RESOURCE UTILIZATION IN HETEROTROPHIC VS AUTOTROPHIC MARINE SHRIMP PRODUCTION

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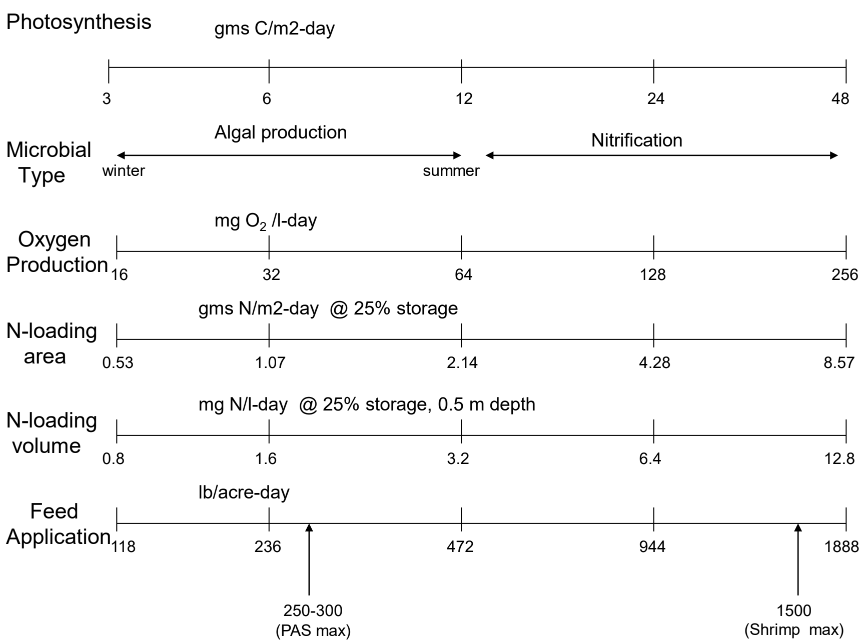
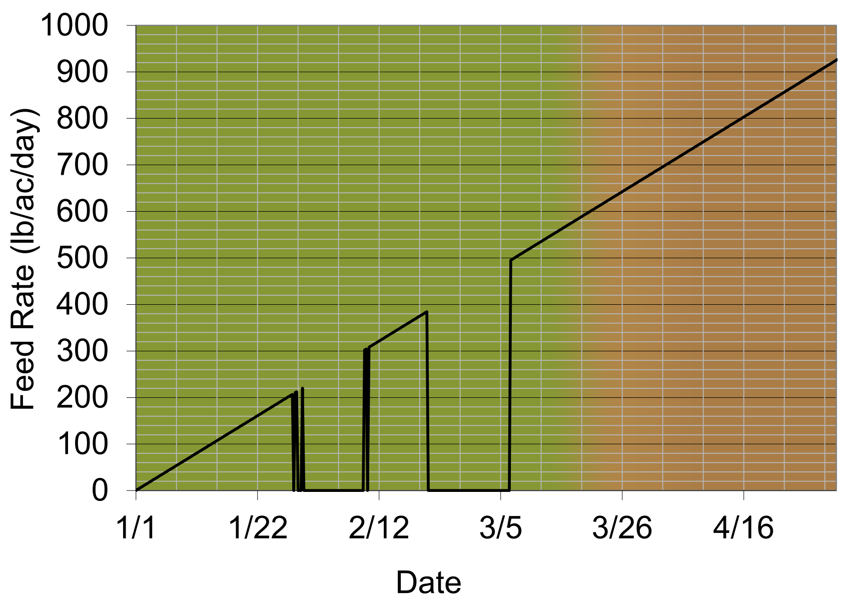
Biofloc = Special case of suspended-cell microbial culture

Algal to bacterial water treatment depending on level of external energy input; feed and solar (algal up to 250- 300 lb-feed/ac-d), Nitrifying at C/N of 9/1 (35% protein), Heterotrophic C/N of 12-15/1





Overview of Aquaculture Intensification [1]

Name, Yield, Feed, Aeration, Solids, Microbial Type, Solids, Inception date

SYSTEM	Yield lb/ac	Feed lb/ac-d	Aeration hp/ac	Type g-C/m^2-d	VSS mg/l	Timeline
Extensive	1,000-2,000	10-30	Wind	Algal (0.5-1)	10-20	1960
Semi- Intensive	4,000-6,000	50-100	1-2	Algal (2-3)	50-100	1980
Intensive pond	10,000-12,000	100-150	6-20	Mixed (3-4)	100+	1990
PAS/SP	15,000-19,000	200-250	7-10	Algal (6-12)	50-100	2000
Super heterotrophic	40,000+	1,000/600	60-80	Heterotrophic	300-400	2006
Super nitrifying	40,000+	1,000	50-60	Nitrification	300-400	2006
Rapid Removal	30,000-44,639	1,500	67-76	Intense Nitrification	70-80	2020

Aquaculture technology has advanced over 60 years; Fish/shellfish yields increased from farm-pond production of 1,000 to 2,000 lbs/acre-year to 40,000 to 50,000 lbs/acre-year in, year-round, climate-controlled, zero-discharge, recirculating aquaculture systems (RAS).

[1] Brune, D. E., Autotrophic and Heterotrophic Water Treatment in Semi-Intensive, Intensive and Super-Intensive Fish and Shrimp Culture, *The Shrimp Book II*, Victoria Alday-Sanz, Editor, 5M Press, 2022. High HP in SH and SN needed for mixing and aeration

One Technique to Expand Production to Super-Intensive Levels; Biofloc Aquaculture

High levels of microbial solids (250-300 mg/l) within culture water

Types of Biofloc Water Treatment

Autotrophic Nitrification (Slow growth, low sludge production)

NH_4 + O_2 = $C_5H_7O_2N$ (Bacterial Biomass) + NO_3 + CO_2

Heterotrophic Bacteria (Rapid growth, requires carbohydrate)

NH_4 + $C_6H_{12}O_6$ (Sugar) + O_2 = $C_5H_7O_2N$ (Bacterial Biomass) + CO_2

Nitrifying (Autotrophic) Water Treatment
(40,000+ lb-shrimp/acre-cycle)

Feed (FCR =1.5/1)
32-36% protein

Ammonia
Excretion
65-75% of
feed-N

→

Fecal Solids
20 - 30% of
Feed
Nitrify = 10%
of fecal

Input C/N = 8-9/1
Solids = 0.3 + 0.03 = 0.33 lb-VS/lb shrimp

Bacterial (Heterotrophic) Water Treatment
(40,000+ lb-shrimp/acre-cycle)

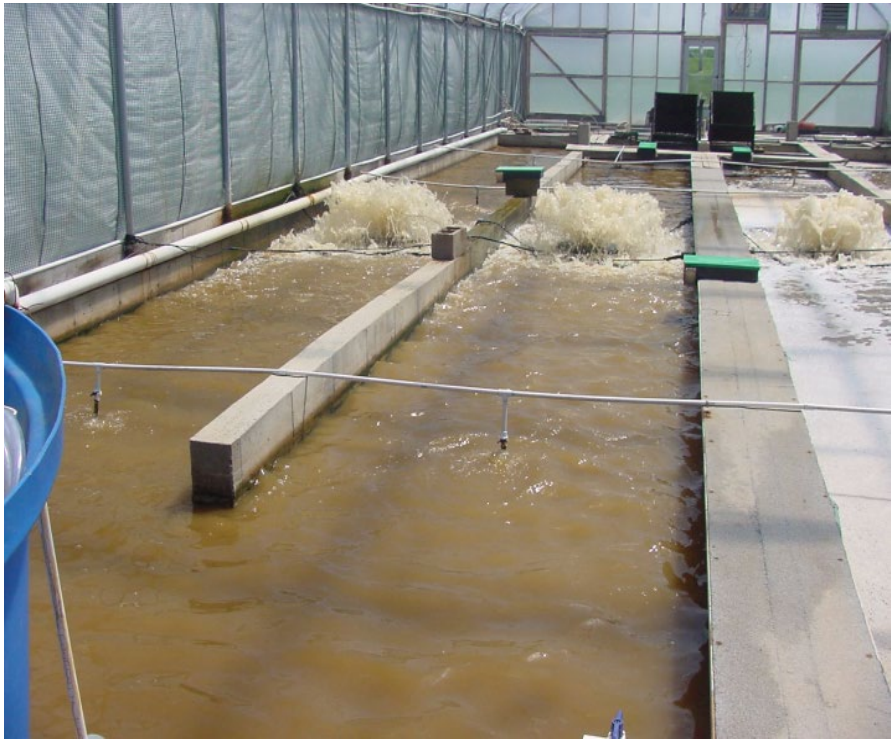
Feed (FCR=1/5/1)
32-36% Protein

Ammonia Excretion 65-75% of feed-N

→

Fecal Solids
30 % of feed
50 % of sugar

Carbohydrate Addition
(~ 85% of feed)



Input C/N =12-15/1
Solids = 0.3 + 0.43 = 0.73 lb-VS/lb-Shrimp
2.5-x Autotrophic solids production

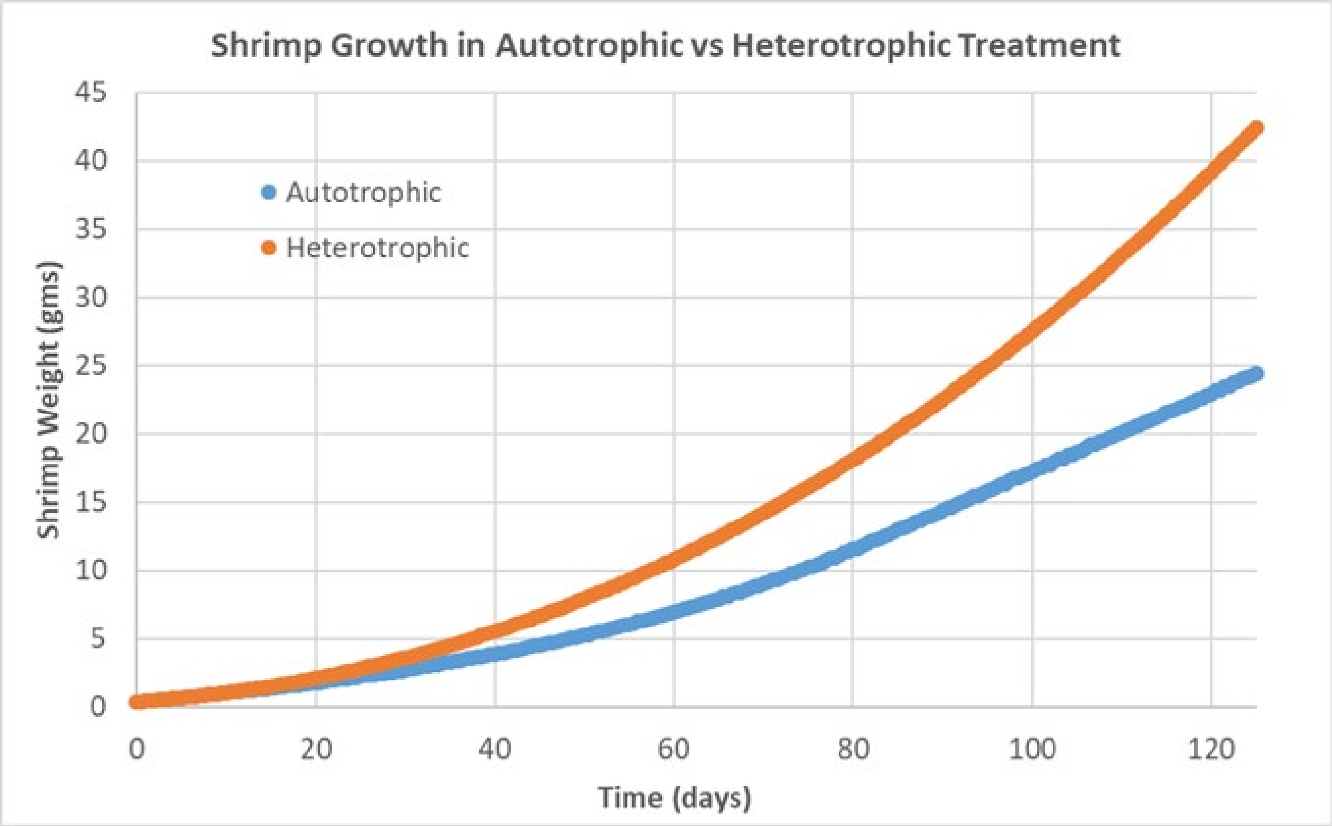
Approximate Heterotrophic Carbohydrate Requirement

100 gm sugar ($C_6H_{12}O_6$) yields 50 gm bacterial biomass (25 gm-C) at C/N of ~5.7/1, assimilating 4.38 gm-N/100 gm-sugar or 22.8 gm sugar required/gm-N

250 shrimp/m^2 at 22 gm = 5,500 gm shrimp x 2-3% feed/day = 165 gm max-feed/day = 6.18 gm-N/l-day (165 gm feed x 36% protein x 16% N x 65% excreted)

6.18 gm N x 22.8 gm sugar/gm-N = 140.9 gm sugar, or 85% of feed addition.

Growth of Marine Shrimp at 45,000+ lb-shrimp/acre
Heterotrophic[1] vs Autotrophic[2] Treatment



Shrimp stocked at 0.4-gm, harvested at 22-gm (20 count/jumbo)
Requiring 90 days heterotrophic (unlimited growth) vs 120 days nitrifying

1) Unlimited shrimp growth based on feeding rate from, Obaldo, L.G. & Masuda, R. 2006. Effect of diet size on feeding behavior and growth of pacific white shrimp, Litopenaeus vannamei. Journal of Applied Aquaculture, 18: 101–110.

2) Autotrophic growth from field observations and model of inhibited growth from, Brune, D.E., Suspended Cell Biofloc for Shrimp Production, Presentation at North Central Regional Aquaculture Center Meeting, Columbus Ohio, 2020

Representative Nitrifying vs Heterotrophic N-Uptake/Oxidation

Maximum N addition rate = 250 shrimp/m^2 x 22 gm/shrimp = 5,500 gm x 0.03/day feed rate x 0.36 protein content x 0.16 nitrogen x 0.65 excreted = 6.18 mg-N/l-day

Typical heterotrophic bacterial growth rate = 0.3 lb-BOD_5/lb-VS-day; At 250-300 mg/l VS = 28-34 mg-C/l-day corresponding to 5.6-6.8 mg-N/l-day (BOD_L/N ~ 20/1)

Observed nitrifier yield = 0.2 gm VS/gm-N, Seasonal feed application of 308-410 gm-N/m^2 or 308-410 mg-N/l (in 1-meter deep culture), predicted nitrifyer biomass = 62-83 mg/l (FCR = 1.5/1, 36% protein, 65% excretion)

Observed aquaculture biofloc nitrifying oxidation rate(1) = 0.02-0.05 mg-N/mg-VS-day (20-50% of biomass). At 0.05 mg-N/mg-VS-day x 62-83 mg/l, N oxidation rate = 3.1- 4.0 mg N/l-day

Observed wastewater treatment nitrifying growth rate(2) = 0.07-0.09 mg-N/mg-VS-day (80-100% of biomass) At 0.09 mg-N/l, N oxidation rate = 5.6 mg-7.4 mg-N/l-day

Typical aquaculture biofloc management fails to maximize nitrification treatment capacity Enhanced system (such as "rapid removal") approaches waste-water nitrification capacity, however cost of enhanced bacterial biomass management is significantly higher

1) Brune, D. E., Autotrophic and Heterotrophic Water Treatment in Semi-Intensive, Intensive and Super-Intensive Fish and Shrimp Culture, The Shrimp Book II, Victoria Alday-Sanz, Editor, 5M Press, 2022.
2) Metcalf & Eddy, Inc. (2003) Wastewater Engineering: Treatment and Reuse, 4th ed. McGraw-Hill, New York, NY

The Drive to Zero-Discharge Aquaculture

Animal agriculture recovers only a small fraction of feed-N

79 - 88% nitrogen discharged as pollutant

Soy, corn & fish-meal nitrogen inputs

12 - 21% protein nitrogen converted to fish or shrimp

Economic Analysis Based on Prototype, Zero-Discharge, Controlled-Environment, Year-Round, Recirculating Aquaculture System on Private Farm in Missouri

Prefabricated, Concrete-filled PVC Wall-Panels

Inside 6,000 ft^2 Insulated Metal Building on Concrete Pad

Shrimp vs Finfish (Bass) Carrying Capacity
Resource Inputs vs Outputs

	Bass	Auto-Shrimp	Hetero-Shrimp
Harvest size	1.5 lb	22 gm (jumbo)	
Carrying Capacity			
Volumetric (1-meter deep)	0.5 lb/gallon	0.0458 lb/gallon	
Areal	60 kg/m^2	250/m^2 @ 22 gm = 5.5 kg/m^2	
Crops/yr	1	3	4
Yield/m2-yr	60 kg/m^2-yr	16.5 kg/m^2-yr	22.0 kg/m^2-yr
Breakeven income	\$604.07/m^2-yr	\$351.49/m^2-yr	\$453.50/m^2-yr
BI +15%	\$695.62/m^2-yr	\$404.22/m^2-yr	\$521.53/m^2-yr
kwh/lb live wt)	5 kwh/lb	15.2 kwh/lb	11.4 kwh/lb
Input (protein)	0.75 lb/lb	0.54 lb/lb	0.54 lb/lb
Input (sugar)	0	0	0.84-1.3 lb/lb
Waste lb-VS/lb production)	0.31 lb/lb	0.33 lb/lb	0.74 lb/lb

Economics of Marine Shrimp vs Finfish (Bass)

Clean-water Nitrifying Biofilter vs Hetero/Auto Biofloc

Production Cost (Fish vs Shrimp)

Capital Costs ($/lb)	Bass	Shrimp (Auto)	Shrimp(Hetero)
Building	0.232	0.617	0.463
Heat Pump	0.111	0.296	0.222
Generator	0.035	0.093	0.069
Raceways	0.181	0.604	0.453
Filters	0.124	0.156	0.117
Aerators	0.082	0.272	0.204
Pumps	0.013	0.042	0.031
Total Capital	**0.778**	**2.080**	**1.557**
Operating Costs ($/lb)			
Feed	1.500	1.080	1.080
Sugar	0	0	1.032
Animals	0.784	2.428	2.428
Aeration KWH	0.213	0.760	0.570
H/C KWH	0.286	0.760	0.570
Labor	0.638	2.122	1.592
Total Operating	**3.421**	**7.150**	**7.272**
TOTAL COSTS	**$4.20/lb**	**$9.23/lb**	**$8.83/lb**

Aquaculture Production Costs; Pond vs RAS

Estimated Costs/Prices* ($/lb) for Whole/Processed Pond and RAS Products

TYPE/YIELD	Break-Even (whole)	Farm-gate (whole)	Wholesale (processed)	Retail (processed)
POND				
Catfish (0.32 lb fillet)	0.80-1.00/lb	0.85-1.25/lb	5.00-6.00/lb	8.00-11.00/lb
Shrimp (0.6 lb tails)	1.50-1.90/lb	2.00-3.00/lb	5.00-6.00/lb	5.00-12.00/lb
RAS				
Shrimp (0.6 lb tails)	4.00-8.25/lb			13.00-18.00/lb whole
Bass (0.32 lb fillet)	4.00-6.00/lb	5.00-6.00/lb	15.00-18.00/lb	20.00-28.00/lb

Recirculating Systems Production Costs; Marine shrimp = $4.00-8.25/lb, Freshwater large-mouth bass = $4.00-6.00/lb

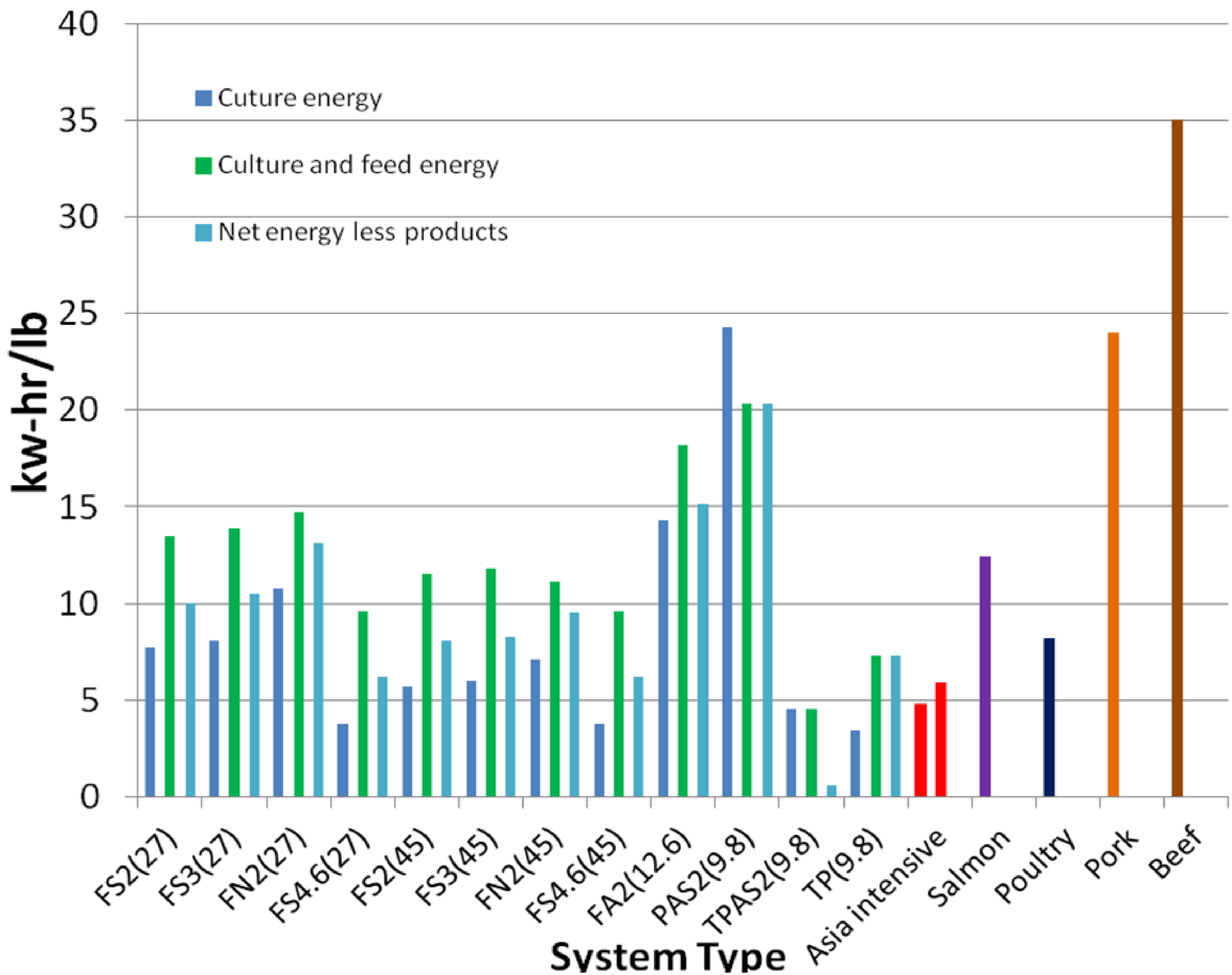
Typical Commodity Farm-Gate Prices; Catfish = $1.00/lb, Largemouth Bass = $6.00/lb, Shrimp = $3.00/lb

Small Volume Niche Market Shrimp Prices; Shrimp =$13-18/lb

Recirculating System Costs = 1-6X commodity price, 45-65% of niche market price

* Break-even costs dependent on scale, species, and system productivity. RAS cost/sales highly variable based on small sample size

Energy Cost vs Type of Production System
Typical RAS finfish = 7-12 kwh/kg live wt. = 3.2 – 4.5 kwh/lb



Summary

- Zero-discharge, controlled-climate, RAS production costs range from $4.20/lb (fish) to $9.23/lb (marine shrimp)
- Heterotrophic shrimp costs ($8.83/lb) similar to autotrophic costs ($9.23/lb), however, heterotrophic produces ~2.5-X more sludge, 0.74 lb sludge/lb shrimp vs autotrophic 0.33 lb-sludge/lb-shrimp, and requires sugar supplementation at 84% of feed.
- Heterotrophic shrimp production yields 22 kg/m^2-yr vs autotrophic of 16.5 kg /m^2-yr vs fish yields of 60 kg/m^2-yr.
- Production energy requirements (per lb live wt) range from 5.0 kwh/lb (fish) to 15 kwh/lb (shrimp) as opposed to 8 kwh/lb (chicken), 24 kwh (pork) and 35 kwh/lb (beef).
- Profitability of zero-discharge RAS will likely require retail sales
- Growers must bear costs of seafood holding, processing, transportation, packaging, and advertising/marketing to sell product directly to consumers

Presentations/Additional Resources

MU Extension Aquaculture Website

https://extension.missouri.edu/programs/aquaculture-extension

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