Aquaponic Farm Design and Economics
In this session we will...

- Create a basic conceptual design for an aquaponic farm
- Layout fish tanks, filtration and growing systems
- Determine plant and fish production
- Estimate farm revenue and expenses
Assumptions for this Exercise

- We have a business plan!
- We’re raising Tilapia
- Water temperature is 72F
- Desired pH range is 6.6 to 7
- No artificial lights except for the nursery and microgreen decks
- Colorado climate
- Climate controlled greenhouse
- Municipal filtered water
So many considerations...

**Business and Environmental Considerations**
- Climate Zone Designation
- Local labor
- Permitted fish species
- Outlet for fish
- Market pricing for desired crops
- Proximity to markets
- Competitive analysis
- Distribution methods, channels
- Security
- Food safety regulations
- Licensing, wholesale, processing
- Insurances
- Business plan (whole other document)
  - Financial
  - Marketing
  - Operations
  - Human Resources

**Site Conditions**
- Fresh water source
- Water quality test, flow rate, reliability, temperature
- Electrical service, reliability
- Propane or natural gas
- Road access
- Equipment delivery method
- Infrastructure
- Locally available construction, plumbing materials
- Sun orientation, obstructions, winter/summer light availability
- Local zoning, permitting and regulatory requirements
- Renewable energy systems
- Grading, fill
- Site drainage, water discharge
- Sanitary sewer
- Utility locates
- Wash station, restrooms
What Is The Optimal pH?

Vegetables: Ideal Soil pH
- Arugula (Roquette) 6.0 – 6.8
- Beans 6.0 – 7.5
- Cress 6.0 – 7.0
- Cucumber 5.5 – 7.5
- Kale 6.0 – 7.5
- Lettuce 6.0 – 7.0
- Mustard 6.0 – 7.5
- Parsley 6.0 – 7.0
- Pepper 5.5 – 7.0
- Spinach 6.0 – 7.5
- Tomato 5.5 – 7.5

Fish: Ideal water pH
- Tilapia 7.0– 7.5
- Trout 7.0– 8.0
- Wipers 7.0– 8.5
- Catfish 5.5– 7.5
- Koi 7.5– 8.0
In any aquaponic system the amount (or number) of plants we can grow is directly related to the amount of nutrient available.
It’s All in the Feed...

- The amount of nutrient available is directly related to the amount of waste the fish produce.
It’s All in the Feed…

- The amount of waste produced is directly related to the amount of feed fed
Therefore the amount of plants grown is directly related to the amount of feed that enters the system

*Dr. Wilson Lennard*
Designing for Plant Production

- Number and type of plants you wish to grow
- The area those plants need to grow (or the max area you can provide)
- How much fish feed the plants require for nutrient uptake
- The weight of the fish required to eat the feed
- The volume of water required for the fish based on stocking density
In our experience

- At Flourish Farms we’ve been consistently running on feed rate ratios between 15 to 20 grams/m²/day for lighter feeding plants such as leafy greens.
At Flourish Farms we use DWC, Media beds, NFT, Vertical Towers and Wicking beds
Deep Water Culture

- Large water volume contributes to thermal mass and overall stability of temperature and pH

- With loss of power or pump, plants remain alive

- Proven through years of research and commercialization

- Simple harvesting and transplanting – conveyor belt
Starting from scratch

- 2,880 sq ft
- Empty greenhouse with a bio secure entrance

30' x 96'
1,184 sq ft of DWC @ 3.5 plants per sq ft
2’ aisle width
5 species – PI Romaine, Bibb Lettuce, Green Star, Mustard Greens, Red Russian Kale
Feed & Fish Production

- 1,184 s.f. of DWC = 110 m²
- 110m² * 20g/m² = 2,200 grams of feed per day (4.8 lbs)
- Annual feed input = 1,769 lbs
- Tilapia Feed conversion ratio 1.5lbs of feed to 1lb of body mass (FCR = .67)
- Annual fish production = 1,179 lbs
  - Annual Feed input x FCR of .67
  - Relatively conservative for Tilapia and assumes slower growth due to lower than ideal temperature
Basic feed & fish calculations

- Average harvest weight = 1.6lbs
- Total # of harvested fish annually = 736
  - (annual fish production gain 1,179lbs/1.6lbs)
- We will have 2 age cohorts in 2 tanks with a 36 week growout
  - Harvests per year = 2.9 (52 weeks/18 weeks)
- Weight per harvest = 406 lbs
  - (annual weight/2.9)
- Maximum stocking density = .4lbs/gal
- Water volume for each rearing tank = 1,000 gal
Fish Tanks

- Tank Design rules of thumb
- Dia:Depth Ratio 3:1 to 6:1
- Hydraulic Retention Time (HRT) in fish tanks 30 to 60 min
- 1,000g tank @ 60minHRT = 17gpm

* Timmons, Ebeling
Inlet flow injection w/ vertical & horizontal pipes

- More Uniform mixing
- Less flow short-circuiting along tank bottom
- More effective solids flushing

*Image credits: Timmons, Culture Tank Design, The Aquaponic Farming Course*
Filtration Components

- Radial Flow Clarifier (RFC) The Primary Solids Removal device
- Mineralization Tank for suspended solids
- Bio-filter for Conversion of ammonia to nitrates
- Degassing Tank
RFC Sizing

- Proven to be up to 85% efficient in solids removal*
- Sizing “Rule of Thumb” 4 gpm per ft² of cylinder surface area
- 17gpm per tank x 2 tanks = 34gpm total flow into the RFC
- 34gpm flow rate = 8.5 ft² ⇒ 40” diameter
- 45 degree cone bottom ideal
- Fine the closest best fit tank – For example, 48” diameter 500 gallon 45 degree cone bottom

• 2005, Davidson, et al
• *Integrated Aqua Systems
Radial Flow Clarifier

*Image credit: The Aquaponic Farming Course*
Additional treatment of lighter suspended solids post RFC is necessary to avoid clogging and fouling of the bio filter.

Heterotrophic bacteria breakdown solids and “mineralize” them into nutrients and other compounds.

Controls level of denitrification.

Mineralization tank – brush filter
Biofilter Sizing

- About 3% of daily feed ends up as Ammonia–Nitrogen in the water*

- 4.8lbs of daily feed @ 3% \( \Rightarrow \) 64g TAN

- Volumetric TAN Conversion rate (VTR) is the grams of TAN per volume of media per day converted into nitrate

- Design VTR = 15gTAN/ft\(^3\)
  - Assuming granular media (>175 ft\(^2\)/ft\(^3\))*

- \( 64gTAN/15g \) VTR\( = 4.3\)ft\(^3\) of media

- Media @ 50% of container volume\( \cong 9\)ft\(^3\) or 64 gallons

- A 64 gallon tank \( \cong 2\)ft diameter x 2.6ft height

* Timmons, Ebeling Recirculating Aquaculture 3rd Edition
Vortex Brewer

- Additional breakdown of solids removed from the RFC
- Nutrient rich water can be reintroduced back into the media beds or used as fertilizer for soil based agriculture
- Water can also be sold to other farmers for additional farm revenue
- This tank is an air driven brewer utilizing air from the existing blower for aeration and vortexing of solids (no additional energy demand)
- 108 sq ft of media beds
- 66 sq ft for nursery based on seedling rotation
- 66 sq ft for microgreens under nursery
- Lab, sink and work surface areas
## DWC Plant Production & Revenue

<table>
<thead>
<tr>
<th>Crop</th>
<th>Raft Sheets</th>
<th>% of system</th>
<th>sq ft</th>
<th>Density planted</th>
<th>Plants in</th>
<th>*Avg. culture</th>
<th>Weekly Rafts</th>
<th>*Avg plants per raft</th>
<th>loss rate</th>
<th>Annual plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Romaine</td>
<td>54</td>
<td>36%</td>
<td>432</td>
<td>26</td>
<td>1,404</td>
<td>5.80</td>
<td>9</td>
<td>21.7</td>
<td>16%</td>
<td>10,515</td>
</tr>
<tr>
<td>Bibb Lettuce</td>
<td>46</td>
<td>31%</td>
<td>368</td>
<td>26</td>
<td>1,196</td>
<td>5.85</td>
<td>8</td>
<td>22.0</td>
<td>15%</td>
<td>8,989</td>
</tr>
<tr>
<td>Green Star</td>
<td>20</td>
<td>14%</td>
<td>160</td>
<td>26</td>
<td>520</td>
<td>5.85</td>
<td>3</td>
<td>22.0</td>
<td>15%</td>
<td>3,914</td>
</tr>
<tr>
<td>Mustard Greens</td>
<td>14</td>
<td>9%</td>
<td>112</td>
<td>28</td>
<td>392</td>
<td>5.78</td>
<td>2</td>
<td>22.2</td>
<td>21%</td>
<td>2,798</td>
</tr>
<tr>
<td>Red Russian Kale</td>
<td>14</td>
<td>9%</td>
<td>112</td>
<td>28</td>
<td>392</td>
<td>5.77</td>
<td>2</td>
<td>22.4</td>
<td>20%</td>
<td>2,826</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>148</strong></td>
<td><strong>100%</strong></td>
<td><strong>1,184</strong></td>
<td><strong>3,904</strong></td>
<td></td>
<td></td>
<td><strong>25</strong></td>
<td></td>
<td></td>
<td><strong>29,043</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop</th>
<th>$ per plant</th>
<th>$ per raft</th>
<th>Sold by</th>
<th>$ per unit</th>
<th>Weekly units</th>
<th>Weekly Revenue</th>
<th>Monthly units</th>
<th>Monthly Revenue</th>
<th>Annual units</th>
<th>Annual Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Romaine</td>
<td>$ 1.75</td>
<td>$ 38.01</td>
<td>24ct</td>
<td>$ 42.00</td>
<td>8</td>
<td>$ 354</td>
<td>37</td>
<td>$ 1,534</td>
<td>438</td>
<td>$ 18,402</td>
</tr>
<tr>
<td>Bibb Lettuce</td>
<td>$ 1.75</td>
<td>$ 38.50</td>
<td>24ct</td>
<td>$ 42.00</td>
<td>7</td>
<td>$ 303</td>
<td>31</td>
<td>$ 1,311</td>
<td>375</td>
<td>$ 15,731</td>
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<td>$ 132</td>
<td>14</td>
<td>$ 571</td>
<td>163</td>
<td>$ 6,849</td>
</tr>
<tr>
<td>Mustard Greens</td>
<td>$ 1.46</td>
<td>$ 32.40</td>
<td>lbs</td>
<td>$ 7.00</td>
<td>11</td>
<td>$ 79</td>
<td>49</td>
<td>$ 340</td>
<td>583</td>
<td>$ 4,083</td>
</tr>
<tr>
<td>Red Russian Kale</td>
<td>$ 1.44</td>
<td>$ 32.30</td>
<td>lbs</td>
<td>$ 7.00</td>
<td>11</td>
<td>$ 78</td>
<td>49</td>
<td>$ 340</td>
<td>582</td>
<td>$ 4,075</td>
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<tr>
<td><strong>Totals</strong></td>
<td><strong>41</strong></td>
<td><strong>$ 945</strong></td>
<td><strong>178</strong></td>
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Pricing, density, culture times and yield data are derived from Flourish Farms in Denver, CO.
Actual planting strategy, choice of crops, and percentage allocation in the system are all up to you and the proper mix you need to satisfy your customers.
### Culture period and loss rate

<table>
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<tr>
<th>Crop</th>
<th>Weekly Rafts harvested</th>
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Loss rate is the difference between the density planted in the rafts versus the actual sellable product.
Price, distribution strategy, customer base, wholesale vs. retail etc. are driven by your business plan and market forces
Revenue per Species/Unit

<table>
<thead>
<tr>
<th>Crop</th>
<th>Weekly units</th>
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<th>Monthly units</th>
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- 100 sq ft of media beds could contribute another 1,500 to 3,000 crops per year
# Microgreens Production & Revenue

<table>
<thead>
<tr>
<th>Microgreens</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Table width</td>
<td>2 ft</td>
</tr>
<tr>
<td>Table length</td>
<td>33 ft</td>
</tr>
<tr>
<td>Table sq ft</td>
<td>66 ft²</td>
</tr>
<tr>
<td>Number of tables</td>
<td>1</td>
</tr>
<tr>
<td>Total table sq ft</td>
<td>66 ft²</td>
</tr>
<tr>
<td>Microgreen flats @ 2 sq ft</td>
<td>33</td>
</tr>
<tr>
<td>Culture period (weeks)</td>
<td>2.0 wks</td>
</tr>
<tr>
<td>Number of harvests annual</td>
<td>26</td>
</tr>
<tr>
<td>Total flats</td>
<td>858</td>
</tr>
<tr>
<td>Loss rate</td>
<td>15%</td>
</tr>
<tr>
<td>Total harvested flats</td>
<td>729</td>
</tr>
<tr>
<td>Revenue per flat</td>
<td>$18</td>
</tr>
<tr>
<td>Annual microgreen revenue</td>
<td>$13,127</td>
</tr>
</tbody>
</table>
Fish Production & Revenue

- Total annual weight of harvested fish = 1,179 lbs
- Average $5 per lb for whole live Tilapia
- Total Fish Revenue = $5,897
Potential Revenue – Year 2

- Leafy Greens in DWC $49,141
  - Includes seasonal production variability
- Microgreens $13,127
- Fish Revenue $5,897
- Total Revenue $68,165
Just a few variables that influence plant production, loss rate & profit!

- Pests
- Startup
- Nutrient Deficiencies
- Operator skills, Management and Training
- Business & Marketing Plan (lack there of)
- Customer & price volatility
- Available light
- Plant species
- Culture time in system
- Performance of biofilter
- Fish species
- Fish feeding or not feeding
- Temperature and environment
- Quality of starts
- Product handling
- Monitoring controls and backup systems
- Food Safety and HACCP plan
- Supply chain consistency
- Water Quality
Estimated Expenses

- **Utilities = $ 5,082**
  - Electricity, gas, water
- **Supplies = $ 8,836**
  - Plug trays, fish feed, adjusters, IPM, packaging, parts
- **General Admin = $ 4,820**
  - Licenses, insurances, professional fees
- **Payroll = $38,322**
  - Wages, Taxes, Workers Comp
- **Total Expenses = $57,060**

*Based upon 40 year old Colorado greenhouse with improper orientation. See passive solar greenhouse at the end of the presentation for better solutions*
What is your lighting cost?
“Climate Battery”
### Executive Summary Cash Flow

<table>
<thead>
<tr>
<th>Exec Summary Cash Flow</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Projected Cash Inflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produce and Fish Sales</td>
<td>$33,088</td>
<td>$68,166</td>
<td>$70,211</td>
<td>$72,317</td>
</tr>
<tr>
<td><strong>Projected Cash Outflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Expenses</td>
<td>$55,349</td>
<td>$57,061</td>
<td>$58,772</td>
<td>$60,535</td>
</tr>
<tr>
<td>Operating Profit (EBITDA)</td>
<td>($22,260)</td>
<td>$11,105</td>
<td>$11,438</td>
<td>$11,781</td>
</tr>
</tbody>
</table>

#### Floor Plan

- **Media Beds**
- **Nursery Flood Table – MicroGreens**
- **Lab/Sink**
- **DWC 74 x 8 592 sf**
- **Tank 1 1,000g**
- **Tank 2 1,000g**
- **Harvesting Work Space**
ENERGY-EFFICIENT
AQUAPONICS GREENHOUSES
2,880 SQ. FT. GREENHOUSE + AQUAPONICS

PRODUCES:
35,000 HEADS OF LETTUCE PER YEAR
using deep water culture beds.
Chard, kale, microgreens, etc. also possible.

1,000 LBS. FISH PER YEAR
from aquaponic fish tanks

ONGOING HARVESTS
of high-value crops grown in media beds

USES:
50% LESS ENERGY
compared to conventional greenhouses. Greenhouse can be 'self-heating' with Ceres’ Ground to Air Heat Transfer (GAHT™) System

90% LESS WATER
compared to conventional agriculture
Estimated production and resource use varies by crop selection, growing conditions and climate.

Ceres Greenhouse Solutions is an industry leader in advanced, high-efficiency greenhouses. Colorado Aquaponics was founded by JD and Tawnya Sawyer to help businesses and communities design and build successful aquaponic systems. The Sawyers also own The Aquaponic Source and Flourish Farms, a 3,000 sq. ft aquaponics greenhouse in Denver, Colorado (right). Together, Ceres and Colorado Aquaponics work to integrate proven aquaponics systems into high-performance greenhouses for truly sustainable year-round food production.
Aquaponics and passive solar greenhouses enable truly sustainable and resilient year round food production. With the right building and a thoughtfully designed growing system, commercial aquaponics becomes practical and profitable.

JD Sawyer
Create, Innovate, Educate, Integrate, Evolve

jim@coloradoaquaponics.com