Blue Acre Appalachian Aquaponics

System overview and reccomendations for expanding the production capacity of the Blue Acre Appalachian Aquaponics Facility to include crops such as tomatoes, cucumbers and peppers.

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Executive Summary

Each greenhouse cultivation system was evaluated to maximize production and create predictable yields by controlling and balancing greenhouse environmental conditions.

Recommendations

Crop diversity, nutrients, and production goals:

- Expand production capability to tomatoes, cucumbers and peppers with a new hydroponic fertigation system.
- Dedicate existing vertical grow racks and ceramic media beds to high-value specialty herbs sold locally and processed at the Mountain State Co-Hop for enhanced distribution.
- Use OMRI-listed organic nutrients for both the vertical systems and the new hydroponic channel injection system. The entire facility uses organic production methods.
- Methods outlined for efficiently planting DWB and NFT systems to meet production goals.

Facility Automation:

- Control methods for air and water temperature critical for optimizing fish and plant production.
- Replace the non-functioning legacy Wadsworth controller with a less expensive highly capable Growtek computer system to automate greenhouse climate control - side curtains and ridge vents, heating, Vapor Pressure Deficit (VPD) (humidity), and lighting.

Labor efficiency and workflows

- Reduce labor for fish feeding by using Growtek to automate feed frequency and dose.
- Use Growtek computer to control the automated batch fertigtion system.
- Plant seeding and harvest
    - Use an automated seeder to significantly cut labor to sow 200-plug Grodan sheets.
    - Decrease labor to process lettuce in NFT channels with a low-cost cart.
    - Decrease labor to process and pack lettuce with specific area near the DWB's.

Products

- Sell bags of single-cut leaves from lettuce heads; equipment needs are a washer, dehydrator and bagger to decrease labor costs.
- In general, hydrolysate revenue is higher than selling whole fish meat but producing hydrolysate with the discards from the higher priced fish fillets can increase revenue.

Cost Summary List – Total ~$89,000

- LED Lights: Total $41,610 (8) NFT and DWB; (65) Hydroponic area.
- Water Purification: $1,813 total. Chlorine and chloramine neutralization.
- Food dehydrator: ~$9k to dry herbs for local sale – or skip and send herbs to Co-Hop.
- Growtek Computer System; Core for environmental controls: ~$10k. New Hydroponic Fertigation system ~$9k for a Total ~$19k. Fertigation required for new hydroponics expansion to tomatoes, cucumbers and peppers. ~$29k to replace existing controller with a much less capable system – not recommended.
- Washer, Dryer and Bubbler: ~$5,050.
- Hydroponic equipment: $3,500 that includes channels, piping and support structure.
- Water Chilling and Heating: ~$10-$15k for chilling. ~$3k for heating.
- Dehumidifier: ~$9k for reducing winter moisture levels. A smaller unit may be possible.
- Water and Light Monitoring: ~$2,200 pH, EC, light, Carbonate, Fe, NO_3, K, Ca.

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Disclaimer: The equipment and pricing listed in this document reflect rates as of July 2026. Because manufacturers frequently change prices and discontinue product lines, these figures are subject to change. I have focused on recommending high-quality equipment that is reasonably priced.

Description of Facilities at Blue Acre Appalachian Aquaponics

Figure 1. Blue Acre Aquaponics Facility completed in Winter 2019 seen from a front view (top) and an aerial view (bottom) [1].

The Blue Acre Appalachian Aquaponics Building (Referred to as Facility) contains three main sections. The front section, Figure 1 Top and Bottom, left with the white roof, is a 40 ft x 45 ft area containing an office, education area, storage, and rooms that could be utilized for processing fish and for water testing. The middle area under clear panels, Figure 1 Bottom, is a 140 ft x 45 ft Aquaponics growout area of the Nelson & Pade Aquaponics System containing the DWB (Deep Water Beds), NFT Channels (Nutrient Film Technique) and Ceramic Beds. The covered white roof area on the right contains the Nelsen & Pade Aquaculture component including six 500 gallon Fish tanks with the associated biological filtration units. The roofed area on the furthest right contains a nursery system with six 100 gallon tanks.

The facility is not currently producing any vegetable crops. However, the fish are maintained at a reduced density to maintain biofilters and nitrifying bacteria. Thus, daily activities, cleaning schedules, operating procedures including planting and harvesting could not be observed. However, the facility caretaker was instrumental in proving information on facility procedures.

Below, I cover each production system and provide recommendations on crops, nutrients, harvest, and potential maximum yield. Subsequent sections evaluate control of environmental variables for fish and plants to optimize crop production.

Vertical Grow Systems

Vertical growing systems are excellent space saving growing technique, especially for more specialty crops. ZipGrow [2] was an early developer of this type of system and their site includes manuals, studies and links to liquid nutrients.

The Blue Acre Aquaponics Facility has Just Vertical Free Standing Grow Racks with a total of 8 growing sides (Fig. 2).

Figure 2. Just Vertical Free Standing Grow Racks. Shown are 3 double Units and one single Unit - at the end as the LED lights of one Unit shines on the facing Unit.

- They are self-contained units and easily moved. Nutrient solution is contained on the bottom and pumped to the top where it trickles down through the plants. There are 8 vertical grow racks (3 double-sided and 2 single-sided).
- Each rack has 210 growing ports with 1680 plant sites for the 8 units.
- Crops
    - A variety of crops ranging from herbs, leafy greens, dwarf varieties tomatoes and peppers and strawberries can be grown with this system [3].
    - Yield per unit (210 plant ports) from the manufacturer:
        - 60 lbs per month in leafy greens – lettuce and kale
        - 48 lbs per month in herbs – *e.g.*, basil peppermint, sage, shiso
        - 60 lbs per month in fruiting plants – strawberries, tomatoes (6-10 inches).

    - Total herb production per month for all units is 384 lbs (48 lbs/month * 8). This level of production appears optimistic but even a 50% reduction provided use of organic nutrients yields ~190 lbs herbs /month. I would combine herbs from the vertical grow beds with those of the ceramic beds and dry to sell locally, or send to Mountain State Co-Hop that provides co-packing, marketing and distribution services for dry goods that meet FDA requirements [4]

Leafy Greens

- Mini head lettuce such as the Little Gem-type Bibbs (*e.g.*, Volcana, Gatsbi, Kolibiri) and Romaine/Cos Varieties (*e.g.*, Dragoon, Breen, Truchas, Tendita) can be grown in the vertical racks, but I would reserve vertical racks for higher value products such as herbs and possibly strawberries and focus mini head production in the NFT system.

Fruit

- While dwarf varieties of fruits such as tomatoes and peppers can be grown in vertical growing systems, I would focus production on vertical grow racks on specialty, higher value crops such as herbs and possibly strawberries. I recommend production of tomatoes, cucumbers and peppers in the proposed new channel systems (described below) for ease of growth and higher yields. Several sites for seed purchase of dwarf varieties are listed below; a web search provides many more sources.
- Dwarf tomato purchase and information
  - Red Robin Tomato Seed [5]
  - Pinocchio Orange Micro Dwarf Tomato Seed. [6,7]
- Dwarf peppers. [8,9]
- Strawberries
  - Strawberries are a popular flavorful and higher income crop worth pursuing. Most strawberries require specific temperatures (Day: 65ºF-75ºF, Night: 50ºF-55ºF) and high light levels depending upon growth phase; a DLI (Daily Light Integral – a measure of the total amount of light a plant receives during a day) of 17 mol m^{-2} d^{-1} – 20 mol m^{-2} d^{-1}. [10] This is similar to light levels required by tomatoes.
  - Seasonal yearly temperature records for Blue Acre Aquaponics are not available. Air temperature was ~120ºF during a visit on 20 May 2026. However, after opening ridge vents and side curtains temperature decreased to ~85ºF. This may limit strawberry production to spring-bearing and day-neutral varieties. However, there are heat tolerant varieties that are well worth exploring. [11,12]
- Herbs

Herbs can be sold fresh in bunches. In addition, herbs can be dried and sold at local markets or within West Virginia. Drying increases shelf life and decreases the amount of product that needs to be sold fresh – and potentially perishing. Selling dried herbs to another vendor or across state lines falls under federal regulation. In this scenario, herbs need to be processed in a commercial kitchen registered and inspected with the FDA. The product needs meet requirements of federal labelling and the facility needs to follow Good Manufacturing Practices (GMP). I would recommend focus on the product itself and send product to Mountain State Co-Hop that provides co-packing, marketing and distribution services for dry goods. [4] Herb production from the vertical beds could be combined with those grown in the ceramic media beds.

Nutrients for Vertical Grow Systems

- I recommend use of OMRI-listed Pre-Empt for the vertical grow systems. OMRI (Organic Materials Review Institute) is a nonprofit that reviews products to verify they meet organic standards. Pre-Empt was formulated specifically for closed loop hydroponic systems cultivating lettuce, leafy greens, basil and herbs.[13]Along with a microbial inoculant TerraBella [14] it allows for organic production of herbs.

Food Dehydrator

- $9,153 Premium Commercial Dehydrators 2 Zone / 28 Tray / 130 sq. ft Tray Area $5,995 +$239 (mesh mats) + $1,295 (28-CUD cooling trolley) + 28 Pan Trays ($995) +28 Stainless Steel Mesh Trays ($629) = $9,153 (130ft^2). [15]

Ceramic Media Beds

- The Facility has three ceramic media beds; all four feet wide by ~49, 41 and 41 feet long.
- Ceramic media beds provide a stable root anchor for plants and are highly porous. The porosity allows for a high gas exchange rate and a large surface area for aerobic bacteria. The ceramic media beds receive clarified wastes from the ZDEP system and are nutrient rich systems. The ZDEP system receives effluent from the fish tanks where is it digested and mineralized. The clarified effluent contains fine suspended particles easily processed by the media beds but which would cause problems in the DWB's (root fouling). The ZDEP system should be drained frequently – daily, if it observed that inflowing pipes contain particulates.
- I would keep the media bed surface area covered to minimize evaporation; when planted (as it always should be) evaporation decreases but transpiration increases.
- Plants suited to the media beds are cut-and-come again plants and those plants that have a long grow period.
- I would grow herbs in the vertical grow beds. I would leave tomato, cucumbers and peppers to the proposed hydroponic channel fertigation system. It is easier to change ratios of nutrients in an injection system than a system that relies only on fish effluent.
- There are 5-6 LED lights over the ceramic beds. They could be lowered to 3-4 feet above the bed surface as this area is the site for the hydroponic fertigation system. Light intensity can be adjusted by the controller and needs to measured and adjusted depending upon the crop.[16]

Plants suited for media beds

- Salad greens - Arugula, Wasabi arugula, Beets
- Greens - Bok choy, Raddichio, Scallions, Mustard greens, Shard
- Herbs – Basil, Parsley, Thyme, Rosemary, Sage, Chives, perhaps Tarragon
- Root crops – Ginger, Turmeric and Carrots. Fresh roots can get $17/lb in the affluent markets near Shepherdstown. One problem with ginger and turmeric is that the ceramic media attaches to the roots and makes harvest more difficult.
- Cabbage, Broccoli, Cauliflower, Radishes, Chinese Cabbages and Turnips for cooler weather production. Turnip is a root crop.
- Tummeric and ginger as well as other herbs grown in the ceramic beds and vertical grow beds could be processed at Mountain State Co-Hop co-pack that provides co-packing, marketing and distribution services for dry goods.

Leafy Green Production

Leafy green production is optimized in NFT channels and DWB's and was the original focus of the Nelson & Pade aquaponics system. Production design capacity was approximately 150,000 heads per year or 2,885 heads per week. [17] Leafy greens grow well with the high nitrogen provided by the fish effluent.

Below is a weekly production seeding and harvest schedule provided separately for the DWB and NFT systems.

Recommendations for leafy green production

Nursery → Harvest

- In the nursery, seedlings are started in 1 inch square Grodan starter grow plug sheets (200/sheet) and placed in the five 11in by 10ft NFT trays located at the ends of the NFT bench.
- Time in nursery is approximately 11 days or 1.6 weeks. This period can be adjusted depending upon growth.
- Growout starts when the seedling are moved from the nursery area to rafts in the DWB or to the NFT channels where they remain until harvest.
- The NFT channels were serving as a nursery for DWB in previous operation of the facility. I recommend that both systems operate independently to maximize production. After transferring seedlings from the nursery to the growout DWB and NFT channels, plants would not be moved until harvest. Transferring older plants from the NFT to the DWB increases labor and can stress plants.
- The five 11 in by 10 ft channels in the NFT area is the nursery area and the entire Grodan slab fits in the channels. Light intensity should be measured to ensure levels are adequate for seedlings; 100-200 $umol^{m-2}s^{-1}$ for lettuce at 14-16 hours per day. LED lighting might be needed.

46 days is a typical growth to maturity for lettuce (*e.g.*, Monte Carlo romaine from Johnny's Seeds). Below are production scenarios (heads/week) for life cycles of 32, 39, 46, 70 days. The faster growth periods 32 and 39 reflect the faster growth exhibited in warm seasons and 46 and 70days represent the slower growth exhibited in colder seasons.

From limited data, variability in seasonal production at the facility appeared due to seasonal environmental conditions, particularly temperature. One focus of this study is to provide methods to maintain stable environmental conditions at the Facility and maximize production and create a stable yield.

Aquaponics (and other soilless systems such as hydroponics) typically report faster growth when compared to growth in soil systems. [18] Blue Acre Aquaponics reported a time to maturity of 32 days in spring and 70 days in winter [19] with the difference likely due to the interaction of seasonal changes in temperature and light.

- The growing cycles described below assumes one harvest per week. The number of 2ft x 4ft bed rows (DWB) or number of channels (NFT) planted is obtained by dividing the available number of rows (32 in DWB) or channels (108 in NFT) by the life cycle in weeks – adjusting number of rows or channels planted if not a whole number.

DWB

Below is an example production analysis for a 46 day cycle.

- 46 day cycle – 6.6 weeks.
- 11 days in nursery – 1.6 weeks. Nursery is the time spent growing in the 1in x 1in Rockwool cubes (Time can be adjusted depending on germination speed).
- 5 weeks in growout.

Each of the four DWB's contains 32 rows of 2ft x 4ft rafts placed side by side for a total of 64 rafts/bed (Fig. 3). Since plants will be in growout for 5 weeks, 1/5th of the growout rafts will be seeded each week. Full production starts once all channels and DWB trays are filled. All rafts will be filled after 5 weeks. When the seedlings reach maturity - after 5 weeks in the growout area – they are harvested and new seedlings from the nursery will replenish these harvested beds.

The number of rafts planted in weeks 4 and 5 are different, as 32 rows does not divide equally by 5. In this case, 5 weeks x 6 rafts = 30 rows. One row is added to the harvest in weeks 4 and 5. This increases production for those weeks. Figure 3 illustrates the number of trays in each bed per week for this example. If equal numbers of plants are desired per harvest, rafts can be partially planted each week. If growout time is a fraction of a week, nursery time can be adjusted to make growout time in weeks be a whole number. For example 70 day (10 week) cycle in winter is 8.4 weeks after a 1.6 week nursery period. In this case, a longer nursery time of 2 weeks allows for an 8-week growout period.

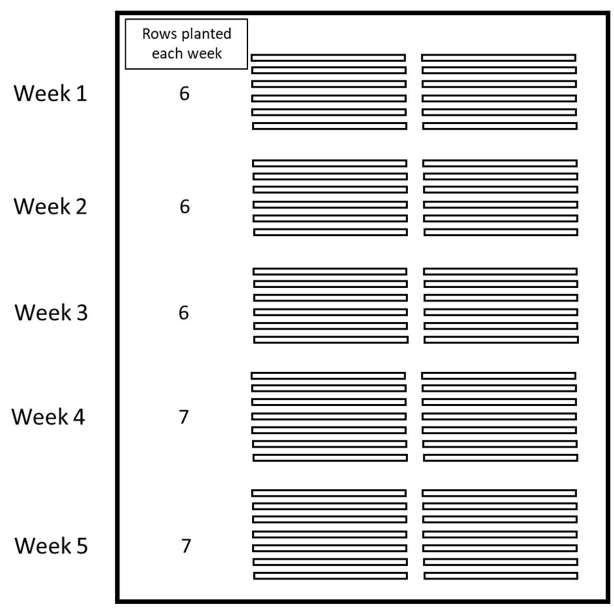

Figure 3. DWB with the total number of rows (32) divided for a 5 week growth cycle in the growout area. The small rectangles represent 2ft x 4ft trays each with 18 grow sites: 12 rafts each for weeks 1-3 and 14 rafts each for weeks 4-5.

Winter growth cycles or the slowest growth cycle represented at the coldest and cold spring and fall months are 70Day (Table 1) and 46 Day (Table 2). The warmer periods have shorter growth cycles, 39 Days (Table 3) and 32 Days (Table 4). The number of heads per week increases from 576 to ~1,584 depending upon growth cycles, 70 to 32 days, respectively.

Table 1. Full head production by week for a 10 week grow cycle (70 days). 2 weeks in nursery area and 8 weeks in the DWB.

Week	Number of Rafts Planted per Bed	Number of Rows Planted	Number of Plants per Raft	Number of Beds	Number of Heads/Week
1	8	4	18	4	576
2	8	4	18	4	576
3	8	4	18	4	576
4	8	4	18	4	576
5	8	4	18	4	576
6	8	4	18	4	576
7	8	4	18	4	576
8	8	4	18	4	576

Table 2. Full head production by week for a 6.6 week grow cycle (46 days). 1.6 weeks in nursery area and 5 weeks in the DWB.

Week	Number of Rafts Planted per Bed	Number of Rows Planted	Number of Plants per Raft	Number of Beds	Number of Heads/Week
1	12	6	18	4	864
2	12	6	18	4	864
3	12	6	18	4	864
4	14	7	18	4	1008
5	14	7	18	4	1008

Table 3. Full head production by week for a 5.6 week grow cycle (39 days). 1.6 weeks in nursery area and 4 weeks in the DWB.

Week	Number of Rafts Planted per Bed	Number of Rows Planted	Number of Plants per Raft	Number of Beds	Number of Heads/Week
1	16	8	18	4	1152
2	16	8	18	4	1152
3	16	8	18	4	1152
4	16	8	18	4	1152

Table 4. Full head production by week for a 4.6 week grow cycle (32 days). 1.6 weeks in nursery area and 3 weeks in the DWB.

Week	Number of Rafts Planted per Bed	Number of Rows Planted	Number of Plants per Raft	Number of Beds	Number of Heads/Week
1	20	10	18	4	1440
2	22	11	18	4	1584
3	22	11	18	4	1584

NFT

Seeding and number of channels planted for desired production per week for the 108 NFT channels is illustrated below. Each channel has a capacity of 15 plants (every other hole planted to provide room for mature heads). Growth cycles are as in the DWB system. Winter growth cycles or the slowest growth cycle represented at the coldest and cold spring and fall months are 70 Day (Table 5) and 46 Day (Table 6). The warmer periods have shorter growth cycles, 39 Days (Table 7) and 32 Days (Table 8). The number of heads per week increases from 195 to 540 depending upon growth cycles, 70 to 32 days, respectively.

Table 5. Production by week for a 10 week grow cycle (70 days). 2 weeks in nursery area and 8 weeks in the NFT.

Week	Number of Channels	Number of Plants per Channel	Number of Heads/Week
1	13	15	195
2	13	15	195
3	13	15	195
4	13	15	195
5	14	15	210
6	14	15	210
7	14	15	210
8	14	15	210

Table 6. Production by week for a 6.6 week grow cycle (46 days). 1.6 weeks in nursery area and 5 weeks in the NFT.

Week	Number of Channels	Number of Plants per Channel	Number of Heads/Week
1	21	15	315
2	21	15	315
3	22	15	330
4	22	15	330
5	22	15	330

Table 7. Production by week for a 5.6 week grow cycle (39 days). 1.6 weeks in nursery area and 4 weeks in the NFT.

Week	Number of Channels	Number of Plants per Channel	Number of Heads/Week
1	27	15	405
2	27	15	405
3	27	15	405
4	27	15	405

Table 8. Production by week for a 4.6 week grow cycle (32 days). 1.6 weeks in nursery area and 3 weeks in the NFT.

Week	Number of Channels	Number of Plants per Channel	Number of Heads/Week
1	36	15	540
2	36	15	540
3	36	15	540

<u>Total Leafy Green Production by Warm and Cold Season</u>

Total production is calculated separately for full heads and for mini head lettuce. Variability in production can be minimized by controlling light and temperature – which affects growth cycle. The objective is predictable year-round production for markets.

Full Head

Average warm season production (32 and 39 day growth cycle) is 1817 units per week and average cold season production (46 and 70 day growth cycle) is 1012 units per week resulting in a mean annual production is 1,412 head per week (Table 9). Proportion of total head production between DWB and NFT is 74% and 26%, respectively.

Table 9. Full head production by grow technique and growth period. Range in number of heads is due to different number of rows or channels planted each week. 18 heads planted in each 2ft x 4ft DWB raft and 15 heads in each 10ft channel.

<table>
<tr><th>Growth Period</th><th>DWB Production per week</th><th>NFT Production per week</th><th>Total Production per week</th><th>Mean Total Production per week</th><th>Mean Production per week Cold Season (46 and 70 Days) and Warm Season (32 and 39 days)</th><th>Mean Production per week for Warm and Cold Seasons</th></tr>
<tr><td>70 Days (10 weeks)</td><td>576</td><td>195-210</td><td>771-786</td><td>779</td><td rowspan="2">1,012</td><td rowspan="4">1,414</td></tr>
<tr><td>46 Days (6.6.weeks)</td><td>864-1008</td><td>315-330</td><td>1179-1338</td><td>1246</td></tr>
<tr><td>39 Days (5.6 weeks)</td><td>1152</td><td>405</td><td>1557</td><td>1557</td><td rowspan="2">1,817</td></tr>
<tr><td>32 Days (4.6 weeks)</td><td>1440-1584</td><td>540</td><td>1980-2124</td><td>2076</td></tr>
</table>

Full head production at the optimum growth of 32 days averages 2,076 (calculated from weekly production values). The system designed by Nelson & Pade had a targeted higher production of 2,885 heads per week. However, higher head production can be obtained by harvesting prior to full maturity or by planting smaller varieties. Single serving mini head lettuce can be grown at higher densities with 6 inch spacing instead of the 8 inch spacing required for full head lettuce. While mini heads allow for higher density they result in a smaller product.

Mini Heads

Average warm season production (32 and 39 day growth cycle) is 3,019 units per week and average cold season production (46 and 70 day growth cycle) is 1,682 units per week resulting in a mean annual production is 2,351 head per week (Table 10). Proportion of total head production between DWB and NFT is 79% and 21%, respectively.

Table 10. Mini head production by grow technique and growth period. Range in number of heads is due to different number of rows or channels planted each week. 32 heads planted in each 2ft x 4ft DWB raft and 20 heads in each 10ft channel.

Growth Period	DWB Production per week	NFT Production per week	Total Production per week	Mean Total Production per week	Mean Production per week Cold Season (46 and 70 Days) and Warm Season (32 and 39 Days)	Mean Production per week for Warm and Cold Seasons
70 Days (10 weeks)	1024	260-280	1284-1304	1294	1,682	2,351
46 Days (6.6.weeks)	1536-1792	420-440	1956-2232	2070		
39 Days (5.6 weeks)	2048	540	2588	2588	3,019	
32 Days (4.6 weeks)	2560-2816	720	3280-3536	3451		

Full Head and Mini Head Comparison

A focus on mini head production can provide higher head numbers (Figure 4) similar to those cited in vendor documents.

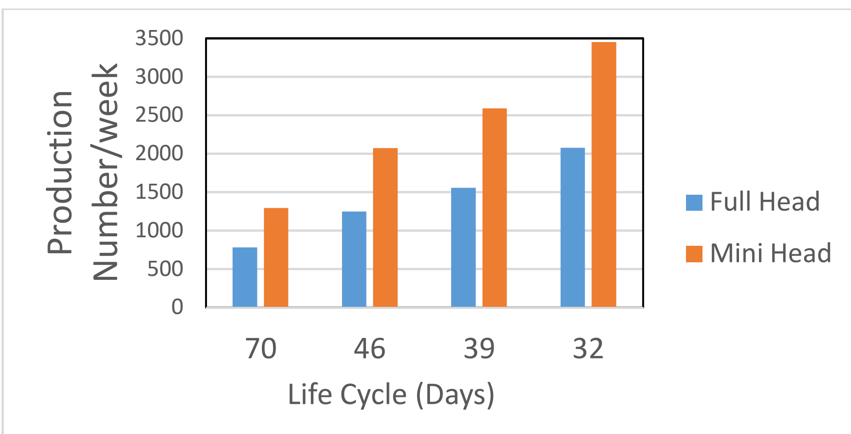

Figure 4. Full and mini head production for total production of the DWB and NFT systems for different days to maturity. 70 and 46 days are cooler growth periods and 39 and 32 days are warmer growth periods

Mini head lettuce is typically grown at a 6 inch spacing. [20,21] The NFT channels at Blue Acre Aquaponics have 4 inch spacing. If a trial of growing mini heads at 4 inches indicates crowding, new holes at 6 inches can be drilled in the plastic covers. Alternatively, new channel covers can be drilled with 6 inch spacing.

The choice of whether to produce full or mini heads depends upon the balance between lower price per unit of smaller heads but high sales or the higher price but fewer sales of full sized heads. The 18 hole rafts in use at the facility provide full head lettuce with the typical 8-inch spacing without crowding. Increasing the number of holes per raft to 32 heads provides the 6 inch spacing for mini heads (Figure 5) and increases mean production at the 32 day cycle to 2,731 mini heads per week from the previous mean of 1,536 full size heads per week; a 56% increase in the number of heads.

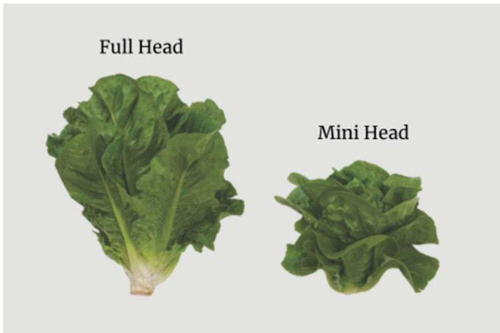

Figure 5. Relative difference in size of a full head Salvius romaine (left) and a mini-head Dragoon romaine. From https://www.johnnyseeds.com/.

Mini head lettuce typically require 6 inch spacing or 20 plants per 10ft channel. At 32 days to maturity, the number of mini heads produced is 720 versus 540 full size heads produced; a 40% increase.

The formula for calculating the breakeven revenue price for producing mini heads versus producing full heads is shown below. The mini head price is based on the full head price.

$$Price\ Mini\ head = \frac{Price\ Full\ head\ x\ Number\ Full\ head}{Number\ Mini\ head}$$

Using mean production numbers from warm season (DWB + NFT = 2076) revenue of full heads priced at \$3/head is \$6,228 per week. Mini head production is 3451. The same revenue is achieved setting mini head price at \$1.80/head. Increasing mini head price to \$2/head provides \$673 increase over full head price of \$3.

Marketing mini heads at slightly lower prices than full head prices may increase profit margins; however, consumer preference and demand in local markets will determine whether this approach is successful. This analysis assumes labor to plant seed trays (reduced if a seeder is purchased) and harvest and other costs are approximately equal. However, handling 1,375 more heads per week is likely to significantly increase the expense for handling.

<u>Bagged Lettuce Leaves</u>

Selling prewashed bags of lettuce is another marketing option. One cut can be made at the base of the one inch square rockwool media separating the head into uniform leaves. Mixing different color variety lettuce and selling in pre-washed lettuce bags is an attractive marketing option offering convenience for the buyer. Mini heads are one-cut varieties that allow easy salad mixes. [22]

- Lettuce is sold at farmers markets under the single cut rule for agriculture. Salad cut greens are cut once at harvest and sold. No further processing is permitted. Head lettuce are also cut once and sold. Aquaponics lettuce is harvested with a root. This provides for one cut above the root to separate leaves from the head. Available cutters might be useful. [23]
- The following is a synopsis of the FMSA rules. The ceiling, set by FMSA (FDA Food Safety Modernization Act) changes yearly for inflation. The specifics (labeling on product or booth) are found in the Farmers Market Vendor Guide [24]
  A farm is eligible for a qualified exemption if the average 3 year value of sales 2023-2025 is less than $686,476 and the direct sales to qualified end users must have exceeded sales to others. [25] Qualified end-users are either 1) the consumer of the food or 2) a restaurant or retail food establishment located in the same state or in the same Indian reservations the farm or not more than 275 miles from the farm. A not covered farm is a farm in which the average 3 year value for 2023-2025 is less than $34,324.
- To qualify as sales the "The consumer of the food" (number 1 in the previous bullet) is 1) An individual 2) Has no geographical boundaries. An individual from another state could purchase food and it is a qualified sale. 3) Direct to consumer formats: CSA (Community Supported Agriculture) farm stands and direct online sales shipped directly to individuals. My understanding is that a Distributor or a Food Hub is a business not a consumer.
- One cut to vegetable is allowed but any further cuts (for example, a Ready-to-Eat cut salad mix) requires a licensed commercial kitchen and other requirements. [26]
- An exemption should be filed. It is recommended to file a Food Safety Plan that is FSMA compliant to provide your practices and have a recall plan for safety and to reduce lability. Contact aodell@wvda.us for an exemption and for guidance.
- Assuming 2,076 head per week production $3/head is about $324k (2,076 heads/week *x* $3/head *x* 52weeks/year). This is assuming the high full head production at a 32 day growing cycle. This provides room for other sales – herbs, hydrolysate, fish fillets and tomatoes and peppers and still fall below the $686,476 threshold. The exemption applies to sales of all foods but 50.1% is required sales to a qualified consumer. However, sales to distributors or cooperatives that aggregate products fall under other regulatory guidelines and requirements for licensed commercial kitchens.
- Currently, the Mountain State Co-Hop processes dry goods and jarred goods. Expanding to vegetable processing would make possible new opportunities and new markets for small West Virginia farms. This would provide a pathway for WV Grown produce providing economic opportunities, jobs and healthy food. This issue is well known. [27] Blue Acre Aquaponics is a showcase facility highlighting the production capabilities and economic potential of modern technology to West Virginia farming. It also illustrates the challenges of processing and distribution and market expansion that many small-scale farms face in West Virginia.
- Weight of mini lettuce heads range from 0.2 to 0.4lbs (90-180gr) and full size weights range from 0.5 to 1.3lbs (227-590gr). [28] While bagged lettuce is sold on a weight basis, full heads are sold by the head. Lettuce head weights should be determined to assess whether selling lettuce leaves (one cut only – see below) may provide for additional revenue.

- Whole heads could be sold to schools. Some schools, hopefully, still do some food processing in the kitchen. Chefs, sous chefs and even prep cooks could take the head and chop it into one inch squares with one quick, easy and satisfying stoke. The instant salad is placed directly into the salad bin to be devoured by hungry students eager for tasty, organic and colorful lettuce (mix in some red varieties). Bins filled by demand; rooted lettuce head remains fresh for 2-3 weeks. Provide an incentive by offering a Lettuce Chopper with a lettuce subscription package.
    - $200 Garde LETCUT1 1" x 1" Square Lettuce Chopper. [29]
- Records are required. While time consuming, production data provides the required information for determining economic viability. Recording values for environmental parameters and control should be automated to the maximum extent possible to decrease the time commitments demanded by manually adjusting for temperature (air, water), oxygen, lighting and fish feeding (see section Environmental Controls – Greenhouse and Hydroponic System).

<u>Processing small amounts of lettuce (200-400 lbs) for local sales or distribution</u>.

<u>Whole Head Processing Time</u>

- Roots wrapped around rockwool mineral plug. Not washed. Estimated time to harvest, Root-wrap and clamshell 200 heads of lettuce is 1.5 hours.

- Clam shell - $200 Lettuce Crisper Box/400. [30] Options are available from other vendors
- Bags - $212 Hydroponic Herb and Produce Sleeves. Open funnel shaped bags that hold a full head of lettuce with roots. [31] Options are available from other vendors

<u>Leaves</u>

One cut at base to separate leaves from base.

Washing Lettuce – The process places 200 lbs of greens in a 100 gallon stock tank with cold water and a bubbler, drying in a spinner and bagging. Estimated time to wash and dry using equipment below is about 1.5 hours. Estimated time to bag once washed is about 40 minutes using a Wicketed blower system for a total of 2 hours 10 minutes.

- Washing Drying and Bagging
    - Bubbler - $479 Greens Bubbler. [32]
    - Bubbler - $375 Quick-Clean Greens Bubbler. [33]
    - Stock tank - $111 Rubbermaid Brute 100 Gal. Structural Foam Stock Tank. [34] A 300 gallon tank is also available.
    - Drying – DYI conversion of washing machine to a greens drier. [35]
    - Drying - $147 Chef Master 5 Gallon Manual Salad Spinner 90005. Washes 5-6 heads of lettuce per load. [29]
    - Drying - $3,880 Hobart SDPE-<u>11</u> 20 Gallon Electric Polyethylene Salad Dryer - 1/4 HP. [29] Stainless version $5,036.
    - Drying - $4,493 Delfield SALD-1 22 Inch Electric Stainless Salad Dryer with drain - 1/4 HP. [36]

    - Bagging - $580 AIE-400BO Bag Opener. [37]
    - Bags - $80 11 x 20 Wicketed Clear Micro Perforated Bags 30 holes/psi. [38]

Full head production for the DWB and NFT channels per week for warm season (32 and 39 days) is 1,817 heads (Table 9.). This level of production does not warrant purchase of an automated production line meeting UL/NSF sanitary certifications. Moreover, local, state and federal regulatory guidelines for the facility would be required. At present, processing facilities in West Virginia are limited; the two Mountain State Co-Hop process dry goods and jarred goods, not produce.

- Placing 1,817 whole heads in clam shell containers and placing into a two layer box at 20/seconds per head would take about 10 hours. This is a minimum for a person working non-stop for 10 hours.
- Boxing 1,817 whole heads at 10 seconds per head is about 5 hours.
- 51 to 74 boxes would be required depending upon 24 heads/box or 36 heads/box, respectively (using 1 1/9- bushel boxes).
    - $3.50 each $1,960 per 560. [39] Waxed. Other vendors available and a non-waxed box could be used.
- As for all producers, a market for fresh, healthy, organically grown nutrient rich products is a vital key for this enterprise to be successful.

Recommendations

- Purchase of a seeder would allow quick seeding of 200 nursery plants at a time and decrease labor costs. Employees spend ~40% of their time planting. [19] Hand seeding, even using pelletized lettuce seeds, is too time consuming. Any reduction in time spent on this task is beneficial.
    - $1,620.74 Berry Seeder System – Complete system includes base unit, 200 precision plate, and ½" x 200 dibbler plate. Crop King Inc (see attached Quote).
- Plant small lettuce varieties if root growth from large varieties, *e.g.*, Monte Carlo romaine, clog channel flow. Johnny's Seeds has a variety of hydroponic performers with mini-heads such as the Little Gem-type Bibbs (*e.g.*, Volcana, Gatsbi, Kolibiri) and Romaine/Cos Varieties (*e.g.*, Dragoon, Breen, Truchas, Tendita).
- Harvest full-size lettuce heads before maturity if roots clog the channel.
- Instead of moving NFT channels to different area of the facility to process at harvest, a cart would allow for a person each side of the cart to harvest a channel next to the NFT channels (Fig. 6). The cart would be rolled to the NFT area and channels would be rolled onto the cart. Figure 6 shows a cart dimension that would provide sufficient room to place a box on the cart to hold the harvested lettuce.

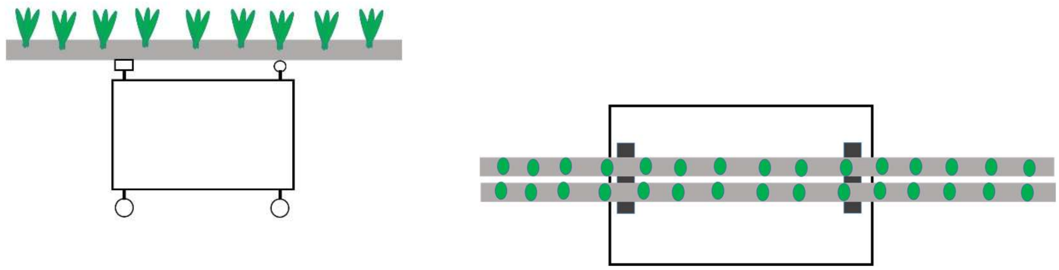

Figure 6. Side view of an approximately 5 ft x 5 ft cart (left) with one round roller and one square rest top rollers that hold two 10 ft long NFT channels. Top view shows channels on a center placed roller.

Fish Production

I have dealt with Lakeway Tilapia [40] for purchase of Blue Tilapia fingerlings. Lakeway Tilapia has excellent service and their website contains a wealth of knowledge about raising and breeding tilapia.

Under optimal conditions, tilapia can grow to a pound in about 240 days. Lakeway Tilapia provides daily grow out feed charts utilizing various sizes Purina feed; AquaMax Fingerling Starter 300 followed by AquaMax Grower 400 with final growout using AquaMax Dense 4000. These charts assume 100% feed conversion rates (FCR) which is food added to fish biomass. Typically, they are 1:2.1 to 1:4.1. [41] Moreover, growth rate also differs based on oxygen levels and stocking densities.

Optimal growth rates assume tank temperatures of 88°F and pure strain food grade Blue tilapia. A one-pound final weight in 240 days is a best-case scenario.

Tilapia growth is predicable at different stages. For example, average daily growth rate per day for fry (days 1-14) are 10-20% body weight increase per day. At harvest (around day 240) daily growth is approximately 1.5% and weight gain is about 2-3 grams per day. Thus, after growing to approximately one pound the costs per pound of tilapia increase due to the additional feed costs due to the slow weight gain (in addition to maintenance costs such as pumping and oxygenation).

Maximum fish densities for systems like those installed at Blue Aquaponics is approximately one pound of tilapia per 3.74 gallons of water or 0.27 lbs of tilapia per gallon. [42] [43] Higher levels of tilapia production are possible but high output systems require specialized oxygenation systems, carbon dioxide strippers, enhanced solids removal and high levels of nitrification. [44] The maximum number of tilapia per 500-gallon growout tank At Blue Acre Aquaponics is approximately 114 one-pound fish (using 425 gallons for clearance at top of tank due to splashing and fish volume).

Since the six 100 gallon fry/fingerling tanks are not connected to the six 500 gallon growout tanks optimal growth conditions are much easier to control. Environmental conditions such as temperature, oxygen and nutrients in the 500 gallon growout tanks can change as they pass through four DWB's and three media beds on the greenhouse floor. Thus, fry/fingerlings should be grown in the more optimally controlled fish rearing system to the maximum size stocking density of 0.27 lbs per gallon then transferred to the 500 gallon growout tanks until harvest.

It takes approximately 114 days to grow 100 fingerlings to a density of 0.27 lbs per gallon. This results in 24 lbs of tilapia with fish at 1.5-2.5 inches and weighing about 3.8 ounces (109 grams).

120 days in the 6-nursery tank and 120 days in the 6-growout tank provides for a 20-day cycle (120 days)/6 tanks). The operational loop for a 20-day cycle is as follows. Nursery Tank 1 is stocked with a batch of 100 fish. After 120 days these fish are transferred to a 500 gallon growout tank and a new batch of 100 fish is started in the nursery tank. Fish are on the Purina Aquamax 4000 feed used in the 500 gallon tanks (see section on Fish Feeding). Nursery tanks 2-6 are stocked in 20-day intervals and the same procedures followed. Once all nursery tanks are full, 120 days will have passed and the first growout tank is ready to be harvested. Fish from tanks 2-6 are harvested in 20-day intervals. If a longer interval between harvests is desired, two nursery tanks can be stocked with 100 fish each and following the same procedure described above yields harvesting intervals of 40 days; 200 lbs of fish instead of 100 lbs of fish are harvested.

Advantages of frequent fish harvests are that plants receive a more constant nutrient supply due to decreased fluctuations of the input of fish feed and the bioreactor processes a more constant input of organic material. Feed per tank at transfer of nursery to growout tanks and at harvest, respectively, is 0.4 lbs and 1.5 lbs. On a 20 day cycle the bioreactor handles 1.1 lbs (1.5-0.4) less organic material immediately after harvest and 2.3 lbs (3-0.7) less on a 40 day cycle. This reduction in feed results in less nutrients produced and organic material that needs to be processed by bioreactors. This could impact plant production and bioreactor efficiency. Moreover, 20 or 40 day harvest cycles affects labor requirements. Processing 100 lbs versus 200 lbs of fish, cleaning of one or two growout tanks, cleaning and stocking of one or two nursery tanks.

Tilapia production for the 20 (18 harvests) or 40 day (9 harvests) interval is 1,800 lbs a year. Nelson & Pade states 6,000 lbs per year for the Commercial six 500-gallon fish tank growout system at the facility. [45] Attaining 6,000 lbs of production may be possible but not likely at the Facility. Ideal temperature for growth is a compromise between fish and plant growth.

The facility is currently in a semi-dormant state with no tilapia or plant production. 2024 tilapia production data indicated a 12-month growout time of 225 fish/month with a yield of 38.25 lbs fillets/month. Feed conversion rates were calculated at 3.78, much higher than typical ranges of 1:2-1:4. Slow growth rates were attributed to cold temperatures, improper feeding practices and stress from poor water quality from the few data points available. [19] Time in nursery was not available.

- I recommend starting with the stocking densities described above and monitor temperature, oxygen, whether clarifiers and biofilters can process the organic content and whether nutrient output for plants is sufficient, under or over required concentrations. Stocking densities could be increased if environmental parameters are at optimal levels. Monitoring oxygen requires an instrument. I recommend the oxygen sensor with the Growtek controller (see section Environmental Controls – Greenhouse and Hydroponic System).

- How harvest cycle impacts nutrient levels, processing of organic material (bioreactor efficiency) and oxygen levels should be monitored and adjusted for optimal growth conditions.
- Yearly temperature measurements are needed to provide data on heating and cooling requirements for fish and plants.
- Oxygen, temperature monitoring and feed input needed for evaluating system function should be automated with records for evaluation (See section Environmental Controls – Greenhouse and Hydroponic System for description of the Growtek controller system).

Environmental Parameters

Oxygen levels for Blue tilapia should be maintained at 5-7mg O_2/l. [46,47] Plants also benefit as high oxygen levels reduces plant pathogen incidence and generally results in higher plant growth due to its impact on root respiration, root and shoot growth and water and nutrient uptake [48] and references within.

Recommendations

- Determine the efficacy of oxygen input from the air stone bubbler system by closely monitoring oxygen levels over a diurnal period. The air blower for the bioreactors should be on continuously to provide for nitrification (conversion of ammonia to nitrate). However, after evaluating diurnal oxygen levels, the two 1 HP regenerative blowers for the stone bubbler oxygenation system could be turned on as needed when oxygen levels go below a specific set point. This would require an oxygen monitor and a motor blower controller included in the proposed Growtek controller equipment list.
- If only manual oxygen readings are possible, take them early morning when they are typically at their lowest.
- Oxygen levels of 7mg/l levels are near 100% saturation at 88°F. [49] Bubblers are sufficient for current tilapia density levels as, at this time, fish are maintained in the facility, however, oxygen levels might not be at optimum levels and fish may be stressed. Harvest weight of 1 lb after 240 days is an indication of suitable environmental conditions. Monitoring oxygen levels is important as levels can change quickly due to organic matter input and mortality, especially during warmer periods as oxygen saturation levels decrease with higher temperatures and altitude.
- In addition, high oxygen levels can also increase plant production. [48,50]
- Other methods of oxygenation can be pursued if levels consistently fall below 5 mg/L or if higher fish production is desired. A pure oxygen concentrator delivers on-demand oxygen. Oxygen is transferred to water by use of oxygen cones where downward water contacts upward oxygen bubbles or by low-head oxygenators (LHO) where oxygen and water mix over a series plates. These systems are used in aquaculture facilities that maximize fish density, not necessarily for an aquaponics system that balances fish density with plant production.
- If the aquaculture section of the facility is enclosed to allow for separate heating for the aquaculture component, an LED light should be placed in the growing area. Low light levels increases aggression in tilapia while higher light levels decreases stress levels. [51] Growth rate and feed conversion ratios are significantly increased with light levels of approximately 35µmol/m²s. [52]

Water Purification

- Water supplied by municipal systems is likely to contain chloramine and chlorine that are harmful to fish. Use Fish Farming Solutions® Aquadechlor™ to remove chlorine and chloramine.
    - $19.99 Aquadechlor 8 oz (https://aquadechlor.com/). It treats thousands of gallons.
    - It will need to be injected into the water supply at a specified concentration on bottle.
- Evapotranspiration will be high in the hot summer months; it is likely that ~150 gallons per day replacement water will need to be treated. The fish tank has a replacement line from the municipal water supply. The proposed fertigation system does not.
- The equipment in Table 11 is an automated system that doses incoming municipal water prior to replacing fish tank water (DWB and NFT) and the hydroponic fertigation system. It consists of a Dosatron pump that doses a specific amount of Aqudechlor into incoming water. Treatment is essentially instantaneous. The treated water goes to fish tanks (input controlled by a water level valve) and to the hydroponic system as needed. Water level in the hydroponic fish tank is controlled by a liquid level sensor controlled by the Agrowtek.

Table 11. Supplies for an automated dosing equipment to treat municipal water to remove chlorine and chloramines.

Item	Function	Cost	Vendor
Dosatron D14MZ3000AFBPHY	Water-powered inline injector.	$1,432.00	Growers House Growershouse.com
Agrowtek SXLV-10 Level Sensor	Pneumatic air-pressure variable water level sensor. Measures organic nutrient water depth without any liquid contact.	$319.00	Direct from Agrowtek Official Store
3/4" Insert Barb x 3/4" Female NPT	PVC plumbing adapters	$12.00	Home Depot
Electric Solenoid Valve (3/4" NPT) JFSV00010	Normally Closed valve wired to your RD8i relay board to control the hydroponic tank fill cycles.	$50.00	https://ussolid.com/products/ Or other vendors
Total		$1,813	

Tilapia production

Cost per fish that reach one pound in 240 days (food grade) is $2.50-$2.71 (Table 12) depending upon the purchase of a replacement plan. Food grade fish are predominantly male as they grow faster than females. Aquaponics grade fish ($2.31) are lower in cost but comprise individuals with a range of slow to fast growth rates. Systems with one tank will be able to harvest a few large individuals at a time as they attain weight leaving the remaining fish to supply plant nutrients. Blue Aquaponics has six growout tanks harvested on a rotating schedule that minimizes fluctuations in nutrient supply but also maximizes tilapia production.

Table 12. Cost of Lakeway Blue Nile tilapia in Food grade or Aquaponics grade fish. Aquaponics Grade. Food grade are predominantly male and exhibit a fast growth rate for a 1 lb fish at approximately 240 days. Aquaponics grade has approximately equal numbers of males and females with fish exhibiting different growth rates. A Replacement Plan guarantees live fish on arrival. Both grades would produce restaurant quality fillets.

Tilapia Type	Number	Price each	Replacement Plan	Fish Cost	Shipping	Total Cost	Cost per Fish
Food Grade Blue Tilapia	100	1.70	20	190	80	270	2.70
	100	1.70		170	80	250	2.50
Aquaponics Grade Blue Tilapia	100	1.51		151	80	231	2.31

Feed costs range from $1.11 to $4.68 per fish depending upon feed source (Table 13).

Table 13. Cost of feed from Lakeway Tilapia and TSC per 100 fish. Lakeway Tilapia starter feed includes Spirulina discs and small pellets (Aquamax 300 and 400) for 100 fish in nursery tanks. Aquamax 4000 used in growout tanks. Top line – All feed purchased from Lakeway Tilapia. Line 2 – Starter feed from Lakeway Tilapia and growout feed from TSC. Line 3 – Spirulina discs from Lakeway Tilapia and Aquamax feed from TSC. Shipping of feed is included in the cost for Lakeway Tilapia. TSC feed shipped to store. Price prorated per batch of 100 fish.

Feed Source	Starter Feed + Algae discs (From Lakeway Tilapia)	Aquamax 4000	Aquamax 300	Aquamax 400	Total	Cost per fish
Lakeway Tilapia	$63.69	$394.09			$457.78	$4.58
TSC	$63.69	$88			$151.69	$1.52
TSC for Aquamax and Lakeway Tilapia for Spirulina discs	Algae Discs $2.88	$88	$9.63	$10.50	$111.00	$1.11

The total cost of a one-pound fish for feed and fish purchase (food grade tilapia at $2.50-$2.70/fish) and feed ($1.11-$4.58) ranges from $3.61-$7.28. This does not include labor and energy costs.

Recommendations

- The first goal is to achieve stable fish production of 100 lb batches (1 lb/Fish). Once fish production is stabilized, total costs including labor can be evaluated. Data on temperature, and energy for pumping water and oxygenation are necessary for these estimates.
- Maximum tilapia yield will require use of hi-quality Blue Nile food grade tilapia. Production differences between Aquaponics grade and other grades should be evaluated once the system has been optimized to assess whether other grades offer similar production.
- Breeding tilapia could reduce cost per fish. The area across from the nursery tank is an ideal location for breeding tilapia. Lakeway Tilapia provides information on setting up a system [53] and provides breeding pairs colonies for $249. [54] An alternative to a breeding colony, is the purchase of 100 ungraded tilapia in order to start several breeding colonies. Lakeway Tilapia also provide technical support. One breeding colony can produce 600-4000 fry per month amply meeting the 100 fry needed at the facility. If the colony does not produce for a month (an occurrence that does happen according to the Lakeway Tilapia fish manager), fry can be purchased in order to keep production on schedule.
- Breeding colonies may provide a cost advantage depending upon the labor cost. Purchase of a complete tilapia breeding system is about $6,317 from Pentair. [55] However, purchasing individual components is a viable option with an estimated cost of $1,000 or less depending upon available supplies. These include two aquariums (~30 and ~75 gallon), air pumps and stones, filtration system, aquarium heater.
- Estimated costs for keeping a breeding colony is approximately $4,665/year. This estimate includes Spirulina algal feed discs for $52 ($2.88/4 oz *x* 18 batches per year), estimated electricity costs of $50 for air pump and filtration system pumps and $4,563 for labor (30 minutes per day at $25/hour). Purchase of 18 batches (365 days/20 days per cycle) of food grade Lakeway Tilapia at $250 per batch is $4,500. In this scenario, purchasing fingerlings from Lakeway Tilapi (or another vendor as appropriate) is recommended. Costs savings can be achieved by decreasing labor costs to 15 minutes of care per day ($2,281) or by purchasing tilapia at a lower price. With a new system coming on line, I would recommend purchase of fast growing Blue Nile tilapia in order to optimize production. Production for fish and plants for a stabilized system can be compared to the production achieved when variables such as fish grade or plant variety are changed. It is probable that once established and with experienced personnel, that colony maintenance is less than 30 min/day. Labor costs can be decreased by providing an internship to an interested high school student to assist with the breeding colony. Selling tilapia fry can also provide an additional income stream.
- Lakeway Tilapia claims that due to the limited shelf life for Aquamax and the low volume of sales, feed from large chain supply stores may be old and past the expiration date. Expiration date should be checked upon purchase from large chain supply stores [56]. Lakeway Tilapia claim their food is fresh, they ship only the amounts needed per

batch of 100 fish and that they are selling at cost. The large price difference between TSC and Lakeway Tilapia is the shipping.

- TSC also sells 50 lb bags of Aquamax 300 and Aquamax 400 for $110 and $84, respectively. The expiration date should be checked. 88 lbs of Aquamax feed is required per 100 fish in the growout tanks. Growout Purina Aquamax 400 is ~$1.68/lb. Organic USDA certified feed (Aquaorganic) is $8.23/lb (three 30 lb bags at $360 and $380 shipping. [57] Ordering bulk may decrease price but feed will require refrigeration. Organic feed would be required for USDA Organic Certification. However, I would not pursue USDA Organic Certification until after I evaluated the additional costs for production including feeds and documentation costs. In addition, I would be certain of a buyer (s) committed to purchase the volume required for economic viability.
- Purina fish food has no preservatives and has a limited shelf life. TSC fish feed bags are 50 lbs. 4.4 lbs of Aquamax 300 and 6.3 lbs Aquamax 400 are used per batch of 100 fish. Put extra feed in an airtight container and freeze.

<u>Fish Feeding</u>

Feeding amount and frequency of feeding per day is dependent on fish size (Table 14). Fry typically arrive on site from the supplier at 9.5 grams or fingerling stage. Time management analysis by Regen Aquaculture showed that fish feeding cost about $7,000 per year. Purchasing fish feeders to decrease time allocated to feeding fish would be cost effective.

Unfortunately, many excellent commercial grade feeders (*e.g.*, Arvo Tech and Vibratory Feeders – both available from Pentair) are approximately $1k each (Vibratory Feeders) and go up in price very quickly. These feeders are used in research facilities and are cost prohibitive for small scale producers. However, other lower cost feeders are available that will function for an aquaponics system.

- Nursery tanks start at 37 g feed/day apportioned over 6 feeds/days. This is a small amount of feed able to be handled by a small feeder.
    - $858 (6) $142.95 KSF-2 Automatic Koi Pond Fish Feeders for Custom Mount. (https://superfeederstore.com/). Each feeder is controlled by the Growtek GCX via the RD8i relay. The controller automatically increases required feed per day.
- A larger feeder is needed for the 500 gallon grow tanks. A SpinTech can deliver about 120 g feed/day apportioned over 40 g feed per cycle (3 cycles/day; 2 cycles/day would be ~60 g feed/day. Each feeder is controlled by the Growtek GCX via the RD8i relay. The controller automatically increases required feed per day.
    - $900 (6) $149.99 SpinTech 12v Directional Digital Fish Feeder Kit. https://www.nativeoutdoors.com).
- There are DIY plans for augur based feeders online. I made the auger feeders used at the Shepherd University Aquaponics Facility.
- Each of the 12 tanks (nursery and growout) will be on a separate feeding schedule as each will be offset by 20 days. Additionally, nursery tanks receive feed 6 times a day and growout tanks receive feed 2-3 times per day. Feeding may be exciting at first but will quickly be drudgery, a time consuming and an error prone process. I recommend the use of automated feeding system. The feeders will need filled and

checked, but not needing to weigh and feed multiple times a day will be a significant time reduction.

Table 14. Feeding schedule and frequency of feeding for Blue Nile Tilapia.

Life Stage	Days	Days in Feeding Stage	Fish Size at end of Feeding Stage (Inches)	Fish Weight (g)	Feeding Frequency (Per Day)	Daily Ration (% of Body Weight)	Feed
Hatch to Fingerling	0-42	42	2	0 - 9.5	Continuous	17	Algae Pellets
Fingerlings	42-70	28	3	9.5 - 28	6 - 10	4	Purina AquaMax 300
Growers	71-102	31	4.5	28 - 58	3 - 4	3	Purina AquaMax 400
Adults	103-243	140	12	58 - 470	2 - 3	1.5	Purina AquaMax 4000

Fish Products

Typical products from fish production include whole fish and fillets, fertilizer from fish waste and manufacture of fish hydrolysate. The facility has processing equipment for processing fish hydrolysate. Fertilizer from fish waste is not viable at Blue Aquaponics as the ZDEP® system from Nelson & Pade separates fish waste and sends it to the media beds where it is broken down releasing the nutrients for increased plant production.

Any tilapia to be consumed (fillets or whole fish) should be processed in the purge tank for 5-7 days. The purge tank is not connected to the fish production tanks and has three main objectives 1) remove the muddy flavors found in fish raised in aquaculture (muddy flavor are caused by geosmin and 2-methylisoborneol (MIB) compounds produced by bacteria and blue-green algae normally found in aquaculture facilities. They accumulate into fat tissues and results in off flavors undesirable to most people [58] 2) improve texture as a period in cool oxygenated water firms up the meat, and 3) clears out the digestive tract to make cleaning easier. Adding salt (~7 ppt) does not improve flavor but reduces osmotic stress, prevents opportunistic infections for fish under stress by acting as a mild disinfectant and allows for transport with reduced mortality. [47]

Selling Fish

Below are requirements for selling tilapia. A filleting service with a non-profit for veterans and active military for sales of tilapia fillets and whole fish may be in place. [17] If so, this greatly expands sales opportunities for fish products. The following is a general outline of the requirements and regulations that govern selling fish. Requirements include:

- Aquaculture License: a commercial fish license from the West Virginia Department of Agriculture (WVDA). [59]
- Certificate of Wholesomeness: this document certifies that tilapia were farm-raised, farm location and that no unapproved FDA medications were used in fish rearing. [24]
- Local Health Permits: fish are potentially hazardous foods and the Mingo County Health Department will need to issue a food permit for un-eviscerated tilapia. [60]

Whole tilapia

Blue 52 Market could sell tilapia with no incision into an internal body cavity. Requirements for whole fish listed above. I would encourage pre-orders for fish in order to keep the minimum number of fish on ice. A few fish could be displayed on ice for on-the-spot purchase; any remaining would be processed into fish hydrolysate. I am assuming a price of $3.00/fish. Freezing fish with guts is not recommended. [61]

Fish can be killed by application of a manually applied blunt force trauma (cranial concussion) followed by exsanguination by a cut at the gill arches (the fleshy tissue under the gill plate) in accordance with AVMA Guidelines For the Euthanasia of Animals. [62]

Fillets and whole fish gutted and skinned

Cutting into a fish for sale qualifies as fish processing and requires a HACCP certification (Hazard Analysis and Critical Control Point). The operator will need to be certified to develop a HACCP plan for the operation and one person will need to have Seafood HACCP Certification. [63] In order to process tilapia, the facility will need a clean room with stainless steel equipment (best), a certified water source and a septic system; municipal water and sewage is easier to certify than well water. In addition, a Fish Processing License issued by WVDA will be needed. [59] Products are cleaned and scaled whole tilapia and fillets.

Hydrolysate

The Blue Acre Facility produces a liquid fertilizer hydrolysate. The recipe produces 120 liters (32 gallons) of product utilizing 24 liters (6.3 gallons) of fish or approximately 53 lbs of tilapia. Prices for smaller sized units of hydrolysate command a higher resale volume. A web search for hydrolysate prices per batch of 31 gallons ranges from $420 for selling one bulk batch to $1,860 from selling the equivalent quantity in 124-quart units (Table 15). The bulk rate per gallon (provided as cost per 31 Gal batch produced at the facility) is based on an average price of a 256 or 275 gallon IBC tote from five vendors (Agrothrive LFK High Potassium Liquid Organic Fertilizer $1,500 – not entirely fish hydrolysate, Organic Gem Liquid Fish Fertilizer $2,125, Brown's Fish Fertilizer $1,675, Neptune's Harvest Hydrolyzed Fish Fertilizer $2,596, GS Plant Foods Organic Liquid Fish Fertilizer $2,995) and estimating $1,500 shipping.

Table 15. Hydrolysate price for different size units of Hydrolysate. Using low prices from five vendors.

Volume Hydrolysate	Price	Price for 31 Gallons
Quart	$15	$1,860
Gallon	$35	$1,085
5-Gallon	$135	$837
Entire Batch 31 Gallons (Mean of 5 vendors)	$420	$420

There are two main approaches for fish production: processing the entire fish into hydrolysate or removing fillets for sale with only the discards processed into hydrolysate. Assumptions are:

- Price for hydrolysate is $420 per 31-gallon batch. Selling smaller volume units provides higher prices.
- Fillet and whole fish prices used in price comparisons are from local supermarkets. Whole frozen cleaned and scaled tilapia is $4.25/pound at the Logan Supercenter Walmart. Frozen skinless and boneless fillets range from $4.37 to $6.28 depending upon whether in a 4 or 2 lb package, respectively. Fresh fillets average $8.00/pound. These are typical prices in other regions, *e.g.*, panhandle of West Virginia.
- Costs for fish processing are not included. Labor for gutting and scaling is estimated at 83 cents per fish and $1.67 per fish for fillet production (2 and 4 minutes, respectively, at $25/hour).
- No data is available on cost for hydrolysate production including labor. The assumption is that costs for fish processing and hydrolysate processing are approximately equal.
- Selling fillets or any processed fish product requires proper licensing and facility inspections outlined earlier.

Selling 53 whole fresh fish at $3/pound yields $159 while the 53 fish processed into hydrolysate yields $420 (Table 16). Selling whole fresh fish is not economically viable especially considering that total production costs per one pound fish is $3.61 (using the lower end of feed costs). Moreover, the production costs for fish do not account for labor and energy costs. At 80% dress-out, 265 fish are needed to produce 53 lbs of discards. Selling 265 whole frozen gutted and scaled fish at $4.24/lb yields $1,124; adding the $420 from one batch of hydrolysate yields $1,544 (Table xx). Processing the 265 fish into hydrolysate yields $2,100. Thus, selling whole frozen gutted and scaled fish is also not economically viable. Producing hydrolysate yields an increase of $556 over selling frozen fillets at $4.37/lb, however, once fresh fillet price increases to $8.00/lb, selling fillets from 177 fish results in a $443 increase over producing only hydrolysate (Table 16).

Table 16. The first row shows revenue obtained from using the indicated number of fish needed for one batch of hydrolysate compared to price selling whole fish for consumption (first three columns). The middle 2 columns are revenue obtained by using the discarded portion of whole fish to produce hydrolysate and whole fish gutted and scaled and sold. An 80% dress-out means that 80% of the fish weight is fillet with the remaining 20% discarded and used for hydrolysate production. The last 3 columns are revenues obtained from frozen or fresh fillet production (30% dress-out), and using the discards for hydrolysate production. The second row are totals summing fillet revenue and the revenue of one batch of hydrolysate from the discards. The third row shows revenue if all fish went into hydrolysate and no fillets were produced.

Volume Hydrolysate	Price	Number of Fish Needed (1lb/Fish)	Whole Fresh Ungutted ($3.00/lb)	Number of Fish Needed (80% Dress-out)	Whole Frozen Gutted and Scaled ($4.24/lb) (80% Dress-out)	Number of Fish Needed (30% Dress - Out)	Frozen Fillets ($4.37/lb)	Fresh Fillets ($8.00/lb)
Entire Batch 31 Gallons (120 Liters)	$420	53.0	$159	265	$1,124	177	$772	$1,413
			Revenue of one batch of hydrolyste from discards + Fillets		$1,544		$1,192	$1,833
			Revenue using all fish for Hydrolysate Production with no Fish Fillets		$2,100		$1,400	$1,400

- Removing fillets from fish processed into hydrolysate may change its nutrient content. Nutrient content (NPK) should be determined and included in the product labelling.
- In optimal conditions, 100 lbs of fish produced every 20 days is approximately two batches (31 gallons each) of hydrolysate worth $880. It will take approximately two 20-day cycles to produce the fish needed (177 fish per batch at 30% dress-out) reducing hydrolysate production. Fish production cycles will affect product production and delivery.
- It is likely that revenue of $420 per batch of hydrolysate is a low estimate. Selling smaller units of hydrolysate can exceed revenue generated from fish fillets. Revenue (without more details on production costs) generally favors hydrolysate production over fillet production.
- Fillets have strong regulatory and strict processing procedures. Filleting requires initial training and care must be taken to produce a product meeting strict purity standards. Fish that are filleted require purging and additional labor in handling. Frozen fish require freezer space and associated energy costs. Hydrolysate production does not have the same regulatory purity standards requirements and can be stored without refrigeration.

- Unsold fillets can be processed into hydrolysate, decreasing waste and offsetting production costs.
- From the preliminary calculations presented, it is difficult to produce profitable production of Blue Nile tilapia in an aquaponics facility that needs to balance plant and fish environmental requirements. Aquaculture facilities in warm areas focus on the Wami/Mozambique Hybrid as it has predominantly male production and grows to harvest in 4 months in intensive aquaculture facilities under optimal environmental conditions. [64] The Blue Aquaponics facility requires costly heating/cooling and is not focused exclusively on aquaculture. However, tilapia produce the waste that drives leafy green production and with processing, tilapia can provide protein (fillets) and hydrolysate products that can be profitable.
- One of the objectives for the Blue Aquaponics facility is to provide locally sourced healthy fish protein and vegetables in a USDA-designated food dessert. When financially viable, there should be a commitment to produce fillets for human consumption.

Optimal Water Temperature and Water Temperature Control

Optimal water temperature for the aquaponics facility is a compromise between the cooler temperatures preferred by lettuce and the warmer temperatures preferred by tilapia.

Optimum temperature range for Blue Nile tilapia is 80°- 88°F [65,66] and can survive at temperatures as low as 47°F. Feed charts for the optimal growth for Lakeway food grade Tilapia assume 88°F.

Optimum water temperature range for lettuce is 65°F-74°F. [67,68] Root temperature affects lettuce growth more than air temperature. Optimizing root temperature at 75°F provided for a marketable crop even if air temperature reached 100°F. [69] Lettuce growth is higher increases with lower temperatures. For example, lettuce production was higher at an average temperature of 77°F than 81°F in the Virgin Islands Aquaponics facility. [70]

I recommend an initial target water temperature of 75°F, acknowledging that both species will have lower growth rates. Water temperature can be adjusted upwards if tilapia production is low (impacting hydrolysate and fillet production) or lower if lettuce are bolting or root damage or disease is detected.

Cooling for Blue Acre Aquaponics consists of ridge vents, roll-up sidewall curtain vents, and horizontal airflow fans. Vents, curtains and fans will decrease air temperatures (on a 20 May 2026 visit, the greenhouse temperature was ~120°F that cooled to 85-90°F after ridge vents and side curtains were opened) but water temperatures will rise as air temperatures rise. Kermit has approximately 120 days above 75°F with 19 days above 90°F. [71,72] Summer insolation and hot temperatures will increase system water temperatures well above 75°F and it is likely that additional measures for regulating water temperature will be needed. With few exceptions, night temperatures are below 75°F. The floating rafts on the DWB's insulate the beds and prevent heat gain and loss; however, insolation and the regenerative blowers that pump hot air through the water greatly increase the heat transfer resulting in high heat gains in the day balanced (hopefully) with heat losses at night. However, there is continuous heat gain in hot seasons and cooling in cold seasons. This creates less than optimal temperature conditions and fluctuations, especially of temperature and oxygen, can have large impacts on plant and fish production.

- To optimize temperature control you need to have a record of year-round air and water temperatures. The requirements and recommendations for chilling and heating water provided below are estimates based upon temperatures expected at this facility and temperatures I have experienced at other facilities. It is likely some method of chilling water during hot days and heating water at cold days will be needed to maintain a constant target temperature of 75°F. Spot temperatures of 84°F taken summer 2022 and 79°F (Date not provided) indicates warmer water temperatures in the warm season. [19] Unit size (BTU of cooling) for temperature control; unit size needs to be determined from data collected at the facility.

In aquaponics, plants and fish are grown in water; water temperature is the important variable influencing growth. Air temperature also affects water temperature and will be discussed in a separate section. Below, I provide two methods to reduce water temperature during the hot season 1) reduction of heat input to water from regenerative blowers and 2) chilling water through the use of an air cooled chiller. The two methods can used concurrently.

Reduce Air temperature from Air Pumps

Two 1-HP regenerative blowers at the facility blow compressed air through fish tanks and DWB's; the resultant bubbles oxygenates water for fish and plants. However, compressing air heats air and as bubbles rise through the water, about 4,000-4,500 BTU/hr is transferred to the water. The ~20,000 gallons of this system easily absorbs this BTU input but it is a 24/7 input that needs to be accounted for in system heat gain or loss. The estimated 20,000 gal for the system is based on Fish tanks 3,000 gal (6 x 500 gal), DWB's 14,363 ((4) 8ft x 60ft x 1ft), Media beds 1,438 Gal ((3) 4ft × 40ft × 1ft assuming 40% water-holding porosity) and Filtration and Sump Tanks 1,200 gal (clarifiers, mineralization, and degassing sumps).

Reducing the time that regenerative blowers operate –cycling on an off as needed - will decrease heat transfer during hot days (see section on oxygen). While heat from the blowers is not needed in hot days and needs to be removed. At cold temperatures, the heat provided by the blowers is beneficial.

Cooling the hot air in bubbles will reduce this heat transfer. One method to cool the hot compressed air is passing it through a jacketed pipe containing cool water as the hot air leaves the regenerative cooler. Below is a description of a 12 ft section of stainless steel pipe (copper is toxic to fish and shrimp) jacketed with cool water.

- 12 ft of straight 1.5 inch stainless steel pipe with an internal twisted ribbon turbulator jacketed with 2.5 PVC pipe with 1-2 GPM cold water counter flow to air flow will reduce outlet temperature of air to approximately 74-80°F.
    - SS pipes are 1.5" x 48" Sanitary, 304 Stainless Steel, Tri Clamp Spool, BHO Extractor Column (https://shop.distillery-equipment.com).
    - Turbulators are just 4 pieces of 1/16 x 125 inches x 47 inches long flat SS bar. They are twisted into a gentle corkscrew, placed inside the SS tube, in order to increase air turbulence that allows for greater heat extraction.
    - Check back pressure with 0-5 PSI gas gauge; a comparison without the jacketed pipe should be less than 2 PSI.

- Each section of jacketed pipe can be made for less than $500.
- Water requirement is about 1-2 GPM.
- Water could be one pass from hose and drained or recirculated by pump from a reservoir. The reservoir could be chilled if needed.
- I would use a high efficiency low RPM pump (*e.g.*, a 1/8 HP 115 watt PerformancePro Artesian2) for circulation.

<u>Water Chiller</u>

A second method to chill water is using an air cooled chiller. Spot summer temperatures of 84°F and 79°F (summer 2022 and 2023, respectively) [19] indicate a summer heat gain and it is likely that the system has gains of 10-20°F. These are sufficiently large to require an air-cooled chiller (Figure 7).

Figure 7. An air-cooled chiller showing a cooling air conditioner unit on top that supplies chilled refrigerant to a cooling loop that flows through coils in an enclosed PVC unit below. Water pumped from the Bio-Organic Filtration tank is cooled as it circulates around the chilled coils and cycled back.

- The MT-7 Aqua Logic Air Chiller unit provides 60,000 BTU of cooling and handles 30-60 GPM (https://aqualogicinc.com/product/multi-temp-chillers-air-cooled/). Unit choice is based on expected heat load and the turnover GPM of the system. However, temperature records are needed to determine actual cooling requirements. Turnover is the number of times water is renewed (1-2 times/hour) and based on fish tank volume (~3,000 gallons). Flow rate in the Aquaponics system is estimated to be 50-67 GPM (Gallons per Minute). A 1/3 HP pump circulates water from the Bio-Organic Filtration tank (water from this tank goes to the fish tanks) to the chiller and back. The chiller could run 8-10 hours during the daylight hour of the hottest days of the year. Cooler night temperatures provides passive cooling but this likely to be offset by heating from the regenerative blowers. Night temperatures would probably need to be below 65°F for cooling to be greater than warming due to slow rate of radiated heat from the system and input of heat from the blowers. A combination of vents and fans cooling the air temperature in addition to cycling the regenerative oxygenation pumps allows for more effective nighttime cooling. Hot days will require active cooling to optimize fish and plant production.

Recommended Air Chiller (for high chilling load)

- Aqua Logic MT-7, 5HP, 208-240V, 1PH Air Chiller 30-60 GPM
  - Only part of the water is chilled.
  - Cost to run for 10 hours is ~$9.75 or about 62.1 kWh. This may increase if there is Time-of-Use billing. Chilling would generally be needed during day hours at high insolation when additional electric charges are assessed. Heating would generally be needed during colder night temperatures when rates are lower.
  - $9,917.99 (https://www.customaquatic.com) (List price is $14,700; Installation estimated $1,500 to $4,000).
- Aqua Logic MT-3, 3HP 208-240V, 1PH Air Chiller 20-40 GPM (for lower chilling load)
  - This unit removes 36,000 BTU and could be used for lower chilling requirements
  - Circulating pump sized slightly larger than the lower GPM of the chiller to account for friction losses in piping.
  - Cost to run for 10 hours is ~$4.58 or about 26 kWh.
  - Price ~$7,500; (https://www.customaquatic.com). Installation estimated $1,500 to $4,000.

Circulating Pump

- PerformancePro Artesian2 A2-1/3-63, 230V, High Efficiency Low RPM Water Pump - $1,108 from https://www.thepondguy.com/
  - Cost to run pump for 10 hours is ~$0.69 or 4,4 kWh.
  - Circulating pump sized slightly larger than the lower GPM requirements of the chiller to account for friction losses in piping.

Summary recommendation for chilling water in hot seasons.

- I would assess whether the regenerative blowers are needed 24/7 to maintain oxygen levels. If not, they can be turned on intermittently as needed from direct measurement of oxygen levels using an automated system with a controller (Growtek; Section Environmental Controls – Greenhouse and Hydroponic System).
- During the hot season, cool the hot compressed air coming out of the regenerative blowers by passing it through a jacketed pipe to prevent heat transfer to the water.
- Install a chiller if temperature increases above targeted 75°F; size determined from temperature measurements.
- In the cold season turn off the flow of cooling water in the jacket and allow the hot compressed air from the regenerative blowers to transfer heat to the water.
- The small open water in the DWB’s where the floating rafts meet the side could be important for heat loss from the beds. A small piece of foam attached to the side of the DWB’s would reduce heat transfer.

Greenhouse Air Temperature

Heating to maintain the air temperature of the greenhouse at 68°F is provided by three Modine natural gas heaters using 875 MMBtu of natural gas at a cost $8,347. [73]

A recommendation of installing bubble wrap insulation at $35,660 (including $700 labor estimated at 20 hours at $35/hour) would provide savings of $3,417/year with a ROI of ~10 years. Included are electricity savings of $78/yr by reducing use of T5 fluorescent bulbs; this savings requires removal of a metal panel roof and insulated insulated section of the greenhouse. SolaWrap bubble wrap [74] (not cited specifically in the energy study) has an R-Value of 1.7, is guaranteed against UV degradation for 10 years (with claims of 30+ years of proven field use) and a light transmission of 83%. The 3mm acylic sheets used at the facility have a visible light transmission of 92% and a R-value of ~0.9. Acrylic sheets provide structural stability; replacement with bubble wrap should be carefully considered. SolaWrap bubble wrap is a permanent installation; some bubble wrap is placed seasonally for colder weather. Bubble wraps installed on top or bottom of the existing acrylic panels would be difficult to install and remove and have a life span of about 4 years. Use of SolaWrap could be considered for curtains although it may require different motors and spacing for the roll as it is 0.34 inches thick (8.5 mm) and weighs 1.31 oz per square foot (410g/m^2).

Temperature records are need to determine seasonal changes in heating/cooling at the facility as many factors interact to impact heating and cooling requirements. For example, the replaced 1000W Metal Halide Bulb produced 199,152 BTU of heat (~3,688 BTU/hr per lamp x 54 MH lamps). The LED replacements produce ~24,000 BTU/hr (~443 BTU/hr per lamp x 54 LED lights). The 175,152 BTU/hr difference will need to be made up with additional heating in the winter but decreased cooling in the summer.

Air Temperature for New Hydroponic Production of Tomatoes, Cucumbers and Peppers

Greenhouse air temperature is focused on the adult phase of the plant after transplanting into the greenhouse. Seed germination and seedling temperature requirements differ between tomatoes, cucumbers and peppers and can be better controlled in a seedling nursery area following accepted practices. Growth requirements of tomatoes, cucumbers and peppers at the fruiting stage are similar enough that optimizing light, temperature, nutrient and humidity levels for tomatoes will be sufficient for growing cucumbers and peppers.

Air temperature requirements are slightly higher for tomatoes than leafy greens. However, given that water temperature is regulated, leafy greens can tolerate high air temperatures (see discussion in section Temperature and Temperature Control).

Ranges of suggested temperatures for greenhouse tomatoes indicate lower temperatures at night and higher temperatures during the day and lower temperatures during cloudy and sunny periods (Table 17). [75] In addition, lower temperatures are indicted during day at low light, or cloudy, periods.

Table 17. Target temperature for day-night and cloudy-sunny periods for tomatoes.

Minimum Temperature (°F)	Low light (Cloudy Days)	High Light (Sunny Days)
Night	63	64
Day	66	70

Other temperature ranges suggest 58 - 63 °F at night and 70 -78 °F during the day. [76] Specific varieties may do better at different temperatures and will need to be evaluated for the facility. Up to 75% of tomato respiration occurs at night with a potentially significant loss of carbohydrate reserves. [76] Lower night temperatures reduces metabolism and more energy can go to fruit formation and flavor. Maintaining a constant temperature between day and night can decrease yield. A 6°F difference between cool nights and warm days (<68°F and 75°F, respectively) resulted in significant increases in fruit number and total weights. [77] High temperatures, above 85°F, increase plant metabolism and contribute to development of small fruits. It also affects pollen germination and plants don't produce the color pigments lycopene and carotene. [78] Lettuce bolts at temperatures greater than 85°F. [28]

A cold root zone is less active with lower nutrient and water uptake. Cold roots cannot provide the water uptake for the high transpiration that occurs when morning insolation increase foliage temperatures quickly. This causes dark tops and limp leaves. [79] If needed, a small aquarium heater could heat the PreEmpt nutrient solution in the hydroponic fertigation tank to minimize the difference between the substrate and greenhouse air to 9-11°F (5-6°C).

Even with freezing temperatures, on sunny days the high tunnel (double plastic layer) at the Shepherd University Farm heats enough to require ventilation. Greenhouse temperatures at Blue Acre Aquaponics will do the same. This insolation is included in the provided 2022 facility heating costs but water and temperature targets proposed in this study may change the overall energy budget. With automation, during winter days with high insolation, solar inputs could be allowed to increase air temperatures to 75°F for tomato, cucumber and pepper production. Dropping the night greenhouse temperature to 64°F decreases heating loads. However, it increases the temperature difference between the DWB water at 75°F water and air. Since both systems use gas, net consumption is likely to remain the same.

LED Grow Lights

Light is vital for plant growth and drives photosynthesis and ultimately, crop yield. Light impacts morphology, biomass or yield, time to harvest, nutritional content, taste, secondary compounds, developmental stage, flower production, and leaf production or fruits. Different plants require different intensity and duration of light. LED lights can control light intensity, duration and spectrum to provide optimal light energy for photosynthesis. Two parameters are manipulated to optimize lighting conditions for plants: PPFD and DLI.

PPFD

Light intensity or the Photosynthetic Photon Flux Density (PPFD) measures how much light hits an area at a specific moment. Units are $\mu mol \cdot m^{-2} \cdot s^{-1}$.

DLI

The total amount of photosynthetically active light that a plant experiences over 24 hours is called the Daily Light Integral (DLI). It is a combination of light intensity and the duration of that intensity. Units are $mol/m^2/day$.

Lettuce plants do not require as much light as tomatoes and will exhibit leaf tip burn at light levels optimal for tomatoes.

- Typical light levels for lettuce are ~15 DLI and 200-400 PPFD
- Typical light levels for tomatoes, cucumbers and peppers are ~20-35 DLI and 400-900 PPFD
- Light requirements change during growth stages.

Tomato
Seedlings (2-3 weeks)
- PPFD→ 200-300 PPFD and DLI 15 $mol/m^2/day$
    - Duration 12 hours

Vegetative growth phase (3-4 weeks)
- PPFD → 400-600 and DLI of 20
    - Duration 13-14 hours

Flowering and fruiting
- PPFD → 600-900 and DLI 25-30
    - Duration 14 hours

<u>Providing Supplemental Light with LED's</u>

While summer sunlight is generally adequate for photosynthesis – though low DLI plants like lettuce may require shading during high summer insolation – light levels often drop below optimum during cloudy days or during the winter season. Tomato, cucumber and pepper plants need intense light, especially during their fruiting phase and will require supplemental LED light.

Simply turning lights on and off at full intensity could result in light stress resulting in leaf curling, bleaching, scorching and even stunted growth. Instead, LED's are controlled by an automated light controller or DLI Controller. A sensor attached to a controller constantly monitors ambient light and dims, brightens or turns off LED lighting when natural light is sufficient to ensure optimal growth during cloudy days or during short winter days. This maximizes energy savings.

<u>DWB LED Lighting Requirements</u>

For the DWB's natural light is sufficient for 7 warm months (March-September) and needed for the five colder October –November months (Table 18). LED's provide ~46% of the light requirement in January and December and ~24% of the light needed in February and November.

The DLI Deficit is the difference between the sunlight DLI inside the Greenhouse and the targeted DLI and is made up by ramping up the LED's. The Average Daily LED Run Time is the time it takes the LED lights running at 100% to make up that DLI Deficit. LED lights don't necessarily run at 100% capacity; the controller spreads the deficit over the 16 hour photoperiod with a target PPFD of approximately 260 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for lettuce production. A negative DLI Deficit indicates incoming solar radiation exceeds that required for optimum growth. Shading may be required. Each DWB should have 12 fixtures placed end to end 5 ft apart on a center row. Currently, each bed has 7 lights. PPFD measurements need to be taken to evaluate LED fixture height and number. Energy cost is estimated at ~$1,500/year.

Fish and lettuce production are tightly coupled; a large mismatch between waste produced and nutrient uptake by plants will destabilize the system. The result is lower fish and plant production. LED light supplements maximizes the plant component.

Table 18. DWB lighting requirements. Estimated total solar radiation in DLI outside the greenhouse structure and the DLI available to plants after a 35% light loss after passing through greenhouse polycarbonate panels. The light deficit is the difference between the Target DLI (15 for lettuce) and the indoor DLI. The Average Daily LED Run Time (Hours) is the time it takes the LED's at 100% to produce the light equivalent to the DLI deficit. The controller regulates 12 Aelius A300xr LED fixtures per bed at different intensity levels depending on fluctuating light needs to maintain optimum light conditions over a 16 hour photoperiod. Cost use rate of $0.14 per kWh. Facility monthly DLI are midpoints from DLI maps. [80] Suntracker also provides DLI data. [81]

Month	**DWB** (mol/m²/day)				Average Daily LED Run Time (Hours)	Total Monthly Electricity Used (kWh)	Monthly Cost
	Outdoor DLI	Indoor DLI (35% Loss)	DWB Target DLI	DLI Deficit			
January	12.5	8.1	15	6.9	7.4	3520	$493
February	17.5	11.4	15	3.6	3.9	1676	$235
March	27.5	17.9	15	-2.9	0	0	$0
April	32.5	21.1	15	-6.1	0	0	$0
May	42.5	27.6	15	-12.6	0	0	$0
June	42.5	27.6	15	-12.6	0	0	$0
July	42.5	27.6	15	-12.6	0	0	$0
August	37.5	24.4	15	-9.4	0	0	$0
September	32.5	21.1	15	-6.1	0	0	$0
October	22.5	14.6	15	0.4	0.4	192	$27
November	17.5	11.4	15	3.6	3.9	1796	$251
December	12.5	8.1	15	6.9	7.4	3520	$493
					TOTALS	10,705	$1,499

NFT LED Light Requirements

Requirements for NFT are similar to DWB but differ in magnitude; NFT channels are 570 ft^2 while DWB's total 1,920 ft^2. Natural light is sufficient for 7 warm months (March-September) and needed for the five colder October –November months (Table 19). LED's provide ~46% of the light requirement in January and December and ~24% of the light needed in February and November. The DLI Deficit is the difference between the sunlight DLI inside the Greenhouse and the targeted DLI and is made up by ramping up the LED's. The Average Daily LED Run Time is the time it takes the LED lights running at 100% to make up that DLI Deficit. LED lights don't necessarily run at 100% capacity; the controller spreads the deficit over the 16 hour photoperiod with a target PPFD of approximately 260 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for lettuce production. A negative DLI Deficit indicates incoming solar radiation exceeds that required for optimum growth. Shading may be required. Energy cost is estimated at ~$445/year.

The NFT system should have14 fixtures placed in two parallel rows of 7 lights each placed at ~8ft end to end. Currently, the system has 6 lights. PPFD measurements need to be taken to evaluate LED fixture height and number.

Table 19. NFT lighting requirements. Estimated total solar radiation in DLI outside the greenhouse structure and the DLI available to plants after a 35% light loss after passing through greenhouse polycarbonate panels. The light deficit is the difference between the Target DLI (15 for lettuce) and the indoor DLI. The Average Daily LED Run Time (Hours) is the time it takes the LED's at 100% to produce the light equivalent to the DLI deficit. The controller regulates 14 Aelius A300xr LED fixtures per bed at different intensity levels depending on fluctuating light needs to maintain optimum light conditions over a 16 hour photoperiod. Cost use rate of $0.14 per kWh. Facility monthly DLI are midpoints from DLI maps. [80] Suntracker also provides DLI data. [81]

Month	NFT ($mol/m^2/day$)				Average Daily LED Run Time (Hours)	Total Monthly Electricity Used (kWh)	Monthly Cost
	Outdoor DLI	Indoor DLI (35% Loss)	DWB Target DLI	DLI Deficit			
January	12.5	8.1	15	6.9	7.5	1045	$146
February	17.5	11.4	15	3.6	4.0	498	$70
March	27.5	17.9	15	-2.9	0	0	$0
April	32.5	21.1	15	-6.1	0	0	$0
May	42.5	27.6	15	-12.6	0	0	$0
June	42.5	27.6	15	-12.6	0	0	$0
July	42.5	27.6	15	-12.6	0	0	$0
August	37.5	24.4	15	-9.4	0	0	$0
September	32.5	21.1	15	-6.1	0	0	$0
October	22.5	14.6	15	0.4	0.4	57	$8
November	17.5	11.4	15	3.6	4.0	533	$75
December	12.5	8.1	15	6.9	7.5	1045	$146
					TOTALS	3,178	$445

Hydroponic System LED requirements

The hydroponic system contains five 60 ft long channels. 65 high-efficiency 650W LED fixtures, 13 per channel provide supplemental light. Natural light is sufficient for 3 warm months (May-July) and needed the remainder of the year (Table 20). Sixty seven percent of the light requirements in December and January need to be supplemented. The Average Daily LED Run Time is the time it takes the LED lights running at 100% to make up that DLI Deficit. LED lights don't necessarily run at 100% capacity; the controller spreads the deficit over the 16 hour photoperiod with a target PPFD of approximately 600-900 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for tomato production. The illuminated footprint affects energy usage with more light required for larger areas. The current estimate used a 25 ft x 60 ft area (variable spacing between rows) for a total yearly electricity cost of $4,740. Reducing the area to 4.3 ft spacing between rows (17.2 ft x 60 ft) reduces yearly electricity costs to $3,786.

Table 20. Hydroponic System lighting requirements. Estimated total solar radiation in DLI outside the greenhouse structure and the DLI available to plants after a 35% light loss after passing through greenhouse polycarbonate panels. The light deficit is the difference between the Target DLI (25 for tomatoes) and the indoor DLI. In parenthesis is the percent of DLI that needs to be supplemented by LED for each month. The Average Daily LED Run Time (Hours) is the time it takes the LED's powered at 100% to produce the light equivalent to the DLI deficit. The controller regulates 65 high-efficiency 3 µmol/J 320 W LED fixtures per bed at different intensity levels depending on fluctuating light needs to maintain optimum light conditions over a 16 hour photoperiod. Lights deliver canopy intensity of 449 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (PPFD). 5 parallel crop rows with canopy area of 139 m^2. A negative DLI Deficit indicates that incoming solar radiation exceeds that required for optimum growth. Cost use rate of $0.14 per kWh. Facility monthly DLI are midpoints from DLI maps. [80] Suntracker also provides DLI data. [81]

Month	Hydroponic System (mol/m²/day)				Average Daily LED Run Time (Hours)	Total Monthly Electricity Used (kWh)	Monthly Cost
	Outdoor DLI	Indoor DLI (35% Loss)	DWB Target DLI	DLI Deficit			
January	12.5	8.1	25	(67) 16.9	10.4	6733	$943
February	17.5	11.4	25	(54) 13.6	8.4	4910	$687
March	27.5	17.9	25	(28) 7.1	4.4	2843	$398
April	32.5	21.1	25	(15) 3.9	2.4	1496	$209
May	42.5	27.6	25	(-11) -2.6	0	0	$0
June	42.5	27.6	25	(-11) -2.6	0	0	$0
July	42.5	27.6	25	(-11) -2.6	0	0	$0
August	37.5	24.4	25	(2) 0.6	0.4	249	$35
September	32.5	21.1	25	(15) 3.9	2.4	1496	$209
October	22.5	14.6	25	(41) 10.4	6.4	4139	$580
November	17.5	11.4	25	(54) 13.6	8.4	5261	$737
December	12.5	8.1	25	(67) 16.9	10.4	6733	$943
TOTALS						33860	$4,740

LED Lighting and BTU Heat Load

LED lighting is estimated to contribute approximately 19% to the total heat load of the facility (Table 21). The hydroponics 65 LED fixtures contribute the largest component of the LED load 71% (116 MMBtu), followed by 22% (37 MMBtu) for DWB LED's and 7% (4 MMBtu) for the NFT LED's. Other appliances may use natural gas in the facility but are not accounted for in this analysis. Except for September and October, LED heat contributions are lower than what is required to heat the greenhouse so LED heat contribution will supplement the Modine heaters. September indicates that venting will be required. Temperatures change quickly from beginning to end of September; transition months will be variable for greenhouse heat requirements. LED lighting will provide all heating requirements in October, however, other heat inputs (*e.g.*, regenerative pumps) may require greenhouse venting.

Table 21. Percent contribution of LED light fixtures to energy load. Facility loads from energy audit. [73]

Month	Estimated MMBtu Added per Month Hydroponics (25 DLI)	Estimated MMBtu Added per Month DWB (15 DLI)	Estimated MMBtu Added per Month NFT (15 DLI)	MMBtu Used at Facility (2022)	Percent MMBtu From LED Fixtures
January	23	12	4	138	28
February	17	6	2	186	13
March	10	0	0	130	7
April	5	0	0	106	5
May	0	0	0	62	0
June	0	0	0	34	0
July	0	0	0	14	0
August	1	0	0	2	43
September	5	0	0	1	510
October	14	1	0	14	107
November	18	6	2	49	53
December	23	12	4	139	28
Total	116	37	11	875	19

<u>LED Purchase</u>

A PPFD distribution map is needed to verify that light levels are sufficient for the chosen DLI and photoperiod. Optimizing plant growth in winter periods will require additional LED fixtures. The Aelius midrange 320 Watt fixtures with efficient 3 umol/J are sufficient for supplemental light. LED prices and offers change frequently and frequent offers on older applicable models may lower cost.

NFT Channel Area XRF for lettuce production

- The facility has 54 (I presume from the number of replaced MH lamps) Aelius XR 320 Watt LED lights. The DWB's and NFT Channel area will require a total of 62 fixtures – 48 for DWB + 14 for NFT = 62. An additional 8 fixtures are needed
- $4,560 – (8) $570 Aelius 300 XRF. [82] This full visible spectrum is better suited for lettuce as it has more blue light.

Hydroponics REDD Spectrum for tomato production.

- $37,050 - (65) $570 Aelius 300 REDD Spectrum. This light reduces the green/white wavelengths with emphasis on heavy red and targeted blue light to maximize flower production and tomato fruit. [82]

- Total $41,610

<u>Environmental Controls – Greenhouse and Hydroponic System</u>

Greenhouse Environmental Controls

A VersiSTEP multi-zone computerized environmental controller was installed at the Facility that provided automated controls for the following equipment:

Venting
- Rack and Pinion Roof Vent (two)
  - (6) DC (24v) automated drive vent motors and controls
  - Somewhere in the facility are breaker panels, contactors, relays, transformers, and wiring
- Roll-Up Side Wall Curtain Vent
  - (2) DC (24v, 80nm, 100watt, 3.0a) automated drive curtain motors and Link4 controls.
- Roll-Up End Wall Curtain Vent
  - (1) DC (24v, 80nm, 100watt, 3.0a) automated drive curtain motor and Link4 control
- Horizontal Airflow Fans
  - (14) 18" Quietaire horizontal airflow fans
  - 115v, 1/10hp, 1.30a, 1 speed

Heat
- (3) Modine (model # PDP250A) natural gas fired unit heaters (1/3hp, 115v, 1phase, 60 cycle) 200,000 BTU

Lights
- Four banks of Grow Lights.

This system has experienced a critical failure, although manual operation of curtains and ridge vents indicate that contactors/relays that control the motors in the Contactor Panel are still functioning. The VersiSTEP Controller from Wadsworth unit is discontinued and replaced with a Seed Control Package. A quote to replace/upgrade the system at the Facility is $29,560 (including estimated ground freight). Quote attached to this document.

This system includes control for:

Old Functions - Curtains, Ridge vents, Air gas heaters, and Grow lights
- Temperature
- PAR (Photosynthetically Active Radiation)

New Functions

- Relative Humidity → Good for humidity control but I recommend using VPD for humidity control
- Vapor Pressure Deficit → New sensor to control dehumidifier. Instead of an arbitrary RH percentage it includes temperature in the decision process. It controls for a safe VPD zone for plants. This can save electricity if the dehumidifier is not needed
- CO_2

I recommend to not upgrade the old VesriSTEP to the Seed Control Package for $29,560 and instead opt for the AgroTek automated controller that integrates all functions (listed above) plus oxygen and fish feeding in addition to an automated fertigation pumping system and water supply for the Hydroponics System for ~$19,000.

Wadsworth Control Systems specializes in greenhouse automation and climate control systems. Their system includes wired contactor panels and focus on temperature and light controls. Their system does not include controlling components for a hydroponic fertigation system or automated fish feeding. EC and DO sensors can be added to their system but they are on top of the quoted price above. In summary, I would need to purchase the upgrade for the temperature, VPD and lights, I will need to add EC and DO sensors, but will still not have controllers for separate dosage pumps for tomatoes, cucumbers and peppers.

- While I could add an EC sensor the Wadsworth controller can't use those readings to adjust a dosing pump. I would need to purchase a third-party feeder and manage fertigation needs with Anderson's J+ Advanced Ratio:Feeder® Controller. These are additional costs on top of the $29,560.
- The Agrowtek GrowControl GCX can simultaneously run HVAC/VPD climate contactors and control the hydroponic dosing pumps. The software can control 14 independent nutrient recipes. As needed, the Agrowtek controller automatically shifts the dosing pumps to inject the correct balance of parts A, B, C, and pH adjusters specifically for tomatoes, cucumbers, or peppers.
- AgrowTek has an option to add a PAR sensor to a VPD sensor. Typically, one PAR sensor located centrally, detects incoming PAR and adjusts all lights automatically dimming or increasing intensity of the LED lights as conditions change. The GrowTek system can also control light with a separate PAR sensor in this fashion. However, I have included two SXC sensors that monitor temperature and humidity and that also include a PAR sensor. One sensor monitors the tomatoes and another monitors lettuce. The PAR sensor monitors light in a zone-specific area and dims LED's as needed separately in the tomato and lettuce area. The SXC sensor includes an integrated PLIR (Plant Leaf Infrared) sensor to monitor leaf temperature remotely. VPD can be calculated with the leaf temperature, ambient temperature and humidity. Two sensors can work together in one room in an average or a priority loop. For example, lettuce could be set as the primary trigger as it is more sensitive to stagnant humidity (Low VPD) and the controller can open ridge vents or curtains or turn on a dehumidifier for real-time transpiration monitoring. Of course, a single PAR sensor would function and reduce cost.
- An Optical Dissolved Oxygen Monitor was added to the GrowTek system to provide oxygen values and to cycle regenerative pumps as needed ($2,428). Oxygen probes are not cheap but are needed as oxygen is a primary driving variable. The optical DO sensor

is low maintenance, long life span and require fewer calibrations. An oxygen sensor would need to be added to the new Seed package from Wadsworth. Monitoring oxygen levels is needed for targeting optimal growing conditions for fish and plants.

- A large cost-cutting approach for the new Agrowtek controller is to use the existing Wadsworth contactor panel that contains the heavy-duty mechanical contactors, reversing relays, and power transformers needed to drive curtain and ridge motors. The Agrowtek RD8i relays will interface with the mechanical relays. It is likely that a new Contactor Panel will need to be purchased from Wadsworth – even if it says the used panel will be used "Only if in Good Condition" - as the new contactor panel contains newer solid state relays, fuses and wiring blocks specific to the new Seed's computer. Using the existing contactor panel is cost effective.
- An environmental controller is needed even if the hydroponic system is not installed; side curtains, ridge vents, oxygen monitoring, VPD calculation and humidity control, chilling and heating are all essential. Remove the components – Terralink Substrate sensor ($747) and the hydroponic sensors ($730) from Table 22 and not purchase items in Table 23, leaves a controller for the Facility for approximately $10,000. This provides a solid control system with future expansion capabilities at a much better price point – a savings of ~20k.
- For the Growtek controller I have added 2 additional RD8i relays for control of fish feeding in the 6 nursery tanks and the 6 growout tanks ($1,000). Labor savings makes this cost effective.
- The Growtek controller would control the water purification – removal of the chlorine and chloramine - for the automated fertigation hydroponic system (water input to the batch tanks as the purification happens back at the unit near the municipal water entry). The fish tanks, while using Aqudechlor for water purification, utilize a mechanical float valve for water replacement.
- Please note that site specific requirements may modify needed equipment components.

Controller Replacement Growtek

Table 22. Core components for a GrowTek Controller. This system controls lights, heating, chilling, oxygen, VPD and the automated fertigation system required for hydroponics. Final system price in Table 23.

Item Description	Brand	Model	Quantity	Unit Price	Total Price	Function
GrowControl GCX Controller	Agrowtek	GCX + WiFi	1	$2,848.00	$2,848.00	Central master processing unit with 10.1" touchscreen
Aspirated Climate & PLIR Sensor Box	Agrowtek	SXC+ Series	1	$488.00	$488.00	Dual-zone climate and leaf infrared temperature tracking
Aspirated Climate, CO2, & PLIR Sensor Box	Agrowtek	SXC+ Series	1	$607.00	$607.00	Dual-zone climate, gas, and leaf infrared temperature tracking
8-Channel Dry Contact Relay	Agrowtek	RD8i	4	$500.30	$2,001.20	Heavy equipment switching (curtain reversal & irrigation pumps)
4-Channel 0-10V Dimming Module	Agrowtek	DXV-4	2	$319.00	$638.00	Crop-specific dynamic photoperiod lighting dimming
Terralink Substrate Sensor	Agrowtek	TDR-VWC	3	$249.00	$747.00	Root-zone moisture content data mapping
GrowNET 8-Port Buffered Hub	Agrowtek	AT-HX8	2	$249.00	$498.00	Prevents voltage sag across long bulk data wire runs
Optical Dissolved Oxygen Monitor	Agrowtek	SXO2	1	$2,428.00	$2,428.00	Inline real-time parts-per-million (ppm) oxygen tracking
Hydroponic Sensor Box & **Probes**	Agrowtek	SXH	1	$730.00	$730.00	Master hydroponic base tank data kit (pH, EC, Temp)
Industrial 24VDC Power Supply	Mean Well	HDR-15-24	1	$20.00	$20.00	Restores electrical power on the GrowNET bus loops
Solid-Core Cat6 UTP Cable	Generic	Cat6-Solid	1	$145.00	$145.00	1000ft bulk data wire spool for electrical installation
Core Equipment Subtotal:					$11,150.20	

Table 23. Two options for nutrient delivery for the GrowTek hydroponic fertigation system. Top: Equipment for a fully automated direct injection system. Bottom: Equipment for a batch mixing tank configuration. See text for description of the two options.

Top – Direct Injection System

Item Description	Brand	Model	Quantity	Unit Price	Total Price	Function
Core Subtotal	Agrowtek	Growtek Core	1	$11,150.20	$11,150.20	Master Wi-Fi controller, dual SXC sensor boxes, hubs, and core data relays
Hydroponic Sensor Box & Probes	Agrowtek	SXH Kit	2	$730.00	$1,460.00	Specialized inline plumbing assemblies for real-time flowing chemistry verification
AgrowDose Quad Peristaltic Pump	Agrowtek	AD4i	3	$1,079.00	$3,237.00	Intelligent digital pump blocks mapped directly to mid-stream injection ports
The Inline Static Mixer	Pulasfeeder	Stm100-pvc	1	$323.99	$323.99	Mixes injected fluids
The Booster & Recirculation Pump	Aeromixer	MiniMixer	1	$249.00	$249.00	Line-boosting pressure pump
The Inline Probe & Injection Block	Terraponics	Min-line Manifold	1	$240.00	$240.00	Mount ports and inject solutions
				Total:	$16,660.19	Fully Automated Direct-Injection Configuration

Bottom

Item Description	Brand	Model	Quantity	Unit Price	Total Price	Function
Core Subtotal	Agrowtek	Growtek Core	1	$11,150.20	$11,150.20	Master Wi-Fi controller, dual SXC sensor boxes, hubs, and core data relays
Hydroponic Sensor Box & Probes	Agrowtek	SXH Kit	2	$730.00	$1,460.00	Dedicated water chemistry monitoring (pH, EC, Temp) for reservoirs 2 and 3
AgrowDose Quad Peristaltic Pump	Agrowtek	AD4i	3	$1,079.00	$3,237.00	Intelligent digital pump blocks for automated multi-part liquid dosing
High-Pressure Submersible Pump	Grundfus	Grundfos SBA-3-45-A 1HP	3	$881.00	$2,643.00	Submersible utility pumps dropped into reservoirs to drive pressure line emitters
Motorized 3-Way Source Valve	US Solid	BAV-3W-24VAC	1	$145.00	$145.00	Automatically switches pump intake between raw reservoir organics and fresh rinse water
End-of-Line Solenoid Purge Valve	US Solid	PSV-B-24VAC	1	$45.00	$45.00	High-flow terminal drain valve that opens to flush sediment past emitters straight to the waste drain
Anti-Siphon Backflow Preventer	Watts	LF009-1	1	$225.00	$225.00	Industrial-grade plumbing safety block to ensure organic fertilizer never back-siphons into the fresh water supply
Hydroponic Reservoir	Stock Tank	100 Gallon	3	$120.00	$360.00	100-gallon food-grade plastic nutrient storage barrels
Total Hydroponic System:					$19,265.20	Batch Mixing Tank Configuration

The core components in Table 22 provide environmental control and fish feeding for ~$10k (not including the hydroponic sensor and the Terralink substrate sensors). The fertigation option in Table 23 is ~$8k for the Batch and ~$5k for the Injection system. They differ in their ability to handle nutrients. The fully automated direct injection system (Top) does not have tanks. The concentrated nutrients in small volume containers and are pumped out using small tubes. When irrigation triggers, a high-pressure booster pump draws water, and the intelligent (controlled by the Agrowtek computer) peristaltic pumps inject micro-doses of nutrients as needed directly into a pressurized mid-stream mixing manifold to the pulsafeeder static mixer which flows to the plants. The 30-50 psi system high-pressure system is vulnerable to blockage caused by particles in the solution. Soluble nutrients do well with this type of system. There is no mixing of nutrients, the computer sets the dosage depending upon the recipe that can change in different growth requirements during the growth cycle.

Nutrients in the Batch system (Bottom) are formulated for each plant tank. For example, Tank 1 for tomatoes, Tank 2 for cucumbers and Tank 3 for peppers. The concentrated nutrients (Ca, Mg, P, K and pH Up or pH Down) are in smaller jugs. Depending upon the recipe, dosage pumps draw from the concentrated jugs and mix nutrients with water in the large 100 gallon container. The controller monitors the pH and EC sensors and controls the volume of added nutrients. An irrigation signal sends fertilizer from each tank to its respective plant. The batch system is low pressure (a high capacity pump is still required to send water to the emitters) and easily filtered whereas the filtering required by organic nutrients in a high pressure system can result in large pressure drops. The computer varies the recipes for different growth phases. For example, the tomato fruiting phase needs more potassium and phosphorus. The controller recipe changes and the dosage pumps draw more nutrients from the potassium and phosphorus jugs into the large tomato tank. The higher target EC values are detected by the EC sensor and the controller stops the dosage pump. The computer handles all the chemical ratios, pump run-times and the math.

While many controller components are shared, it is difficult to re-plumb one type of system to the other. For example, a switch from batch to high pressure requires removal of the 100-gallon holding tanks, install high-pressure check valves, mounting a pressurized static mixing manifold. Additionally, you need to completely change the timing code and calibration settings inside the Agrowtek controller.

I recommend the batch system for organic nutrients and the pressurized injection system for soluble nutrients.

<u>Hydroponic Channel Components</u>

Growout components include the channels, stands, pipes and emitters (Table 24). Elevating the channel with concrete blocks is cost effective; steel stands can be purchased at a higher cost. Trellis wires and supports are not included. Greenhouse purlins generally support the weight of the vines (cucumbers and tomatoes). If not, grounded 4 x 4 posts at each end of the channel with a wire strung posts at 11 ft can be used to hang the vertical strings.

Table 24. Channels, piping and structural items for the hydroponic system.

Item	Vendor	Units	Quantity	Unit Cost	Subtotal
Jiffy Finesse Growbags (70/30 Chip/Pith Blend, 100cm)	Hort Americas	Bags	100	$6.50	$650.00
Netafim 10.6 GPH Emitter Assemblies (10.6 GPH Button + 36" White 1/8" Tube + Elbow)	Drip Depot	Per Emitter	500	$0.79	$395.00
Netafim PC Spray Stakes (Blue) (Single-Spray Pattern, Inward Arc)	Drip Depot	50 Pack	10	$24.95	$249.50
Netafim 1" Manual Disc Filter (120-Mesh Super T-Filter)	Drip Depot	Per Filter	3	$115.50	$346.50
1" FNPT x 3/4" Perma-Loc Adapters (Threaded Filter-to-Pipe Transitions)	Drip Depot	Per Unit	6	$4.99	$29.94
3/4" Black Polyethylene Pipe (Solid Mainline Tubing)	Drip Depot	4 Coils (1000')	4	$261.09	$1,044.36
Irritec Perma-Loc Tubing Tee, Ends, Coupling- Tubing Size : 3/4"	Drip Depot	Per Unit	6	$4.99	$29.94
Irritec Perma-Loc Tubing Elbow - Tubing Size : 3/4"	Drip Depot	Per Unit	24	$3.70	$88.80
Misc EMT Hardware	Home Depot	Items	1	$75.00	$75.00
13/4" Electrical Metallic Tubing (EMT Structural Rail Support)	Home Depot	Per 10' Stick	40	$11.53	$461.20
Standard 8"x8"x16" Concrete Block (Structural Anchoring/Ballast)	Home Depot	Per Unit	65	$2.67	$173.55
			Total		$3,544

Power Conditioning

The GrowTek computer should be protected against power surges. This is required equipment to protect expensive electronics and prevent downtime.

- $200. CyberPower CP1500AVRLCD3 Intelligent LCD UPS Battery Backup and Surge Protector, 1500VA/900W UL Certified

Water Heating

An aquaponics system maintained at 75°F will lose heat to the air in a greenhouse maintained at 68°F or dropped to 64°F for night time temperature (*e.g.*, for tomato production). Heat transferred from water to air will increase energy requirements for heating water heating but this heat ultimately radiates reduces use of the Modine heaters for air. A spot temperature of 69-70°F taken 11 Nov 2023 indicates colder water temperatures in the cold season. [19]

Sizing a heating system is difficult without data. A heat loss estimate for the Blue Acre Facility can be inferred from the likely upper level of heat loss from installed aquaponics systems. Nelson and Pade have installed systems in almost all states and internationally. The largest heater offered by Nelson and Pade increases water 10°F above ambient and is 8 kW or 27,000 BTU. Heat transfer estimates derived by applying evaporative, convective and conductions equations are sensitive to values placed on unknown input variables and yield a large range of BTU/hr heat loss. While operations are currently paused, previous year-round production and some spot temperatures indicates environmental parameters within acceptable limits not requiring control for large temperature swings.

Electric Water Heating Option

- $2,200 Nelson and Pade 8 kW Titanium heater
- Easy to install if a breaker and outlet is available.
- $380/month Operating cost 14 hours/day

Gas Water Heater and Heat Exchanger

- This section is for an in-house project. Commercial versions are available. This heater operates similarly to the air cooled chiller. One pump supplies hot water in a heating loop to the heat exchanger. A second pump circulates water from the aquaponics system around this heated coil and returns heated water to the system.
- Gas water heater – At facility and supplies the hot water. It has an internal thermostat.
- $235 - 55K BTU 316L Stainless Steel Shell & Tube Heat Exchanger (https://www.brazetek.com/bt-st-55-1-heat-exchanger). The system can transfer up to 55K BTU but will transfer what is needed.
- $1,956 (2) PerformancePro Artesian2 Low RPM Pumps
- $36 Inkbird ITC308S Temperature Controller for Aquarium with Submersible Probe, Heating Cooling Outlets Thermostat for Heater and Cooling Fans. This monitors Fish Tank water; if cool, it will start the pumps – the loop from the Fish Tank and the loop of heated water from the hot water heater.
- $300 miscellaneous pipes and fittings
- Total = $2,527
- $130 Operating cost 14 hours/day

- I recommend the natural gas option as operating costs are about 3 times lower.

Humidity

Different crops requirements for humidity vary but can be targeted at 65-70% for lettuce, cucumbers, tomatoes, peppers; values are typically lower for herbs 40-60%. High humidity cause a variety of problems.

- Fungus and bacterial diseases thrive in humid environments
- Humidity affects Vapor Pressure Deficit (VPD) which is the difference between moisture in air (humidity) and amount of moisture that the air can hold at full saturation (temperature regulated). VPD values are low when humidity values are high. High humidity and low VPD means the plant cannot transpire and pull up nutrients (Ca and K) from the roots. Plants stress out in these conditions.
- Dripping from condensation on greenhouse walls and ceilings can spread disease.

Winter humidity levels in aquaponics systems are difficult to manage as levels are high due to evaporation from the media beds, transpiration of crops, aeration and evaporation from fish tanks, filtration and sump tanks. In addition, the three non-vented gas heaters input about 9.24 gallons (74 pints) of water per hour. Ways to decrease humidity levels are:

- Cover fish tanks with clear covers such as acrylic panels that allow for light penetration but trap some of the moisture. This is low-cost to implement.
- Ventilation – or Purge and Heat cycles. On the cold, clear winter days vent the greenhouse from the ridge for 60-90 seconds which allows for hot, wet air to escape to be replaced with cold dry air. This increases energy costs.
- Add a dehumidifier. I added a dehumidifier to the 18 ft x 100 ft aquaponics system at Shepherd University to reduce fungal infection and allow for plant nutrient uptake (as transpiration is inversely correlated to humidity levels). I would track humidity-VPD - levels at the Blue Acre Facility and assess whether Purge and Heat cycles are sufficient to control humidity; I suspect a dehumidifier will be needed.
- Place dehumidifiers near media beds as they release high levels of moisture.
- A dehumidifier adds heat to the system. The Quest 506 adds about 30,000 BTU/hr decreasing use of the natural gas blowers that input water vapor in the air.
- Two smaller units could be placed near high moisture sources – media beds and fish tanks. This provides redundancy if one unit fails and equalizes humidity levels in the greenhouse, although circulation fans may already provide adequate distribution.
- Maintain continuous air circulation.

Cost

- $8,830 The Quest 506 commercial 500 pint dehumidifier (https://growwithgreenlight.com/).
- Removal is ~14 pints per hour.
- Humidity levels will determine the size of the unit needed; a smaller unit has a lower initial cost and lower operating costs.
- $5.00 - Cost per 12 hours run time (draw is 2,700 W). Removes ~168 Pints.
- Drygair (Drygair.com) produces high end dehumidification units for commercial greenhouses but are much more expensive.

Proposed System for Tomato, Cucumber and Pepper Production

This section describes the design for a commercial greenhouse hydroponic system for tomato, cucumber and pepper production. It uses the Growtek computer system described above (Table 22, Table 23 Bot) and the components in Table 24. The nutrient delivery and temperature control in the hydroponic system operates independently from that in the aquaponics system. Air temperature and humidity levels are focused for tomato production but works well for all system components – NFT Channels, herb vertical grow system, DWB and fish.

The proposed system uses commercial methods to grow greenhouse hydroponic tomato using five 60-foot channels, 10-inches wide, to grow tomatoes, cucumbers and peppers in Jiffy Coco Growbags (Figures 8 and 9). The five raised channels are located next to or on the media beds (Fig. 9). System components:

Nutrients and Nutrient Delivery

1) Stock tanks hold nutrients and pH adjusters
2) Fertilizer mulita dosage pumps draw concentrated nutrient solutions from different stock tanks to a Day Tank. Different nutrients are dissolved into separate tanks. Using soluble salts:

Tank A – Base nutrients NPK (KNO_3, KH_2PO_4 and $MgSO_4$ – Potassium Sulfate, Mono Potassium Phosphate and Magnesium Sulfate).
Tank B – Calcium compounds and iron ($(CaNO_3)_2$ and chelated iron).
Tank C – Micronutrients (Manganese, Copper, Molybdenum, Cobalt, Boron, Zinc).
pH Up – Potassium Hydroxide (KOH).
pH Down – Phosphoric Acid or other acids.
Day Tank – This is a central tank the controller mixes nutrients and pH adjusters (by use of different dosing pumps) in the desired proportions. This tank is aerated and temperature controlled. A small aquarium heater can keep contents warm and a chiller is at the end of the middle ceramic bed. This is called a batch system. Tank nutrients and pH are adjusted by an inline injection system drawing from small concentrated jugs. This allows for flexibility in changing nutrient concentrations during the growth period of the plant.

3) A Control Unit monitors adjusts the line pressure, pH and the EC (electrical conductivity of the solution) with sensors. It can also monitor the humidity in the grow bag. This unit can be programmed to backwash and clean lines and provide different mixes of nutrients during the grow cycle. It also controls the schedule of nutrient delivery to the plants via a pressurized pump.
4) Plants are grown in bags filled with media; examples include perlite, peat moss, coco coir, Rockwool and mixes of media) placed in a channel. A typical size is 100cm x 15cm x 10cm (L x W x H) and can hold 3 tomato plants.
5) Channels hold growbags and can be of different length. Channels are raised off the ground with stands that maintain a slope to the collection pipe ultimately flowing to the nutrient reservoir so nutrients can be reused. Alternatively, channels can be hung from the purlins, however, purlins may need to be reinforced to withstand the weight of the channels (up to 900 lbs for each channel with channel weight, water and tomato plants and fruit).

6) A Main nutrient delivery line connects to sublines that run down each channel. Smaller tubes connect to each grow bag that delivers the nutrient through an emitter (that deliver a specific volume of water) attached to a stake that delivers the nutrient to the root zone.

It would be difficult to move the media beds due to the buried pipes connecting them to the ZDEP effluent. ZDEP is an integral component of the aquaponics system and cannot be removed.

Figure 8. Left panel is a Jiffy Growbag showing development of a strong root system. Middle panel shows Growbag with multiple plants in a channel , and Right Panel shows channel with Growbags. The small tubes are nutrient supply lines pumped from the day tank. Excess nutrients are collected in the channel and go to a nutrient reservoir. From https://hortamericas.com.

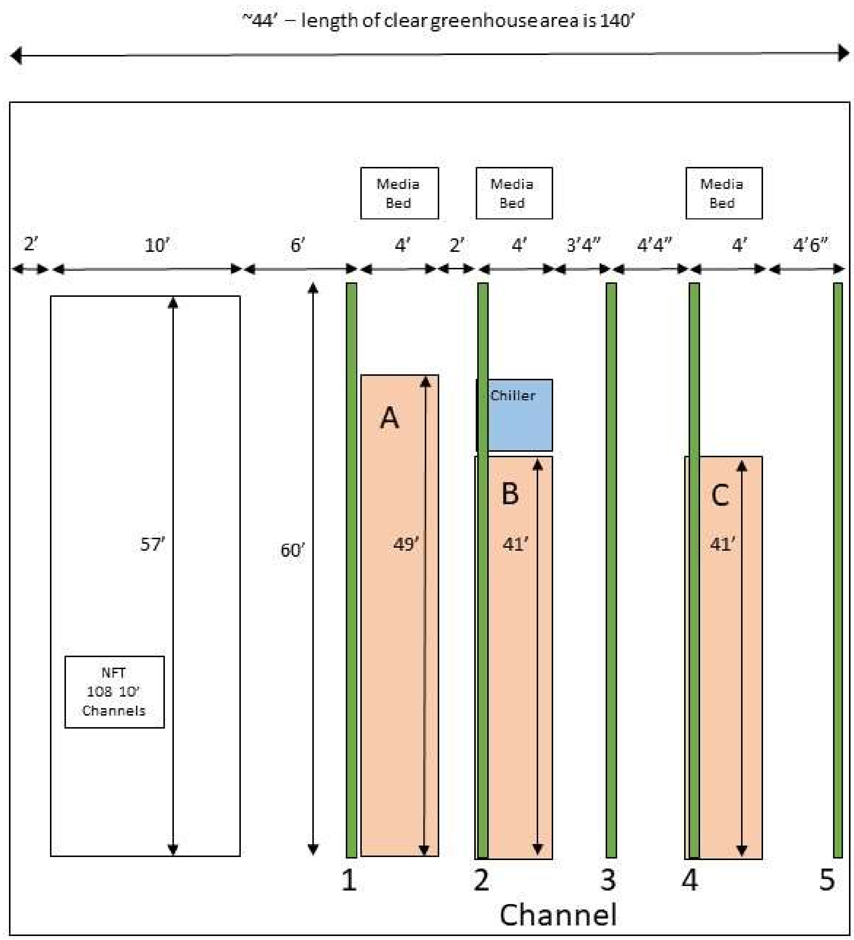

Figure 9. Proposed location of the 5 channels of the hydroponic systems. Channels are placed 3-5ft apart to access plants and allow for ventilation. Channel 2 is located on top of the media bed as there is only a 2 ft walk-way between the media bed and channel. Ground support structures are stands placed every 5 ft. Ground support structures on the media bed for Channel 2 will need to be modified. This channel may need to be same length of the media bed as the structure at the head may impact placement. This channel could be removed. If kept, I would plant peppers in channel 2 as the shorter plants allow for easier harvest from the 2 ft aisle. Channel 4 should be moved to the aisle if it is determined there is sufficient space to access growing vines. Standard foam insulation (4 ft x 8 ft) can be placed between Channel 5 and the wall to minimize cold spots.

For initial production, setting a fertilizer program for tomatoes will work well for other plants. However, an advanced fertigation pump as proposed here (*e.g.*, GrowTek) allows for different plants in different channels to be fertilized differently specific to their requirements at different growth stages.

Two types of nutrient solutions can be used in automated fertigation hydroponic systems: soluble nutrients and organic nutrients.

Soluble Nutrient Solutions

Soluble nutrients are those that dissolve easily in water (also termed synthetic, inorganic, chemical or mineral). These nutrients are the easiest to use and the least expensive to purchase and provide many advantages. Nutrients are provided in a mineralized form that plants can immediately take up and do not need to be broken down by microbes to be made available as do nutrients bound in organic materials. It is easy to mix nutrients in precise concentrations for the different nutrient requirements depending on growth stage [83,84]

Since nutrients are dissolved in water they do not clog pumps, emitters or delivery lines. They are sterile as there are no organic compounds that feed bacteria and they have a long shelf life.

Organic Nutrient Solutions

Organic hydroponics uses nutrient solutions derived from organic plant and animal material or naturally mined compounds. Nutrients, like phosphorus, potassium and nitrogen, are only available to the plant after they are broken down or mineralized by microbes. Mineralization takes place in the grow bags and is similar to the soil microbe- plant interactions. Several aspects of using organic nutrients make the system management different – and depending upon the perspective, more difficult and labor intensive. Since nutrients are bound in organic compounds that need to be mineralized, there is a delay in availability. The delay impacts productivity, and, in general, production in organic systems is lower than in systems that use soluble nutrients [85]

In addition, there needs to be an established thriving microbial community to enable nutrient release. Oxygenation becomes critical to prevent anaerobic zones. Mixing organic nutrients is not as complicated as they are added in a single source. However, organic mixes lack the high nutrient levels that heavy feeders like tomatoes in fruiting stage need. Additional calcium, phosphorus, potassium and magnesium are required; all can be obtained with OMRI certification. [86,87]

Organic nutrients are in a colloidal form, not completely soluble, are thicker and leave residues that need to be cleaned and that clog pumps, emitters and delivery lines. However, automated line-flushing programs in the proposed fertigation system (Growtek) automate this operation. In addition, organic materials are not as stable as their synthetic counterparts and can ferment. Aeration and stirring are needed in the batch tanks.

Organic production using organic nutrients such as Pre-Empt in hydroponic systems are more challenging and require closer management, but possible according to Hort Americas personnel. Pre-Empt. [13] is an organic hydroponic nutrients that doesn't clog automated fertigation systems and is highly refined, fully water-soluble, and pre-digested. A microbial inoculant (TerraBella) [88] is added along with Pre-Empt to enable the mineralization process. Additional nutrients mentioned above will be required.

Organic Pre-Empt can also be used in a hybrid system utilizing by adding water soluble inorganic nutrients such as Calcium Nitrate and Mono-Potassium Phosphate, however, the claim that crops are produced organically cannot be made.

Tomato, cucumber and pepper production with organic nutrients parallels the organically produced lettuce at Blue Acre Aquaponics. Growing with organic nutrients does not assert the claim for USDA Certified Organic; that is a separate category requiring meticulous record keeping of materials used, seeds and is costly. The requirement for high cost organic fish feed probably precludes organic certification for lettuce production. However, if desired, using certified organic nutrient inputs for the hydroponic system could allow pursuit of USDA organic certification. Organically produced vegetables typically command higher prices due to benefits of flavor and nutrition; the extent of this benefit is an active area of research. For example, tomatoes grown organically had increased phytonutrients than those grown in soluble fertilizers. [89,90]

Choice of Grow Bag

A grow media substrate needs to allow for easy flow, not clog, and provide pores for oxygenation. Mineral fertilizers flow easily in the smaller fiber matrix of Rockwool NG2 slabs that allows for excellent moisture control. However, they clog easily when using nutrient solutions like Pre-Empt that contain fine colloidal particles. The small pores trap the organic material in Pre-Empt establishing anaerobic zones that result in root rot.

Other media bag choices are coarse-grade perlite bags. They drain well but have poor water retention and any perlite that escapes can clog pumps. A 70/30 coco/perlite blend is also good for use with Pre-Empt as the coir can retain moisture and support beneficial microbes, but any perlite that escapes can damage pumps. I recommend use of Jiffy Growout 100% coco slabs. The Jiffy Growout 100% coco coir bags combine small and large coir pith that allow for easy passage of the larger colloidal particles in Pre-Empt and higher oxygen levels. In addition, the organic material has a high cation exchange capacity and supports a robust microbial community. After use, the coco coir can be composted.

I would start tomatoes in a 1-inch rockwool cube, move them to a rockwool 4x4 block placed on a Jiffy Growout slab when roots show at the bottom of the cube.

Estimated Production with Organic Nutrients and Soluble Nutrients

Production is based on all parameters and management at optimal levels and based on five 60 ft long channels using Jiffy Growout bags. Records should be kept on average production per plant. The analysis assumes a 30% lower production per plant for organic production than for soluble fertilizers. [85] This is mostly due to the delay in breaking down and delivering nutrients in organic systems; synthetic nutrients are available instantly and growth is maximized.

- Tomatoes - 2 channels, 18 bags/channel, 36 bags total, 108 plants at 3 plants/bag.
    - Soluble nutrients 25 lbs per plant 2,700 lbs total.
    - Organic nutrients 17.5 lbs per plant 1,890 lbs total
- Cucumbers - 2 channels, 18 bags/channel, 36 bags total, 72 plants at 2 plants/bag.
    - Soluble nutrients 25 lbs per plant 1,800 lbs total
    - Organic nutrients 17 lbs per plant 1,224 lbs total
- Peppers – 1 channel, 18 bags/channel, 18 bags total, 54 plants at 3 plants/bag
    - Soluble nutrients 10 lbs per plant 540 lbs total
    - Organic nutrients 7.6 lbs per plant 412 lbs total

- Soluble nutrient use is estimated at 150 lbs (cost is based on full bags of nutrient).
    - Hort Americas Hydroponic Fertilizer (9-7-37): $96.00 per 25 lb bag.
    - Haifa Calcium Nitrate GG: $54.75 per 55 lb bag.
    - Haifa Bittermag Magnesium Sulfate: $45.50 per 55 lb bag.
    - Ultrasol K Plus Potassium Nitrate: $79.00 per 50 lb bag.
    - Total $275

- Pre-Empt 1 oz per gallon with added nutrients (*e.g.*, Ca) to bring to target EC.
    - Need 39 gallons Pre-Empt (~$14 per gallon (bulk IBC 275 gallon tank $3,020 with estimated $750 shipping) Subtotal $532
    - Organic additives and inoculant (TerraBella $225, Gypsum (Ca) $12, K $53, Epsom (Mg) $40, P $136 Subtotal $466
        - OMRI approved additives from Amazon, USAGypsum.com, Hort Americas and Cronknutrients (Cronk Nutrients PuurPhos (0-12-0).
    - Total $1,277

Growing produce with organic nutrients costs $0.28 per pound, compared to $0.05 per pound using soluble nutrients—a 6 fold increase (Table 25). In comparison, Chowdhury *et al.* calculated a cost increase of 5.3 times using Pre-Empt. [91] Producing organically is clearly more expensive.

Table 25. Cost of production per pound for organic and soluble nutrients. Cost per lb of vegetables assumed to be equal. Pre-Empt purchased in 275 Gallon IBC for $3020 and estimated $750 shipping.

Nutrients	Nutrient Cost	Tomato Production (lbs)	Cucumber Production (lbs)	Pepper Production lilbs)	Total Production (lbs)	Cost/lb
Pre-Empt + Additives	998	1890	1224	412	3526	$0.28
Soluble Inorganic Nutrients	275	2700	1800	540	5040	$0.05

I would leverage the knowledge of the folks at Hort Americas for organic production using Pre-Empt. They developed and sell the Pre-Empt product and would be able to assist with questions. I would also explore a mutually beneficial sponsorship relationship as they do with other farms. Blue Acre Aquaponics has a unique suite of growing techniques (vertical herb production, DWB, NFT Channels, hydroponics and aquaculture) with a strong community focused desire to provide food and employment in a USDA-designated food desert. Success at Blue Acre Aquaponics would provide practical benefits to the community and exposure to organic growing practices, techniques and products from Hort Americas.

Pollination

Many varieties of cucumbers are parthenocarpic and require no pollinators. Peppers and tomatoes require pollination. A bumblebee colony can easily pollinate a 30 ft x 200 ft greenhouse. They last 9 weeks, sometimes longer, and cost ~$180-$290 with $100 shipping https://www.arbico-organics.com/ and https://greenmethods.com/ and incur a recurring charge of about $150/month (assuming colony cost of $200 with $100 shipping). Other options include leafcutter bees and mason bees and mechanical vibrators. Humidity levels affect pollen transfer and should be kept between 50-80%; too low and pollen does not stick and if too high pollen becomes sticky and does not get released. [92,93]

Nutrients

Nutrients in an aquaponics system are derived from fish feed and fish waste. Beneficial bacteria in the biofilter convert the toxic forms of nitrogen to nitrate that is used by plants. Plants absorb the supplied nutrients. Aquaponics systems are focused on leafy greens as they grow fast and have lower nutrient requirements than do fruiting plants like tomatoes, cucumbers and peppers that have high nutrient demands. However, chelated iron, calcium carbonate (for pH and pH buffering) and potassium are added to aquaponics systems as these nutrients are low in fish feed.

Below is a description of added nutrients, pH adjustors and parameters usually measured in aquaponics systems.

- Potassium (K) is added as Potassium Carbonate or Potassium Silicate. Typical levels for leafy greens are 20-50 mg/L.
- Iron (Fe) is added as Chelated Fe-DTPA. Chelated iron does not precipitate out of the system. Levels are 1-2.5 mg/L.
- Nitrate is produced in the biofilter that processes fish waste. Managed up to 150 mg/L. Exceeding this level means you have too few plants that can uptake the nitrate or you have too many fish. Approximately 60 grams of fish feed per square meter of plants daily although up to 100 grams can be added depending upon type of plants. [94]
- Calcium (Ca) 40-70 mg/L. Typically added as Calcium Hydroxide with pH adjustment. Add Calcium Carbonate if pH doesn't need to increased. Don't let values exceed ~70 as Ca affects plant uptake of K. Calcium is taken up by a plant with water uptake. If evapotranspiration is low Ca is likely to be limited. Good air flow and lower humidity assist with Ca uptake.
- Carbonate hardness (150-350 mg/L) measures dissolved bicarbonate and carbonate in the water and is a measure of the buffering capacity of water to neutralize acids. Adding Potassium Carbonate will increase carbonates. Adding water by dilution can reduce levels.
- pH – kept at 6.4-7. Nitrifying bacteria (in biofilter) optimum is ~7.5 (7-8), with nitrification stopping below 6. Tilapia pH optimum is 7-8. If low, Calcium Hydroxide $Ca(OH_2)$ or Potassium Hydroxide (KOH) is added. This stabilizes acid and also adds nutrients. Phosphoric acid is added if pH is too low. This decreases pH and adds the nutrient phosphorus.
- Micronutrients (Zn, Mn, B, Cu, Mo) are typically fine in aquaponics from the fish feed. However, they may not be available at the higher pH in aquaponics systems. Chelated blends or kelp based additives can be added if plants exhibit specific nutrient deficiencies.
- Table 26 lists macronutrient and micronutrient ions and their functions.

- Concentration is the amount of a substance dissolved in water. Commonly expressed as milligrams per liter (mg/L) which is how many mg of a substance is dissolved in a liter of water. 1 mg/L is equal to 1 ppm (parts per million).

Table 26. Important macronutrient and micronutrient ions and their function.

Macronutrient Ions

Nutrient	Ion Formula	Primary Function in Plants
Nitrogen	NO_3^- (Nitrate), NH_4^+ (Ammonium)	Leaf and vegetative growth
Phosphorus	$H_2PO_4^-$, HPO_4^{2-} (Phosphate)	Root development and flowering
Potassium	K^+	Water regulation and enzyme activation
Calcium	Ca^{2+}	Cell wall structure and strength
Magnesium	Mg^{2+}	Central component of chlorophyll
Sulfur	SO_4^{2-} (Sulfate)	Protein synthesis and enzyme formation

Micronutrient Ions

Nutrient	Ion Formula	Primary Function in Plants
Iron	Fe^{2+} (Ferrous), Fe^{3+} (Ferric)	Chlorophyll production and respiration
Manganese	Mn^{2+}	Photosynthesis and nitrogen absorption
Boron	BO_3^{3-}, $H_2BO_3^-$ (Borate)	Cell wall formation and sugar transport
Copper	Cu^{2+}	Enzyme activation and stem strength
Zinc	Zn^{2+}	Hormone production and growth regulation
Molybdenum	MoO_4^{2-} (Molybdate)	Converts nitrates into amino acids
Nickel	Ni^{2+}	Nitrogen metabolism and seed germination

- EC – Electrical Conductivity. EC measures how well a solution conducts electrical current which is directly related to how many dissolved ions are in the water. The higher the EC value, the more ions in solution or more nutrients in the water. It does not indicate the specific types of nutrients (ions) nor does it tell you the ratios of ions to each other.

Ions that are synthesized are pure nutrients (also termed synthetic, inorganic, chemical or mineral). They dissolve readily in water and are immediately available. However, nutrients in organic systems are bound in complex organic substances. The nutrients are present but are not disassociated into ions so don't contribute to EC. Systems with organic feeds may have low EC but can have high nutrient content. Bacteria need to break down or mineralize these organic compounds in order to become available to plants. Measuring trends in EC values are important in organic systems. They should not rise or decrease quickly. Dips could indicate microbial suppression or nutrient toxicity. EC values can rise as microbes become more active even if no organic matter is added. Nutrient levels in an automated fertigation (the new proposed hydroponic system) relies on an EC sensor that determines a targeted EC level. If EC is low the controller automatically adds more stock nutrient solution. Targeted EC values for organic systems are lower than those of systems that rely on soluble nutrients (Table 27). These are general EC values; target values are plant and nutrient specific. [95]

Table 27. Comparison between EC values in organic based and salt based hydroponic systems.

Stage	Salt-Based System (Soluble Nutrients)	Organic System
Seedling / Early Veg	0.6 – 1.0 EC (≈ 300–650 ppm)	0.4 – 0.8 EC / ~200–500 ppm (initial low EC expected)
Veg / Rapid Growth	1.2 – 2.0 EC	0.8 – 1.6 EC (microbes gradually lift available ions)
Transition / Early Flower	1.8 – 2.4 EC	1.0 – 2.0 EC
Full Flower / Yield Phase	2.2 – 3.2 EC	1.5 – 2.5 EC (watch for ion accumulation)
Late / Ripening	1.8 – 2.5 EC	1.2 – 2.0 EC (flush more often)

Determining EC, pH, Oxygen, Carbonate hardness, Light and Nutrient Levels

EC
- $105 Bluelab Truncheon Nutrient Meter (https://bluelab.com) Available at other vendors. The hydroponics system will have EC sensors used to create recipes. The vertical system and DWB will not.

pH
- $80.95 pH Pen Large Display ATC (https://aquaponics.com)

Oxygen
- Determination of oxygen levels is required for the fish and plants. Oxygen levels are monitored, displayed and recorded by oxygen probe in the greenhouse controller. The controller can cycle regenerative pumps as needed.

- Carbonate Hardness
  $13.49 API GH and KH Test Kit. (https://www.theaquaponicsource.com).

Light Intensity
- $550 MQ-500: Full-Spectrum Quantum Meter. Measures PAR (Photosynthetic Active Radiation) PPFD (photosynthetic photon flux density), or “quantum” in µmol $m^{-2}s^{-1}$. (https://www.apogeeinstruments.com).
- $211 Advanced Quantum PAR Meter. (https://www.theaquaponicsource.com).

- Photone App. Free download. ~$7.00 to unlock features. Pro subscription ~$30/year. I have not used this App.

Nutrient determination

The three elements typically low and monitored in aquaponics systems are iron, calcium and potassium. Nutrient monitoring at an external laboratory is expensive, especially if frequent determinations are needed when evaluating fertilizer dosing for different plants and plant at different growth stages. Meters listed below are cost effective solutions. I recommend testing Nitrate and potassium with Ion Selective Membrane probes. They are accurate and easy to use. Sensors last at least 6 months (I have used mine for 11 months) and the sensor tip can be replaced for ~$175 when the meter does not calibrate. Purchase calibration solutions NO_3: 30 ppm and 150 ppm; K: Purchase the 150 ppm and dilute to 10ppm and 100 ppm and reprogram the meter for different calibration points; Ca: Purchase 150 mg/L and dilute to 10 mg/L and 100 mg/L and reprogram the meter for different calibration points.

Iron
- $74.99 Iron Checker HC. Iron levels should be between 2-3 ppm. (https://gogreenaquaponics.com). Options available from other vendors.

Nitrate
- $416 Horiba LAQUAtwin NO3-11 Meter (https://www.forestry-suppliers.com)

Potassium
- $416 Horiba LAQUAtwin K-11 Meter (https://www.forestry-suppliers.com)

Calcium
- $454 Horiba LAQUAtwin Ca-11 Meter (https://www.forestry-suppliers.com)

Laboratory Testing

I recommend water testing for major and minor nutrients once the aquaponics system is functioning and after 4-6 months of uninterrupted successful operation. At that time, in-house values of iron, nitrate, potassium and calcium can be compared to lab values.

Two laboratories in West Virginia to test for aquaponics water are:
- WVDA Environmental Laboratories in Moorefield WV (https://agriculture.wv.gov/divisions/regulatory-and-environmental-affairs/environmental-programs-moorefield/)
- Analabs, Inc in Crab Orchard WV (https://analabsinc.com/)

Labor

A Human Resources assessment was completed in 2024. [19] Weekly tasks associated with the hydroponics system below.

Hydroponics

- Equipment care: 6 hours (solutions, daily system checks, filter, lines emitters, sensor calibration, tank cleaning, pump checks.
- Plant care: 12 hours (pruning, stringing, supporting branches and fruit, nursery)
- Harvest: 12 hours (collecting, processing, cleanup and record keeping)

Aquaponics components

- Fish – nursery and tank – Breeding tilapia (?) feeding, harvesting
- DWB production – nursery, planting, harvesting
- NFT production – Nursery, planting, harvest

Vertical Grow System

- Seed, harvest herbs
- Maintain stock nutrient solutions

General

- Cleanup – DWB rafts, tanks, purge, channels, vertical grow bed
- Nutrient analysis
- Check on automation – oxygen, pH, chiller, humidity

The longest days will be harvesting and processing. Weekly for packing leafy greens and on a 20 or 40 day schedule for fish processing. Fish could be frozen or at least refrigerated to provide a time buffer until processing. Lettuce requires quick harvest and processing into coolers. I did not see a specific area/table for lettuce harvest especially needed if lettuce leaves are washed and bagged. The area between the DWB's and the NFT channels could be utilized for this purpose.

- I recommend 2 full time people and part time help if needed during harvest days. I would consider a paid internship. Enthusiastic community members and high school students can contribute to the Facilities success while learning valuable skills that leads them to launch agricultural businesses.

<u>Development of New Products and Business Venture Collaboration</u>

The immediate focus of the Blue Acre Appalachian Aquaponics should be in optimizing Aquaculture BWB's, NFT Channels, Vertical Grow Beds, Ceramic Beds and the new Hydroponic System. Optimizing will require careful monitoring of environmental parameters and installation of LED lights and control systems if needed. A year-long data set of environmental parameters is needed to guide production. Exploration of new production systems become viable once existing processes are optimized or new business ventures are launched with partners. Blue Appalachian Aquaponics could lease the facility for a variety of new ventures, share profits through combined offerings, or trade aquaculture labor for equipment use.

Hydrolysate Production for Hydroponic Use

Hydrolysate is sold in bulk and regularly used to enhance nutrients for crops grown in soil (see vendors in hydrolysate section). Most hydrolysate is not sufficiently refined or processed for use in hydroponic fertigation as the viscous solution fouls and clogs emitters, drip lines and screens. A project in association with university researchers or commercial hydroponic vendors (*e.g.*, Hort Americas) could assess use of how hydrolysate produced at Blue Acre Aquaponics could be modified for use in hydroponic systems (see [96] and references within).

Use of an in-house product would decrease input costs and could spin-off a business venture in partnership with Blue Acre Appalachian Aquaponics.

<u>Possible Ventures</u>

Across from the six 100 gallon nursery tanks is an approximately 12 ft x 24 ft area that contains three currently inactive tanks. While small, it is contained in a conditioned greenhouse, accessible to temperature controlled water and a Growtek controller for monitoring and control. This infrastructure opens up the potential for innovative projects.

- Prawns and Shrimp
  - https://www.aquacultureoftexas.com/aquaponics.htm
  - https://www.miami-aquaculture.com/freshwater-prawns
- Crayfish
  - https://liveaquaponics.com/
- Spirulina
  - https://algaeresearchsupply.com/
  - Fed to Tilapia fry.
- Koi, Goldfish, fancy guppies, tilapia and other stocking fish
  - A partner could raise tilapia for commercial sale with the agreement of providing Blue Acre Appalachian Aquaponics fingerlings for the operation. This project along with in-house generated organic nutrients could considerably decrease input costs.
- Culinary microgreens
  - https://www.johnnyseeds.com/vegetables/microgreens/
- Fodder for chickens and livestock
  - https://foddertech.com/products/table-top-hydroponic-sprouting-systems/
  - Small to commercial systems can be found at https://www.farmtek.com/
- Duckweed
  - https://hortamericas.com/blog/news/could-duckweed-be-the-next-big-vertical-farm-crop/
  - Duckweed is a wonder plant with 40-45% dry weight as protein. Good for tilapia and humans.

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Quote for Berry Seeder

Estimate

CropKing Inc.
134 West Drive
Lodi OH 44254
(330) 302-4203

#23577

7/9/2026

Bill To
Blue Acre Appalachian Aquaponics
Attn: Peter Vila
15 Lower Burning Creek Rd.
Kermit, WV 25674

Ship To
Blue Acre Appalachian Aquaponics
Attn: Peter Vila
15 Lower Burning Creek Rd.
Kermit, WV 25674

Phone	Terms	Rep	Account #
		Heather	Blue Acre Appalachian Aquaponics

Item	Site	Quantity	UOM	Rate	Amount
SEE1000 Berry Seeder System-- Complete system includes the base unit, 200 precision plate, 200 pelleted plate, and 1/2" x 200 dibbler plate	Main	1		$1,462.00	$1,462.00

Subtotal	$1,462.00
Tax Total	$91.74
Shipping Cost	$67.00
Total	$1,620.74

SPECIAL ORDERS: Require 50% down w/balance due before order ships.

Shipping Quotes are Valid for 7 Days

1 of 1

Quote for Wadsworth Seed Control

WADSWORTH Control Systems | 5541 Marshall Street, Arvada, Colorado 80002 1.800.821.5829 www.WadsworthControls.com
Maintaining the Climate for Growth

Seed Control Proposal

PREPARED FOR:	Peter Vila Blue Acre Appalachian Aquaponics 15 Lower Burning Fork Rd Kermit, WV US 25674 (304) 580-6581 pvila65@gmail.com	Job Name: Job Location: Estimate No.: Estimated: Expires: Prepared by: Sales: Job Type:	Blue Acre Aquaponics Kermit, WV 25674 C-26-522602-1 05/28/26 08/26/26 Nick Earls Nick Earls Food Production

Equipment List

Greenhouse Qty	Sensors: 1-Temp/RH/VPD/PAR/CO2 Description		Greenhouse Outputs Used	Data
3	Unit Heater - Gas Fired		2	(120V, 1-Ph, 1/3HP, 7.7Amps) Modine PDP25
8	Horizontal Air Flow (HAF) Fan		1	(120V, 1-Ph, 1/15HP, .9Amps) Quietaire
6	Horizontal Air Flow (HAF) Fan		1	(120V, 1-Ph, 1/15HP, .9Amps) Quietaire
3	Roof Vent Leaders (LST)		4	(24VDC, 1-Ph, 1HP, Amps) Kankit 180nm
2	Grow Lights	Bank #1	1	(240V, 1-Ph, HP, Amps) Master GReen 90251
9	Grow Lights	Bank #2	1	(240V, 1-Ph, HP, Amps) Master GReen 90251
32	Grow Lights	Bank #3	1	(240V, 1-Ph, HP, Amps) Master GReen 90251
11	Grow Lights	Bank #4	1	(240V, 1-Ph, HP, Amps) Master GReen 90251
6	Rollup Side Vents		8	(24V, 1-Ph, HP, Amps) Kankit 80nm
			20 of 24 Outputs Used	

VersiSTEP Control Upgrade (model discontinued)
Original File: Kermit Aquaponics Facility - 125762
Reusing existing contactor panel (ONLY IF IN GOOD CONDITION)

Total Sensors Used: 1 out of 16 — 20 outputs used of 24 Total outputs for Site

	Qty	Description		Price
M-4400		**Seed Control Package Including:**		**$22,373.00**
M-4400	1	Seed 24 Output Multiple Zone Control System		
M-5650	1	Custom Contactor Zone 1 Panel - 36" X 30"		
E-5840	1	Apogee Guardian with Full Spectrum Quantum Sensor	Reads temp/rh/vpd/par/CO2	
M-4444	1	Seed Sphere Software		
S-5433	1	Weather Station Replacement Tee Assembly w/Sensors Amp P/	Resuse weather station pole	
S-9336	1	Liquid Level Control Relay LCP2J250 With 8-Pin Socket 70169-D		
G-0406	100 ft	Cable 2 Pair Shielded 22 AWG 2W985 Carol 1352	For new guardian sensor	
		Engineering for Custom Seed Control Package		**$1,430.00**
M-9940	1	Seed Control designed and engineered drawings		
		Site Visit for Technical Service, Demonstration and/or Training		**$4,975.00**
SV1	1	1 Day Site Visit		
			TOTAL:	**$28,778.00**
			Estimated Ground Freight:	$782.00

NOTES:
1. Wadsworth Controls cannot build custom contactor panels unless drawings are ordered.
2. Customers without drawings pay $120/hr for installation telephone support. This charge is waived if you buy drawings.
3. The estimated price excludes installation.
4. Estimated freight is provided for budgetary purposes. Actual freight will be determined at time of shipping.
5. Payment by Credit Card will have any surcharge fees applied.

Thank you for allowing Wadsworth Control Systems, Inc to estimate your greenhouse control system. Your business is very much appreciated.

To place this order, please send your purchase order to: orders@wadsworthcontrols.com
Please include final list of equipment and overhead sketch with north direction.

Wadsworth Control Systems, Inc. qualifies as a Women's Business Enterprise per Federal Office of Management and Budget Policy Letter 80-4.

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BY PLACING AN ORDER FOR GOODS AND/OR SERVICES, BUYER IS ACCEPTING AND AGREEING TO THESE TERMS. BUYER REPRESENTS AND WARRANTS THAT: (A) IT HAS THE RIGHT, AUTHORITY, AND CAPACITY TO ACCEPT AND AGREE TO THESE TERMS; AND (B) IT IS OF SUFFICIENT LEGAL AGE IN ITS JURISDICTION OR RESIDENCE TO PURCHASE AND USE GOODS AND TO ENTER INTO THIS AGREEMENT. IF YOU DISAGREE WITH ANY PROVISION OF THESE TERMS, YOU SHOULD NOT PURCHASE GOODS OR SERVICES FROM WADSWORTH.

1. PRICES: Prices are F.O.B. place of manufacture and do not include taxes or delivery charges. Absent of proper prior proof of tax exemption, Wadsworth calculates, charges, and collects from Buyer tax according to applicable laws.

2. TERMS AND METHOD OF PAYMENT: Unless otherwise provided, orders must be prepaid in full prior to an order moving to production. Buyer will reimburse Wadsworth for collection costs, including reasonable attorney's fees.

3. DELIVERY: Delivery is F.O.B. Wadsworth's facilities. Promises of delivery from stock are subject to prior sales. Delivery dates are not guaranteed but are estimated on the basis of immediate receipt by Wadsworth of all information to be furnished by Buyer and the absence of delays, direct or indirect, resulting from or contributed to by circumstances beyond Wadsworth's reasonable control.

5. CONTINGENCIES: Wadsworth is not responsible for any failure to perform due to causes beyond its control. These causes shall include, but not be restricted to, fire, storm, flood, earthquake, explosion, accident, acts of the public enemy, war, rebellion, insurrection, sabotage, delays in transportation, inability to secure raw materials or machinery for the manufacturer of its devices, acts of G-d, acts of governments, or any agencies thereof, judicial action, and strikes.

6. LIMITED WARRANTY: Wadsworth warrants that goods of its own manufacture are free from defects of material and workmanship at the time of shipment by Wadsworth and extending for a period of 12 months thereafter. This limited warranty: (a) does not extend to goods subjected to misuse, neglect, accident, improper installation or alteration; (b) is in lieu of any and all other warranties, express or implied; (c) may be amended only by written instrument signed by a Wadsworth officer. The sole liability of Wadsworth under this limited warranty is limited to replacing, repairing or issuing credit (at Wadsworth's sole discretion) for any good returned to Wadsworth during the warranty period. Wadsworth's obligation shall be additionally conditioned upon (a) Wadsworth being promptly notified upon discovery of such defects by Buyer, (b) the good being returned to Wadsworth, transportation charges prepaid by Buyer, within 13 months from the date of shipment from Wadsworth, and (c) Wadsworth's examination of such unit revealing, to Wadsworth's sole satisfaction, that any defect has not been caused by misuse, neglect, improper installation, repair, alteration or accident. Wadsworth extends no warranty of any kind to parts or components purchased by Wadsworth. TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, IN ADDITION TO THE ABOVE WARRANTY LIMITATION, IN NO EVENT WILL (A) WADSWORTH BE LIABLE FOR ANY INDIRECT, CONSEQUENTIAL, EXEMPLARY, SPECIAL, OR INCIDENTAL DAMAGES, INCLUDING ANY DAMAGES FOR LOST DATA OR LOST PROFITS, ARISING FROM OR RELATING TO THE GOODS OR SERVICES, EVEN IF WADSWORTH KNEW OR SHOULD HAVE KNOWN OF THE POSSIBILITY OF SUCH DAMAGES, AND (B) WADSWORTH'S TOTAL CUMULATIVE LIABILITY ARISING FROM OR RELATED TO THE GOODS AND SERVICES, WHETHER IN CONTRACT OR TORT OR OTHERWISE, EXCEED THE FEES ACTUALLY PAID BY YOU TO WADSWORTH OR WADSWORTH'S AUTHORIZED RESELLER FOR THE PRODUCT AT ISSUE IN THE PRIOR SIX (6) MONTHS (IF ANY). THIS LIMITATION IS CUMULATIVE AND WILL NOT BE INCREASED BY THE EXISTENCE OF MORE THAN ONE INCIDENT OR CLAIM. WADSWORTH DISCLAIMS ALL LIABILITY OF ANY KIND OF WADSWORTH'S LICENSORS AND SUPPLIERS.

7. TECHNICAL ADVICE: Wadsworth assumes no obligation or liability on account of any recommendations, opinions or advice as to the choice, installation, or use of goods. Any such recommendations, opinions or advice are given and shall be accepted at your own risk and shall not constitute any warranty or guarantee. The limited warranty set forth in Section 6 above is and shall not be enlarged, diminished of affected by, and no obligation or liability shall arise of grow out of Wadsworth's rendering of technical advice or service in connection with your order, the goods furnished by Wadsworth, or services provided by Wadsworth.

8. REMEDIES AND LIMITATION OF LIABILITY: If you claim that Wadsworth has breached any obligation under any order, whether of warranty or otherwise, Wadsworth may request the return of the goods and (at its option) tender to you the purchase price paid by Buyer. In such event, Wadsworth shall have no further obligation with respect to such goods except to refund such purchase price upon redelivery of the goods. If Wadsworth requests the return of any goods, such goods shall be redelivered to Wadsworth in accordance with Wadsworth's instruction and solely at Wadsworth's reasonable expense. Buyer is responsible in such circumstances for all other costs. The remedies contained in Sections 6 and 8 of these Terms constitute your sole recourse against Wadsworth for breach of any of Wadsworth's obligations under any sales contract, whether of warranty or otherwise. In no event shall Wadsworth's liability exceed the amount paid by the Buyer for the goods or services.

9. PATENTS: Wadsworth may in its sole discretion indemnify Buyer against one or more claims alleging that any good or service solely of Wadsworth's own manufacture infringes a valid U.S. patent, so long as Wadsworth is notified promptly in writing and given authority, information, and reasonable assistance (at Buyer's expense) necessary to defend such claims. Buyer will indemnify and hold harmless Wadsworth against such claims arising out of Wadsworth's compliance with specifications provided by Buyer. This Section 9 will not apply to infringement involving goods or services manufactured by Wadsworth as a part of or in combination with goods or services manufactured or provided by third parties. If goods or services manufactured solely by Wadsworth are held to infringe a valid U.S. patent and their use is enjoined, Wadsworth, if unable within a reasonable time to secure for you the right to continue using such goods or services, will at its sole option either (a) secure for Buyer a license to non-infringing goods or services; (b) modify such goods or services so that they become non-infringing; or (c) accept the return of the enjoined goods or services and refund the purchase price paid therefore.

10. WAIVER: Each shipment made under any order shall be treated as a separate transaction, but if Buyer defaults under any agreement with Wadsworth, Wadsworth may cancel further shipments without affecting its rights against Buyer. Failure or delay by Wadsworth to enforce any these Terms will not constitute a waiver of its rights against Buyer and does not affect its right to require future performance thereof.

11. TERMINATION: Wadsworth may cancel any unfilled orders unless Buyer shall, upon written notice, immediately pay for all goods delivered or shall pay in advance for all goods ordered but not delivered, or both, at Wadsworth's option.

12. LAW: THESE TERMS ARE GOVERNED BY THE LAWS OF THE STATE OF COLORADO WITHOUT REFERENCE TO PRINCIPLES OF CONFLICTS OF LAW. Any action for breach hereof or any covenant or warranty must be commenced within one year after the cause of action has accrued unless such provision is not permitted by applicable law.

13. TITLE: Title for Wadsworth goods and services passes to the end user at the time of Wadsworth delivery to the freight carrier.

14. INSTALLATION: There may be laws in the jurisdiction that you install a particular good applicable to where and how to install that good. You should check that you are in compliance with all relevant laws in your jurisdiction. Wadsworth is not responsible for any injury or damage caused by self-installation.

15. SURVIVAL: These Terms survive the expiration or termination of any order or of these Terms.

16. AMENDMENT OR MODIFICATION: These Terms may only be modified, amended, or waived in a writing signed by a duly-authorized Wadsworth officer.

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Last Updated: 9/2024