability Office, and Rachel Kent. Without their enthusiasm and organization, our project would never have achieved its consistently high levels of outreach. (Note: We will continue adding to this section until submission to Kim Wind)

Appendix

APPENDIX A

Quick Project Fact Sheet:

Project name: Dartmouth Big-Green Energy House

Project Summary: Renovate existing greenhouse using solar passive technologies to serve as a lighthouse model for Upper Valley farmers and experiential research space for undergraduate and graduate students.

Project goals:

- To place Dartmouth at the forefront of reducing fossil fuel emissions from conventional greenhouse crop production.
    - Provide an alternative to propane greenhouse heating during colder seasons by incorporating passive solar energy through climate battery technology for interior climate control
- To serve as a lighthouse model serving Upper Valley farmers transitioning to sustainable
- To create an experiential space for future undergraduate term classes and undergraduate and graduate research projects
- To connect our undergraduate community to our broader community in the Upper Valley

  food production systems
- To replace the current passive greenhouse at the Dartmouth Organic Farm that is in a state of disrepair
    - To continue using a grandfathered footprint of buildable land that will be lost if the greenhouse is demolished or its use changes

Methods:

- Designing and building a passive solar greenhouse regulated by a Ground to Air Heat Transfer (GAHT) system, otherwise known as a climate battery
- Advertising models of sustainable food production to the wider Upper Valley community

Project Outcomes:

- Experimental and interdisciplinary space for Dartmouth professors, graduate and undergraduate students/classes

- Extended growing space and time for Dartmouth Organic Farm operations, providing green space for students during the winter term (from 3 seasons to 4)

- Make Dartmouth a hub of engagement for local farmers to connect with students and each other as they explore new greenhouse technologies for a changing climate

Funding Sources:

1. Applied for Irving Grant <$100,000
2. Irving Institute suggested finding another source to fill the gap between Irving amount and project cost
3. Grant point person at Irving Institute: Stephen J. Doig

APPENDIX B

Methods – Interview Protocol:

1. Reach out to farms presented in Irving Proposal (those that have greenhouses, those that have climate batteries, those that have neither) with an initial email
2. Provide options for meeting virtually (phone call, Zoom) if they agree and are available
3. Set up an interview that includes the following:
    a. Provide an introduction to outline the mission and goals of the project and the role that they may be playing initially and down the road; ask questions we have set up in our interview questions document
    b. We initially tried to do two separate interview times, however through trial and error, we soon realized that there were more efficient ways to go through the process. By streamlining the process to only have one interview, it became much easier scheduling-wise and took up less of the farmer's time.
    c. Share background of project in preliminary email then again at beginning of interview.
        i. What the Organic Farm plans to build (the greenhouse and the climate battery) and what they hope it will stand for (the lighthouse model and a research facility that can help not only Dartmouth but the farmers in the Upper Valley)Go into key questions regarding the greenhouse and the climate battery.
    d. Ask about their design process for those that have current structures as well as any advice they may have for us just beginning the process of constructing our on after receiving the Irving Grant
    e. Gain information about their current farm structure/sustainable innovations (some farms have insight into other processes and products that we may not have considered that would be a good addition to not only the Greenhouse but the farm as well)

f. Gain information about current farmer networks they may be apart of
g. Gauge interest in creating a relationship with Dartmouth Organic Farm and Greenhouse Committee into the future for research and community building purposes (we do not want to pressure any farmer or individual into feeling that they need to be apart of this process but we do want to encourage them to participate if they feel they can benefit from our research while also offering us any helpful information).

APPENDIX C

Methods – Interview Questions:

1. Commitment to working with Farmer Relations group and Greenhouse Committee
    a. Timeline for project: the short 10-week term versus the long term process of building the greenhouse (1 year+)
        i. Irving Grant: we have officially been selected to receive the grant and can move forward in the process of building the greenhouse and climate battery.
    b. Other ENVS 50 groups' roles and objectives
        i. Farmer Relations, Dartmouth Funding, Energy Design, Event Coordination, Publicity Synthesis
2. Overall process of creating/using greenhouse
    a. Motivation behind building a greenhouse and its benefits? What kind of challenges have come up?
        i. It's important to get a full picture rather than just the end result. It is beneficial to know any obstacles we may face in the process so we can be prepared and know fully what we are getting into.
    b. What was the design/planning process - any financial assistance?
        i. We are just in the beginning stages of the greenhouse so it would be helpful to know what the process may look like and the steps we may have to take. It would also help us to know what financial assistance, if any, they received to help us inform other farms and farmers of where they could potentially look for regarding outside funding to build their own greenhouse and battery if they wish to upon seeing how their own process goes.
    c. Is it year round, what materials were used, how long have they had one, how long do they anticipate it will last, what are the heating/cooling mechanisms, how big is it, what type of plants does it support, any upkeep/extraneous costs?
        i. It is helpful to ask the specifics of what it took to build their own greenhouse as this will greatly help out our design team for the Dartmouth Organic Farm greenhouse and how our plans will flesh out.
    d. What advice would they give us?
        i. Any advice that we can receive from those who have already gone through the process would help us tremendously and continue the reciprocal relationship that we are trying to build.
3. Climate battery
    a. Background information if they haven't considered one? What is their opinion on them?
        i. We have reached out to all types of farms, including those that either do not have a 4-season greenhouse or a climate battery. It is important to get both sides and opinions on why some farms have pursued this endeavor and why some have not led us in a direction that will result in the best possible outcome.

4. Lighthouse model benefits
    a. Projects/research that could be done at Dartmouth Organic Farm greenhouse that farmers could benefit from.
    b. We don't simply to conduct research projects that would simply benefit those here at Dartmouth but also those who have helped us throughout the development process along the way (the farmers) and therefore have to save room to conduct projects that they would like to see and could benefit them.
    c. What would they hope to gain from collaborating with Dartmouth's potential greenhouse?
    d. We have laid out our mission as stating what farmers may benefit from working with us but we want to hear directly from them what their vision is and what they hope to gain as a result of being a collaborative partner with both the Greenhouse Committee and the Dartmouth Organic Farm.
    e. Mention relationship with Dartmouth Organic Farm in the future and what the project hopes to accomplish
        i. Although our work as students and as the Farmer's Relations team will end this term in regards to the project's entirety, it is far from over. We want these relationships that we are building with farmers to extend past our time here and to continue and grow with the Greenhouse and the benefits that will be accrued from it.
        ii. It would also be beneficial to not only connect farmer's with the Greenhouse committee here at Dartmouth, but to also connect the farmers with one another, especially local and regional farmers who may be interested in sustainability and green energy as well as infrastructure and climate batteries specifically.

APPENDIX D

Summary of Reviewed Literature:

Our research has led us to discover many informative pieces of academic literature helping to inform our understanding of the goals and motivations of the Greenhouse Committee, the development of our interview protocol, and how best to interact with farmers. The following section reviews key pieces of literature that were particularly relevant to the work we conducted and for the continuation of this project.

In an article by Camille Lacombe, Nathalie Couix, and Laurent Hazard in *Agricultural Systems* titled "Designing agroecological farming systems with farmers: A review," the field of agroecology is described as a "new paradigm whose aim is to redesign farming systems" with its implementation including the engagement of farmers through a "radical transformation of their practices, their way of reasoning, and their participation in local knowledge production and innovation processes" (208). The article reviews the role of farmers and other stakeholders in participatory research projects, and how this impacts their learning and engagement when transforming local farming systems. Methodologies mentioned include shared project leadership between farmers and researchers and organized co-designs that are used to account for the "singularities of farmers' situations and of the local activity system to be transformed" with the broader goal of developing agroecological farming systems in mind (Lacombe et al., 2018, 208).

In "Community-University Research Partnerships: Devising a Model for Ethical Engagement", authors Linda Silka and Paulette Renault-Caragianes propose a model for achieving ethical research in partnerships between communities and universities. The model addresses questions revolving around the ethics of collaborative work, including: "Who decides which problems are worthy of study? Who decides how the research will be conducted? Who owns the data once they are collected?" (Silka & Renault-Caragianes, 2006, p.171). The article begins by addressing a prominent issue within research partnerships in which members of the partnership have different goals, approaches and anticipated outcomes. A common example of this is that researchers hope to end the project with a publication, while community members seek a solution to a problem they experience in their own lives. These circumstances often lead to tension and a power dynamic not conducive to a productive, collaborative work environment. The authors mention how "differences in power at the heart of these interactions often make it difficult for community members to have a voice in the research" (Silka & Renault-Caragianes, 2006, p. 172). The research model developed and outlined in this paper works to balance the goals of all involved. Part of the recommended model and solution is to think in terms of "research cycles" rather than "one-shot studies" when it comes to projects that interact with the community (Silka & Renault-Caragianes, 2006, p. 178). This practice will help to create a "community repository of knowledge" that is available to the community and is a space of continuing accumulation of knowledge and problem solving, even after researchers transition to other projects, allowing communities to independently access and further the research (Silka & Renault-Caragianes, 2006, p. 178).

In "Challenges in Creating Local Agri-environmental Cooperation Action Against Farmers and Other Stakeholders" from *The Macaulay Institute*, the "current extent of, and the future potential for, local cooperative activities involving farmers and the management of diffuse water pollution, biodiversity and habitat protection, and landscape design" is analyzed (Davies et al., 2004, p. 5). These three areas of environmental concern are identified by the Scottish Agriculture and Environment Working Group's Custodians of Change and concentrate on the potential for "stimulating local level, bottom-up collective actions led by farmers" with the term "cooperation action" denoting a wide range of activities and goals ranging from informal 'neighbouring' activity to large multi-partner formal partnerships" It is therefore important to distinguish between bottom-up, farmer-to-farmer collective actions, which we term 'cooperation'; and top-down, often agency-led collective actions, which we term 'coordination' (Davies et al., 2004, p. 5).

In "Farmers and researchers: How can collaborative advantages be created in participatory research and technology development?" in *Agriculture and Human Values*, differences in research approaches of farmers and scientists are analyzed and specifically how these differences are related to "the conditions under which both groups engage in experimental work" (Hoffman, Probst, and Christinck, 2007, p. 355). This article analyzes the respective comparative advantages of both farmers and scientists, as well as knowledge management and technological innovation within their different fields. Participatory research is discussed, and specifically in terms of the different knowledge and skills that farmers and professional researchers possess, which "may compliment each other," and specifically that "by working together the two groups may achieve better results than by working alone" (Hoffman, Probst, and Christinck, 2007, p. 355). The article suggests these complementary roles for farmers and researchers are largely important when setting research priorities, therefore, there is a need for decentralized community-based technology testing that makes use of the farmers' experimentation and dissemination capacity. Additionally, formal research should be more open to farmers' informal experimentation and greater attention should be paid to the externalization of expert farmers' tacit knowledge. Finally, opportunity costs should be respected if farmers dedicate time to research (Hoffman, Probst, and Christinck, 2007, p. 358). The authors note that a "collegial research relationship between farmers and researchers can yield synergies by combining indigenous and scientific knowledge, providing quicker solutions to real problems at the local level, and strengthening local innovation development, and so on (Hoffman, Probst, and Christinck, 2007, p. 358). However, some critics argue that there are few concrete examples of new technologies that have been developed by farmers and researchers working together" (Hoffman, Probst, and Christinck, 2007, p. 358).

Also of importance, the article discusses how farmers have “comparative advantages in evaluating and testing new technology” By “living and practicing agriculture in a specific location, farmers deal with their whole farm, family, natural, and social environment simultaneously...life, work, and studying form an integrated whole” meaning that the farmer “considers the complexity of his farming system when evaluating the innovations s/he or others generate” with their main objective being the “guaranteed production of crops and improved livelihood” (Hoffman, Probst, and Christinck, 2007, p. 359). On the other hand, professional researchers “tend to live under completely different circumstances” given that they are “employees, often living in urban centers, rarely practice agriculture, and usually separate their work from their private life” and “tend to specialize in a particular discipline; their focus is on analysis and theory, and their incentives for innovation are recognition and their scientific career, which earns them a living” (Hoffman, Probst, and Christinck, 2007, p. 359). That being said, the “generator of technology and users are no longer one and the same,” thus it is often difficult for professional researchers “to know farmers’ preferences and to understand the complexity of their situation” (Hoffman, Probst, and Christinck, 2007, p. 359). Finally, it is worth noting that “recognition from colleagues, ideas about respectable and rigorous research methods, insight into donor policies to obtain funding, and publishing in peer-reviewed scientific journals are more relevant to the researcher than generating results applicable on the farm” (Hoffman, Probst, and Christinck, 2007, p. 359).

In “Reciprocity: An ethic for community-based participatory action research” reciprocity is defined as “an ongoing process of exchange with the aim of establishing and maintaining equality between parties" (Maiter et al., 2008, p. 305). The authors discuss reciprocity in relation to a specific community-based participatory action research project that examined mental health services for immigrant communities in Ontario, Canada (Maiter et al., 2008, p. 305). Here it is discussed the structural and organizational limits of reciprocity and a set of guidelines (Maiter et al., 2008, p. 321). The guidelines first focus on establishing respectful relationships in which all involved agree to provide resources. The most important input here is time, as it is an important part of developing and maintaining the relationships that will ultimately be the basis of any project. The next guideline encourages partnerships to recognize both long term and short term goals and to identify these as part of a “longer cycle of exchange” (Maiter et al., 2008, p. 322). Additionally, it is recommended that all stakeholders recognize power dynamics as well as many potential limitations to reciprocity in different circumstances (Maiter et al., 2008, p. 322). By addressing these limitations from the outset of a project, partnerships will be better prepared to address why obstacles and challenges may arise during research and the ongoing project (Maiter et al., 2008, p. 322).

In “Social capital and farming at the rural-urban interface: the importance of nonfarmer and farmer relations" in *Agricultural Systems*, urbanization, growth, and development of rural, agricultural areas is assessed. Here, the authors examine these topics in the context of farming and entrepreneurial adaptations, in addition to how farmers might attempt to develop various forms of social capital and “neighborly relations" with “nonfarm neighbors to mitigate social constraints created by nonfarmer concerns at the rural-urban interface” (Sharp and Smith, 2003, p. 913). The authors discuss some of the challenges that farmers are currently facing, including tensions between “nonfarm, rural residents” as well as urban areas as urban and agricultural areas begin to be closer together (Sharp and Smith, 2003, p. 914). Expectations presented by community members and other nearby farmers may constrain farmers, particularly as rural areas become more densely populated (Sharp and Smith, 2003, p. 914). A key recommendation by the authors states that “for agriculture to continue to be valued as a part of communities at the rural-urban interface, there is a need for community development that creates social capital and increases understanding of the protection, environmental, and aesthetic goals of diverse local stakeholders" (Sharp and Smith, 2003, p. 925). Sharp and Smith see social capital as an important tool in mitigating tensions and obstacles, as well as potentially providing positive benefits to the viability of local agriculture (Sharp and Smith, 2003, p. 924).

In a chapter titled "The Power of Experience: Farmers' Knowledge and Sustainable Innovations in Agriculture" by Stuiver, Leeuwis, and van der Ploeg in the book *Seeds of Transition: Essays in Novelty Production, Niches, and Regimes in Agriculture*, the authors detail the importance of farmers' knowledge and the role it plays in bringing about sustainable innovations in agriculture. This knowledge and its role often differs significantly from the knowledge and role of scientists and researchers. The authors also discuss various institutional changes that may be required in agricultural knowledge systems in order to encourage scientists and researchers to implement more farmer knowledge in their agricultural studies.

Relevant Textbook Information

For this class we were assigned to read *The Year-Round Solar Greenhouse: How to Design and Build a Net-Zero Energy Greenhouse* by Lindsey Schiller and Marc Plinke, to provide greater context and background information on the purpose of creating a new greenhouse at the Dartmouth Organic Farm, as well as the benefits that would result for the Upper Valley community. Given that the Greenhouse Committee hopes to use part of the greenhouse as a research space, it is imperative that research findings are relayed back to the farmers. In Chapter 17, the book describes how to create a greenhouse environment that would be conducive to our aforementioned goals. The first goal is to have an integrated design that includes using organisms in the greenhouse such as worms and bees that are beneficial to the plants and vegetables chosen. The soil is also important when discussing organic matter, as it is essential that soil contains rich organic matter, allows for healthy biologic activity, drains well, is rich in nutrients, low in salts, and has a neutral pH. When creating a planting plan, insects play a huge role, thus picking plants that are beneficial to certain insects such as alyssum, composite flowers, chives, dill, fennel, marigold, and mint are worth looking into. Additionally, plants that are nitrogen-fixers and that mimic nature are good for experimentation. Although insects are important in this system, it is also important to remember that pests exist. Therefore, a pest management system must be taken into consideration and implemented. Finally, water sources must be considered when constructing the greenhouse and a functioning, manageable watering system must be installed.

APPENDIX E

Resources and Deliverables:

1. Working document for other funding opportunities for farmers: https://docs.google.com/spreadsheets/d/1AHMkXHL_jb0t-jaC4vQTGncMIoe2JI8wkKi9iifElBo/edit?usp=sharing

Grant Name	Organization	Amount	Application Details	Who qualifies

USDA Rural Energy for America Program Renewable Energy Systems & Energy Efficiency Improvement Grant	USDA	$20,000 or less	To complete an application for this program, you must be pre-registered with the System for Award Management (SAM) and also have a Data Universal Number System (DUNS) number. Neither of these applications cost money, but they can take time so be sure to get this taken care of right away. If you are already registered with these systems, you do not need to do it again.	agricultural producers with at least 50% of their gross income coming from agricultural operations; small businesses in eligible rural areas
SARE Grants	USDA Sustainable Agriculture Research and Education	Varies depending on grant	Submit Project Report - Grants are administered by SARE's four regional offices. Visit the appropriate region to learn which grant type is right for you and to access application instructions	Farmers, Researchers, Graduate students, Extension agents and other educators (only within U.S.)
Value Added Producer Grants	USDA	Planning Grants $75,000; Working Capital Grants: $250,000	Applicants should put together the required information at least a month before the application deadline. The extra time allows collection of other required materials such letters of commitment or support from other organizations, a work plan and budget, and other information. Copies of required forms are available from your nearest Rural Development Office. See the Forms & Resources tab for optional forms that may assist you in	Independent producers, agricultural producer groups, farmer- or rancher-cooperatives, and majority-controlled producer-based business ventures, as defined in the program regulation, are eligible to apply for this program.

			developing your application.	
Foundation for Food and Agriculture Research Grants	Foundation for Food and Agriculture	Broad Range depending on category/type of project/research	You must apply to an open funding opportunity through the online Grant Management System.	We support research addressing big food and agriculture challenges. This research generates actionable results that benefit farmers, consumers and the environment.
	U.S. EPA			
	NSF CNH			
Agriculture and Food Research Initiative - Foundational and Applied Science	EPA			
Energy, Power, Control, and Networks (might not be related to ag enough for farmers to get it)	NSF			

2. Local Farm Information: https://docs.google.com/spreadsheets/d/1YSlcHDxTxvj-3d5p23HVbgSh4fj8P7NiHqxwicUkmK0/edit?usp=sharing

Farm Name	Farm Contact Name	Did we get an email response?	Was there a phone call?	Was there an interview?
Long Wind	Dave Chapman	Yes	Yes	Yes
Hip Peas	Dan Birnstihl	Yes	Yes	Yes
Sunrise	Chuck Wooster	Yes	No	No
Edgewater	Pooh Sprague	Yes	Yes	No
Red Shirt	Jim Schultz	Yes	Yes	Yes
Cedar Circle	Michelle Shane	Yes	Yes	Yes

3. Long Wind Farm questions: https://docs.google.com/document/d/1K_zdzDoPMmyVsKYxxf-tL2fNKYTNsItvIu_gtpJg4MY/edit?usp=sharing

4. Hip Peas Interview Notes: https://docs.google.com/document/d/17r0IeB0wSXCqU6HhHiVTjC-RAAKOVzewdEQDY6FC4Rw/edit?usp=sharing
5. Red Shirt Farm Interview Notes: https://docs.google.com/document/d/1vodo43Vv1Yq4jhJmqkDA3wPQ-FU5Ggf6whqvWOumPek/edit

APPENDIX F

Calculation Formulas and Variables:

Formulas:

- Heat transfer in BTU/hr through surface area A: H = $A\ U\ (t_i - t_o)$ where U is the U value of the material, t_i is the interior temperature, and t_o is the outside temperature.

- Heat transfer through a roof in BTU/hr: $H = 1.15\ A\ U\ (t_i - t_o)$ -- includes 1.15 multiplier because of radiation into space

- Embodied carbon of concrete: E= V(C) where V is the volume of concrete in cubic yards, and C is CO2 emissions in pounds per cubic yard. C=400lbs/yd3 per Concrete.org.

- Climate battery soil thermal mass and water thermal mass heat capacity calculations

  - Water thermal mass: 1103 cubic feet

  - Soil thermal mass: 4800 cubic feet

  - Water specific heat capacity: 4.18 J/(cm^3*K)

  - Wet soil specific heat capacity: 1.28 J/(cm^3*K)

  - Total specific heat capacity of water thermal mass: 130,553,940 J/K

  - Total specific heat capacity of wet soil thermal mass: 173,977,600 J/K

APPENDIX G

Longevity and Material Properties:

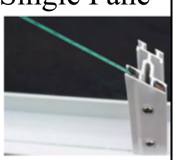
The longevity and effectiveness of a greenhouse depends on the unique properties of construction materials.

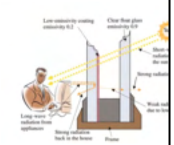
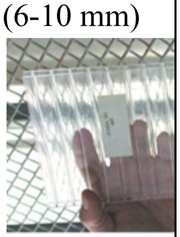
(1) Glazing is the translucent material that covers a greenhouse . When selecting a greenhouse glaze, the design must consider the materials' properties such as longevity, strength, weight, cost, light transmittance, thermal conductance, maintenance requirements, and flammability (Evans, n.d.).

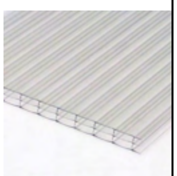
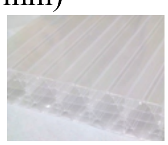
Glazing Key Terms:

Light Transmittance	Describes the quantity of available light transmitted by the material.
R-Value	Resistance to heat-transfer (insulating quality). U-Value (measures heat transfer) is the inverse of the R-Value and is thus not included in the following tables.
Life Cycle Assessment (LCA)	Cradle to grave analysis of environmental impacts encompassing all stages over a product's lifetime
Yield Tensile Strength	The resistance of a material before permanent deformation occurs. Can be measures with PSI
PSI	Pounds per square inch

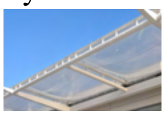
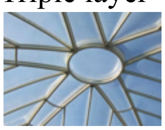
Glazing Options:

Tempered Glass	Longevity (in Years)	Light Transmittance	R-Value	Yield Tensile Strength (PSI)	Cost (per sq. foot)	Material Properties	Sustainability
Single Pane 	25+	88-93 %	0.9	9,427	Low	- Low R-value - Heavy - Can shatter	- Glass is not biodegradable - LCA of 2.94 kg CO2 eq m^{-2} $year^{-1}$ - Material recycling carbon footprint -417 +/- 176 kg CO2 e/t
Double Pane 	25+	75-80 %	1.4	9,427	Moderate $5	- Balanced light transmission and insulation efficacy - Can be sealed well - Heaviness requires framing support	- Glass is not biodegradable - LCA of 2.94 kg CO2 eq m^{-2} $year^{-1}$ - Material recycling carbon footprint -417 +/- 176 kg CO2 e/t

						- Can shatter	
Double pane, Low-e 	25+	60-70 %	2-4	9,427	High	- High cost -Roof applications	- Glass is not biodegradable - LCA of 2.94 kg CO2 eq m^{-2} $year^{-1}$ - Material recycling carbon footprint -417 +/- 176 kg CO2 e/t
Polycarbonate	Longevity (in Years)	Light Transmittance	R-Value	Yield Tensile Strength (PSI)	Cost	Material Properties	Sustainability
Single Layer 	10-15	90%	0.9	8,500-10,200	Low	- Low cost - Low efficiency - Can be bent over a curved frame(semi-rigid) - Resistant to hail - Lightweight - Easy installation - Required complementary parts (special screws for thermal expansion, edge vapor barrier, end caps, gaskets)	- Plastics are not biodegradable - Plastics are pollutants - LCA of 1.45 kg CO2 eq m^{-2} $year^{-1}$
Double wall (6-10 mm) 	10-15	80-85 %	1.5-2	8,500-10,200	Low-Moderate $3	- Low-moderate cost - Light-weight and durable - Low R-values - Resistant to hail - Lightweight - Easy installation - Required complementary parts (special	- Plastics are not biodegradable - Plastics are pollutants - LCA of 1.45 kg CO2 eq m^{-2} $year^{-1}$

						screws for thermal expansion, edge vapor barrier, end caps, gaskets) - Wide range of roof and wall applications	
Triple wall (8-16mm) 	15-20	70-80 %	1.8-2.3	8,500-10,200	Moderate $5	- Moderate Cost - Good balance of insulation and light transmission - Susceptible to thermal expansion - Recommended for colder climates - Resistant to hail - Lightweight - Easy installation - Required complementary parts (special screws for thermal expansion, edge vapor barrier, end caps, gaskets)	- Plastics are not biodegradable - Plastics are pollutants - LCA of 1.45 kg CO2 eq m^{-2} $year^{-1}$
5-layer (32 mm) 	15-40	50-60 %	4	8,500-10,200	High $7	- High cost - Very insulating - Low light transmission - Recommended for harsh and sunny winter climates - Resistant to hail - Lightweight - Easy installation - Required complementary parts (special screws for thermal expansion, edge vapor barrier, end caps, gaskets)	- Plastics are not biodegradable - Plastics are pollutants - LCA of 1.45 kg CO2 eq m^{-2} $year^{-1}$

Polyethylene	Longevity (in Years)	Light Transmittance	R-Value	Yield Tensile Strength (PSI)	Cost	Material Properties	Sustainability
	2-4	90%	0.83	1,450-2,030	Low $0.01	- Low cost - Short lifespan - Poor thermal performance - Poor sealing ability -Easily damaged	- Plastics are not biodegradable - Plastics are pollutants - Material recycling carbon footprint 29-155 kgCO2 e/t
Acrylic	Longevity (in Years)	Light Transmittance	R-Value	Yield Tensile Strength (PSI)	Cost	Material Properties	Sustainability
Double wall (16mm) 	20-30	80-90%	2	6510-12,500	Moderate $5	- Moderate cost - Longer lifespan - Bends over a shallowly cured frame - Strong - Recommended for roofs and wall applications	- Plastics are not biodegradable - Plastics are pollutants - Mixed plastics recycling carbon footprint 339 kgCO2 e/t
Ethylene Tetrafluoroethylene (ETFE) film	Longevity (in Years)	Light Transmittance	R-Value	Yield Tensile Strength (PSI)	Cost	Material Properties	Sustainability
Single layer 	25-30	85-95%	1	5,100	High Cost $125-175	- Lower carbon footprint - Long-lasting - Very elastic - Lightweight -Non-adhesive	-100% recyclable - Minimal energy required for transportation and installation

						properties produce a "self-cleaning effect" - needs reinforcing for stability	
Double layer 	25-30	85-95 %	2.0	5,100	High Cost $125-175	- Lower carbon footprint - long-lasting - very elastic - lightweight -non-adhesive properties produce a "self-cleaning effect"	-100% recyclable - minimal energy required for transportation and installation
Triple layer 	25-30	85-95 %	2.9	5,100	High Cost $125-175	- Lower carbon footprint - long-lasting - lightweight - very elastic -non-adhesive properties produce a "self-cleaning effect"	-100% recyclable - minimal energy required for transportation and installation

(2) Frames provide the greenhouse' structural stability

Frames Key Terms:

Tensile Strength	The resistance of a material to break under tension.
PSI	Pounds per square inch

Type	Material Properties	Tensile Strength (PSI)	Longevity (in Years)	Sustainability
Galvanized Steel	- Strongest building material suitable for snow and wind loads - Durable	76,870-88,473	70+	- Recyclable (zinc and steel) - LCA of 17.3 MJKg

	- Requires specialized foundation - Can be insulated in a variety of ways, including with metal panels - Recommended for greenhouses sized from 1,000 to 3,000> sq. ft.			
Aluminum Frame	- Low-maintenance (no re-painting required) - Reduces energy efficiency because it is an excellent head conductor - Recommended for greenhouses sized from < 1,000 to 3,000> sq. ft.	34,809 - 50,763	40-45	- Releases pollutants during the mining process - Aluminum is abundant in nature, constituting 8% of the earth's crust - 231.9 MJ/kg to produce primary aluminum - 16.233 MJ/kg to produce secondary aluminum - Aluminum is easily recycled without any quality degradation, thus making it more sustainable with more uses
Polyvinyl chloride (PVC)	- Resistant to environmental degradation - Strong tensile strength	2,080-7,790	75-100	- 79-84 MJ/kg to produce - 100-year total embodied energy: 73,000 MJ/100' (8") - Production emits damaging substances such as chlorine gas, dioxin, ethylene, vinyl chloride, phthalates, and

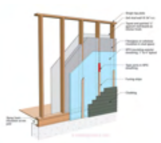
				mercury. - Easily recyclable

(3) Walls provide insulation to the greenhouse structure.

Wall Key Terms:

R-Value	Resistance to heat-transfer (insulating quality). U-Value (measures heat transfer) is the inverse of the R-Value and is thus not included in the following tables.
PSI	Pounds per square inch

Type	Brand	Product Name & Brand	Thickness	R Value	Wall Properties	Sustainability
Steel	Metl-Span	LS-36™ Insulated Roof and Wall Panel	2.5”	20.37	- Made with either galvanized steel or aluminum-zinc coated steel	-Foam core is foamed-in-place, non-CFC & zero ODP polyurethane
Concrete (foam forms around concrete)	Durisol Building Systems	Durisol 3.5” foam inserts	12”	21	- Expensive - Good for attached greenhouses	- Portland cement, a constituent of concrete, emits 1 ton of carbon dioxide and 1 ton of other GHGs per ton of Portland cement. - Cement utilizes limestone - a non-renewable resource

Wood 	NA	2x6 Advanced Frame Wall	8”	23	- Durability risks: moisture damage from rain water penetration, condensation is decreased with insulating sheathing but still a threat - Stud space can be insulated with Fiberglass batt,sprayed cellulose, sprayed fiberglass, and blown cellulose,	- Wood is a renewable resource

(4) The Foundation is a greenhouse’s backbone, preventing shifting from the pressures of time and weather conditions.

Type	Description	Material Properties	Longevity (in Years)	Sustainability
Concrete Piers	- Tubes of concrete buried in the soil below the frost line	- Moderate cost - Fast installation - Suitable for wide range of sizes and applications	70-90	- Portland cement, a constituent of concrete, produces emits 1 ton of carbon dioxide nd 1 ton of other GHGs per ton of portland cement. - Cement utilizes limestone - a non-renewable resource
Concrete Wall and Footer	- Concrete wall below the frost line	- Very expensive - Useful for	70-90	- Portland cement, a constituent of

	and anchored by a footer	attached greenhouses		concrete, produces 1 ton of carbon dioxide and 1 ton of other GHGs per ton of portland cement. - Cement utilizes limestone - a non-renewable resource
Insulated Concrete Forms	- Interlocking blocks of foam insulation with a central void	- Relatively inexpensive - Highly insulated foundations (R value = 20). - Fast installation	70-90	- Portland cement, a constituent of concrete, emits 1 ton of carbon dioxide and 1 ton of other GHGs per ton of Portland cement. - Cement utilizes limestone - a non-renewable resource

(5) Pipes intake air from the peak of the greenhouse, circulate air underneath the structure in a network of pipes called a manifold, and return air to plant level where moderal temperatures are ideal.

Pipes Key Terms:

Embodied Energy	Energy consumed by all processes, from mining and processing resources to product delivery

Type	Material Properties	Longevity (in Years)	Sustainability
Polyvinyl Chloride (PVC) Pipes	- Resistant to environmental degradation - Strong tensile strength - Does not corrode - Sustains smoothness over time - Cost-efficient and relatively sustainable	75-100	- Production emits damaging substances such as chlorine gas, dioxin, ethylene, vinyl chloride, phthalates, and mercury. - Easily recyclable - PVC energy pumping demand is 50% less than HDPE - 100-year total embodied

			energy: 73,000 MJ/100' (8")
Corrugated High Density Polyethylene (HDPE) Pipes	- Potential for oxidation - Potential for strain creep (deformation) - not subject to internal corrosion - smooth inner wall	50	- HDPE energy pumping demand is 100% more than for PVC - 100-year total embodied energy : 186,000 MJ/100' (8")

(6) Fans drive the flow of air through the greenhouse's pipe system.

Fans Key Terms:

Rotations Per Minute (RPM)	The number of fan rotations per minute. A higher RPM delivers greater air circulation.

Type	Material Properties	Longevity (in Years)	Sustainability
⅓ HP HAF Fans 	- open hinged front wire guard for easy maintenance - Motor allows variable speed operation - Single-phase direct drive motor provides up to 1725 RPM. - Totally enclosed motor with sealed ball bearings, automatic thermal overload protection - 3 aluminum fan blades. - Powder coat finished fan guard to resist corrosion - Hot dipped galvanized bracket to resist corrosion - 10'L, 115V/230V power cord.	- 2 Year Limited Warranty	- Releases pollutants during the mining process - Aluminum is abundant in nature, constituting 8% of the earth's crust - 231.9 MJ/kg to produce primary aluminum - 16.233 MJ/kg to produce secondary aluminum - Aluminum is easily recycled without any quality degradation, thus making it more sustainable with more uses

APPENDIX H

Barn Raising Event Handouts:
https://venngage.net/ps/o7z84IjKKXo/barn-raising-brochure

Building Instructions

Materials

- 1500ft 4" socked corrugated perforated drain pipes
- 8x 5" diameter manifolds, max. 17' long
- 4x intake pipes
- 4x exhaust pipes
- 4x thermostats
- 4x 20" 1/3HP HAF fans, capable of pushing 5,000+ CFM
- Rigid foam board, either polystyrene or polyiso

Instructions

- The ground must be excavated to the appropriate depth, usually around four feet deep, using a skid steer or hydraulic excavator. Be sure this is above the water table.
- Lay out pipes with approximately 2-foot spacing. Pipes should be equal in length. If using a multilayered design, either connect layers with longitudinal drain pipes or have them operate separately with individual fans and exhaust pipes.
- Build the greenhouse.
- Install intake fans so they reach the peak of the greenhouse.
- Install inline fans into the intake pipes.
- Install exhaust pipes so they reach about plant level.
- Install thermostats that automatically turn on fans when cooling or heating is necessary.

About Us

"Dartmouth's Big Green-Energy House offers the opportunity to showcase a lasting project that fosters good health and well-being by furthering resilience on three levels (individual, social, and natural environment) and motivating the execution of other collaborative efforts in education, research, and transitions in sustainability." - Professor Theresa Ong

In planning for the "Dartmouth Big Green-Energy House," the Environmental Studies capstone class of Spring 2021 hopes to pioneer a path towards the adoption of energy-efficient 4 season greenhouses not only in New England but throughout cold winter regions generally, further strengthening local food networks and improving access to organic, locally sourced, nutritional produce year-round.

GET IN TOUCH

Find us on Instagram: @DartmouthBigGreenEnergyHouse
Facebook: Dartmouth Big Green Energy House
& at our blog: https://journeys.dartmouth.edu/biggreenenergyhouse/
Email: Theresa.W.Ong@Dartmouth.edu

Climate Batteries

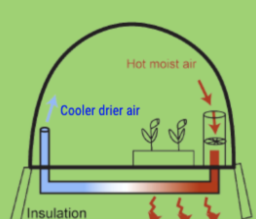
Dartmouth Big Green-Energy House

What is a climate battery?

The new Dartmouth Greenhouse will increase from a three-season greenhouse to a four-season greenhouse. This is because of the implementation of climate batteries. Climate batteries received the name 'battery' because of their capability to store energy and heat, and have those energy stores be called on to heat the greenhouse on demand, even in the deep freeze of Hanover winters. Climate batteries are a network of tubes, fans, and insulated soil mass that store heat for long periods of time. The tubes store heat while the fans circulate that energy into the greenhouse as needed to maintain ideal growing conditions.

Why use one?

At Dartmouth, we have a mission to challenge our institution and its students to engage with the intersectional human and environmental problems of a rapidly changing planet and to utilize the strength we have in the realms of research, innovations, teaching models, and human capital in order to tackle global sustainability challenges. Geothermal energy is considered a renewable resource, one that replenishes to replace the portion depleted by usage, which means that it can play an important role in reducing the use of fossil fuels and other non-renewable energy alternatives that are harmful to the environment.



Barriers

- Can be costly (Dartmouth's design will cost roughly $120,000
- COVID-19 raises additional challenges with labor shortages and higher costs of building materials
- Zoning must be considered, and other compliance issues (environmental impact assessments, Americans with Disabilities Act
- Alternatives can include thermal mass or active heating systems

Benefits

- Environmental: Increased efficiency can lower greenhouse gas (GHG) emissions and other pollutants, as well as decrease water use
- Economic: Improving energy efficiency can lower individual utility bills, create jobs, and help stabilize electricity prices and volatility
- Utility System: Energy efficiency can provide long-term benefits by lowering overall electricity demand, thus reducing the need to invest in new electricity generation and transmission infrastructure

Additionally, there is no visible or exposed outdoor equipment, it's quiet, it has dual heat and cooling, and, because it is operable in the Winter, it can maximize crop output by transitioning your 3-season greenhouse to 4 seasons!

APPENDIX I

Barn-Project Factsheet:

Why is energy efficiency important? Why should farmers in the upper valley use it?

Environmental: Increased efficiency can lower greenhouse gas (GHG) emissions and other pollutants, as well as decrease water use.
Economic: Improving energy efficiency can lower individual utility bills, create jobs, and help stabilize electricity prices and volatility.
Utility System Benefits: Energy efficiency can provide long-term benefits by lowering overall electricity demand, thus reducing the need to invest in new electricity generation and transmission infrastructure.
Risk Management: Energy efficiency also helps diversify utility resource portfolios and can be a hedge against uncertainty associated with fluctuating fuel prices.

How does a climate battery or ground to air heat transfer (GAHT) system work?

"During the day when the greenhouse interior is being heated by the sun, the climate battery fans push this heated air from high in the greenhouse down through the underground heat exchange tubing. This warm, moist air cools as it runs through the tubing, depositing heat by conduction into the surrounding soil, and condensed water vapor with latent heat through perforations in the tubing. This cooled, dryer air returns to the greenhouse space, cooling and drying the greenhouse, and regaining its capacity to absorb moisture and heat from the greenhouse again. It is a simple form of the heat pump cycle, that takes advantage of the latent heat energy stored in water vapor, and the phenomenon of condensating said vapor by bringing the air temperature down to dew point through heat transfer to the cooler soil" (How Climate Batteries Work).

How it Works
Geothermal (also known as ground-source) heat pumps transfer heat stored in the earth into your building during the winter, and transfer it out and back into the ground during the summer to keep your space cool. Geothermal includes three principal components:

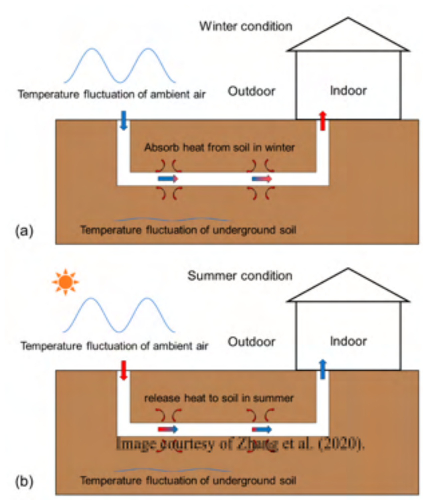


Image courtesy of Zhang et al. (2020).

Ground Loop
A series of connected pipes buried in the ground circulate water to absorb heat from, or relinquish heat to, the surrounding soil, depending on whether the equipment is providing heat or cooling. In other words, it uses the earth as a heat source during winter and a heat sink during summer.
Heat Pump
The mechanical system that compresses a refrigerant to efficiently move heat into or out of a building. During winter, the heat pump removes heat from the water in the ground loop and transfers it to the building. During summer, the process is reversed.

Heat Distribution Subsystem
Conventional ductwork is generally used to distribute heated or cooled air from the geothermal heat pump throughout the building.

How is a climate battery or GAHT system sustainable climate control / an example of green energy?

“A climate battery is a system that pushes warm humid greenhouse air underground through buried tubing to transfer heat to the greenhouse soil, storing heat energy for times of needed heating. We refer to the system of tubing, risers, manifolds, fans, and the insulated mass of soil it interacts with all as the climate battery. It is referred to as a battery for its capacity to store energy. Also known to be called a subterranean heating and cooling system (SHCS), Ground to Air Heat Transfer System (GAHT), geo-air exchanger, or “low-grade” geothermal” (Climate Battery FAQ).

Benefits:

- Uses energy more effectively. Heat pumps concentrate and transfer heat rather than generating it directly, delivering one-and-a-half to three times more heat energy to a building than the electrical energy they consume.
- Dual heat and cooling
- Cost savings
- Whisper quiet
- Lower emissions
- Filters and dehumidifies the air
- Easy to operate
- No visible or exposed outdoor equipment

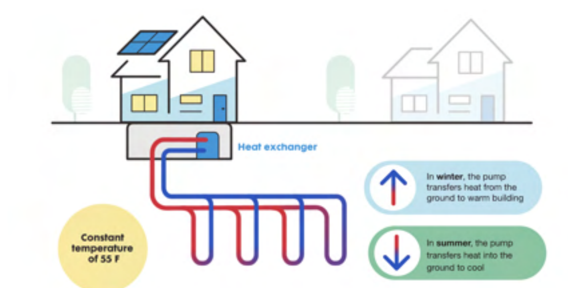


Image courtesy of: ConEd.com

What are community greenhouses? How do they empower our communities and promote resilience?

Our goal with this project is to construct a model climate battery greenhouse at the Dartmouth Organic Farm that will serve as an example of sustainable energy transitions for local farmers and community members. The “Dartmouth Big Green-Energy House” will serve as a lighthouse model of sustainable food production that provides research, education, and outreach opportunities with the overarching goal of encouraging sustainable energy transitions in agriculture (Ong et al., 2021).

The Big Green-Energy House will support the Organic Farm to grow crops year-round, benefitting the College and wider community, as the farm typically donates at least a third of their produce to local non-profits dedicated to alleviating food insecurity in the Upper Valley. We hope for the “Dartmouth Big Green-Energy House" to pioneer a path towards adoption of energy efficient 4 season greenhouses not only in New England but throughout cold winter regions generally, further strengthening local food networks and improving access to fresh, locally sourced, nutritional produce year-round. To do this, we will continuously solicit farmer ideas for future use-inspired convergent research questions (Ong et al., 2021).

The “Dartmouth Big Green-Energy House” is comparable to a community garden. Community gardens are plots of land used for growing food by people from different groups/communities, typically people with limited access to their own land. Distinct from top-down efforts by government organizations to create green spaces such as botanical gardens, community gardens are bottom up, community-based, collaborative efforts to grow food. Whether cultivated through a system of individual/family plots, or tended as a whole by a group of citizen volunteers, community gardens involve the leadership and active participation of area residents to plan and care for these socio-ecological spaces (Okvat and Zoutra, 2011).

Empowerment is ‘a process: the mechanism by which people, organizations, and communities gain mastery over their lives (Perkins, 1995). Theoretically, community gardening could contribute to empowerment outcomes such as mastery and sense of control, largely via control of resources (food, land, tools) by disadvantaged people, and enhance connections, health, and well-being, because community gardening involves multiple empowerment processes. For example, connecting with others, participation in decision-making, targeting local issues, and resisting globalization (of food production) might have empowering influences (Okvat and Zoutra, 2011).

Koay and Dillon (2020) examined the relationship between community gardening and a number of mental health benefits, in the forms of subjective well-being, stress, resilience potentials, and resilience factors (self-esteem, optimism, and openness). Their results indicate that, after controlling for age and levels of connection to nature, community gardeners reported significantly higher levels of subjective well-being than individual/home gardeners and non-gardeners, indicating that engagement in community gardening may be superior to individual/home gardening or non-gardening outdoor activities. Further, community gardeners reported higher levels of resilience and optimism than the non-gardening control group.

Many studies propose that, when individuals experience stressful life events, their positive assets such as trait resilience and self-efficacy can be activated to support them for successful adaptations and active coping. The construct of resilience can be employed to illustrate the ability to bounce back from stress to optimal levels of well-being. Alternatively, resilience refers to the ability to enable individuals to adapt to hardships or the ability to enable individuals to adapt well to stressful situations and the ability to deal with shocks and unexpected changes. Community gardening has been proposed as a means to foster good health and well-being by furthering resilience on three levels (individual, social, and natural environment), strengthening social resilience, and motivating the execution of other neighborhood improvements.

How will the efficacy of this project’s climate battery be measured/evaluated?

The Irving Grant Proposal for the Dartmouth Big Green-Energy House proposes a method for measurement.

“To evaluate the efficacy of climate batteries, the greenhouse will include a wall separating experimental and control sides and a switch to manage battery function. Students will research NOFA (Northeast Organic Farming Association) guidelines for battery construction and propose designs that optimize thermal energy and light efficiency for our region within the practical constraints voiced by farmers. In evaluating options, students will consider criteria including cost, ease of installation, and coefficient of performance (COP), which is a ratio of the energy produced by and required to operate the system. While our climate battery will serve as the main heat source, existing solar panels at the Dartmouth Organic Farm can serve as a clean energy source for backup heat and lights.”

“Once the greenhouse is built, sensors will be installed in a standard grid throughout the greenhouse floor and also vertically, paired with outdoor sensors that measure ambient temperature, soil temperature, and moisture. Energy audits will be conducted and autochambers installed to measure soil carbon fluxes and other greenhouse gas emissions in control and battery plots.”

"To understand implications for production and ecological sustainability, we will plant mono and intercropped plots of Solanum lycopersicum and Solanum tuberosum, tomato and potato seedlings in the ground. These two closely related Solanaceous plants differ in allocation of resources to above or below ground tissue, a tradeoff well documented in plants. We will measure wet and dry mass along with fruit and tuber yields to assess impacts of climate battery technology on above and below ground growth allocations in polyculture and monoculture production systems. To assess fruit and tuber quality, sugar content will be measured using a refractometer. Slower, more even growth can increase sugar and nutrient content, improving taste and nutrition. Finally, we will use economic models to estimate net profits from yield and quality of crops minus the energy and infrastructure costs incurred with and without a climate battery" (Ong et al., 2021).

What potential barriers exist to implementing a climate battery at your farm?

Given the scale and novelty of constructing a greenhouse powered by renewable energy with passive heating applications such as the Big Green Energy House, barriers are inevitable during development of such a project. The cost of a comparable project is estimated to be roughly $120,000.00, with the largest portion of that sum embedded in labor and construction costs. We recommend hiring a project manager, as well, who will oversee development of the greenhouse. It should also be noted that developing during the COVID-19 pandemic may pose additional challenges with labor shortages and exceeded costs of building materials due to supply chain disruptions. With any development project, zoning is always a major factor to consider prior to groundbreaking. Anyone who wishes to construct a greenhouse must be in accordance with local, state, and federal zoning regulations and may have to be in touch with governments, construction consultants, and environmental regulation agencies to ensure the project is adequately zoned for erection. An EIA (environmental impact assessment) should be conducted prior to groundbreaking; many independent environmental consulting agencies will do this for a few thousand dollars. ADA compliance and required setbacks (typically around 50ft) are also important factors to consider. The good news with developing a project like a greenhouse is that while upfront costs may be steep, long term yields should be bounteous with minimal upkeep. With any renewable energy project, a greenhouse especially, the developer's ROI (return on investment) will be high. In essence, most costs are upfront. From a design standpoint, most materials associated with development are now being mass produced and easily sourced with the exception of climate batteries and passive heating systems. Such technologies will comprise the brunt of the cost; however, the climate battery using GAHT system technology is also largely responsible for positive environmental impact and significantly lower energy costs throughout the life of a greenhouse. Alternatives to climate batteries include active heating systems, which are typically either powered by steam or electricity, depending on local infrastructure.

Appendix I Works Cited:

Climate Battery FAQ. *Eco Systems Design, Inc.*, http://www.ecosystems-design.com/faq.html.

Climate Battery Greenhouse. *Threefold Farm*. https://threefold.farm/climate-battery-greenhouse.

DIY Greenhouse Plans. (2018). *Ceres Greenhouse*. https://ceresgs.com/greenhouses/diy/.

Ogden Publications. *How to Design a Year-Round Solar Greenhouse*. Mother Earth News. https://www.motherearthnews.com/organic-gardening/how-to-design-a-year-round-solar-greenhouse-zbcz1502.

Environmental Protection Agency. (2018). Local Energy Efficiency Benefits and Opportunities. *EPA*.

Farm-Energy. (2019). Introduction to Energy Efficiency and Conservation on the Farm. *Farm Energy*.https://farm-energy.extension.org/introduction-to-energy-efficiency-and-conservation-on-the-farm/.

GAHT Systems: A Geothermal Option. *Ceres Greenhouse.* https://ceresgs.com/environmental-controls/gaht/.

How Climate Batteries Work. *Atmos Greenhouse Systems*. https://atmosgreenhouse.com/how-climate-batteries-work.

Koay, W. I., & Dillon, D. (2020). Community Gardening: Stress, Well-Being, and Resilience Potentials. *International Journal of Environmental Research and Public Health*, 17(18), 6740.

Li, Guozhen & Tang, Llewellyn & Zhang, Xingxing & Dong, Jie & Xiao, M. (2018). Factors affecting greenhouse microclimate and its regulating techniques: A review. *IOP Conference Series: Earth and Environmental Science.* 167. 012019. 10.1088/1755-1315/167/1/012019.

National Foundation for Educational Research in England and Wales, & Dillon, J. (2005). Engaging and learning with the outdoors: The final report of the outdoor classroom in a rural context action research project.

Okvat, H. A., & Zautra, A. J. (2011). Community gardening: A parsimonious path to individual, community, and environmental resilience. *American journal of community psychology*, 47(3-4), 374-387.

Ong, T., Hicks Pries, C., Braasch, L., McBride, M., and Danieu, A. (2021). The Dartmouth Big Green-Energy House: impacts of geothermal energy technology for agriculture. Proposal: *Irving Institute for Energy and Society*.

Perkins, D. D., & Zimmerman, M. A. (1995). Empowerment theory, research, and application. *American journal of community psychology,* 23(5), 569-579.

Schultz, J. Climate Battery Greenhouse: Energy Efficient and Sustainable Winter Growing. *Northeast Organic Farming Association of Massachusetts*. https://www.nofamass.org/wp-content/uploads/2020/07/Fact-Sheet-6-8-5x11-1.pdf.

Zhang, Chong & Wang, Jinbo & Li, Liao & Wang, Feifei & Gang, Wenjie. (2020). Utilization of Earth-to-Air Heat Exchanger to Pre-Cool/Heat Ventilation Air and Its Annual Energy Performance Evaluation: A Case Study. *Sustainability*. 12. 8330. 10.3390/su12208330.

Videos:

YouTube. (2019). How to Build a Greenhouse. *YouTube*. https://www.youtube.com/watch?v=Bbibe0yuiew.

Climate Batteries. *Eco systems design, inc.* http://www.ecosystems-design.com/climate-batteries.html.

YouTube. (2020). How To Build a Climate Battery - Day 3 - Construction In Passive Solar Greenhouse. *YouTube*. https://www.youtube.com/watch?v=5g92Smw2Hic&list=RDCMUChqxlr587JCD5I9veE62s1w&start_radio=1&rv=5g92Smw2Hic&t=648.

APPENDIX J

COVID-19 Restrictions & Policies for Student Events:

Event/Activity is Characterized as:

- A group of any size, but no greater than twenty-five in-person.
- Hosted by a college recognized organization or department/office.
- Registered with the College and hosted in an approved College space.
- Following all facility expectations, room requirements, and College policies.
- Any use of organization funds.

Health & Safety/Social Distancing

- Masks/face coverings are required at all gatherings/events/activities.
- All events/activities/meetings must follow physical distancing guidelines.
- Physical distancing, also known as social distancing, means keeping a safe distance, at least 6 feet or the length of two arms, between yourself and other people who are not from your household. This applies in both indoor and outdoor spaces.
- Physical distancing should be practiced in combination with other preventive measures including, but not limited to, wearing a cloth face covering, not touching your face with unwashed hands, covering your nose and mouth with a tissue when coughing or sneezing, and washing your hands often with soap and water for at least 20 seconds or using a hand sanitizer that contains at least 60% alcohol if soap is not available.
- Students holding events must wipe down all surfaces used after their event. Materials for sanitizing surfaces will be provided in designated event locations.
- Organizations/departments are required to take attendance at events and record participants.
- Anyone that is experiencing COVID symptoms must not attend any in person event.

Event Capacity: Event gathering sizes must follow Dartmouth's Event Limit policy and follow facility occupancy guidelines. For occupancy information, please visit EMS (Dartmouth's reservation system)

- Gatherings or events are limited to no more than 9 people if unscheduled, and no more than 25 for gatherings/events that are scheduled.
- Organizers of events and gatherings of fewer than 9 people should continue to ensure that there is adequate space (typically one-third of room capacity) to accommodate the event and participants.

Location of Events/Activities/Meetings: Events/activities/meetings will be limited to specific locations on campus only. No off-campus events are permitted unless approved by the Office of Student Life (in consultation with the COVID Core Group as needed). For a list of locations, please visit EMS to make a reservation.

Event Registration and Attendance: All events/meetings/activities of any size must be registered through the recognizing department or office. Most student organizations will use the Engage platform to register events. Attendance must be tracked for all events/meetings/gatherings and be kept within Engage or another system determined by the overseeing office. More details will be provided by the overseeing department, but the event registration/reservation process will follow these steps:

- Register event in Engage. (http://engage.dartmouth.edu)
- Department reviews event.

- Reserve space in EMS (http://ems.dartmouth.edu)

Tabling: Tabling is permissible in specific outdoor locations with prior approval for informational purposes only. Social distancing guidelines must be enforced, and organizations are encouraged to limit interaction with others. Individual materials, single-serve/individually packaged food and beverage, giveaways, and swag are permitted.

Food/Beverage: Only small, single serve/individually packaged food and beverage items are permissible at events/meetings as long as facilities/space policies and social distancing protocols are followed. No food may be consumed in spaces where eating is prohibited. No serving, sharing, or cooking of food is allowed.