Greenhouse Hydroponics:

<u>**Table of Contents**</u>

Abstract: Sustainable food procurement and alternative farming have gained significant traction in recent years as powerful mechanisms in addressing social and environmental issues of sustainability. Moreover, college campuses are at the frontline of many sustainability efforts in our country. Those experimenting with and supporting alternative farming production methods, specifically hydroponics, have reaped considerable benefits academically, sustainably, even economically. Hydroponics, a typically greenhouse production method wherein crops grow submerged in nutrient solution rather than soil, wield many advantages over soil-based conventional farming methods, and show evidence on college campuses of academic engagement between students and their communities and reduction in food miles. The purpose of this research is to guide Skidmore in its consideration of investing in a hydroponic facility, a pertinent learning and sustainability tool that can assist the College in attaining its sustainable food procurement goals. To gather data on the feasibility and sustainability impact that hydroponics could have on Skidmore's campus, we conducted and analyzed student surveys, existing literature, regional stakeholder interviews, Skidmore records, and initiatives on college campuses in our region. Data from Skidmore student surveys, existing literature and consultation with relevant stakeholders all firmly support the financial, social, and sustainable benefits of hydroponic initiatives and that Skidmore is an ideal small scale venue for a successful hydroponic project. In sum, our findings indicate that even with low financial, labor, and energy investment, hydroponics is the best commitment in support of Skidmore's sustainable and educational goals, and can easily be maintained and scaled up for greater future yield and profit.

Key words: Hydroponic Farming; Sustainable Food Procurement; Greenhouse; NFT; Food Miles; Food Security; Sustainability.

food production closer to consumers. Hydroponics, a type of controlled-environment agriculture that primarily uses artificial lighting to grow plants stacked in layers, as an alternative production system can help achieve the dual goals of conservation of resources on limited land while also providing food security.[5]

It is important to acknowledge that hydroponic farming cannot completely replace the conventional production systems for crops that people grow and depend on today.[6] However, prolific studies in the field firmly support that the alternative farming method has the ability to provide food security for some communities and reduce loss of arable lands and biodiversity by using a fraction of the water and energy demands compared to conventional production methods.[7] Hydroponics as an alternative production system can be sustained under a variety of settings, from home projects to commercial systems. Particularly amongst higher education efficiency, while addressing food security and social justice issues.[9] When compared to conventional soil-based farming methods, soilless culture consumes roughly 1/20th of overall water, mitigating waste, pollution, and soil runoff.[10] By the same token, hydroponic farming demands 1/5th of the overall space.[11] This alternative farming system maximizes space and resource efficiency without compromising plant growth or quality, rather enhancing these components in some cases.[12] A range of high-nutrient-density crops from fruits, to vegetables, to flowers can be grown hydroponically.[13] With the exception of only a select few crops, such hydroponics, vertical farming, aeroponics, and aquaponics, all of which incorporate growing plants within different substrates under a climate controlled system. These systems are highly variable and adaptable to their surroundings and could potentially use renewable energy, towers, modular farms, or abandoned buildings. More technically, hydroponic farming refers to soilless contact with nutrient solution. Hydroponic farming can lead to significantly high yields compared to conventional agricultural methods, rendering it perhaps the best crop production system for our climatic area.[18]

The ultimate aim of these alternative systems is to farm upwards rather than outwards to help reduce pressure on land traditionally converted and reserved for agriculture. These systems are particularly attractive for use in our region, in the Northeast, particularly in urban areas.[19] Short growing seasons and other geoclimatic conditions of the Northeast preclude high yields, production, and access to local produce all year round through conventional farming methods. In terms of greater community benefits, hydroponic farming can help communities facing food scarcity, especially during low light winter months to have fresh and clean produce year round. In the Saratoga Springs community, about 8% of the population is food insecure[20], half of which have been found to be potentially ineligible for government assistance[21]. Although not an immediate goal of our research, previous hydroponic studies have demonstrated the system's potential to be high yielding in such a short time through scaling up or upgrading, which means that extra produce could be provided to a local food bank or market for the purposes of charity at later stages of an application at Skidmore College.[22]

[18] Daina Romeo et al., *Environmental Impacts of Urban Hydroponics in Europe: A Case Study in Lyon,* (Denmark, Aarhus University, 2018).

[19] Andrew M. Beacham et al., *Vertical farming: a summary of approaches to growing skywards,* (UK, The Journal of Horticultural Science and Biotechnology, 2019).

[20] Healthy Capital District Initiative, *Food Insecurity Rate,* (Albany, Healthy Capital District Initiative, 2019).

[21] Healthy Capital District Initiative, *Food Insecure Children Likely Ineligible for Assistance,* (Albany, New York, Healthy Capital District Initiative, 2019).

[22] Vanessa Sulma, et al., *Economic viability for deploying hydroponic system in emerging countries: A differentiated risk adjustment proposal,* (Brazil, Federal University of Grande Dourados, 2018).

The project examines the applicability of a hydroponic facility at Skidmore College as a way to address the importance of locally sourced food and boost Skidmore's sustainable food goals. Academic institutions of all sizes and capacities across the country have been leaders at the forefront of sustainable innovation, including ambitious commitments to recycling[23], renewable energy[24], transportation alternatives[25] and alternative farming[26], as exemplified through campus plans and other sustainable initiatives. The Association for the Advancement in Sustainability in Higher Education (AASHE) recognizes that the influence, financial resources, and educational capacity that schools can afford to issues of sustainability place them in unique positions to become key leaders in the promotion of sustainable development.[27] Skidmore, with its autonomous nature from governing structures and its smaller scale administration, has

hydroponics, such as student demand, scale, and budget operations, and curate the best suggestions for Skidmore's needs and capacity.

3) Consultation and semi-

Limitations

We had to end the hydroponic pilot project and data collection related to testing the pilot project due to COVID-19 related measures and the closing of Skidmore as of mid-March 2020.

grow. (See Table 1, which outlines the initial budget for purchasing the necessary components of the pilot system)

The FM is advantageous for beginners as it requires minimal upfront costs, labor, maintenance, prior knowledge, and technology, and can have a relatively high productivity. Dr. Crosby relayed that electrical independence is preferable for maximal sustainable benefits, stating that if the “electricity goes off...nothing’s going to die” (Crosby, 2020). The consultations with Dr. Crosby further offered solid risk-mitigating strategies as we prepared for instances that something goes awry during the plants’ development process (e.g., FM systems can promote algae growth when the roots and water are subject to constant light exposure, hogging nutrients from the crop.) However, we learned that as long as the water reservoir is either opaque or shielded by a dark cover, the system should be full proof with daily check ins. The risk we did not plan for was the inability to continue daily check ins, as the COVID-19 related measures required shutting down all learning spaces and laboratories on campus.

Table 1: Pricing Sheet for Pilot Project Set Up

Pilot Project	Item	Quanity	Unit Price	Total Price

impressive 1,200 pounds of various vegetables, but production is unfortunately limited by the short growing season of the Northeast. Additionally, Mark Miller, Director of Skidmore Dining Services, shared that lettuce consumption alone amounts to nearly 250 pounds, or 166 heads, a week. Miller explains that “even when the garden grows lettuce, and they give us ten or twelve heads which is a great harvest, it will be gone by lunch period”. A hydroponic facility can see that Skidmore’s potential growing season is extended to an all year venture. Even better, our recommended hydroponic system, to be further detailed in our recommendations section, can produce 288 plants a week working at full capacity, significantly supplementing the quantity and selection of produce for our dining facilities, from basil, lettuce, spinach, and practically any other leafy green produce the Dining Services outsources.

We germinated the seeds in a propagation tray starting on January 28, 2020, seeding 98 rockwool cubes with varying numbers of five different plants as follows: 28 spinach seeds, 28 lettuce seeds, 14 basil seeds, 14 parsley seeds, and 14 cilantro seeds (**Figure 1**). Exactly three weeks later on February 18, over half of the seedlings (~54%) had sprouted, including 10 spinach sprouts, 28 lettuce sprouts, 13 basil sprouts, and 2 parsley sprouts, totaling 53 successfully germinated seeds. The following day, we transplanted the germinated seeds into the FM system, which was designed using a styrofoam board outfitted with 55 holes (**Figure 2**) manually cut out. The 2x3 foot flood table was filled with a nutrient solution composed of five gallons of water and 1.5 tablespoons of Pure Blend Pro Grow nutrient solution (**Figure 3**).

The images displayed show merely a glimpse of what this pilot would have potentially produced if COVID-19 had not derailed the project and its valuable data. We had intended to germinate another round of seedlings, replicating exact conditions and proportions, perhaps

III. Literature Review

Review of Hydroponic Systems

There are namely two techniques of hydroponics: solution culture and media culture method.[30] Fundamentally, hydroponic systems allow for plant roots to maintain direct contact with nutrient rich water solutions and ample oxygen. The solution culture method contains a few subcategories, but the technique generally allows plants to grow in a solution culture with their roots directly suspended in the nutrient solution.[31] In its variety of forms, solution culture hydroponics can adopt a wide array of technologies and methods for production.

The *continuous-flow solution culture method* employs a water pump to circulate the nutrient solution, recycling excess solution to reduce water waste. Daily m7(on,3 0 0 1 461.7 501.65 Tm0 00000 growth. In a greenhouse, these conditions can be either manually or automatically sustained. In the absence of proper nutrient requirements and regular monitoring of pH levels, electrical conductivity (EC), dissolved oxygen (DO) content, temperatures, relative humidity (RH), and CO_2 levels, the plants and system are subject to failure. The optimum pH range for the nutrient solution is 5.8-6.5, the optimum range for EC is between 1.5 to 2.5 dS/m, and optimum DO concentration is about 8 ppm.[34] Maintaining a temperature range in the greenhouse of 75-82 (~25) will provide optimum photosynthesis for the plants. As for CO_2 concentration, 1000 to 1500 ppm is optimal for speedier growth.[35] Any sudden or severe alterations to these environmental parameters can interfere with critical plant processes such as photosynthesis, respiration, transpiration, enzyme activity, and other chemical processes infecting or killing the plants.[36] All routine monitoring and/or daily maintenance can be performed at once and by one individual with knowledge of hydroponic systems.

Risks and Costs of Hydroponic Systems

As previously stated, there are potential risks involved when growing hydroponically, but they can all be mitigated with proper maintenance and technological assistance. Daily tasks can include monitoring or balancing pH and nutrient levels, water contamination, as well as monitoring climate conditions, pests, electrical blackouts, and other potential breakdown of system components. The more elementary the system, the less expensive it will be and less monitoring it would require. However, if the hydroponic system involves complex

[34] Fraz Ahmad Khan et al., *A Review on Hydroponic Greenhouse Cultivation for Sustainable Agriculture,* (Turkey, International Journal of Agriculture Environment and Food Sciences, 2018).
[35] Melissa Brechner & A.J. Both, Hydroponic Lettuce Handbook, (Ithaca, Cornell University, 2013).
[36] Ibid.

technological systems, prices and routine maintenance tend to increase to ensure everything is running at all times.

stakeholder data to inform us on the most economical and sensible hydroponic facility for Skidmore.

Fixed costs would be the bulk of Skidmore's upfront investment in a proposed hydroponic facility. Costs are associated with greenhouse material, construction, labor and other components of the selected system. Financing a potential greenhouse is the leading step to obtaining, installing and profiting from any given hydroponic system. Sulma and colleagues' (2018) report on the feasibility of hydroponic systems in emerging economies can provide comparable references for Skidmore and its limited budget. The investment proposal of a hydroponic alternative on small properties can achieve economic viability in about four to five months.[39] The article describes that the investment from a local bank was the "line of credit that piping to the roof of the greenhouse, collecting rainwater runoff to feed back into the growing reservoir.[42] Retrofitting even the most elementary hydroponic system with renewable energy technology is affordable and implementable.[43] Like any garden, labor and maintenance will be required to keep the system in check, as this will be another cost related risk.

With these potential risks in mind, there are fundamental mitigation efforts to make any hydroponic system more resilient. Research indicates that a controlled environmental greenhouse could be the first line of resilience, enabling the systematic optimization of climate and light for plant development.[44] Maintaining a hydroponic system indoors in a greenhouse or insulated room can also better manage pest control. By the same token, our capstone chose a hydroponic system that requires little up front cost, minimal maintenance, minimal prior technical knowledge, and can be managed over time by timers and technology. These relatively convenient aspects of the *Ebb and Flow system* match directly with Skidmore's fiscal and size capacity, minimizing resource consumption and maximizing yields under a modest budget.

Hydroponic Initiatives at U.S. Higher Education Institutions

Recognizing its plentiful benefits, including community engagement, food justice, environmental education, and consumer consciousness, higher education institutions in the U.S. have been supporting hydroponics. Hydroponics brings food production closer to consumers and provides opportunities of self-sufficiency for entire communities, cities, and college

[42] Jim Grefig, *Cornell Gardening Resources Horizontal Hydroponic Unit Plants,* (Ithaca, Cornell University, 2008).
[43] Daina Romeo et al., *Environmental Impacts of Urban Hydroponics in Europe: A Case Study in Lyon,* (Denmark, Aarhus University, 2018).
[44] Paolo Sambo et al., *Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective,* (Switzerland, Frontier in Plant Science, 2019).

campuses.[45] Amongst higher education institutions, hydroponics has worked as both an exceptional environmental learning tool and fiscally responsible way to achieve sustainable food procurement. A hydroponic initiative mandates student volunteerism and potential employment in order to maintain a consistent production cycle.

While some of these initiatives started and are run as a student club, some are incorporated into the research agenda of a faculty who oversees the operations and maintenance. Majority of these initiatives have started in the last decade with a donation from a regional business, alumni or student funds. While some of them still require additional funding to operate, the amount of food produced and supplied to their Dining facilities provides a fresh food source, a source of pride for the school (mainly Dining facilities, students and sustainability staff), and a learning opportunity to be integrated into STEM related classes. These models suggest that there is not one system that is favored over others; rather, schools choose different systems depending on their financial capacity and investment and interest of faculty, staff, and students that are key to maintaining the system. While it is important to note that some of the initiatives that started as student projects did not continue,[46] others continue to expand, such as at Ithaca College[47] and Goucher College.[48] What makes one system continue while another does not go beyond one-time initiative? The following examples discuss some of these key elements, from faculty and student dedication, to diverse funding sources to operate the system in its initial phases.

[45] Daina Romeo et al., *Environmental Impacts of Urban Hydroponics in Europe: A Case Study in Lyon*, (Denmark, Aarhus University, 2018).
[46] William J. Hopkins, *Good Food Project Goes Extremely Local with Hydroponic Window Farm*, (Pennsylvania, Swarthmore College, 2010).
[47] Paula Turkon, *Interview by Borowka et al.*, New York, April 22, 2020.
[48] Nicole Tocco Cardwell, *Lessons from Goucher C* *-op Farm*, (Palo Alto, Bon Appétit Management Company, 2014).

Hydroponics and Social Justice in Boston College's College Bound Program aims to achieve social justice through hydroponic growing and other STEM-focused projects.[49] AASHE's Sustainable Campus Index (SCI) states that through Boston College's use of "hydroponics and social justice track, students learn how to grow vegetables through hydroponic systems and solar systems to sell at farmers markets, while developing an understanding of food justice impacts in local communities and beyond."[50]

Rochester Institute of Technology (RIT) has shared similar advantages following their installation in August 2019 of a hydroponic facility within a recycled shipping container. This cost-saving, upcycled innovation produced over 40 pounds of leafy greens in its first month of operation and continues to provide much needed produce to the school's dining facilities. The project is young, but the school's growers hope to harvest regularly every week once they establish a consistent growing cycle.[51] Kory Samuels, the director of RIT Dining, strongly supports the hydroponic project, noting it is merely "the first of many progressive steps" that will help boost their institution's academic and sustainable record, from "recruitment efforts for new students, [creating] collaborative partnerships with multiple colleges…[and pushing] to expand" their sustainability goals.[52]

Clark University too has been at the forefront of hydroponic innovation, with two of their former students launching their company Freight Farms in 2010.[53] Their vision of a

49 Boston College Lynch School of Education and Human Development, *College Bound*, (Boston, Boston College, 2020).
50 The Association for the Advancement of Sustainability in Higher Education, *Sustainable Campus Index*, (Philadelphia, AASHE, 2019).
51 Felicia Swartzenberg, *Thinking Outside the Box: RIT Hydroponic Farm Changes the Dining Experience*, (Rochester, RIT, 2019).

simple, widely accessible facility that is both resource efficient and local aligns perfectly with Skidmore's goals of creating a sustainable campus predicated on economic, environmental, and social values. On the value of their school's hydroponic facility, one student writes:

> *will yield a harvest year-round, regardless of the season. The agricultural operation requires no special skills just a willingness to embrace technology, and an awareness that a food source existing right outside your door is a pathway toward individual health*
> *54*

The Freight Farm at Clark is an integral component for the school to reach its own food goal, which is a commitment "to serve 20% [sustainably sourced] food as measured by expenses by 2020."[55] The student-ran initiative was barely three years into its hydroponic project when the school had reached 14 percent sustainably sourced food. In an interview, Michael Newmark, General Manager of Clark University Dining Services, stated the following about the impact that hydroponic production had on their campus' food operations:

> *We identify the lettuce anytime it is used on campus. Customers see that it was grown on campus and that makes them feel even better about their food choice and selection. Our culinary team has also shown further engagement on local purchasing since the [Leafy Green Machine] has been brought on campus and it has added to the program in*
>
> *56*

Similarly, Ithaca College has a hydroponic and aquaponic system on campus. Paula Turkon, Professor of Environmental Studies and Sciences at Ithaca College, oversees a collaborative research group of students since 2013. The research teams work to assess the nutrition and system mechanics and development, "while students are engaged in unique research efforts in order to gain a better understanding of a more sustainable style of

54 Ibid.
55 Office of Sustainable Clark, *Food, Water, Landscape*, (Massachusetts, Clark University,

agriculture."[57] Students run routine daily maintenance over their recently expanded hydroponic and aquaponic systems that provide fresh produce to the dining facilities of Ithaca College.[58] We interviewed Professor Turkon who shared the following with us: One student amongst this group is paid to ensure dependability, and at least seven other student research volunteers collaborate on the hydroponic and aquaponic system every year. Since the systems have started, the systems have successfully cultivated produce and they sell it to their Dining Services, "who reap the greatest benefit throughout the winter season when fresh herbs are scarce." The costs of operation are financed "with support from ambitious alumni and departmental funding of $1500 a year." Turkon further notes that this stipend now far surpasses their expenses to run operations, which became financially viable not even four months into installing their system.[59]

Students at the University of Pittsburgh have long been fulfilling their intentions to help their academic and local community by addressing food insecurity and providing educational and technical resources on and off campus through their hydroponic production. Run by a group of passionate and knowledgeable students since 2015, Pitt Hydroponics club, dubbed Pitt Hydro, "has already farmed enough...vegetables to overflow local food pantries."[60] With a little financial assistance from their school's "student-run Green Fund Advisory Board"[61] and a lot of assistance from motivated and constructive students, Pitt Hydro has inspired educational outreach through hydroponics to "affect change in the community" both on and off campus.[62]

[57] Ithaca College Aquaponics and Hydroponics, *Ithaca College Aquaponics and Hydroponics,* (Ithaca, Ithaca College, 2015).
[58] Phil Lempert, *A Lesson to Supermarkets From Universities*, (Chicago, Grocery Business, 2018).
[59] Paula Turkon, *Interview by Borowka et al.*, New York, April 22, 2020.
[60] Priya Ray, *Hydroponics in Homewood: Pitt students at the farm next door,* (Pittsburgh, The Pitt News, 2020).
[61] PittSustainability, *Pitt Green Fund,* (Pittsburgh, University of Pittsburgh, 2020).
[62] Priya Ray, *Hydroponics in Homewood: Pitt students at the farm next door,* (Pittsburgh, The Pitt News, 2020).

Even during the coldest months, Pitt Hydro's PVC-pipe hydroponic systems are "capable of producing 20-50 plants in a single growth cycle", and "at one point, the club was able to donate 25 pounds of lettuce to the Pitt Pantry."[63] William Sauerland, sophomore and Pitt Hydro president, shares that their hydroponic initiative is far from perfect, yet nevertheless has offered a "deep educational component" for "the community and the students", and "despite its limitations," maintains a significant advantage over traditional agriculture by virtue of "energy efficiency, retained nutritional value and space."[64]

Muhlenberg College is also acclaimed for its hydroponic and food sustainability program, earning the school a spot in Sierra Club's top ten "Coolest Schools" in 2019. Their hydroponic herb garden grows "various herbs and lettuces" that are "utilized in the Dining Commons" for garnishes and freshly prepared salads.[65] This hydroponic project has even lent its hand to the surrounding local community, creating a number of mutually beneficial relationships for their school and surrounding small businesses and farms. Ryan Ehst, owner of neighboring hydroponic farm Butter Valley Harvest (BVH) in Bally, Pennsylvania, has been involved with the hydroponic and sustainable dining program at the College since 2010. Ehst has donated equipment to their hydroponic facility, and in turn, student researchers work each year with his team to enhance yields and ecological footprint.[66]

St. Joseph's College of Maine, a school virtually indistinguishable from that of Skidmore's student and administrative body, runs a highly productive hydroponic facility operated entirely by a student trio. The school received its first hydroponic growing system, dubbed the Leafy Green Machine, as a generous donation from Hannaford's Charitable

63 Ibid.
64 Ibid.
65 Muhlenberg College, *A Greener Tomorrow*, (Pennsylvania, Muhlenberg College, 2019).
66 Ibid.

the College aims to “ensure that the qua food.[79] Further, as aforementioned in Table 2, Skidmore consumes almost 250 pounds of lettuce per week, as was uncovered in interviews with Director of Dining Services, Mark Miller. Skidmore also consumes similar amounts of spinach and arugula, albeit this varies by season. Skidmore's garden is able to produce these foods and a range of others, including beets, beans, carrots, garlic, kale, and over a dozen other crops.[80]

Skidmore is also committed to civic engagement and sustainability education on campus. In "The Plan for Skidmore College 2015–2025," the College expresses support for civic engagement programming, noting its role to provide these opportunities to students; this component will be analyzed to a greater extent in the *Discussion* section.[81]

V. Findings

Stakeholder Interviews

A hydroponic system is useful for both educational and recreational purposes, and because hydroponic growing is relatively simple to learn, there is a low barrier of entry for individuals interested in maintaining this system. Similarly, a hydroponic system offers economic incentives that might help attract Skidmore to pursue its own greenhouse hydroponic system. Yet, along with a more robust, long-lasting and resilient greenhouse hydroponic system comes both enhanced yields and quality of produce and higher up front costs. These resources cannot come from the Sustainability Office, as an interview with the Sustainability Office suggested that it currently does not have the financial capacity or resources to incorporate a

[79] Ibid., 4.
[80] Otieno-Rudek, et al., *Skidmore Community Garden Annual Report 2017*, (New York, Skidmore College, 2017).
[81] Skidmore College, *Engaged Liberal Learning The Plan for Skidmore College: 2005--2015*, (New York, Skidmore College, 2015).

hydroponic facility into its programming. Moreover, it is unlikely that Skidmore will be able to provide the staff essential for the hydroponic facility in light of budgeting, zoning, and other restraints.

From our interviews with stakeholders there has been a consistent emphasis on hydroponic farming elevating the three pillars of sustainability. Specifically, Justin Reuter, CEO of the Boys and Girls Club of Albany, spoke extensively about the benefits hydroponics brought to the community. Furthermore, the Boys and Girls Club of Albany were donated funds from SEFCU credit union to purchase a Freight Farm which continuously supplies 1,100 meals daily.

Schools of our relative regional, administrative, and population capacity have gone about spawning their alternative farming initiatives in similar ways, mainly through seeking financial assistance from their department or public grants. Turkon at Ithaca College says they are able to operate with support from ambwning t operation.

> We don't use chemical pesticides. We use natural controls… these right here contain a predatory mite; Encarsia Formosa, and these protect our plants...they're good mites that are predaceous on pests. Koppert is the vendor of choice.

Using these natural predatory mites will allow a system to be resilient without the use of pesticides, which can further the opportunity to become certified organic. Water and electricity demands are different throughout each system. When cut for any reason, it can severely affect plant health and the operation as a whole. With the use of additional solar panels either on top or next to the greenhouse will allow for a natural source of energy to power the greenhouse and system. Furthermore, a backup generator and even a backup pump would be necessary for making any system more resilient.

We asked Professor Paula Turkon what precautionary measures they take to make their system more resilient and she responded with a heavy emphasis on having a backup generator. Additionally, for their aquaponic system she stated that the use of multiple pumps was used as a fail safe, in case there is something wrong with one pump, a backup pump will allow the system to not fail entirely. The great thing with hydroponics is if there is any contamination that comes up it is very easy to start and stop the system to sanitize. With all risks involved in hydroponics, professor Turkon added, "there is a huge pedagogical value to this. This is a great platform to boost sustainability and social justice issues." To mitigate these risks mentioned involves diligent students and professors to perform daily check ins as this is crucial for any type of agriculture. Additional risk mitigation would include plug in generators, rainwater collection to reduce water usage, and solar panels to ensure a natural source of energy can be supplied to the greenhouse to reduce emissions and costs of energy.

Skidmore Hydroponics Survey Results

We collected fifty survey responses evenly spread across an array of class years, which helped us assess students' awareness about and perceptions of hydroponic systems. Although most student respondents, about 75 percent, claimed they were aware of on campus sustainable food initiatives, only about a third of those respondents, a measly 34 percent, were aware of Skidmore's '25 by 25' sustainability agenda. These responses show that Skidmore has yet to execute enough sustainable food goals and enhance more awareness of these sustainable initiatives amongst its student body.

When prompted to respond with their opinions and satisfaction levels of Dining Facilities' vegetable/produce options, students responded in various ways in terms of their dining behavior. Roughly 65 percent of students report cooking for themselves, which is typical, as many upperclassmen students live in on or off campus residences with kitchens. However, roughly thirty percent of students report eating mostly at Skidmore's on campus Dining Facilities (Dining Hall and Spa), and out of this group, about forty percent report consuming vegetable options there at least daily or weekly. This simple starting point conveys the critical role of fresh produ(h produ(h produ000912 0 6B004C367c)7(ons)-6(u4C367c3(t)703}0912 0 6B004C367ct367c poignant issue for them. These survey results imply that Skidmore students are invested in both sustainable food procurement and general plant-based consumption.

Students also care about the sources of their food and hydroponic cultivation more generally. Nearly nine out of ten students reported that the source of their food is at least moderately to extremely important to them, and if an on campus hydroponic facility can guarantee anything, it is the transparent locality of its produce. Over half of students responded they were aware of hydroponic farming, displaying a rather high level of general shorthand knowledge of the alternative farming method and its key functions and takeaways. Even those students who did not report an awareness or keen understanding of hydroponics, roughly 45 percent, had at least previously heard of the alternative farming method. Cumulatively, the 54 percent who responded with awareness of hydroponics all mentioned that it is a relatively sustainable, water based, soilless, and year-round farming method. Some students who noted awareness and fondness for hydroponic growing added uncertainties about its perceived cost, technology dependence and resource-intensive nature.

Additionally, students responded overwhelmingly positively towards consumption of on

VI. Discussion

assistance on the part of the administration is available, the initial investment would be put towards a baseline garden to be managed by one to two garden managers and maintained daily by interested students from either the ESS department or other departments.

learning provides high motivation and knowledge, contributing to the complex competences of future specialists, which are critical for disciplines such as environmental studies and sciences. For students, this presents a service-learning opportunity, something that is clearly of great value to Skidmore as made evident through its website of Academic Engagement:

"Service-learning coursework includes community service as an experiential learning technique to deepen students' understanding of course content, to build their skills in the application of theory to practice, to increase their experiences with diversity, and to develop their interest in and commitment to social action and social problem solving."

Educators can take similar advantage of access to a hydroponic facility to encourage hands-on sustainability learning methods. Thus, in some capacity, Skidmore ought to consider investing in a hydroponic facility and the social benefits it can offer to the community in addition to the environmental-specific sustainability gains that would come from its creation. A hydroponic facility equips Skidmore to make these invaluable experiences more accessible to the academic community and multiple disciplines. With a little research, it is easy to build a hydroponic system for a school project or a small food production system to simply demonstrate the principles of hydroponics. This will also elevate Skidmore as a beacon of higher education.

The climate and geography, in which these schools are located, among other conditions, make hydroponics a strategically sound and profitable investment. with stark similarities with Skidmore in the Northeast in which the growing season is short. The geographic location of Skidmore College meets every standard under which hydroponics most effectively operates, including a temperate, seasonal climate, a relatively truncated growing season, and its small city area with high building density. In addition to the conveniently well-suited physical conditions for productive hydroponics, we acknowledge too that family and small farming is of significant cultural, historical, and economic import to this region. New York State itself is investing heavily in hydroponic farming, realizing its untapped socioeconomic and environmental benefits and becoming the nation's leader in agriculture policy reform. It is vital as environmentally aware students to both support our regional farmers and also provide exposure to alternative farming practices that promote market diversification and sustainable consumption. Evident through the general tradition of upstate New York as an integral community of small farmers and Skidmore as Saratoga's beacon of higher learning and forward thinking, this capstone's pursuit is both geographically and socially sound to help Skidmore attain its sustainability goals.

As is made clear in research by Tevlin & Blumenthal, a hydroponic system can be one of the tools to help Skidmore reach its goal of 25% by 2025. Still, it is unlikely that an on-campus hydroponic system could alone be the silver bullet solution to meeting Skidmore's food-related sustainability goals; this would require a tremendous shift in purchasing patterns totaling nearly $500,000 from off-campus vendors in the next six years.[86] Ongoing research and promising initiatives pursued at comparable schools support that a well-managed and funded nurture its sacred community values, like civic engagement, at a relatively low cost once the system is installed while also making strides towards reaching its sustainable food goals laid out in its past action plans.

Skidmore makes its commitment to civic engagement clear in a number of places, including in *The Plan for Skidmore College: 2015-2025*, and even takes into account the financial realities that may need to be considered to make civic engagement projects a reality. The plan explains:

> In many quarters, respect for learning as an intrinsic value and the role of colleges in nurturing the virtues of citizenship and civic engagement have been supplanted by concerns about economic access to a college education and the immediate job prospects of graduates. These issues are certainly important and will command our continuing

learning exercises and a hydroponic facility on campus can provide learning opportunities for students.

VII. Recommendations

Overview of Recommendations

expressed as one of its core tenets as a liberal arts institution, and further community engagement. Previous research, in tandem with survey results and Skidmore's general student body demographics, supports the potential for significant educational impact to be had through student research and volunteerism.

- **Continue to pursue new pathways for reaching its sustainable food goals,** assuming that it remains a priority for the College to reach these targets on time. Even the most ambitious aspirations for on-campus hydroponics at Skidmore could not, on their own, bridge the gap between Skidmore's current rate of sustainable food sourcing and its overall targets outlined in Skidmore's " ή kľ ꜛ t ъ t sd permanently damaged by COVID-19 complications. This has heightened the urgency and sheer necessity for retesting similar research in the coming semesters in order to manifest a more sustainable future for Skidmore's campus, academic, and communal body.

Recommendations in Detail

Even before the outbreak of COVID-19, limited administrative funding and capacity served as the primary potential barrier for Skidmore to invest in its first hydroponic facility. Especially poignant now in the wake of pandemic-related restrictions, a student club or some other form of student-operated volunteerism may be necessary for making an operable, efficient hydroponic facility on-campus a reality. As is at least suggested by preexisting literature and Skidmore student survey results, Skidmore's student body appears well-suited to fill this void for volunteerism. Establishing a hydroponic club at Skidmore can ensure the longevity of this valuable opportunity and simultaneously aid Skidmore to achieve its '25 by 25' goal of sustainably procured food.

We hope and recommend that a similar pilot project be pursued by future students, as this data collection was very valuable to our feasibility studies of a Skidmore-specific hydroponic system before the onset of COVID-19 changes. Hydroponics has the unique capacity to benefit students, faculty, and entire departments alike, promoting academic cross-sectionality and interdisciplinary opportunities at low cost and low knowledge barrier. As detailed in **Figure 4**, the costs for the pilot project were surprisingly modest and were assumed by the ESS Department, a definite potential for students seeking to replicate this pilot system. Based on our projections informed by our field and stakeholder research, there is little doubt

and physical capacity. One of those online retailers, Greenhouse Megastore, generated a quote for a commercial greenhouse that is most ideal for Skidmore. The greenhouse is 1,152 square feet with upgradeable features for a controllable environment. In addition to the greenhouse, we recommend the Nutrient Film Technique (NFT) as the system of choice, pictured in **Figure 6**.

NFT is a *continuous flow solution culture technique* where plant roots grow directly in a shallow, circulating layer of nutrient solution, ensuring the plants' reception of sufficient water, nutrients, and oxygen.[90] The NFT system is rather low maintenance and benefits from easy access to the plants, low water and energy consumption, and stabilized pH levels. Unlike media based systems, the NFT system avoids problems related to cost and disposal. Any potential or likely issues to arise from NFT can be easily mitigated; for instance, pump failure can be mitigated with dual or triple pumps to ensure consistent water supply. The features and advantages of NFT as a productive leafy green system were mentioned consistently in various stakeholder and professional interviews. Local farm Shushan Valley Hydro commends the system's reliability and production capacity, as they have used NFT for many years to produce bountiful herbs and leafy g

Figure 5: Pricing Sheet for Automated Greenhouse and NFT System

[illegible]	Senior Greenhouse Teaching Package		1	[illegible]
All components included				
	12 foot finishing channels (18 sites per channel)		[illegible]	
	12 foot nursery channels (72 sites per channel)			
	[illegible] gallon reservoir			
	submersible pumps		2	
	[illegible] foot feeder			
	[illegible] and plumbing kit		1	
	Instructions			
	Pump, float valve, water meter, manifold, plumbing kit		1	
	Pro Grower Starter Kit			
	Consulting for plant varieties and nutrient formulation			
	3 months of seeds (approx. 5K)			
	[illegible] months of nutrients			
	Buffer			
	Calibration solution			
	pH adjusters			
	Water Testing			
				Other Items
	12 months of grower support			
			$34,994.00	Total:

Figure 6: Shushan Valley Hydro NFT System

IX. References

33. Lauren Rubenstein, Wesleyan Partners with Organization to Recycle Surplus Furniture, (Connecticut, Wesleyan University, 2019).
34. Leelanayagi Ramalingam et al., Community Garden Programme – An Analysis of

43. Office of Institutional Research, Fact Book 2019-20, (New York, Skidmore College, 2020).
44. Office of Sustainable Clark, Food, Water, Landscape, (Massachusetts, Clark University, 2016).
45. Otieno-Rudek, et al., Skidmore Community Garden Annual Report 2017, (New York, Skidmore College, 2017).
46. Paolo Sambo et al., Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective, (Switzerland, Frontier in Plant Science, 2019).
47. Patricia Erikson, Student Trio Operates Freight Farm, (Maine, St. Joseph's College of Maine, 2018).
48. Paula Turkon, Interview by Borowka et al., (New York, April 22, 2020).
49. Phil Lempert, A Lesson to Supermarkets From Universities, (Chicago, Grocery Business, 2018).
50. Phyllis Underwood, Interview by Borowka et al., (New York, February 21, 2020).
51. PittSustainability, Pitt Green Fund, (Pittsburgh, University of Pittsburgh, 2020).
52. Priya Ray, Hydroponics in Homewood: Pitt students at the farm next door, (Pittsburgh, The Pitt News, 2020).
53. Raneem Gashgari et al.,Comparison between Growing Plants in Hydroponic System and Soil Based System, (Saudi Arabia, Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering, 2018).
54. Sing Kong Lee, Aeroponic Technology – A Tool for Food Production on Seasteads, (Zurich, Seasteads: Opportunities and Challenges for Small New Societies, 2017).

55. Skidmore College, Engaged Liberal Learning The Plan for Skidmore College: 2005-2015, (New York, Skidmore College, 2015).
56. Stacey White, Campus sustainability plans in the United States: where, what, and how to evaluate? (UK, International Journal of Sustainability in Higher Education, 2014).
57. The Association for the Advancement of Sustainability in Higher Education, Sustainable Campus Index, (Philadelphia, AASHE, 2019).
58. Thomas Eatmon et al., Food Production as an Integrating Context for Campus Sustainability, (New York, World Sustainability Series, 2015).
59. USDA, Hydroponics, (Washington D.C., USDA National Agricultural Library, 2016).
60. Vanessa Sulma, et al., Economic viability for deploying hydroponic system in emerging countries: A differentiated risk adjustment proposal, (Brazil, Federal University of Grande Dourados, 2018).
61. William J. Hopkins, Good Food Project Goes Extremely Local with Hydroponic Window Farm, (Pennsylvania, Swarthmore College, 2010).