Greenhouse Hydroponics:

An Opportunity for Enhanced Academic Learning & Food Sustainability at Skidmore

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"Assuming that nothing can be done is a self-fulfilling prophecy. Nothing can be done by a nation that adopts this stance."

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<u>Table of Contents</u>

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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.

I. Introduction

No region on the planet has gone untouched by one of the most adverse risks of rising global temperatures and climate change: food insecurity. As the world's population burgeons and the threat from climate change transforms food systems (especially the patterns and productivity of crops, livestock and fishery systems), there is a growing concern about how to meet global food demand, which is at an all time high and unprecedented in modern human history.[1] In general, industrial large scale plant and animal agriculture carry large ecological footprints, taking a drastic toll on biodiversity loss, the nitrogen cycle, phosphorus cycle, global freshwater use, and land system change.[2] Not only is the food chain itself at risk of disruptions, but it is also accountable for extensive environmental degradation. A study performed by the European Union identified that the production and distribution of food is responsible for approximately 30 percent of the impacts on climate change and 60 percent of the impacts on eutrophication.[3] Suffice to say, a systematic shift towards sustainable agricultural practices on both global and local scales and in our diets is imperative to address food security under shifting climatic and environmental pressures.

Studies show that arable land per person is declining. With increasing competition posed by urbanization, industrialization, and increasing biofuel production, there is an urgency for the conservation of resources for future generations and utilizing them in environmentally responsible ways.[4] With increasing urbanization, there is also a growing concern for bringing

[1] Intergovernmental Panel on Climate Change, Climate Change & Land, (Geneva, IPCC, 2019).
[2] Diana Liverman & Kamal Kapadia, *Food Systems and the Global Environment: An overview*, (UK, Routledge, 2010).
[3] Daina Romeo et al., *Environmental Impacts of Urban Hydroponics in Europe: A Case Study in Lyon*, (Denmark, Aarhus University, 2018).
[4] Jelle Bruinsma, *The Resource Outlook to 2050: By how much do land, water, and crop yields need to increase by 2050?*, (Rome, FAO, 2009).

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 institutions, hydroponics is a vital environmental learning tool and pertinent way to achieve sustainable food procurement.[8] For the purposes of this capstone, the principal question is about the applicability of soilless farming systems as an alternative but complementary mechanism to serve the dual goals of sustainable food procurement and conservation of resources, in line with Skidmore College's sustainability plan.

Studies demonstrate that alternative soilless farming methods come with numerous advantages over traditional soil growing, including increased growth rate, yield, resource

[5] Bradford D. Coyle & Brenna Ellison, *Will Consumers Find Vertically Farmed Produce "Out of Reach"*? (Milwaukee, Agricultural and Applied Economics Association, 2017).
[6] Celina Gomez et al., *Controlled Environment Food Production for Urban Agriculture,* (Virginia, American Society for Horticultural Science, 2019).
[7] Chenin Treftz, Stanley T. Omaye, *Comparison Between Hydroponic and Soil Systems for Growing Strawberries in a Greenhouse,* (Pakistan, International Journal of Agricultural Extension, 2015).
[8] Thomas Eatmon et al., *Food Production as an Integrating Context for Campus Sustainability,* (New York, World Sustainability Series, 2015).

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 as corn, squash, zucchini, and other viney produce simply due to space limitations, nearly all produce can be grown hydroponically.[14] In terms of technical skills, while leafy greens and herbs require elementary skills to maintain the system, more complex systems demand a more robust yet easily attainable awareness of nutrient requirements and environmental conditions.[15]

Hydroponic farming is at the tip of the umbrella for alternative urban farming and hydrocultural systems. The word hydroponics comes from the roots "hydro," meaning water, and "ponos", meaning labor. There are different techniques of hydrocultural farming, including

9 Nga T. Nguyen et al., *Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements*, (Cambridge, Journal of Visualized Experiments, 2016).
10 Mamta D. Sardare & Shraddha V. Admane, *A REVIEW ON PLANT WITHOUT SOIL - HYDROPONICS*, (India, International Journal of Research in Engineering and Technology, 2013).
11 Ibid.
12 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).
13 Michael Ben Timmons et al., *Advances in Knowledge of Hydroponic and Aquaponic Systems*, (Basel, Horticulturae, 2019).
14 Guilherme Lages Barbosa et al., *Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods*, (Basel, International Journal of Environmental Research and Public Health, 2015).
15 Nga T. Nguyen et al., *Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements*, (Cambridge, Journal of Visualized Experiments, 2016).

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 systems that provide nutrient-rich water directly into plants' roots to facilitate growth.[16] The earliest forms of hydroponic farming date back to the Hanging Gardens of Babylon and the Floating Gardens of China. However, the earliest contemporary reference to the practice was spawned by William Fredrick Gericke at the University of California, Berkeley. Literature demonstrates the utility of hydroponic farming in a world where over one third of the arable land is used for crop growth and is projected to increase by 55% by 2050.[17] The resources required for a hydroponic system vary on the chosen method of growing, but nearly always include nutrient rich water, access to oxygen, artificial or natural light, regular monitoring, and a physically appropriate growing environment**.**

Versatility in the forms of hydroponic systems, as exemplified through real life applications and also scholarly studies, enable growers to cultivate fresh produce year round, indoors or outdoors, in any climatic conditions, and provide invaluable educational opportunities for all. Hydroponics can be scaled up or down to accommodate specific communal, local or regional demands and can even easily be outfitted with renewable energy technologies to satisfy virtually all energy demands. Hydroponic production is highly resilient and consistent if done properly; plants simply expend their energy for flowering, fruiting and vegetative development, eliminating the stress of obtaining nutrients by virtue of constant

[16] USDA, *Hydroponics*, (Washington D.C., USDA National Agricultural Library, 2016).
[17] Food and Agriculture Organization, *Crop Production and Natural Resource Use,* (Rome, FAO, 2019).

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 incredible potential to address environmental issues effectively.[28] Different colleges and universities in the U.S., similar size to Skidmore, have successfully engaged with hydroponic systems. As the findings demonstrate, higher education institutions can be effective and vital experimental hubs for environmentally and financially sustainable alternative farming methods.

Potential Benefits for Skidmore

Access to an on campus hydroponic facility has enormous potential to benefit Skidmore's academic and local community alike. Our college has the capacity to reap the

[23] Lauren Rubenstein, *Wesleyan Partners with Organization to Recycle Surplus Furniture,* (Connecticut, Wesleyan University, 2019).
[24] Kimberly K. Barlow, *Hydropower Plan Marks Pitt's Largest-ever Commitment to Renewable Energy*, (Pittsburgh, University of Pittsburgh, 2018).
[25] Campus Sustainability Office, *Transportation,* (Ithaca, Cornell University, 2020).
[26] Elisa J. Livengood, *Controlled Environment Agriculture Greenhouse,* (New York, SUNY Morrisville, 2020).
[27] Jessica Finlay & Jennifer Massey, *Eco-campus: Applying the ecocity model to develop green university and college campuses,* (UK, International Journal of Sustainability in Higher Education, 2012).
[28] Stacey White, *Campus sustainability plans in the United States: where, what, and how to evaluate?* (UK, International Journal of Sustainability in Higher Education, 2014).

financial and environmental benefits from a small scale hydroponic project. Firstly, it can help supplement Skidmore's sustainable food goals for the Dining Services. Secondly, it can provide educational opportunities within multiple departments for students to learn about alternative farming methods and sustainability in an unparalleled experiential learning environment. Thirdly, this farm can be operational year round, mainly producing leafy greens in its early stages. Indeed, supplemental on-site production of leafy greens that is an important item at Skidmore's dining establishments year-round can drastically mitigate our carbon footprint. Last but not least, a hydroponic farm is a forward thinking and profitable tool to diversify and recruit new students and forge cooperative partnerships with other schools, regional businesses, and the local community.

The research involves an assessment of a simple hydroponic system and its growth potential through a pilot demonstration. While it aims to assess the physical qualities and inputs of the system (i.e., energy, water, nutrients), it also examines the total output potential. The research can provide a model for alternative farming practices and guidelines for institutions similar to ours, particularly on applicability of hydroponics on campus. The results of this study can also guide and support the case for Skidmore's first hydroponic project.

In the following, we start with our research questions and methods. These include a discussion of our initial pilot study implemented during January and March 2020, and the research carried out after the pilot in light of COVID-19 related changes. We continue with a literature review on hydroponics systems and Skidmore College's Sustainability plan. We then start the findings section and examine the alternative farming systems of other college campuses. We end with an extension of our results from this pilot and data from other schools to a cost-benefit analysis of a hydroponic system to be integrated at Skidmore campus.

II. Research Questions & Methods

The project will assess risks and obstacles and provide a cost benefit analysis of the proposed hydroponic facility on Skidmore's campus. Our research questions are:

1) What are the financial and energy inputs associated with implementing and managing a productive hydroponic facility on campus?

2) What are some of the risks associated with hydroponic systems and student perceptions of such a system on campus?

3) How can an on-campus hydroponic facility be a feasible and efficient strategy for Skidmore to complement its Sustainability Plan goals?

Our capstone research adopted several methods including literature review, semi-structured interviews with stakeholders, and on campus student survey administration. The triangulation of data and methods help us understand the issue we are studying better by providing corroborating evidence.[29] We collected data through the following methods:

1) A review of existing literature on hydroponic farming and, more specifically, the strengths and weaknesses of different systems particular to inputs and outputs, financial feasibility, and unique aspects involving organization, maintenance and sustainability.

2) A review of reports: We examined Skidmore campus plans and previous relevant capstones evaluating sustainable food procurement and production on campus. We also utilized reports from other schools including University of Pittsburgh, St. Joseph's College of Maine, Cornell University, and more to inform us of different aspects of class or club

[29] John Creswell, *Qualitative Inquiry and Research Design: Choosing among Five Approaches (2013).*

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

3) Consultation and semi-structured interviews with relevant community stakeholders including the staff of Dining Services, Sustainability Office and CIS Greenhouse, as well as local hydroponic businesses (Shushan Valley Farm, The Boys & Girls Club of Albany), and academicians (from SUNY Cobleskill and Ithaca College). These interviews helped us assess the educational and sustainable impacts hydroponic initiatives have had on college campuses and local communities.

4) Surveys with Skidmore students: The information gathered through fifty survey responses helped gauge student perceptions of Skidmore's sustainable food initiatives, sustainably sourced food, and hydroponic methods.

5) Pilot study: We had the great fortune of transforming an unutilized 3 by 2 foot section of Skidmore's Center for Integrated Sciences Greenhouse (CIS) into a small scale pilot hydroponic system. The pilot was meant to serve as a proof of concept, designed to represent Skidmore's needs and actual capacity. After consulting with local Saratoga Organics & Hydroponics Supply, Skidmore's Dining Services managers, and other regional academic institutions, we chose to grow spinach, lettuce, basil, parsley and cilantro with a Floating Method system. The decision was predicated on several critical factors to be more thoroughly detailed in the upcoming section, but include relatively low upfront cost, simple scalability, low knowledge barrier, and space efficiency.

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. Consequently, the research objectives adapted to these circumstances. The fundamental goal of this capstone has remained intact to guide Skidmore in its quest for food supply chain transparency and consistency in the wake of an uncertain and unstable future. Even with the loss of our hydroponic pilot project, compelling data exists supporting the resiliency and reliability of hydroponic farming under small scale operations, most poignantly in these environmentally unstable conditions. More critically, examples from the national and local scales suggest that a model relevant to Skidmore's seasonal needs, within the confines of Skidmore's health and food safety standards as well as financial capacity is possible to implement.

Pilot Project Design

In January 2020, we launched a pilot hydroponic project on 2x3 foot section in the CIS greenhouse for data collection. After preliminary research, consulting previous literature and many other regional college campuses, we settled initially on the Ebb and Flow method based on fiscal and physical practicality purposes. However, upon further consultation with Skidmore stakeholders and on the counsel of SUNY Cobleskill's Dr. George Crosby, we made slight adjustments to mimic the Floating method (FM) of hydroponics. The only difference in FM is that the nutrient solution is not circulated. Rather, the plant roots remain submerged in nutrient solution as they are fixed onto a floating panel in a reservoir. Also vital, this system performs exceptionally well with leafy greens and herbs, like the spinach, basil, and lettuce we chose to 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
	Low riseFlood Table (2')	1	$42.26	$42.46
	25 Gallon Resevior	1	$69.95	$69.95
	A-OK 1.5 Starter Cubes	2	$15.03	$30.06
	Proporgation Tray	1	$1.74	$1.74
	Europonic Rockwool Conditioning Solution	1	$14.41	$14.41
	Plant Stakes		$3.31	$3.31
	Mondi Mini Dome 4" with vents	1	$5.06	$5.06
	Botanicare Black LP 20 gallon lid	1	$53.51	$53.51
	Seeds (Lettuce, Basil, Spinach)	Provided by Nurcan	$0.00	$0.00
	QB123 V1 Quantium Boards (Lights)	2	$99.99	$199.98
	Pure Blend grow pro (1 quart)	1	$21.95	$21.95
	Gro Pro net pots (2in diameter)	50	$0.20	$10.00
	Large air stone	1	$4.21	$4.21
	Eco Air 1 plus	1	$8.46	$8.46
	1/4" Clear Tubing	4	$0.21	$0.85
Total				$465.95

We conferred food invoices from Skidmore's Murray Aikins Dining Hall for the months of September, October, June, and August of 2019 to get a better overall grasp of Skidmore's food demand and needs for green vegetables in a given year. The invoices showed that a remarkable volume of leafy greens and herbs are purchased multiple times a week, adding to the cost and ecological footprint of fresh produce that the dining facilities have to procure (Table 2). This may suggest a greenhouse hydroponic facility could potentially cut costs, food miles, and service our Dining Facilities.

Table 2: Vegetable produce purchases by month at Skidmore Dining Facilities

Month	Purchase	Cost
September 2019	13 cases spinach, 12 cases basil, 13 cases arugula	$516.74
October 2019	19 cases romaine lettuce, 10 cases arugula, 28 cases spinach	$1,102.48
June 2019	8 cases spinach 8 cases romaine lettuce, 8 cases of arugula, 5 cases of basil	$518.10
August 2019	3 cases arugula, 9 cases spinach, 6 cased of romaine lettuce, 2 cases cilantro	$417.40

Our pilot project settled on leafy greens, including lettuce and spinach, and herbs, including basil, parsley and cilantro. As Table 2 shows, the produce were not only selected because they are often outsourced by Skidmore at high rates, but also because they are uniquely easy crops to grow hydroponically. In 2019, Skidmore's Community Garden produced an 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 even adapting the Ebb and Flow method for cross comparison purposes. We would have used this data to assess relative profitability, sustainability, and general viability of this project proposal for Skidmore.

The following sections outline a review of existing literature and insights from hydroponic initiatives on other college campuses. This information, in tandem with the College's specific fiscal and practical capacity provided by relevant Skidmore stakeholders, informed our recommendation section.

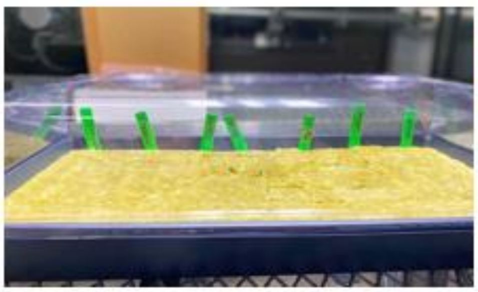

Figure 1: Germination on 01/28/20

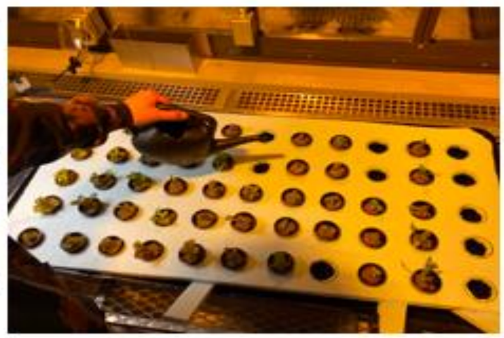

Figure 2: Transplant on 02/19/20

Figure 3: Seed sprout process on 02/11/20

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 monitoring is required for this system to ensure proper function.[32] Alternatively, the *static solution culture method* allows the plant roots to remain submerged in the nutrient solution, eliminating reliance on the pump technology. The *aeroponic method*, known keenly for its high water efficiency, is where plants are anchored in holes on styrofoam panels: The roots are suspended in mid air within a sealed growing container where the nutrient solution is misted over them.[33] While very water efficient, an aeroponic system demands routine monitoring, as the entire system depends on the irrigation and timer technology to ensure proper growth of plants.

Equally paramount are the environmental parameters, which significantly influence high quality and consistent yields. Crops need suitable environmental conditions for successful

[30] Fraz Ahmad Khan et al., *A Review on Hydroponic Greenhouse Cultivation for Sustainable Agriculture*, (Turkey, International Journal of Agriculture Environment and Food Sciences, 2018).
[31] Ibid.
[32] Ibid.
[33] Sing Kong Lee, *Aeroponic Technology – A Tool for Food Production on Seasteads*, (Zurich, Seasteads: Opportunities and Challenges for Small New Societies, 2017).

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°F (~25°C) 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.

For many, the most poignant risk associated with hydroponics is financial. While there is a relatively high initial investment, other costs associated with high energy expenditure, specific technical knowledge, and consistent maintenance can also pose financial risk.[37] Studies focus on the system's reliance on water and electricity, potentially resulting in "costly generator back-ups to cover for power outages," as issues to watch out for both amateur and commercial hydroponic producers. Even taking these risks into account, "once the system set-up" has been "completed," it is cheaper than conventional farming methods to maintain and operate as the system will offer fresh and healthier produce.[38] These financial obstacles also emerged when launching the hydroponic pilot project in CIS: the upfront costs of the system were the largest obstacle. However, we found that for our chosen system design, scale, and produce selection, construction and maintenance were relatively inexpensive.

The pilot project design called for the outsourcing of light fixtures, seeds, nutrient solutions, growing media, air pump, and a growing reservoir, components of an elementary hydroponic system that were easily affordable and attainable and to be further detailed in our pilot project methods section. However, as the research objectives changed course with lack of greenhouse access, our cost projections changed as well. Our capstone no longer relied on financial projections derived from the pilot data, but rather based on previous literature and

[37] New York State Governor's Office, *Governor Cuomo Announces Nation's Largest Hydroponic Commercial Greenhouse Will Open in Monroe County,* (New York, New York State, 2017).
[38]Ali AlShrouf, *Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming,* (Abu Dhabi, Abu Dhabi Food Control Authority, 2017).

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 best serve[d]" the small scale hydroponic program to reach successful profit swiftly.[40] With that in mind, grants would be an exceptionally viable avenue for Skidmore to launch a hydroponic greenhouse production. Whether obtained through public grants, private investments, or through Skidmore's own assets, a hydroponic facility can be both affordable and even profitable with a relatively short payback period.[41]

As any given hydroponic system endures, water and energy inputs can be precarious components that will have to be carefully evaluated to ensure maximum sustainable operations. We can mitigate these demands by using rainwater harvesting as a water resource and even solar panels to close the loop entirely within the garden. For instance, one can eliminate the need for municipal water and potential heavy metals and contaminants through installing PVC

[39] 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).
[40] Ibid.
[41] Ali AlShrouf, *Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming,* (Abu Dhabi, Abu Dhabi Food Control Authority, 2017).

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 College's AG Co-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).
[52] Korey Samuels, *Local Food Produced Right on Campus,* (Rochester, RIT, 2019).
[53] Julia Quinn-Szcesuil, *Freight Farms: Bounty in a Box,* (Massachusetts, Clark University, 2016).

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:

> *"There is no tractor. No barn. Not even soil. Yet by any definition this is a farm, one that 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 and collective sustainability."*[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 University that is essentially sitting in a food desert, in the middle New England's second most populous city"*[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, 2016).
[56] Freight Farm, *7 Questions With Michael Newmark of Clark University and Heather Vaillette of Sodexo*, (New York, Clark University, 2020).

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.

Foundation. Students rave about several aspects of their self- contained, compact freight truck, as it helps feed their College community with “fresh, local, and sustainable...hearty greens”[67] throughout “all four of Maine’s seasons”[68] and has spawned highly distinguished and rare high-tech job opportunities on campus.[69]

Further, a tour of SUNY Cobleskill revealed firsthand the increase in environmental consciousness amongst the student body and local community as a result of its industrial hydroponic facility. Even under the dim light of a January afternoon, the greenhouse brimmed with dense vegetation and students tending to the bountiful tomatoes, leafy greens, herbs, and other vegetables utilized for their research, dining services, and sale to the community.

IV. Case Study: Skidmore College

Skidmore College Sustainability Plan and Strategic Plan: 2015-2025

In 2015, Skidmore College rolled out its *Campus Sustainability Plan*, a set of goals for Skidmore sustainability until 2025. This document outlined goals in many broad categories regarding ways to reduce the school’s environmental impact by 2025, including food related goals. The Campus Sustainability Subcommittee defines sustainably sourced food as “foods [that] can be traced to farms and businesses that are locally owned and operated (within 150 miles)… fair… ecologically sound… [and] humane”.[70]

[67] Elyse Caiazzo, *Saint Joseph’s College Embarks Upon Hydroponic Farming,* (Maine, St. Joseph’s College of Maine, 2018).
[68] Emma Deans, *Saint Joseph’s College Gives Overview of Hydroponics Farm at the Institute for Local Food Systems Innovation,* (Maine, St. Joseph’s College Communications Office, 2018).
[69] Patricia Erikson, *Student Trio Operates Freight Farm,* (Maine, St. Joseph’s College of Maine, 2018).
[70] Campus Sustainability Subcommittee Members, *Skidmore College Campus Sustainability Plan,* (New York, Skidmore College, 2015), 8.

As of 2018, 10 percent of the food purchases in Dining Service met the school's sustainable food criteria.[71] Currently, Skidmore is not on track to comfortably reach these goals by 2025, mostly due to budget constraints, amongst other administrative setbacks.[72] Skidmore's location in the Northeast has a short growing season, limiting its current outdoor community garden output and expanding its dependence upon outsourced produce from regional and external food suppliers who also face the same challenges under these environmental conditions. Tevlin and Blumenthal infer in their research that this has skewed purchasing patterns for Skidmore's Dining Services to favor economic sustainability over environmental sustainability in recent years, severely jeopardizing its success in reaching 2025 sustainability targets.[73] They also speculate that Skidmore has urgent gains to make in curbing food waste, localizing consumption, and slashing food miles, which, until tackled, may persist as a barrier to reaching its '25 by 25' goals.[74]

Skidmore's commitment to sustainability can technically be traced back to 2005, when the College released *The Plan for Skidmore College: 2005--2015*.[75] This report made broad plans and goals, not limited to sustainability, for Skidmore's overall track into the future and created pathways for a variety of its numerous departments and offices. The report states that

71 Finely Tevlin & Isabel Blumenthal. *25 by 25: An Action Plan for Achieving Sustainable Food Procurement by 2025 at Skidmore College*, (New York, Skidmore College, 2019).

72 It is relevant to note that the COVID-19 pandemic further obscures the future of Skidmore's sustainability goals, priorities, and finances. One could reasonably conclude that under such unprecedented and rapid changes not only to Skidmore's circumstances, but to the world's, that local and resilient self sustenance has never been of greater urgency to our school and communities nationwide.

73 Finely Tevlin & Isabel Blumenthal. *25 by 25: An Action Plan for Achieving Sustainable Food Procurement by 2025 at Skidmore College*, (New York, Skidmore College, 2019).

74 Finely Tevlin & Isabel Blumenthal. *25 by 25: An Action Plan for Achieving Sustainable Food Procurement by 2025 at Skidmore College*, (New York, Skidmore College, 2019).

75 Skidmore College, *Engaged Liberal Learning The Plan for Skidmore College: 2005--2015,* (New York, Skidmore College, 2015).

the College aims to "ensure that the quality of food served in our dining halls is consistent with our overall goals for student health and wellness".[76] While information specifically pertaining to food and/or food-related issues was vague and sparse in this report, Skidmore explains healthy food in the context of community wellbeing. The report does not in any way demonstrate an actual measurable, distinct, or outcome oriented sustainable commitment to food procurement. However, a decade later, Skidmore's sustainability agenda became more significant in the *Campus Sustainability Plan*, which offered an enhanced goal oriented agenda. The current Plan, 2015-2025 distinctly emphasized sustainable food procurement through a commitment to 25 percent sustainable food in Dining Services by 2025.

Previous research on campus has identified that installing a hydroponic system at Skidmore "could provide Dining Services fresh and sustainable leafy greens throughout the year and begin to generate profits between 3 and 10 years", depending on labor. Installing an on-campus hydroponic system also perfectly suits the "engagement" aspect of the Campus Sustainability Plan, which states that:

> Collectively we are aware of the progress already achieved on campus and beyond. We must strive to be recognized as an institution that values and practices sustainability in our daily operations and decision-making. To accomplish this, we must continue to offer new educational opportunities as well as increase our communication efforts in order to promote the sustainability work accomplished throughout campus…[77]

Skidmore's on-campus Community Garden currently produces roughly 1,100 pounds of food per year, and over 1,000 pounds of food is purchased by Dining Services in the same time period.[78] Putting this in context, Dining Services has spent an average of $3,232,719 per year on

76 Ibid, 27.
77 Campus Sustainability Subcommittee Members, *Skidmore College Campus Sustainability Plan*, (New York, Skidmore College, 2015), 15.
78 Finely Tevlin & Isabel Blumenthal. *25 by 25: An Action Plan for Achieving Sustainable Food Procurement by 2025 at Skidmore College*, (New York, Skidmore College, 2019).

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 ambitious alumni, diligent student researchers, and ESS departmental funding of $1500 a year. She 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.[82] Additionally, Turkon added that even "with all risks and maintenance involved in a hydroponic or aquaponic system, there is huge pedagogical value to this. This is a great platform to boost sustainability and social justice issues." Turkon's experience with on campus hydroponics is not unlike those shared by swaths of other higher education institutions employing hydroponic systems of their own that have served to enhance student and community engagement and broader issues of food sustainability.

After speaking with Dr. George Crosby at SUNY Cobleskill, he mentioned the use of natural predator mites to ward off any potential pests that might be detrimental to their

[82] Paula Turkon, *Interview by Borowka et al.,* New York, April 22, 2020.

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 produce in the average Skidmore student diet.

When asked if the students were happy with the vegetarian food options at Skidmore's Dining Facilities, roughly eight out of ten students responded that they were somewhat happy, mainly citing insufficient vegetarian options at Spa, lack of diverse options at the Dining Hall, low relative taste compared to non vegetarian options, and general lack of variety in vegetarian selection. The fifteen percent of students who responded that they were unhappy with the vegetarian food options at Skidmore's dining facilities mostly identified as vegetarians and/or vegans, making the issue of diverse and sufficient vegetable options on campus an increasingly 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 campus hydroponically cultivated produce if that option became available at Skidmore's dining facilities. In culmination, roughly 90 percent of students emphasized consumer consciousness, reduced ecological footprint, educational engagement opportunities, sustainable food procurement, and support for Skidmore's sustainable initiatives as positive aspects of consuming hydroponic produce on campus. It is worthy to note that a small percentage of those who supported hydroponic produce consumption on campus raised concerns over cost benefits, influencing their potential support for hydroponic options at Skidmore's dining facilities.

VI. Discussion

Hydroponics is the most sensible form of urban agriculture, considering its adaptability to any climate or site requirements. Considering the stark parallels Skidmore shares with these other institutions of higher education, there is strong promise for the same action and benefit to be tailored to Skidmore's needs and capacity. We can and must be a higher education institution that sets a standard for other institutions to follow in pursuit of education and awareness of this alternative farming practice. Arguably, students are aware of Skidmore's sustainability goals mainly through the College's ample marketing and publication of the issues, yet in actuality have shown weak efforts and thus results as applied to student awareness of sustainable food issues. This goes to show that a hydroponic facility to help supplement the College's food goals and demands would go a long way in terms of effectual sustainability results. Introducing a hydroponic facility carries immense untapped potential to bring sustainable food procurement closer to Skidmore students and help the College make better pace towards its sustainable food procurement goals by 2025.

This is where this capstone's proposal can come into fruition to help meet both the administration's needs and the desires of its students. As existing successful initiatives on other college campuses show even in the absence of accessible resources and financing, a small pilot project can start and then continue to expand, which can still meaningfully serve to fill that critical knowledge gap at a relatively low cost and high margin of efficacy. The aim of this capstone's proposal is to educate the Skidmore community, provide experiential learning in sustainable food procurement, and heighten the awareness and productivity of Skidmore's sustainable initiatives more broadly. Recruiting interested parties for Skidmore's first hydroponic initiative can be coordinated with the Sustainability Office. If the financial will and 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.

It remains apparent through survey results and Skidmore's general communal values and characteristics that the potential is very high for the initiation and success of the first hydroponic initiative on campus. In addition to potential 'pre professional' experience and 'resumé building' as direct benefits resulting from volunteer opportunities at an on-campus hydroponic facility, there are other drivers of student motivation to consider. For instance, research conducted on the functions and norms that drive student volunteering found that "volunteering behavior" amongst "today's young adult university students'" is highly correlative to the behavior of their primary referents, or those closest to them, such as parents, siblings, and friends.[83] Compatible research identifies the central motivation for agriculture-specific volunteerism, concluding that "the love of farming" is "the most essential motivational factor for urban dwellers to" become involved in the project's urban Community Garden Program.[84] According to the College's current demographic enrollment and student survey results, Skidmore is blessed with a sustainably-inclined academic body, of which the majority are urban dwellers belonging to the world's prime metropolitan centers.[85]

For students, access to a hands-on environmental learning tool like a hydroponic facility provides an unmatched opportunity to encourage healthy habits pertaining to local and sustainable consumerism and behavior more generally. Literature demonstrates that experiential

[83] Julie E. Francis, *The functions and norms that drive university student volunteering*, (New Jersey, John Wiley & Sons, 2011).
[84] Leelanayagi Ramalingam et al., *Community Garden Programme – An Analysis of Volunteers' Motivations and Age Groups*, (Los Angeles, International Journal of Humanities and Social Science, 2018).
[85] Office of Institutional Research, *Fact Book 2019-20*, (New York, Skidmore College, 2020).

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 hydroponic facility can make a significant dent in Skidmore's '25 by 25' goal.[87]Antonucci Foods is Skidmore's wholesale distributor of produce and seafood. The College's '25 by 25' plan discloses that Antonucci's catalog is both limited and not devoted to sustainable food procurement. Investing in a hydroponic facility embodies other principles of sustainability that Skidmore identifies in its plan, bringing social and economic advantages in addition to environmental. An on-campus hydroponic system may provide opportunities for Skidmore to

[86] Finely Tevlin & Isabel Blumenthal. *25 by 25: An Action Plan for Achieving Sustainable Food Procurement by 2025 at Skidmore College,* (New York, Skidmore College, 2019), 4.
[87] Paula Turkon, *Interview by Borowka et al.,* New York, April 22, 2020.

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 attention among the range of values that provide reasons for students to attend the College... However, as noted [elsewhere], we remain deeply committed to the principles of liberal learning that Skidmore has long championed— values that are infused within all that we do.[88]

Evidently, Skidmore is privy to the economic constraints facing the College and similar institutions, but nonetheless remains committed to creating pathways for students to pursue civic engagement passion projects both through the classroom and extracurricular avenues (e.g. student clubs). Ultimately, this is because the College sees a responsibility for itself to provide civic engagement opportunities for students, as this is necessary for both an enriched, liberal arts education and for maximizing students' prospects in a potential job market. Skidmore's Office of Community Service Programs reports that "each year, approximately 50 percent of Skidmore students participate in community service" and that the "faculty teach more than 50 service-learning courses."[89] These demonstrate that Skidmore is engaged in high-impact

[88] Skidmore College, *Engaged Liberal Learning The Plan for Skidmore College: 2005--2015,* (New York, Skidmore College, 2015).
[89] Office of Community Service Programs, *Office of Community Service Programs*, (New York, Skidmore College, 2020).

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

VII. Recommendations

Overview of Recommendations

Ultimately, after research, analysis, and discussion, we have arrived at a set of recommendations for the College as it pertains to obtaining a hydroponic greenhouse on-campus. In light of this process, we conclude that it is in the best interest of Skidmore College to pursue the following actions:

- **Continue to review purchasing of all leafy greens from off-campus vendors and compare this to the amount that could be saved if this produce was supplemented by on campus greenhouse hydroponic production.** The amount of food provided by the Skidmore Community Garden is small relative to the total demand for food at the College's dining facilities, and the garden is hamstrung by spatial and climate-based constraints. A hydroponic facility provides unique advantages in terms of spatial efficiency, controlled climate, ease of operation, and myriad other factors that suggest that such a facility may be able to provide a greater total yield to Dining Services than an outdoor garden.
- **Consider integrating a hydroponic greenhouse in various educational capacities.** This may include providing coursework instructing future students in ESS, biology, chemistry, and other departments to create nutrient solutions for plants or evaluate ensuing social and ecological benefits from hydroponic growing. A hydroponic facility represents opportunities for civic engagement, something Skidmore has repeatedly

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 "25% by '25" plan.
    - If Skidmore College is unable or unwilling to create a hydroponic facility, particularly before 2025, this recommendation may be of heightened relevance.
- Through its Student Government Association (SGA), **appropriate future funding towards supporting a student club to be responsible for the hydroponic facility.** Ideally, this would include partnerships between the club and various departments, professors, and other student clubs/organizations. SGA is one amongst several avenues for funding a potential hydroponic club or initiative; other workable options include administrative funding, public grants, or alumni resources. It is neither a secret nor a surprise that the College lacks money to fund student led sustainable initiatives, amongst other fundamental areas. It is instrumental to at least support, if not financially, then at least administratively or departmentally independent research and volunteerism on the part of interested and ambitious students in this subject matter.
- By the same token, **encourage future ESS students (or others) to continue to conduct research that expands on the findings of this report.** Our capstone was unfortunately

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 that with a few diligent students, a hydroponic project can be expected to result in high yields, low costs, energy efficiency, and academic engagement. Conveniently located in the CIS greenhouse, a potential continuation of a pilot hydroponic project is deeply educational, easily replicable, and most importantly, easily scalable given the physical space and financial resources.

The management of the greenhouse would require training to become familiar with hydroponic systems, general maintenance, asset management, and other technicalities. Guidance through written course work or a syllabus of some kind can help better achieve and streamline these challenges and goals along the way. An educational hydroponic curriculum composed by Skidmore student researchers Alex Ricci and Temen Kim outlines basic hydroponic knowledge, including system inputs, maintenance, and general hydroponic system facts. This curriculum can serve as a potential beginners guide to hydroponic systems, and can be further developed over time in accordance with different plants or system adjustments. The curriculum was successfully taught to a senior honors environmental class at Saratoga High School. That being said, if Skidmore wishes to express its commitment to sustainable food procurement and that it is in any fashion serious about achieving its inscribed sustainability goals by 2025, we strongly suggest that the school further invest in a greenhouse hydroponic facility to cut costs for Dining Services, cut food miles drastically, and live more sustainably. **Figure 5** breaks down the pricing for an Automated Greenhouse and NFT system.

Greenhouse Hydroponics and NFT System

There are a plethora of online commercial greenhouse retail stores that offer pre-engineered or even custom options that Skidmore can use to tailor a greenhouse to their fiscal 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 greens year round, as pictured in **Figure 6**. Owner of Shushan Farm Phyllis Underwood exclaims that it is nothing short of remarkable what the NFT can produce in such a confined space.[91]

For purchasing recommendations, Amhydro is a commercial online retailer of NFT systems; **Figure 5** displays the price for an NFT 1200 Farmers Market bundle at $9,999. Included in this system bundle is a slew of propagation supplies, three months worth of medium and nutrients, and an adjustable nutrient controller, which is an excellent risk mitigator, energy

[90] Johan Andri Pratama et al., *Growing Insights and Youth Knowledge in the NFT Hydraulic Application (Nutrient Film Technique)*, (Indonesia, Kontribusia (Research Dissemination for Community Development), 2019).
[91] Phyllis Underwood, *Interview by Borowka et al.,* (New York, February 21, 2020).

saver, and labor alleviator. Their online testimonies inform that after just the first six weeks of establishing a stable growing cycle, growers can expect a consistent supply of 288 plants a week.[92] That production capacity equates to an entire month's worth of lettuce and other leafy greens that Dining Services outsource from their current food supplier. For Skidmore's and Dining Facilities purposes, that means lettuce, basil, cilantro, spinach, arugula, and more all year round free of interruptions. Across the board, the greenhouse NFT system is a perfect aid for Skidmore's future investment in and expansion of hydroponics.

[92] AmHydro, *NFT 1200 Farmers Market Bundle,* (California, AmHydro, 2020).

Figure 5: Pricing Sheet for Automated Greenhouse and NFT System

Full greenhouse	Item	Quanity	Total Price
	Senior Greenhouse Teaching Package	1	$24,995.00
	Get Growing NFT 1200 Farmers Market Bundle	1	$9,999.00
All components included			
	12 foot finishing channels (18 sites per channel)	32	
	12 foot nursery channels (72 sites per channel)	8	
	150 gallon reservoir	1	
	submersible pumps	2	
	10 foot sections of AmHydro Pro table frames	2	
	10 foot covered collectors with Drip Cap	2	
	10 foot feeder	2	
	Float valve and plumbing kit	1	
	Scrub brush and handle for channel	1	
	Instructions		
Propagation Kit			
	3-Tray propagation system kits	1	
	3-Tray propagation heating mat kit	1	
	Pump, float valve, water meter, reservoir, plumbing kit	1	
Pro Grower Starter Kit			
	Consulting for plant varieties and nutrient formulation		
	3 months of seeds (approx. 5K)		
	3 months of Oasis (thin cut) plant medium		
	3 months of nutrients		
	Buffer		
	Calibration solution		
	pH adjusters		
	Water Testing		
Other Items			
	12 months of grower support		
Total:			$34,994.00

Figure 6: Shushan Valley Hydro NFT System

VIII. Conclusions

Over the duration of this capstone process, many salient matters of sustainability on the part of Skidmore College have been exposed. From the singular lens of sustainability, Skidmore has made impressive efforts and values over the years, yet, to reiterate our former ESS colleagues, we implore the administration and Sustainability Office to further invest in and streamline its current sustainability efforts in order to boost not only desperately needed numerical results, but its own repute as an environmentally-committed school. We reflect the official position of countless other academic institutions and businesses that hydroponics represents the future of farming, and every individual to every community it touches is positively impacted, if not transformed, by this unparalleled environmental and social justice tool.

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