Weaver’s Way: A Sustainable Future

A case study aimed at improving sustainable practices at the Weaver’s Way Co-Op

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Introduction

Integrated Symbiotics, LLC is an Sustainable Engineering company focused on agricultural technology, with a special interest in the emerging field of aquaponics. Integrated Symbiotics aims to reduce the energy and water consumption required in traditional agriculture by mimicking natural behavior while combining new advances in automation and monitoring. Integrated Symbiotics was formed by Nicholas Renner, a Chemical Engineer, and Ferman Moody, a Sustainable Designer.

Integrated Symbiotics designs sustainable technologies that ensure healthy practices over the life cycle of urban food. Growing 20% - 50% of food on-site is how Integrated Symbiotics redefines locally sourced food. Converting food waste into renewable energy is an important goal in sustainability to encourage an organic life cycle.

This project evolved from Weaver's Way's commitment to increase its sustainability footprint to match the goals of its organization and community. Integrated Symbiotics was contacted to bring our knowledge and expertise to solve this problem. The following case study is the result of that partnership. The goal of the study is to examine some of the many possibilities that can increase Weaver's Way's footprint by integrating and updating their current resources. Goals include: decreasing water and energy usage by sustainable generation or reduction of current baseline, production of natural food sources through symbiotic techniques, and reduction of greenhouse gas emissions.

In our opinion, sustainability demands a response to climate change, fossil fuel depletion, and environmental degradation through energy and water reduction, as well as reducing chemical waste through organic food systems. Integrated Symbiotics reviewed Weaver's Way's sustainable agriculture practices and were impressed by how ecologically sound, economically viable, and socially just their current programs and facilities are. The suggestions laid out in this plan can help carry that legacy into future decades. In our opinion, authentic sustainability has no universal prescription but should be based on empirical data that clearly defines the needs of the present while designing tools that empower future generations to follow suit.

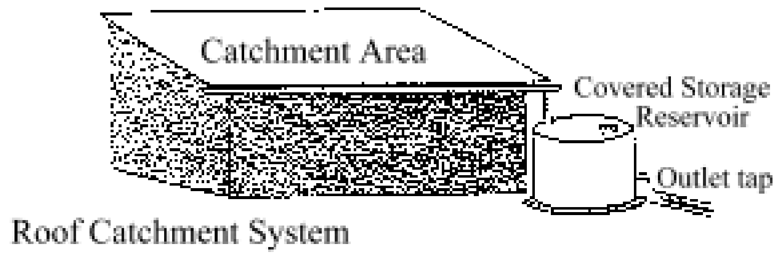
On behalf of Integrated Symbiotics, we hope you find this study enlightening.

- Nick Renner and Ferman Moody

1.0 Rainwater Harvesting and Filtration

Background

Fig. 1.1 Catchment Diagram



Rainwater harvesting is the accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off. Its uses include water for garden, water for livestock, water for irrigation and water for domestic use with proper treatment. In the most basic form of this technology, rainwater is collected in simple vessels at the edge of a roof. Variations on this basic approach include (1) collection of rainwater in gutters that drain to the collection vessel through down-pipes constructed for this purpose, and (2) the diversion of rainwater from the gutters to containers that settle particulates before the water is conveyed to the storage container for domestic use. As the rooftop is the main catchment area, the amount and quality of rainwater collected depends on the area and type of roofing material.

Reverse osmosis is a water purification technology that uses a semi-permeable membrane to remove larger particles from drinking water. In reverse osmosis, an applied pressure is used to overcome osmotic pressure--a colligative property--which is driven by chemical potential--a thermodynamic parameter. Reverse osmosis can remove many types of molecules and ions from solutions, including bacteria, and is used in both industrial processes and the production of potable water. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side.

Chestnut Hill Market

The scope of this section is to examine Weaver's Way's Chestnut Hill Market for rainwater catchment and filtration. The location has large flat roofs that are perfect for catching rainwater. There are some sloped roofs and HVAC equipment along the streetside. A synopsis of how much water can be recovered and how to go about recovering it is outlined below.

The Weaver's Way Co-op Chestnut Hill location allows for a substantial degree of rainwater catchment. The roof at this location was examined and divided into four sections based on drainage path and gutter location. These sections are shown in the bird's eye view of the location's roof seen in Figure 1.2. Section 1 includes the roof to the right of the rear exit and the adjoining area. Section 2 encompasses most of the roof, including the space where the

HVAC equipment is housed and the back area of the main store front's sloped roof. Section 3 is the front of that sloped roof. Section 4 is the roof above the produce section of the market. The calculated area of each section is listed in Table 1.1.

Fig. 1.2 WW Chestnut Hill Roof

Roof Section	Area	
Section 1	876	sq ft
Section 2	6,514	sq ft
Section 3	1,080	sq ft
Section 4	1,400	sq ft

Table 1.1 Roof Sectional Area

Possible rainwater catchment was calculated using three variables: Roof area, monthly rainfall in feet, and an efficiency factor. This calculation shown in Equation 1.1 will yield the volume of rainwater that can be collected for the given timeframe. The sectional area of the roof is the area calculated for each of the drainage sections referenced above. Monthly rainfall data was taken from the National Weather Service and calculated for the lowest month's rainfall (February), the highest month's rainfall (July), and the average monthly rainfall. An efficiency factor of 75% was used to account for evaporation due to Philadelphia's climate and absorption from accumulated solids. These assumptions are listed in Table 1.2.

$$Rainwater\ Collected\ (ft^3) = Efficiency(\%) \times \Sigma Rainfall(ft) \times Sectional\ Area(ft^2) \quad \text{(Equation 1.1)}$$

Assumptions		
High Rainfall	4.33	inch
Low Rainfall	2.64	inch
Avg Rainfall	3.45	inch
Recovery %	0.75	%

Table 1.2 Assumptions

The results for predicted monthly rain collection are displayed in Table 1.3, with the collection values converted to gallons from cubic feet.

Section 1		
Rain Recovery High	1,773	gallons
Rain Recovery Low	1,081	gallons
Rain Recovery Avg	1,415	gallons
Section 2		
Rain Recovery High	13,186	gallons
Rain Recovery Low	8,040	gallons
Rain Recovery Avg	10,519	gallons
Section 3		
Rain Recovery High	2,186	gallons
Rain Recovery Low	1,333	gallons
Rain Recovery Avg	1,744	gallons
Section 4		
Rain Recovery High	2,834	gallons
Rain Recovery Low	1,728	gallons
Rain Recovery Avg	2,261	gallons

Table 1.3 Sectional Water Collection

It can easily be observed from the data that Section 2 of the roof, with the largest area, also collects the most rainwater. Any attempts to collect rainwater from the Weaver’s Way roof should include this area. Rainwater collection totals for all sections in gallons per month and gallons per day are shown in Table 1.4.

Total RW Recovery				
Rain Recovery High	19,980	gallons/mo	666	gallons/day
Rain Recovery Low	12,182	gallons/mo	406	gallons/day
Rain Recovery Avg	15,938	gallons/mo	531	gallons/day

Table 1.4 Total Recovery Potential

These totals assume that all four drainage sections recover and collect water in a central reservoir. However, due to drain locations, this may not be the optimal design. The drains for Sections 1 and 2 are located in the rear of the building, while the drains for Sections 3 and 4 are located at the front of the building. The location for a proposed collection tank would also be located in the rear of the building, because the only room in front of the building is sidewalk space. Re-routing the gutters from Sections 3 and 4 to the back of the building is possible, but it would take a considerable length of piping. As an alternative, Sections 3 and 4 could be left as is while the rainwater from Sections 1 and 2 could be collected into a main reservoir. The collection totals for that scenario are listed in Table 1.5, both in gallons per month and gallons per day.

1+2 RW Recovery				
Rain Recovery High	14,959	gallons/mo	499	gallons/day
Rain Recovery Low	9,121	gallons/mo	304	gallons/day
Rain Recovery Avg	11,934	gallons/mo	398	gallons/day

Table 1.5 Recovery Potential Sections 1 + 2

Collecting this rainwater will allow it to be reused, displacing some of the current water usage of the Chestnut Hill facility. Monthly water usage was obtained through recent bills from the Philadelphia Water Revenue Bureau. Table 1.6 displays that usage in CCF (centum cubic feet) and gallons both per month and per day.

Current Usage			
65	CCF/month	0.67	CCF/day
48620	gallons/month	1,620.67	gallons/day

Table 1.6 Current Chestnut Hill Usage

Potential rainwater displacement is outlined in Table 1.7 for collections of both all possible sections and collection solely from Sections 1 and 2.

Water Savings	
All Sections	33%
Sections 1 + 2	25%

Table 1.7 Water Savings by Percent of Current Bill

To store the collected rainwater, a tank or cistern will be employed. This tank should be sized to accommodate an amount of water that is several times larger than the average rainwater accumulation. This is because rainwater fall is not constant--rather, it comes in several-day intervals. The rainwater from a large storm needs to be held for several days to average out to the accumulation listed above. A tank of 4x the average daily rainfall is recommended. In this case, that would mean a tank size of 1,600 gallons if collecting from Sections 1 and 2, or a tank size of 2,000 gallons if collecting from the full roof.

For full-year operation, the tank or cistern should either be indoors or buried below the frostline. If the tank were exposed outdoors to Philadelphia's winter climate, it would freeze periodically. At best, this would inhibit the collection and purification process of the rainwater; at worst, it could result in a burst tank or pipes and loss of equipment. If located above-ground and outdoors, either (1) a heating element or jacket would need to be implemented, which would not be an ideal option due to operating costs, or (2) the collection system would need to be shut down and diverted when the weather started reaching freezing temperatures, then restarted once the temperatures recovered in the spring.

The reverse osmosis unit should be sized to meet the average daily rainwater collection in order to promote constant filtration. This would be 400 gallons per day for Sections 1 and 2 and 500 gallons per day for the total roof scenario. A unit of this size would draw roughly 250W of electricity. The unit could easily be connected to the grid or be offset by grid-tied solar panels. Six 250W panels would offset grid energy use if desired. Off-grid setup would be less sustainable and much more expensive, due to a need for more equipment. A post reverse osmosis holding tank would also be set up to collect excess water filtered by the unit until it is ready to be used. That holding tank could be plumbed anywhere in the facility with proper back-flow prevention.

With water being billed at $6.18 per CCF, this system would save $130 per month and over $1,500 per year.

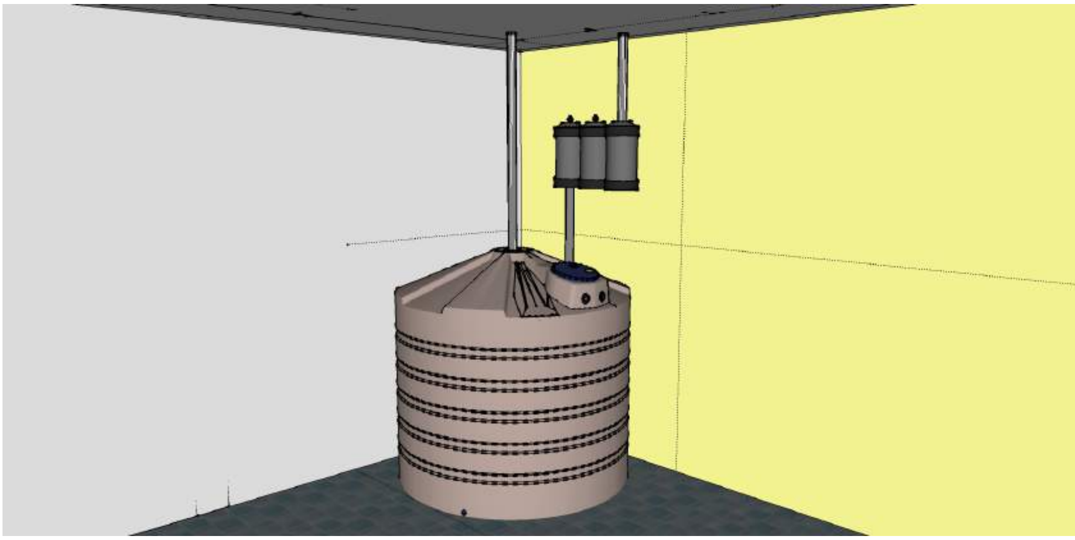


Fig 1.3 Diagram of Holding Tank plus RO Unit

Estimated Cost of Improvements: $8,000 - $14,000
Yearly Savings: $1,500 per year

Mt. Airy Market

The scope of this section is to examine Weaver's Way's Mt. Airy location for rainwater catchment and filtration. The location is made up of three properties from 555 to 559 Carpenter Lane. It has long flat roofs that are perfect for catching rainwater. 557 and 555 Carpenter Lane have sloped canopies connected to small upper-level porches along the streetside. A synopsis of how much water can be recovered and how to go about recovering it is outlined below.

Similar to Chestnut Hill, The Weaver's Way Co-op Mt. Airy location also allows for significant rainwater catchment. The roof at this location was examined and divided into five sections based on drainage path and gutter location. Theses sections are shown in the bird's eye view of the location's roof seen in Figure 1.4. Section 1 includes all of 559 Carpenter Lane. Section 2 is the back half of 557 Carpenter Lane and Section 3 is the back half of 555 Carpenter Lane. Sections 4 and 5 are the sloped roof and porch areas in the fronts of 557 and 555 Carpenter Lane, respectively. The calculated area of each section is listed in Table 1.8.

Fig 1.4 WW Mt. Airy Roof

Roof Section	Area	
Section 1	840	sq ft
Section 2	420	sq ft
Section 3	420	sq ft
Section 4	364	sq ft
Section 5	364	sq ft

Table 1.8 Roof Sectional Area

Possible rainwater catchment was calculated using the same methods and assumptions as the Chestnut Hill calculations. The results for predicted monthly rain collection are displayed in Table 1.9, with the collection values converted to gallons from cubic feet.

Section 1		
Rain Recovery High	1,700	gallons
Rain Recovery Low	1,037	gallons
Rain Recovery Avg	1,356	gallons
Section 2		
Rain Recovery High	850	gallons
Rain Recovery Low	518	gallons

Rain Recovery Avg	678	gallons
Section 3		
Rain Recovery High	850	gallons
Rain Recovery Low	518	gallons
Rain Recovery Avg	678	gallons
Section 4		
Rain Recovery High	737	gallons
Rain Recovery Low	449	gallons
Rain Recovery Avg	588	gallons
Section 5		
Rain Recovery High	737	gallons
Rain Recovery Low	449	gallons
Rain Recovery Avg	588	gallons

Table 1.9 Sectional Water Collection

Section 1 exhibits the most potential rainwater recovery, while the other four sections have collection capacities that are similar to each other. Rainwater collection totals for all sections in gallons per month and gallons per day are shown in Table 1.10.

Total RW Recovery				
Rain Recovery High	4,874	gallons/mo	162	gallons/day
Rain Recovery Low	2,972	gallons/mo	99	gallons/day
Rain Recovery Avg	3,888	gallons/mo	130	gallons/day

Table 1.10 Recovery Potential

As for the Chestnut Hill location, these totals assume that all five drainage sections would recover and collect water in a central reservoir. Again, due to drain locations, this may not be the optimal design. The drain locations for Sections 1, 2, and 3 are located in the alley behind the the market, while the drains for Sections 4 and 5 are located on the street in front of the market. Similar to Chestnut Hill, the location for a proposed collection tank would also be located in the rear of the building, because the only room in front of the building is sidewalk space. It may be difficult to re-route the gutters for Sections 4 and 5 to the building's rear. As an alternative, Sections 4 and 5 could be left as is while the rainwater from Sections 1, 2, and 3 could be collected into a main reservoir. The collection totals for that scenario are listed in Table 1.11, both in gallons per month and gallons per day.

1+2+3 RW Recovery				
Rain Recovery High	3,401	gallons/mo	113	gallons/day
Rain Recovery Low	2,073	gallons/mo	69	gallons/day
Rain Recovery Avg	2,713	gallons/mo	90	gallons/day

Table 1.11 Recovery Potential 1 + 2 + 3

Collecting this rainwater would allow it to be reused, displacing some of the current water usage of the Mt. Airy facility. Monthly water usage was obtained through recent bills from the Philadelphia Water Revenue Bureau. Table 1.12 displays that usage in CCF (centum cubic feet) and gallons both per month and per day.

Current Usage			
20	CCF/month	0.67	CCF/day
14960	gallons/month	498.67	gallons/day

Table 1.12 Current Usage at Mt. Airy

Potential rainwater displacement is outlined in Table 1.13 for collections of both all possible sections and collection solely from Sections 1, 2 and 3.

Water Savings	
All Sections	26%
Sections 1 + 2 + 3	18%

Table 1.13 Potential Water Saving based on Current Usage

A tank of 4x the average daily rainfall is recommended. In this case, that would mean a tank size of 400 gallons if collecting from Sections 1, 2, and 3, or a tank size of 600 gallons if collecting from the full roof.

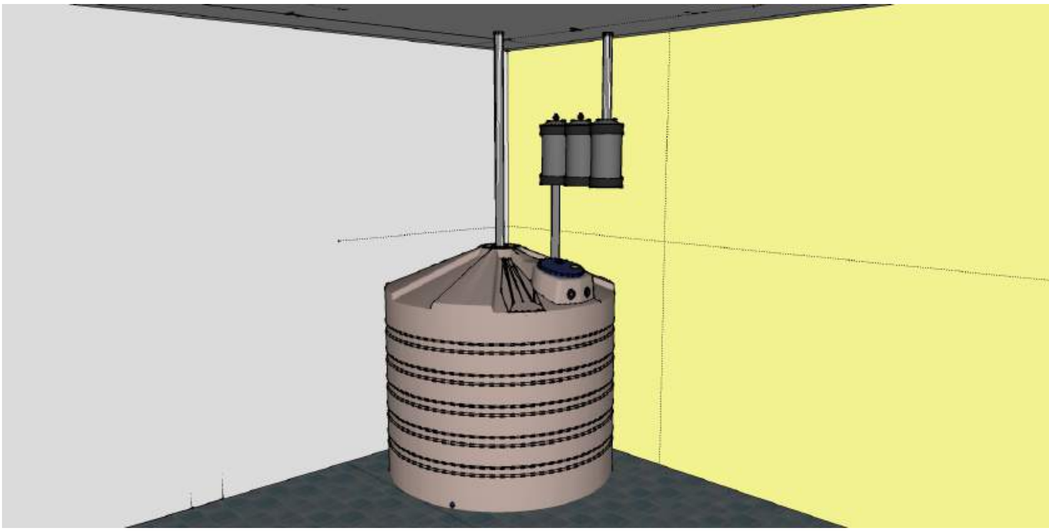


Fig. 1.5 Holding Tank plus RO Unit

The reverse osmosis unit should be sized to meet the average daily rainwater collection to promote constant filtration. This would be 100 gallons per day with Sections 1, 2, and 3, and 150 gallons per day in the total roof scenario. A unit of this size would draw roughly 100W of electricity. The unit could easily be connected to the grid or be offset by grid-tied solar panels. Three 250W panels would offset grid energy use if desired. Off-grid setup would be less sustainable and much more expensive, due to a need for more equipment. A post-RO holding tank would also be set up to collect excess water filtered by the unit until it is ready to be used. That holding tank could be plumbed anywhere in the facility with proper back-flow prevention.

With water being billed at $6.18 per CCF, this system would save $30 per month and over $400 per year.

Estimated Cost of Improvements: $4,000 - $8,000
Yearly Savings: $400 per year

2.0 Aquaponics

Background

Aquaponics is a food production method combining conventional aquaculture, raising fresh water fish or other animals, with hydroponic gardening, the cultivation of plants in water, in a symbiotic environment. In normal aquaculture, excrement from the animals being raised can accumulate in the water, becoming toxic. In an aquaponic system, water from an aquaculture system is fed to a hydroponic system where the by-products are broken down by bacteria into nitrates and nitrites, which are utilized by the plants as nutrients. Clean water is then recirculated back to the aquaculture system.

Aquaponics is a working model of sustainable food production wherein a closed-loop, bio-integrated system gives synergy to aquaculture, vegetables, flowers, and herb production. The nutrient rich effluent of aquatic environments is required to grow vegetation without the use of soil, chemical fertilizers, and excessive farm space. Sustainable reuse materials and water filtration technology are used to design systems for space appropriate applications.

Fig. 2.1 Vertical Aquaponic Drain System

Through a three step nitrification cycle, ammonia is converted into nitrates that are used to fertigate production grow beds. Fish and plants share a symbiotic relationship where plant roots and bacteria remove toxic nutrients from water helping restore a natural environment full of oxygen rich water for fish to breathe.

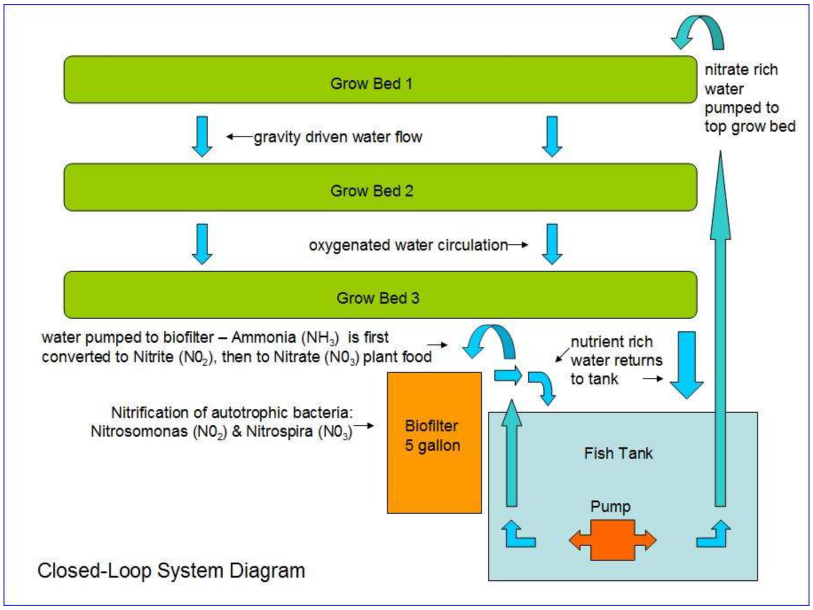


Fig. 2.2 Sustainable Youth Methodology Curriculum

Ammonia that is mainly released through the fish's gills into the aquatic environment is absorbed by the biofilter. There nitrites and phosphorus feed the bacteria *nitrosomonas* and *nitrobacter* producing nitrate, which acts as organic plant food. Healthy plants cleanse water before it is recirculated back into the fish tank.

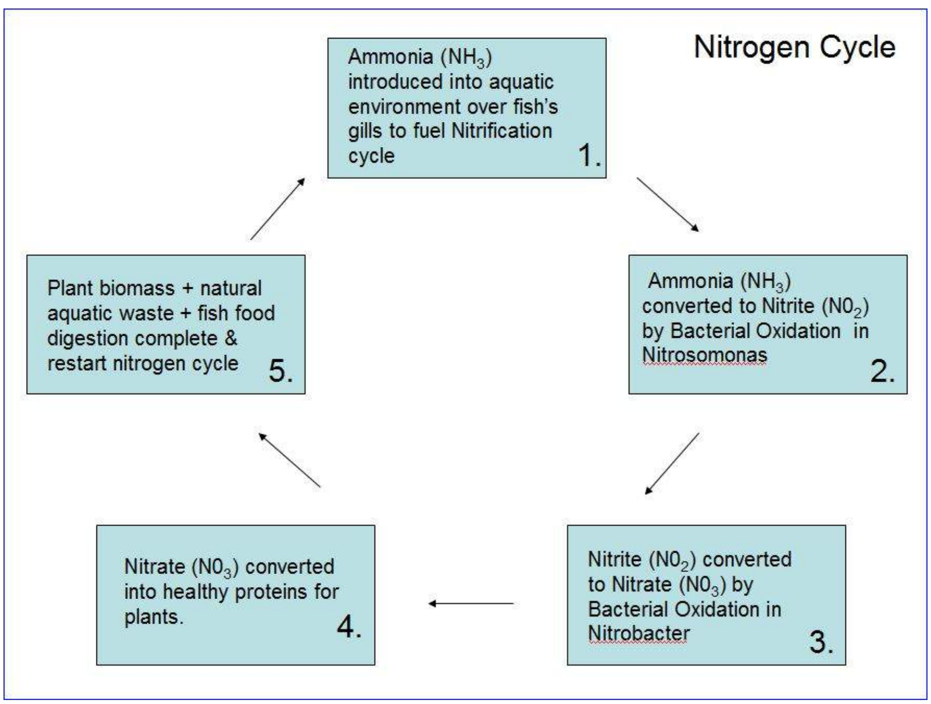


Fig. 2.3 Sustainable Youth Methodology Curriculum - Nitrogen Cycle

In a forty day cycle ammonia levels rise then drop after 15 days, nitrite levels rise and fall within day 9 through day 25, finally giving way to healthy nitrate levels, by day 40. Close monitoring of aquatic environment's biological health daily promotes abundant organic vegetation growth. A healthy ammonia (NH_3) concentration should stay as close to neutral or 0 parts per million (ppm). These levels should be monitored daily to remain aware of the total ammonia nitrate (TAN) available in the water.

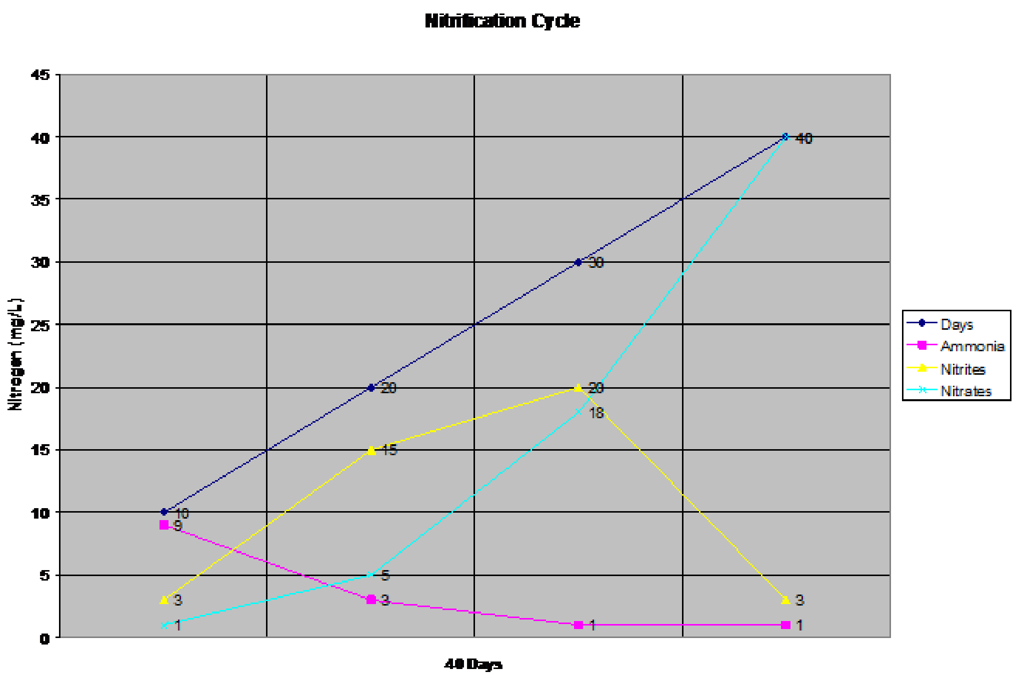


Fig. 2.4 40 day Nitrification Cycle

The average stocking density for trout, tilapia, and catfish in aquaponics is: 1 pound of fish per three gallons of tank water. Mature fish produce eight ounces of fillet within a seven to eleven month grow cycle. To reach healthy adulthood, fish should not be feed more than two percent of bodyweight per day. This can be monitored by only feeding fish in a system what they can eat in five minutes at two feedings per day.

Potential plant and aquaculture yields via aquaponics production are detailed in tables 2.1 and 2.2. The amount for a family of four is generally about three times the amount needed by one adult. All yields are based on garden plant and seed production standards as seen on retail packaging.

VEGETABLE PRODUCTION CHART		AQUAPONICS ADAPTABLE SYSTEM				
PRODUCT	Yield per plant (lbs) (YPP)	Family of 4 food intake (lbs) (F4)	Days to maturity - Soil (S)	Days to maturity - Aquaponics (A)	Yield per 100 plants (lbs) (Y100)	Yield per 10 foot grow bed (lbs) (Y10)
Beans, Lima	0.75	1.25	65	35	80	8
Beans, Snap	6	8.5	65	40	150	15
Cabbage	19.5	11.25	70	35	120	8
Collards	5	1.5	55	35	80	8
Cucumbers	18	23	60	30	200	12
Eggplant	10	11	80	50	115	7
Kale	10	10	55	30	100	7
Leeks	3.5	6	45	30	45	5
Lettuce, Head	1	0.5	80	40	100 heads	10 heads
Lettuce, Leaf	5	5	45	30	50	5
Mustard	5	5	45	30	50	5
Peas, Snap	3	4	65	30	40	2
Peppers	15	11	80	40	120	5
Spinach	11	7	55	35	65	6.5
Swiss Chard	9	9	50	35	85 heads	10 heads
Tomatoes	16	17.5	85	45	165	15
Tomatoes	16	17.5	85	45	165	15
Watermelons	10	3.5	130	65	100 melons	7 melons
Parsley	2.5	3	70	30	250	25

Table 2.1 Yield Per Plant

FISH STOCKING DENSITY					
Tank Size	# of fish 9 month cycle	lb mature fish	lb fish per gallon	Start-up %	Total Fish Weight
500	250	1.5	0.5	20	250
300	150	1.5	0.5	20	150
100	50	1.5	0.5	20	50
50	25	1.5	0.5	20	25
25	12.5	1.5	0.5	20	12.5
10	5	1.5	0.5	20	5
Grow Scenario:					
Nine month grow cycle			1 cubic foot = 7.48 Gallons		
Grow bed volume to Fish tank volume 2:1			Divide gallons by 7.48 to determine cubic feet.[23]		
Grow bed depth: 1 foot = 2' x 7' bed			Cubic feet of grow bed equation – length x width x height		
			ie. 25 gallon tank / 7.48 = 3' cubic feet grow space		

Table 2.2 Stocking Density of Adaptable Aquaponics Systems

Aquaponics Benchmarks, Highlights, & Takeaways:

◊ A synergy of plants and fish create a polyculture that yields a diverse range of both edible and commercial products.

◊ Aquaponics is closed-loop, saving resources through the recirculation of water.

◊ On-site food production.

◊ Fish waste is a renewable source of organic fertilizer which enables vegetation to grow in a third of the time.

◊ One farming technology produces two abundant products, fish, and plants.

◊ Aquaponics can be used to teach youth a skill set based in modern agriculture, functioning as a sustainable playground.

The following scenarios examine potential sites Weaver's Way can integrate aquaponics into their programming and logistics. The sites chosen were the roof of the Chestnut Hill market location, the roof of Philadelphia Salvage in Mt. Airy, and the greenhouses at Saul Farm. The following ideas range from functional designs that utilize areas for production to creative demonstration areas that showcase sustainability as a learning technique.

Chestnut Hill Market

The goal of this system is to produce organic vegetation and fish on-site. These aquaponics systems can also serve as education tool for Weaver's Way's culture of sustainability. The fish tank can be presented in the window/rear entry way adding to patron experience. The effluent will be pumped to a rooftop production garden. The weight of the tank on roof membrane will be alleviated by placement of fish tank on first floor. The following are potential designs.

Fig. 2.5 Chestnut Hill Roof Production Site

Fig 2.6 Roof Garden & Outdoor Cafe

Fig. 2.7 Area B Plumbing Scenario

Fig. 2.8 Countertop Fish Tank

Fig. 2.9 Grow System Area A (left) & Window System Area B (right)

Fig. 2.10 Weaver’s Way Courtyard

Fig. 2.11 Food Presentation & Outdoor Cafe

Fig. 2.12 Donation & Fundraiser Memoriam

Philadelphia Salvage - Mt. Airy Rooftop

Fig. 2.13 Mt. Airy Salvage Roof

Integrated Symbiotics can design aquaponics systems for the rooftop of Philadelphia Salvage. The goal of this system would be to produce 20 - 35% of organic vegetation and fish on-site for Weaver's Way Mt. Airy Co-Op grocery store. Aquaponics systems can also serve as education tool to Weaver's Way's culture of sustainability.

Fig. 2.14 Mt. Airy Rooftop Greenhouse - Carpenter Lane

Fig. 2.15 Inside Greenhouse/Hoophouse Aquaponics & Strawberry Gardens

Fig 2.16 Carpenter Street Rooftop Greenhouse & Green Roof - Mt. Airy

Fig. 2.17 Rooftop Cafe Solar Harvest & Shading

Fig. 2.18   Rooftop Cafe & Wine Garden

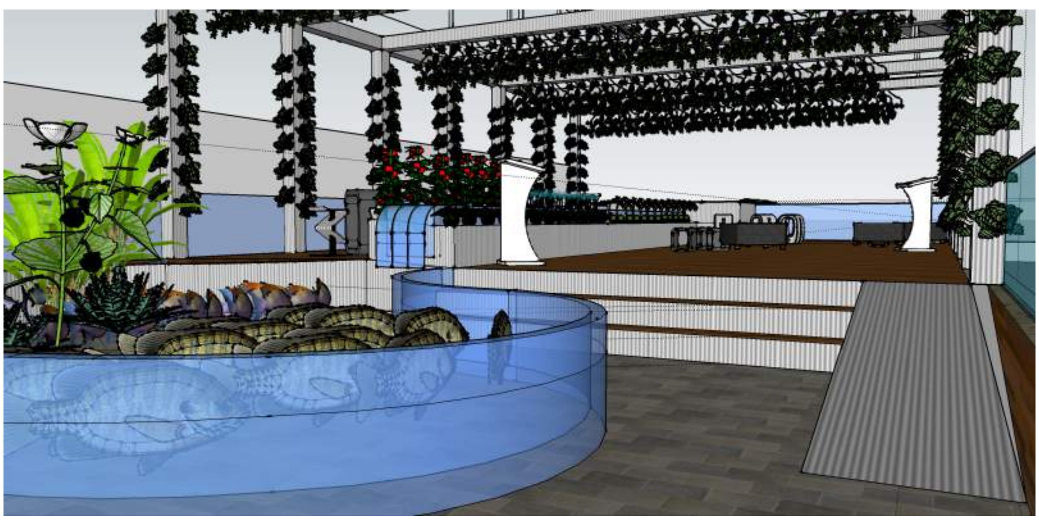


Fig. 2.19 Solar Harvest : Shading : Rainwater Catchment: Vegetable Production

Fig 2.20 Rooftop Cafe

Saul Greenhouses

Saul High School is the largest agricultural farm school in the United States. The school has the largest Future Farmers of America chapter in the State of Pennsylvania and one of the largest in the United States. Integrated Symbiotics can design aquaponics systems for Saul HS/Weaver's Way farm school sites, particularly in the greenhouses located at the back of the farm. These greenhouses serve as a perfect space to provide the protection the systems require for year round production. These greenhouses can be retrofitted with techniques discussed in sections 4 and 5.

Fig. 2.21 Greenhouses at Saul

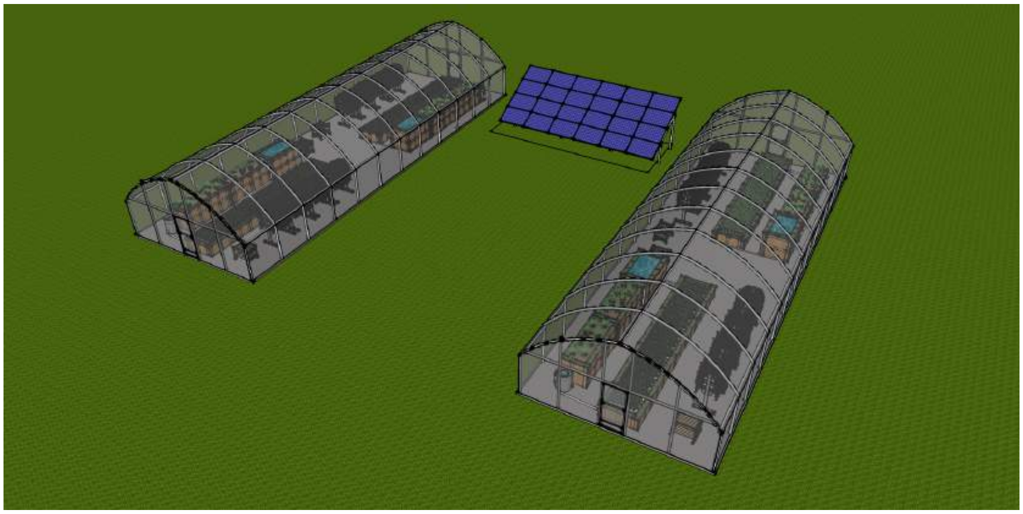


Fig. 2.22 Saul High Tunnel Greenhouse Site

Fig. 2.23 Adaptable Aquaponic System Design

Fig. 2.24 Adaptable Aquaponic System Design

Integrated Symbiotics has a wide range of ideas and innovations involving aquaponics, and a commitment to implement them in the Philadelphia. We are interested in realizing these dreams through potential partnerships. We are happy to discuss scenarios where Integrated Symbiotics will build and maintain systems on Weaver's Way property. The plants and fish grown through these systems can be sold by Weaver's Way through their markets and farm share programs. We also have interest in creating and performing educational programs to the community and to youth at Saul or other surrounding organizations.

Cost Estimate: Dependent on Implementation

3.0 Smart Watering Management

Background

Agriculture is a major consumer of ground and surface water in the United States, accounting for approximately 80 percent of the Nation's consumptive water use and over 90 percent in many Western States. Experts estimate that as much as 50 percent of this water is wasted due to overwatering caused by inefficiencies in irrigation methods and systems. Irrigation control technologies can significantly reduce overwatering by applying water only when plants need it. Weaver's Way already uses drip irrigation. Drip irrigation is about 20% more water efficient than sprinklers are. Tests by the Irrigation Association (IA) have shown smart irrigation controllers to save up to 25% more water than traditional irrigation controllers.

Advances in technology, including the Internet of Things movement, have made it easier than ever to monitor and control your environment. Two major players in the DIY (Do It Yourself) portion of this movement are the Arduino, a micro-controller, and Raspberry PI, a palm sized computer.

The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It’s capable of doing everything you’d expect a desktop computer to do, from browsing the internet and playing high-definition video, to making spreadsheets, word-processing, and playing games.The Raspberry Pi has the ability to interact with the outside world, and has been used in a wide array of digital maker projects, from music machines and parent detectors to weather stations and tweeting birdhouses with infra-red cameras.

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects. Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators. Arduino can be told what to do by writing code in the Arduino programming language and using the Arduino development environment.

Automation Monitoring

In this case, water conservation is explored through monitoring and automation. This project would aim to decrease water usage on Weaver’s Way farms by monitoring the soil and environment, and analyze the collected data to know when crops need watering.

Soil probes would be submerged in the ground amongst the crops, which would collect data such as soil water content, temperature, and atmospheric humidity. These probes would communicate to an Arduino which would collect that data and send it to a central database located on a Raspberry PI. Multiple arduinos would control individual sections of the farm. The computer would organize that data into an easy-to-read format, which can be monitored via web or an application. The computer would also analyze that data, and determine whether crops in each section need watering currently. The Raspberry PI can also pull data from the web such as data from the National Weather Service, to analyze atmospheric humidity and temperature. Over time data is collected that will aid the controller in watering based on past scenarios. That decision would be relayed to another Arduino which would turn water spouts on or off depending on the preferred parameters. A schematic of how this system is connected is seen in figure 3.1.

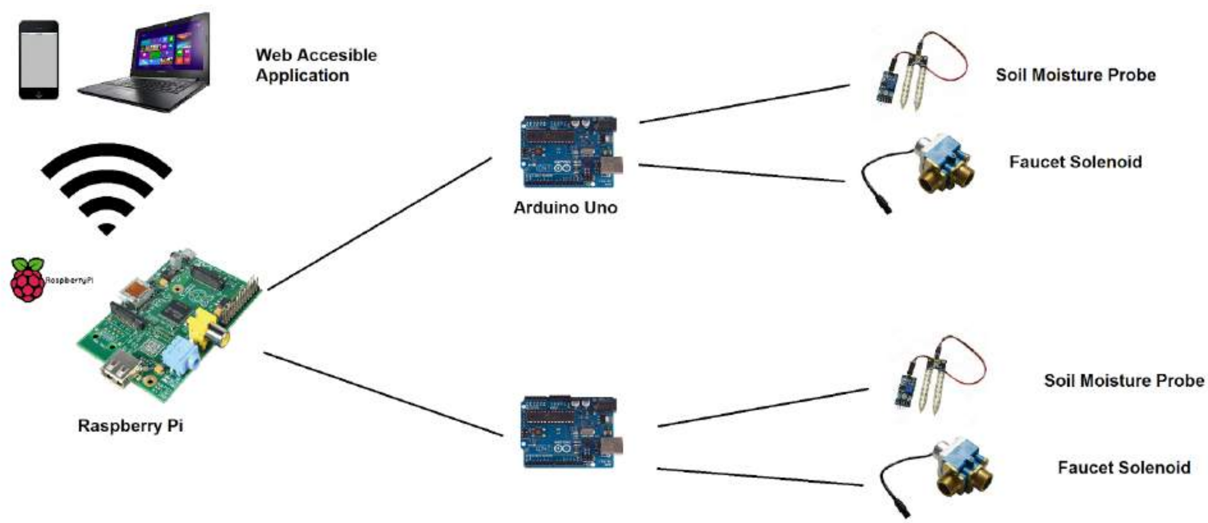


Fig 3.1: Automation Schematic

Water automation can be integrated at Weaver's Way at their Saul location or their plots at Awbury Arboretum, as well as anywhere else crops are grown currently and in the future.

Cost Estimate: Dependent on Implementation

4.0 Anaerobic Digestion

Background

Biogas is primarily methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S), moisture and siloxanes. The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel; it can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat.

A micro-CHP system is a small heat engine (power plant) that provides all the power for an individual building: heating, ventilation, air conditioning, mechanical energy and electric power. It is a smaller-scale version of cogeneration schemes that have been used with large-scale electric power plants. The reason for using such systems is that heat engines, such as steam power plants that generate electric power by burning fuel, are not very efficient. A heat engine cannot be 100% efficient; it cannot convert anywhere near all the fuel it burns into useful forms such as electricity. As a result, heat engines always produce a surplus of low-temperature waste heat, called "secondary heat" or "low-grade heat." Modern plants are limited to efficiencies of about 33-60% at most, meaning 40-67% of the energy is exhausted as waste heat. In the past, this energy was usually wasted. Cogeneration systems, built in recent years in cold-climate countries, utilize the waste heat produced by large power plants, piping hot water from the plant into buildings in the surrounding community.

Micro combined heat and power or micro-CHP is an extension of the idea of cogeneration to the home or small office building in the range of 0.3 - 50kW. Local generation has a higher efficiency, as it avoids the 8-10% energy losses when transporting electricity over long distances and the 10-15% energy losses on long-distance heat transfer. These losses occur because of the difference between the hot energy carrier (water) and the colder external environment.

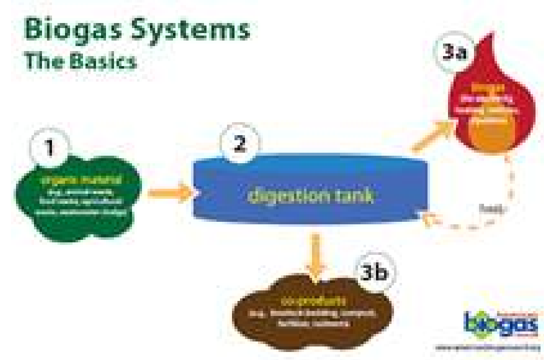


Fig. 4.1 Biogas Systems - American Biogas Council

Saul Farm - Full Compost System

As a primary scenario, feeding the total waste collection from Weaver's Way into an anaerobic digester will be examined. Weaver's Way collects an enormous amount of compost at its Saul Farm facility, averaging about 155,000 lbs per month, equivalent to 70.5 metric tonnes. A digester that could house that amount of compostable waste would conceivably be the size of a normal barn. We will examine the electrical (kW_e) and thermal (kW_t) outputs of the gas when fed into a Combined Heat and Power unit (CHP).

Fig 4.2 Compost at Saul Farm

Calculating the benefits of an anaerobic digester system requires two steps. The first is calculating the amount of biogas that can be recovered from the digestible waste, and the second is determining how much energy can be recovered from the utilization of that biogas.

Currently, Weaver's Way collects about 155,000 lbs of compostable waste per month. Converting to the metric system for ease of calculations, that amount is equivalent to 70,450 kg per month or around 70.5 metric tonnes per month. The International Energy Agency lists the theoretical biogas yield of various feedstocks in its report "Biogas from Energy Crop Digestion."

Material	**Yield (m3/tonne)**	**Material**	**Yield (m3/tonne)**
Cattle slurry	15-25	Straw	242-324
Pig slurry	15-25	Oats grain	250-295
Poultry	30-100	Clover	345-350
Grass silage	160-200	Barley	353-658
Whole wheat crop	185	Potatoes	276-400
Maize silage	200-220	Turnip	314
Maize grain	560	Rhubarb	320-490
Wheat grain	610	Wheat grain	384-426
Sugar beet	236-381	Peas	390
Kale	240-334	Leaves	417-453

Table 4.1 Biogas Yields from Assorted Wastes

Yields range from the low- to mid-double digits for animal wastes, to over 500 m^3/tonne for some grains (see Table 4.1). Most vegetation lies somewhere in the middle of these figures. Considering the varying composition of the waste collected by Weaver's Way, a figure of 200 m^3/tonne is used in the following calculations. That figure is somewhat conservative.

Also taken into consideration is the composition of the biogas. Unlike natural gas, which is 80% methane, final biogas composition is in the range of 60% methane. Methane is the main combustible material in both gases and the fuel responsible for energy production (though natural gas sometimes contains smaller portions of ethane and propane, also combustible gases). Calculations for possible methane production from this feedstock are shown in Table 4.2 below. They can be represented by the following equation:

$$CH_4\,Produced\,(m^3/month) = \%Composition * Feedstock(tonne/month) * \Delta Gas\,Yield\,(m^3/tonne)$$

(Equation 4.1)

Total Compost	155000.00	lbs/month
Total (in Tonne)	70.45	tonne/month
Gas Yield	200.00	m3/tonne
Biogas	14090.91	m3/month
Composition	0.60	CH4/Total Gas
Product	8454.55	m3 CH4/month

Table 4.2 Methane Production

Using these assumptions, the total waste collected at Saul could be producing 8,450 m^3 of methane per month. This total would vary based on composition, but it is a safe approximation. Using that total we can approximate the energy generation possibilities using that gas as a feedstock.

A combined heat and power unit (CHP) using a capability known as co-generation can be used to generate electricity and heating power from the combustion of gas. Current advancements in CHP units have brought about systems with 40% electric efficiency and 50% thermal efficiency. As an example, a system with 100 kW of input energy from gas can be converted into 40 kW of electrical energy and 50 kW of heat (around 170,000 btu/hr, which are the conventional units for thermal energy in the United States).

Using the High Heating Value (HHV) of methane, which is approximately 38 MJ/m^3 , the theoretical input power of the biogas can be calculated as shown in Equation 4.2.

$$Power\ (MJ/month) = HHV\,(MJ/m^3) \times CH_4\,(m^3/month) \qquad \text{(Equation 4.2)}$$

By converting the energy created over the length of the month to the energy created per second, that unit becomes MJ/s. A Mega-watt (MW) is equivalent to 1000 kilo-watts (kW).

Energy Conversion		
Heating Value	38.00	MJ/m3
Power	321,272.73	MJ/month
Power	0.12	MW (MJ/s)
Power	123.95	kW

Table 4.3 Potential Energy Generation

The possible biogas produced from a full-scale anaerobic digester could yield close to 124 kW of input power continuously. This input gas fed into a CHP unit could yield 40% of that power as electricity and 50% as heat.

CHP Efficiency	
Electrical	0.4
Heat	0.5

Table 4.4 Combined Heat and Power Efficiency

This equates to 50 kW of electrical generation and 62 kW of thermal generation, or 211,464 btu/hr (Table 4.5).

Input Power	124	kW
Electrical Power	50	kW
Heating Power	62	kW
Heating Power	211,464	btu/hr

Table 4.5 Generated Heat and Electrical Power

This is the equivalent electrical generation of two-hundred 250 W solar panels running at peak efficiency continuously. The heating power could be used to heat several greenhouses in the winter, depending on the conditions, or be utilized anywhere locally that heat is needed. It is also beneficial to recirculate some of the generated heat through the biogas generator to ensure proper temperature for digestion. The electrical power generation does not have to be used on site and could be sold back to the grid. Table 4.6 depicts the value generated by selling this electricity back to the grid.

Electrical Generation		
Daily kWh	1,189.90	kWh
Monthly	35,696.97	kWh
Energy Price	$0.10	/kWh
Revenue	$3,569.70	$/month
Revenue	$42,836.36	$/year

Table 4.6 Electrical Generation and Payback

Selling this electricity back to the grid could generate over $40,000 per year and would create a return on investment, eventually becoming a revenue-generating process for Weaver's Way.

Assuming a compost density of 1,000 lbs per cubic yard, a facility of more than 155 cubic yards or 4,200 cubic feet would be necessary. Since the majority of the waste would be solid, it would be beneficial to digest this waste in a batch process in a dry environment instead of liquefying the waste to run through a continuous reactor. A multi-compartment batch digester could be designed in a manner similar to a multi-door garage. The waste would be loaded into each compartment throughout the month, and the digestate would be removed from each compartment after a month for further composting.

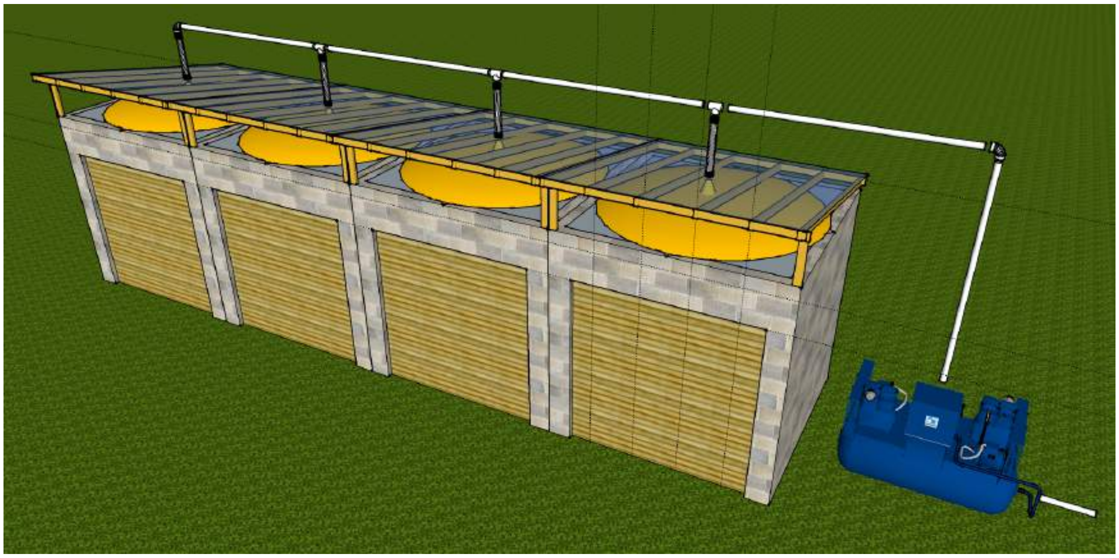


Fig. 4.3 Anaerobic Digester Front

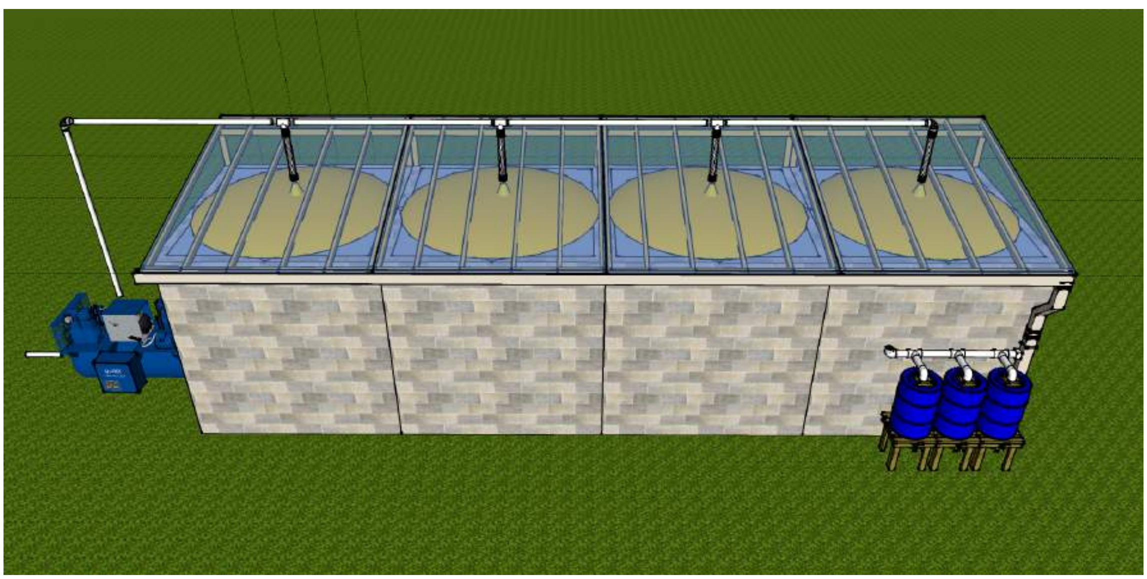


Fig. 4.4 Anaerobic Digester with Rear Rainwater Catchment

PECO currently gives incentives for installing CHP units. PECO customers who install CHP units can recover up to 50% of the costs via installation and use incentives. PECO offers $300 dollars per installed kW up front, and then $0.02 per generated kWh over the units lifetime.

Cost Estimate: $200,000 - $300,000 (Pre-Incentive)
Yearly Revenue: $43,000

Saul Farm - Greenhouse System

In the second scenario, we size an anaerobic digester to fit the power needs of the off-grid greenhouse at Saul Farm. A CHP unit is sized to fit the power requirements of the greenhouse, and the input requirements of the CHP are used to determine optimal digester size and inputs.

In this case, it is useful to work backwards from the electrical power goals to size the amount of compost Weaver's Way would need to digest. The electrical power requirements of the greenhouse at Saul Farm stand continuously at around 1.1 kW. The smallest CHP units in production stand in the range of 1.5 to 2 kWe. For example, in these calculations, a 2 kWe CHP unit is used at full production. To generate 2 kWe, using a 40% efficiency, 5 kW total input energy in the form of biogas must be reached. This is equivalent to 12,960 MJ/month (Table 4.7).

Electric Gen Goal	2.00	kW
E Efficiency	0.40	
Input Gas	5.00	kW
	12,960.00	MJ/month

Table 4.7 Electrical Goals

Using the HHV of 38 MJ/m^3 from Part 1 of this section, a monthly methane input of 341 m^3/month would be needed. At 60% methane, 568 m^3/month of biogas would be needed. Using the previous assumption of 200 m^3/tonne, the solids needed to run this digester would be equal to 2.84 tonnes/month. This is equivalent to 6,242 lbs per months of digestible material, or 4% of the farm's total compost. Using a compost density of 1000 lbs/yd^3, a digester would need to be at least 6.25 cubic yards for a one month residence time. That is equivalent to 169 cubic feet, or an area slightly larger than 10' x 4' x 4'.

Energy Input	12,960.00	MJ/month
Heating Value	38.00	MJ/m3
CH4/month	341.05	m3/month
Methane Ratio	0.60	
Biogas Input	568.42	m3/month
Gas Yield	200.00	m3/tonne
Total Solids	2.84	tonne/month

Table 4.8 Solids Needed for Generation Goals

Cost Estimate: $30,000-$60,000 (Pre-Incentive)

Chestnut Hill/Mt. Airy On-Site System

On-site production of Biogas from both the Chestnut Hill and Mt. Airy locations of Weaver's Way was examined. The production of gas and electricity would help increase sustainability by reducing transportation of the waste and generating power that could offset each location's energy needs.

According to Weaver's Way's annual report, 41 short tons (US) of compost per year are received from Weaver's Way's Mt. Airy and Chestnut Hill locations. Approximately 70% of that waste is from Chestnut Hill, and 30% of that is from Mt. Airy. This represents close to 4,750 lbs/month of compost from Chestnut Hill and 2,050 lbs/month from Mt. Airy. Using the same calculations as before, the energy outputs from these feedstocks are 1.15 kW and 0.50 kW of electricity, respectively. These electrical outputs aren't suitable for even the smallest of current CHP units, though biogas production could be created on-site as a sustainability experiment.

5.0 Renewable Greenhouses

Background

Using some of the above techniques Integrated Symbiotics has examined retrofitting the greenhouses at Saul Farm to function as housing for aquaponic farming, while remaining off-grid. Solutions include powering the greenhouses' electrical components via solar power, retrofitting the greenhouses' propane heater to operate off biogas, and other permaculture improvements.

The main high tunnel greenhouse at Weaver's Way's location at Saul is approximately 46' x 26'. It needs approximately 196,000 btu/hr of heating to keep it warm on the coldest days. That takes into account that the surface area of the greenhouse is approximately 2,800 ft^2, the desired greenhouse temperature is 70F, the lowest outdoor temperatures reached are at 0F, and a heat loss value of 1 for the outer material. This heating need is only for the coldest of times on the coldest days. Most times in the winter the heating needs will be half of that, and no heating is needed for the summer months and the majority of the spring and fall.

The greenhouse has several electrical components used for climate control including fans, window control, and heating devices. However, the greenhouse is not connected to any grid and must be powered by off-grid renewable sources, or else be connected to the grid which is not especially convenient at this location.

Fig. 5.1 Greenhouses at Saul

A second greenhouse is approximately 36 ’x 16’ built approximately 40 feet away which was built in co-operation with programs from Penn State University. Excess heat generated from the modernized greenhouse could be recirculated to this greenhouse, but only when the first greenhouse is not using it’s full capacity on the coldest of days. For aquaponics purposes, this greenhouse could be fit with solar thermal panels to provide water heating, along with use of any proposed solar energy generation. Additional heat would require either an installed heating unit, or use of heat exchange through compost.

Renewable Power

In 2012, a proposal was submitted by the company Alternative Energy Inc. which is a distributor for SunRNR products. The proposal was undersized by several features and suggested to be paired with a backup generator, which would in fact be supplying 90% of the energy on full load days. Their proposal calls for 4 - 135 W panels for a total of 540 W of generation and 2-245 Ah batteries for a total of 490 Ah of storage. A system that runs this greenhouse 100% renewably would cost more than their proposal at $7,500 dollars but would cost much less in cost per unit. If a generator assisted to shelve peak loads (mostly the load for the Modine heater in the winter) the costs would be similarly manageable but with much more reliability and sustainable power.

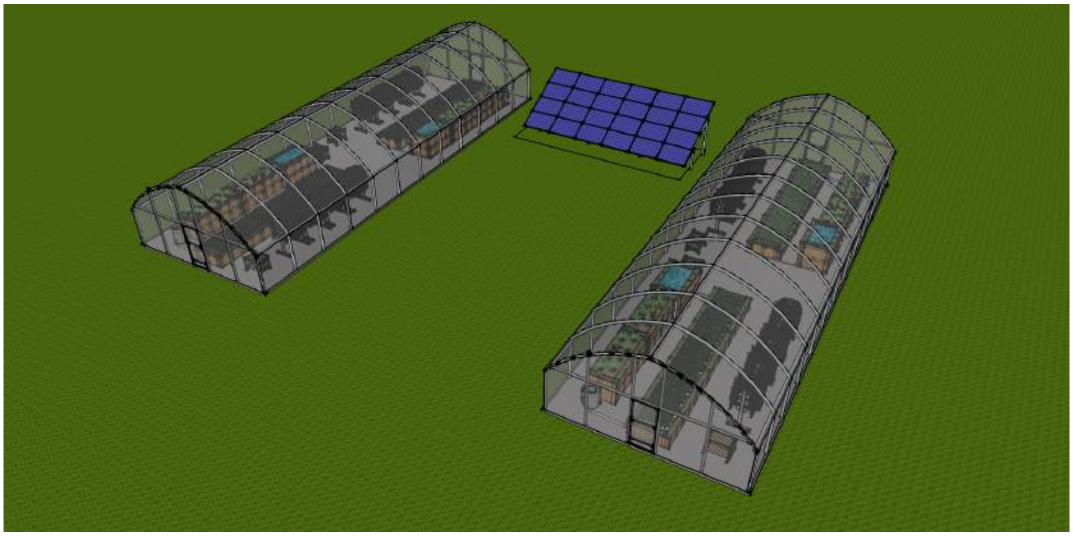


Fig 5.2 Aquaponic Greenhouses with PV System

In order to determine the amount of solar generation and storage needed to run the greenhouse 24/7, the usage of the greenhouse needs to be determined. The interior of the greenhouse is wired at a voltage of 115 VAC. A list of the amperage of all electrical components utilized in the greenhouse was compiled. Their power draw in watts (W) was calculated using the formula $P = IV$ where I stands for amperage and V stands for voltage. The amount of total energy each unit draws in a day was calculated by multiplying the wattage drawn by the time run to find a total in watt-hours (Wh). The Wh of all units, running 24 hours a day was then summed to find the total daily energy generation needs. This is seen in Table 5.1.

Device	Amps	Watts	Hours	Total Wh
AO Smith Ventilation Blower	2.5	287.5	24.0	6,900.0
Acme TB2000 Actuator	0.5	57.5	24.0	1,380.0
Acme TB2000 Actuator	0.5	57.5	24.0	1,380.0
Ceiling Fan	0.7	80.5	24.0	1,932.0
Ceiling Fan	0.7	80.5	24.0	1,932.0
Modine Gas Heater (Blower)	5.1	586.5	24.0	14,076.0
Total	10.00	1,150.00	144.00	27,600.00

Table 5.1 Greenhouse AC Loads

27,600 Wh need to be generated daily to meet the needs of the greenhouse. Since the sun is only shining at peak performance for a small portion of the day, all energy needs to be generated within that window. In Philadelphia's region, that window is listed at 4.2 hours. Using, $P = \frac{E}{t}$ where P is the power requirement of the solar array, E is the total energy generation needed, and t is the time window for generation, it can be seen that the array needs to generate over 6.57 kW. Using standard 250 W panels, the array size should be at least 26 panels. The calculations are shown in Table 5.2.

Panels Required		
Energy needed	27.6	kWh
Hours Sunlight	4.2	hours
Peak kW req	6.57	kW
# Panels @250w	26	panels

Table 5.2 Panel Requirements

Solar generation and battery banks both use direct current, opposed to the units of the greenhouse which are running on alternating current (AC). An inverter is required to convert the electrical pulse from DC to AC. The inverter size needs to cover the peak amount of power drawn by the equipment, in this case 1,150 W. A 1.5 kW inverter will work fine in this instance. A battery bank is required in an off-grid system to store the energy generated during the peak period for use when energy is not being generated. Battery capacity is listed in Amp-hours (Ah). To calculate the amount of batteries necessary the energy usage of the system is divided by the DC voltage of the batteries. Usually this total is doubled to increase the lifespan of the batteries by spreading the energy use out between more units. Assuming an average battery capacity of 240 Ah, which is a normal capacity for many solar batteries, this system would need 19 batteries to function at a high level, though less batteries could be invested in but most likely need to be replaced sooner. No less than 10 batteries should be used for a functional system. However, for a more efficient system the 12 V batteries and panels should be wired at either 24 V or 48 V. If that is the case, battery numbers need to be either a multiple of 2 for 24 V or a multiple of 4 for 48 V. 20 batteries in this case could be wired at 48 V, would be long lasting, and would more than surpass the capacity requirements.

Battery Bank Required		
Total Energy	27,600	Wh
Battery Voltage	12	V
Total Charge	2,300	Ah
Doubled for Lifespan	4,600	Ah
Avg Batt Cap	240	Ah
# of Batteries	19	batteries

Table 5.3 Storage Requirements

Cost Estimate: $10,000 - $25,000

<u>Compost Heating and Aquaponics</u>

Other ways to increase the sustainability of the greenhouse include using biogas to heat the Modine Gas Heater inside the furbished greenhouse. That gas heater requires 200,000 btu/hr of input gas to heat the greenhouse, though this amount is only necessary on the coldest of winter days and on many days would require much less. The amount of biogas to produce this amount of heat can be calculated working backward from the methods used in the section on Anaerobic Digestion, but without the step of sending that gas to a CHP unit. These calculations are shown in Table 5.4.

Gas input needed	200,000	btu/hr
Power in Watts	0.059	MW
HHV	38.00	MJ/m3
CH4/s	0.0015	m3/s
CH4/month	3998.11	m3/month
Biogas/month	6663.51	total gas
Biogas Yield	200.00	m3/tonne
Input in tonne	33.32	tonne/month
Input in kg	33317.55	kg/month
Input in lbs	73298.61	lbs/month
Percent of total	47.29%	% of total waste

Table 5.4 Input Requirements for Gas Generation

It can be seen that it would take digesting 73,298 lbs per month, over 47% of the farm's current composting (155,000 lbs/month), to heat the one greenhouse at the very coldest of temperatures. Using the average compost density factor of 1000 lbs/yd^3 and converting to cubic feet, a digester that size would be have to be in excess of 2000 cubic feet, or a building that is 20' x 10' x 10'. Implementing this process increases sustainability and promotes waste reduction, but isn't the most sustainable or financially prudent option in the long run. Though initial costs would be less it doesn't yield any return on investment.

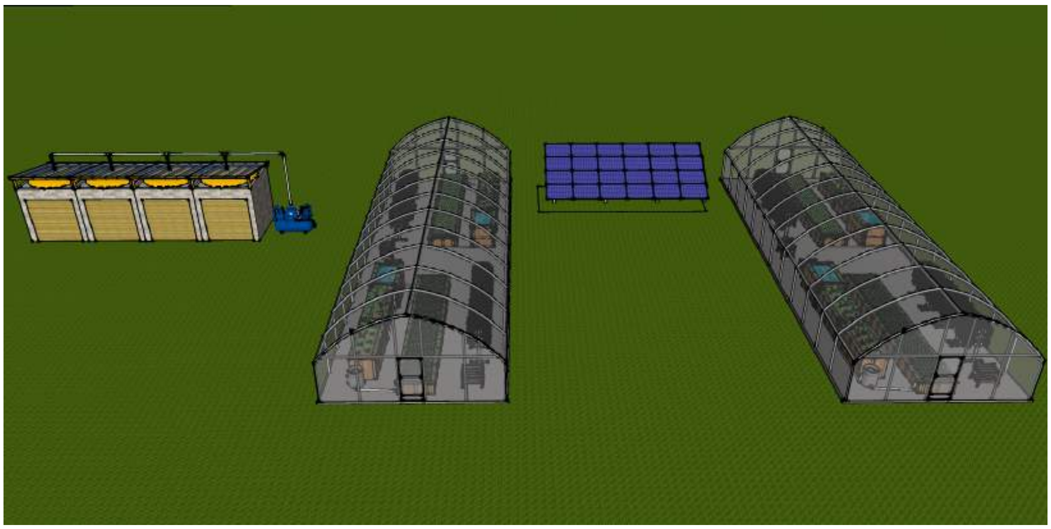


Fig 5.3 Anaerobic Digester and PV Greenhouses

The combination of solar energy for electric needs and biogas for heating needs would make the greenhouse suitable for any use, including the innovations depicted in the aquaponics section of this case study.

Cost Estimate: $30,000 - $50,000

Conclusion

Sustainability is an important ideal to the Weaver's Way Co-Op and it's community. By implementing any or all of the techniques Integrated Symbiotics has discussed in this document, Weaver's Way can considerably increase its sustainability footprint. Not only do they increase the values of the community and Weaver's Way's bottom line, but many of these improvements can increase profits by either cutting costs, or creating new revenue streams. This is the beauty of the Green movement; not only is it morally right, but when implemented correctly, it is also profitable.

- Rainwater Catchment
  - Reduction of water consumption
  - Reduction of stormwater generation and surges
  - Cost reduction from decreased water usage
- Aquaponics
  - Vertically integrated vegetable and seafood production for sales and farm programs
- Water Management
  - Cost reduction from decreased water usage
  - Wireless control and monitoring of water management
- Anaerobic Digestion
  - Reduced greenhouse gas footprint
  - Generation of revenue from biogas usage
  - Incentives from PECO
- Renewables
  - Utilizes infrastructure already in place
  - Best way to provide power to a location without a grid connection
  - Great location to implement aquaponics programs or partnerships

Integrated Symbiotics would like to thank the Weaver's Way community for allowing us to work on this case study. Please feel free to contact us with any questions or comments at any time. Our contact information can be found below. We will be happy to discuss any future implementations, or to help update any inaccuracies or future changes in this report. We look forward to working with Weaver's Way to help implement their sustainable future.

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