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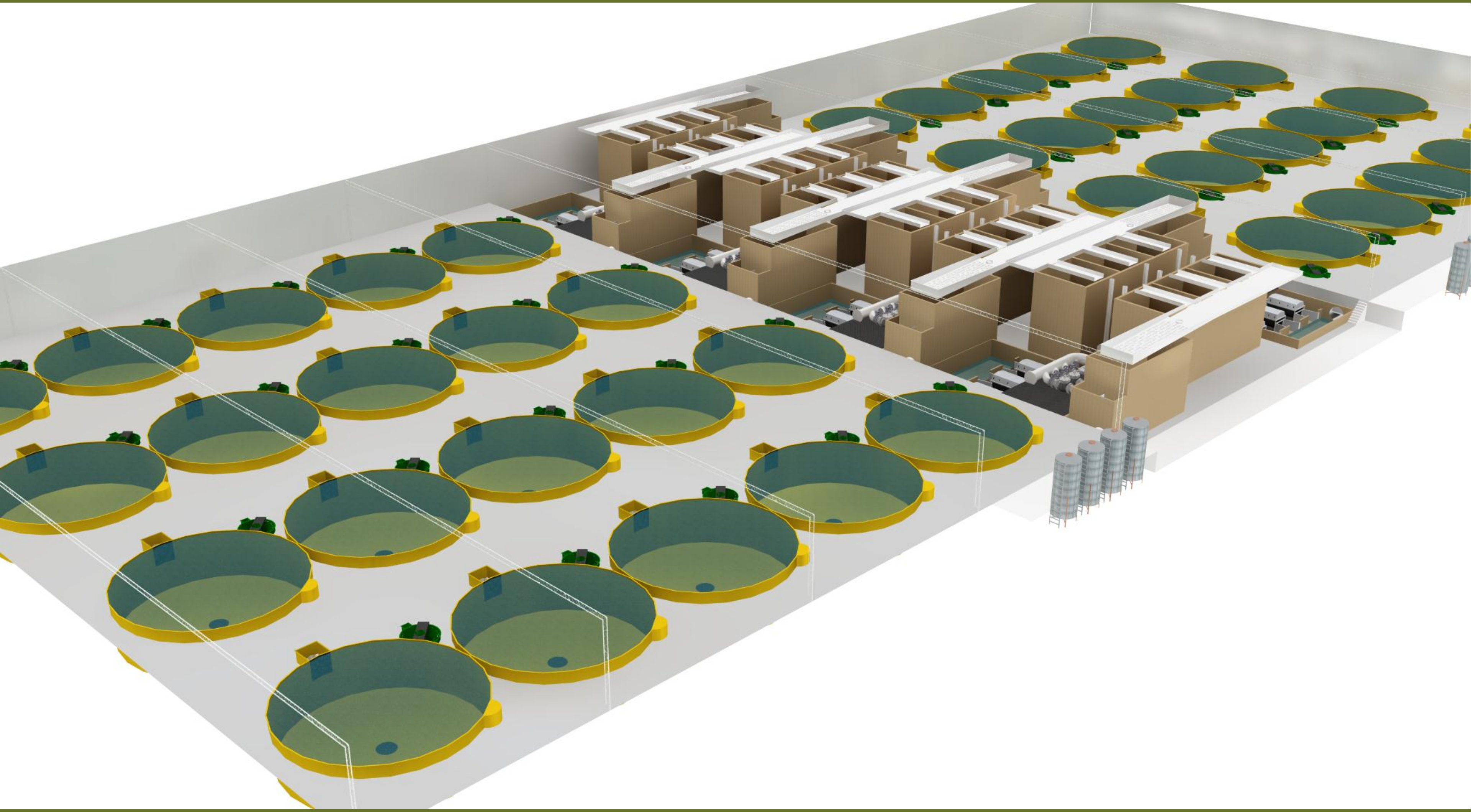
Environmental Performance of a 3,300 mt Land Based Salmon Farm



Brian Vinci

Or…

NOT ALL SALMON ARE CREATED EQUAL

Environ. Sci. Technol. 20

Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems

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Outline

- Salmon Farm Model Description
- Effect of Rearing Density
- Cost Estimation
- Environmental Performance Analysis
  - Energy Consumption
  - Greenhouse Gas Emissions

Bioplan

- Initial Effort – Four egg hatches per year every 3 months targeting 2,500 MT/yr
- First Revision – Increased rearing density targeting >3,000 MT/yr
- Second Revision – Two hatches per year with cold banking to create four groups of fish

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RAS Process Design

- Dual-Drain Culture Tanks
- Radial Flow Settlers
- Microscreen Filtration
- Fluidized Sand Biofiltration
- Cascade Aeration for CO2 Stripping
- Low Head Oxygenation for O2 Addition
- Ozonation

RAS Design Criteria

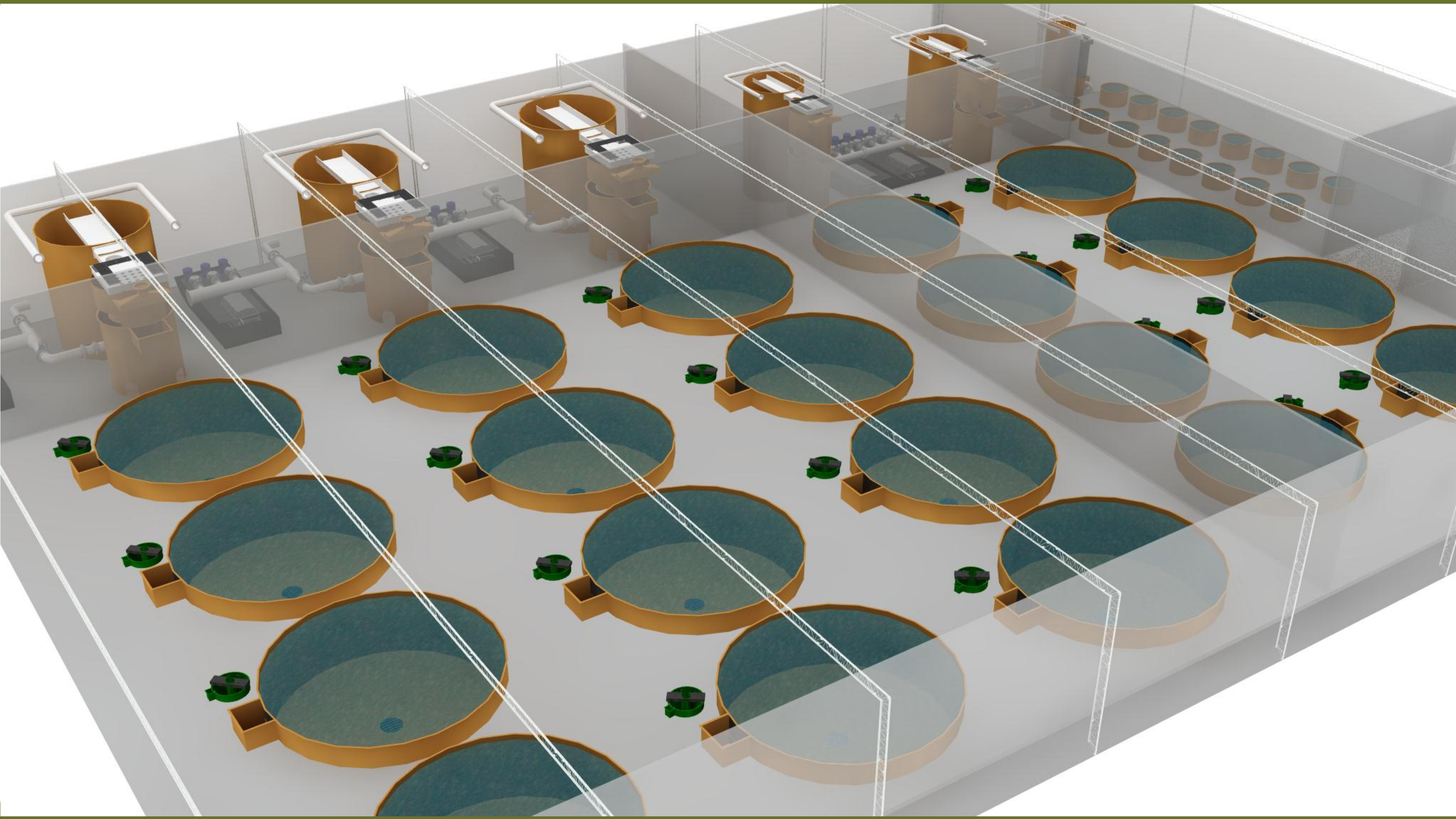
	(Fry)
• Total Suspended Solids of 5 mg/L	
• Total Ammonia Nitrogen of 1.5 mg/L	(0.6)
• Dissolved CO2 of 15 mg/L	(12)
• Dissolved O2 of 100% saturation	
• Nitrate-Nitrogen of 75 mg/L or less	(9)
• Water Temperature of 15ºC	(12)
• Piping Sized for 0.6 m/s and 1.5 m/s	

Updated Data & Inputs

- Thermal Growth Coefficients:
  - Fry 1.25
  - Smolt 1.40
  - Pre-Growout 2.00
  - Growout 2.30

- 88% HOG Yield (after 5% loss in purge)

Fry Rearing



Fry Rearing

- Week 0 to Week 13 (0.18 g to 7.2 g)
- 12ºC Water Temperature
- One RAS:
  - 18 Tanks: 2 m diameter by 1 m deep
  - 1.5 m^3 per minute recycle flow
  - Tank exchange rate of 37 minutes
  - Maximum density of 25 kg/m^3
  - 200% volume exchange per day
    - 9 mg/L Nitrate-Nitrogen

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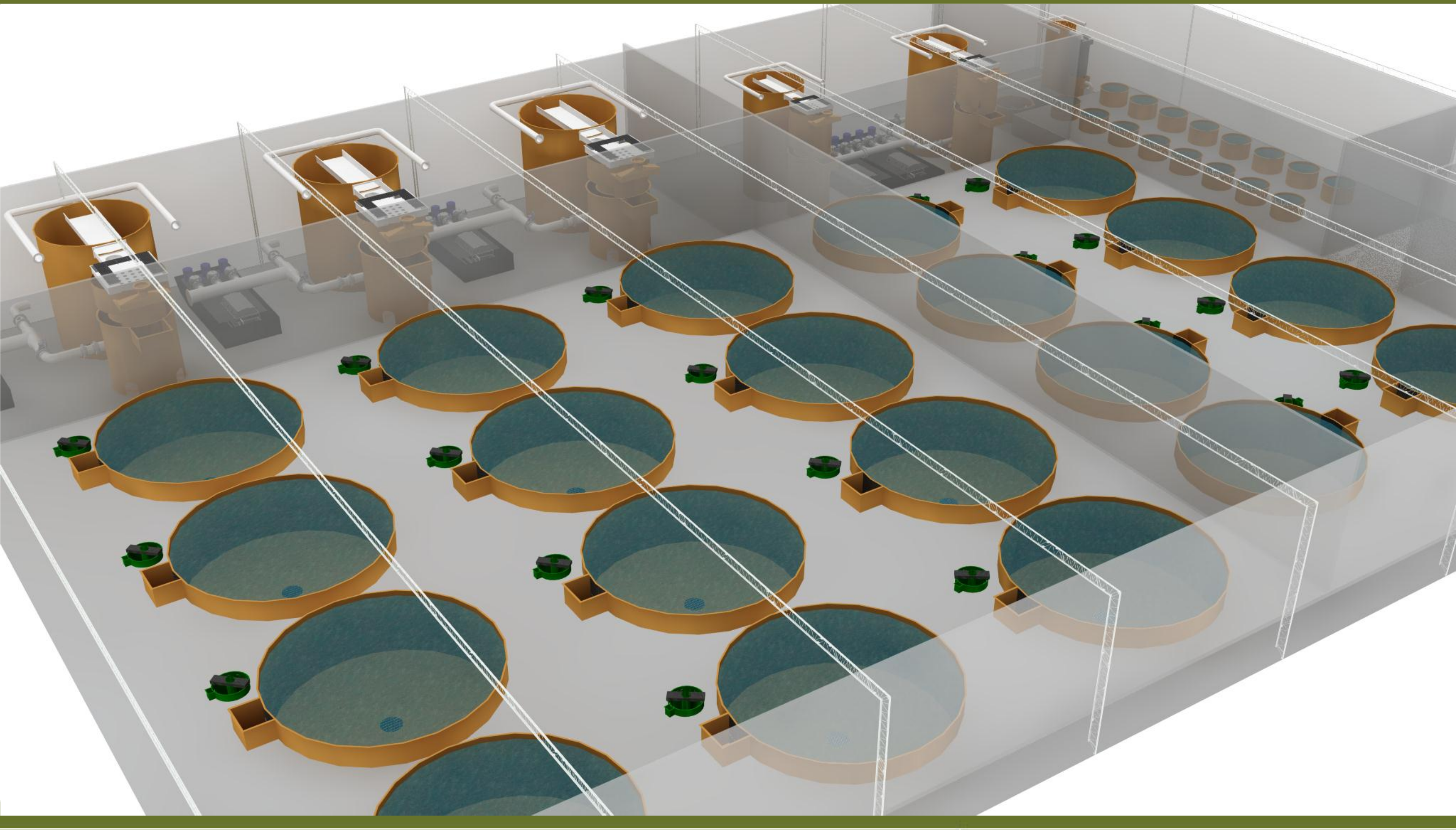
Smolt Rearing



Smolt Rearing

- Week 14 to Week 34 (7.2 g to 105 g)
- 15ºC Water Temperature
- Two RAS:
  - 4 Tanks: 9 m diameter by 2 m deep
  - 11.4 m^3 per minute recycle flow
  - Tank exchange rate of 45 minutes
  - Maximum density of 35 kg/m^3
  - 21% volume exchange per day
    - 73 mg/L Nitrate-Nitrogen

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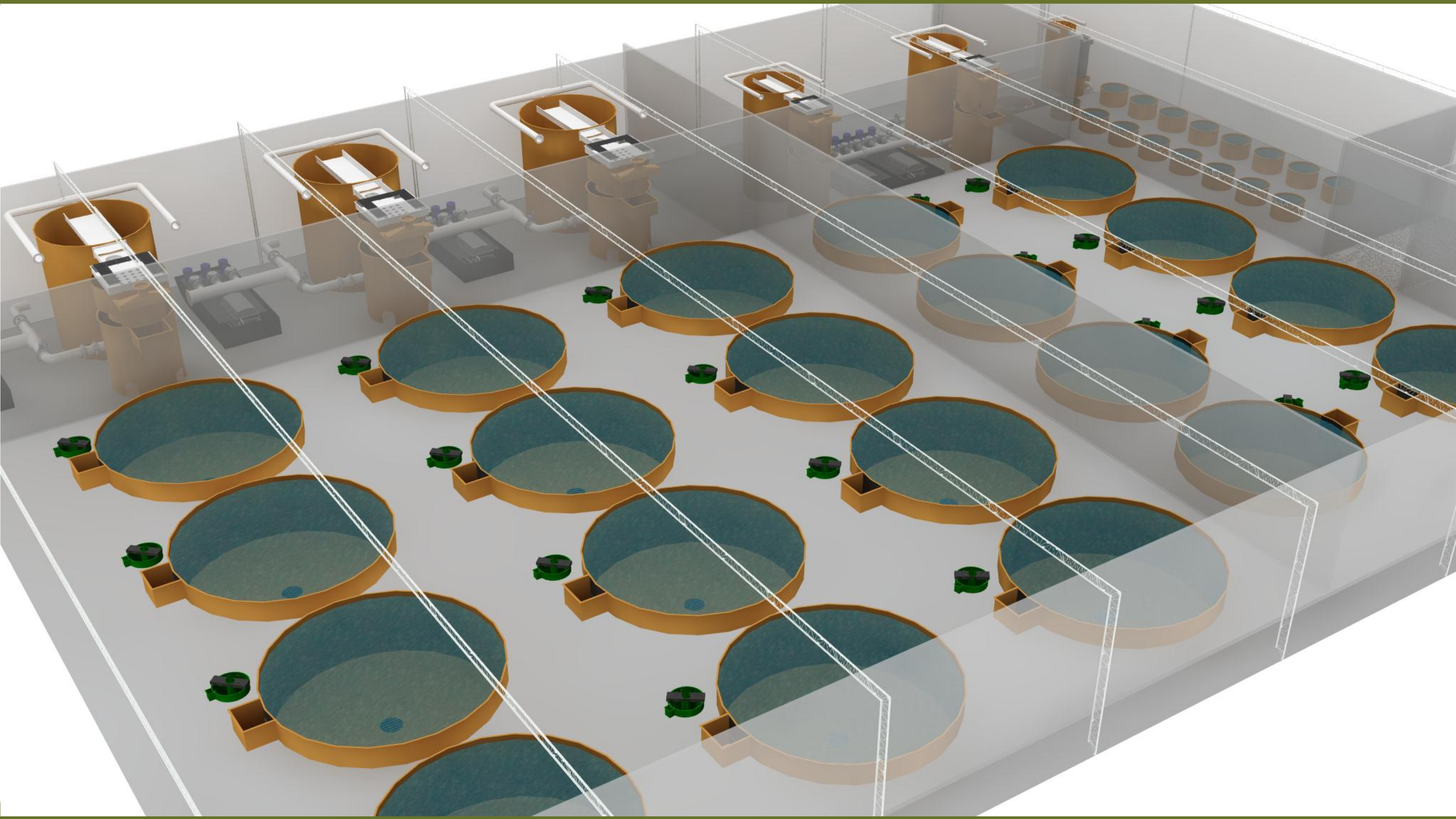
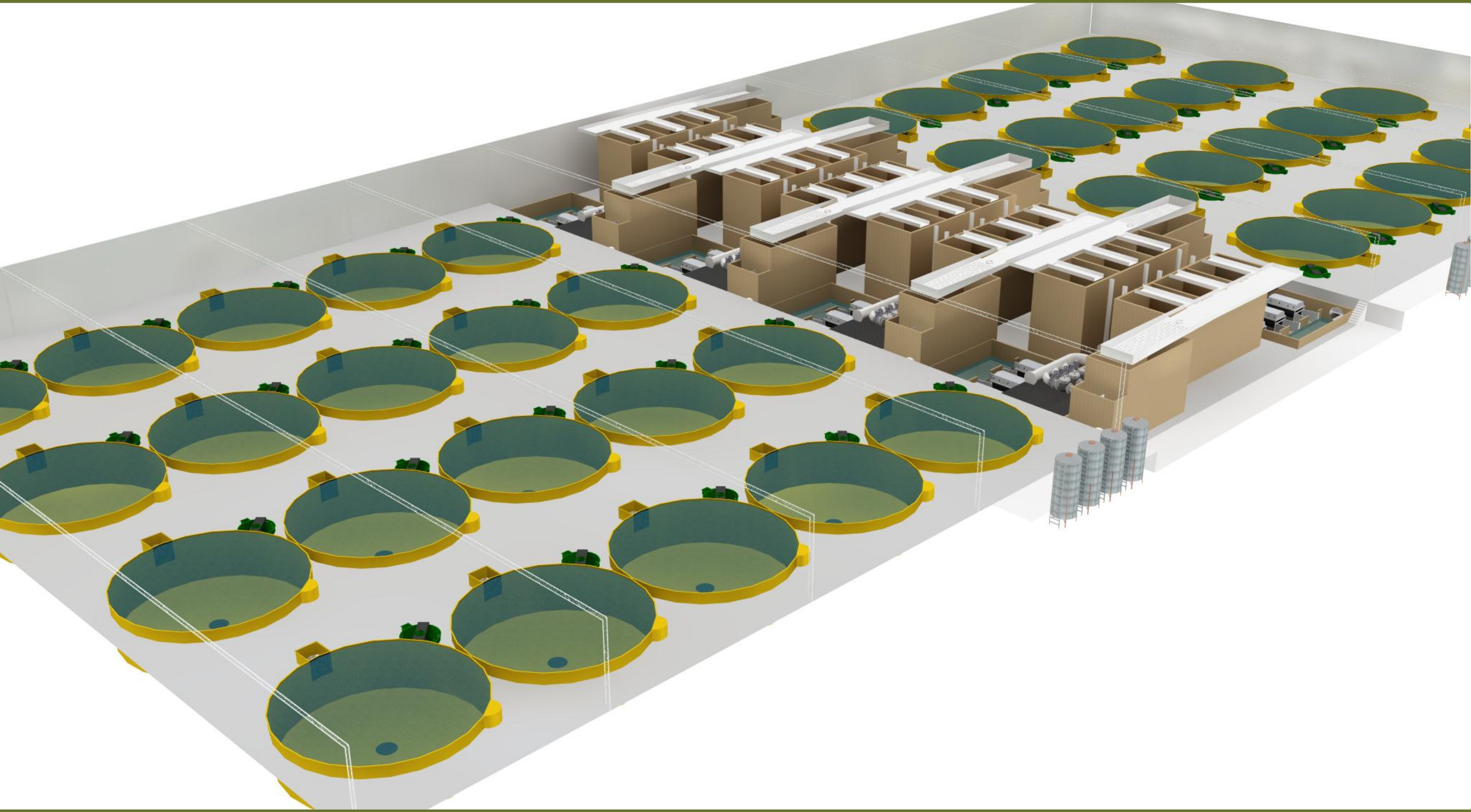
Pre-Growout Rearing



Pre-Growout Rearing

- Week 35 to Week 50 (105 g to 488 g)
- 15ºC Water Temperature
- Three RAS:
  - 4 Tanks: 10 m diameter by 3 m deep
  - 22 m^3 per minute recycle flow
  - Tank exchange rate of 43 minutes
  - Maximum density of 42 kg/m^3
  - 26% volume exchange per day
    - 73 mg/L Nitrate-Nitrogen

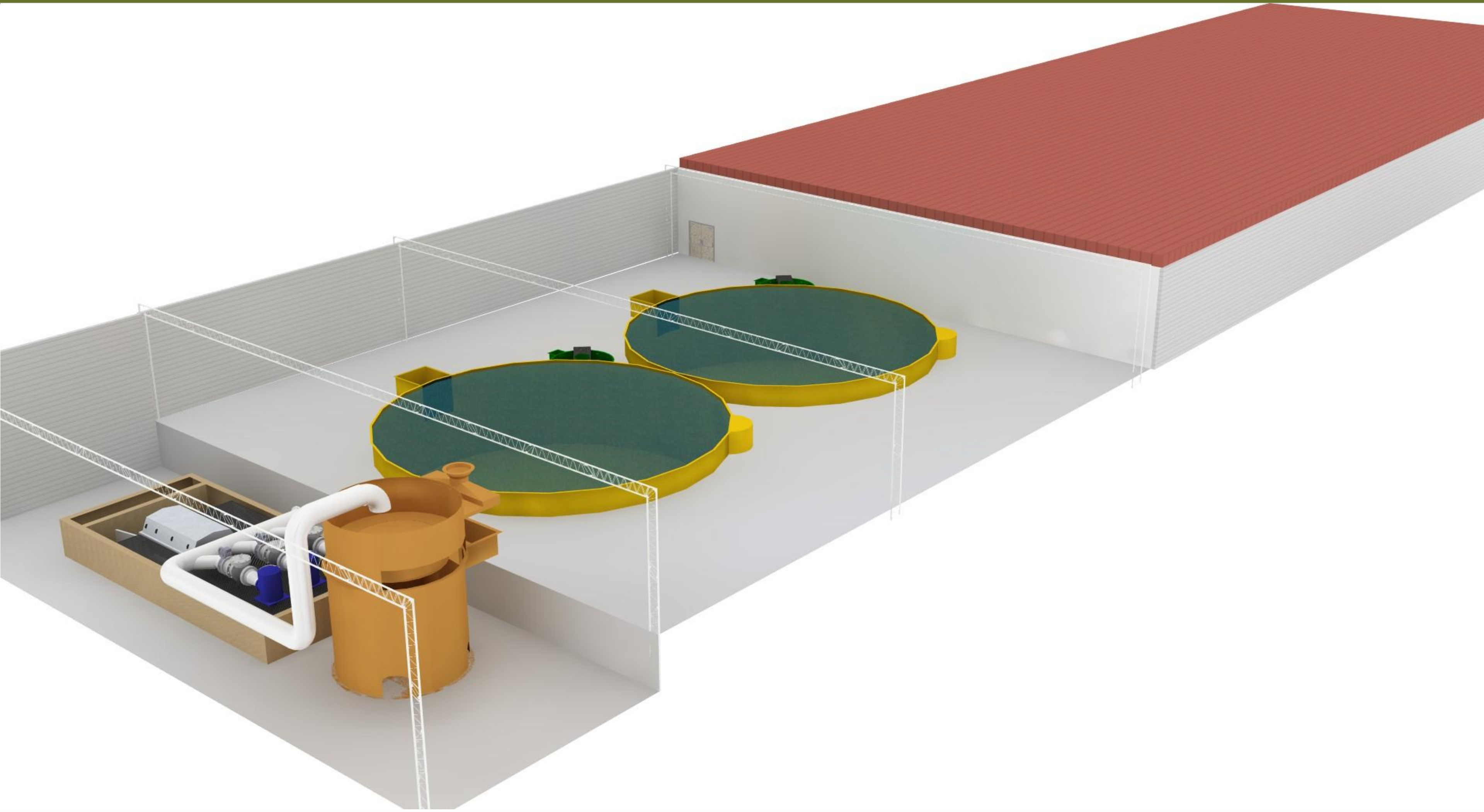
Growout Rearing



Growout Rearing

- Week 51 to Week 90 (488 g to 5000 g)
- 15ºC Water Temperature
- Eight RAS:
  - 5 Tanks: 16 m diameter by 4.25 m deep
  - 94.6 m^3 per minute recycle flow
  - Tank exchange rate of 45 minutes
  - Maximum density of 65 kg/m^3
  - 24% volume exchange per day
    - 75 mg/L Nitrate-Nitrogen

Purge & Processing



Purge & Processing

- Minimum 10-day depuration
- 14°C Water Temperature
- One Partial RAS:
  - – 2 Tanks: 16 m diameter by 4.25 m deep
  - – 37.9 m^3 per minute recycle flow
  - – Tank exchange rate of 45 minutes
  - – Maximum density of 75 kg/m^3
  - – 96% volume exchange per day
    - 0 mg/L Nitrate-Nitrogen

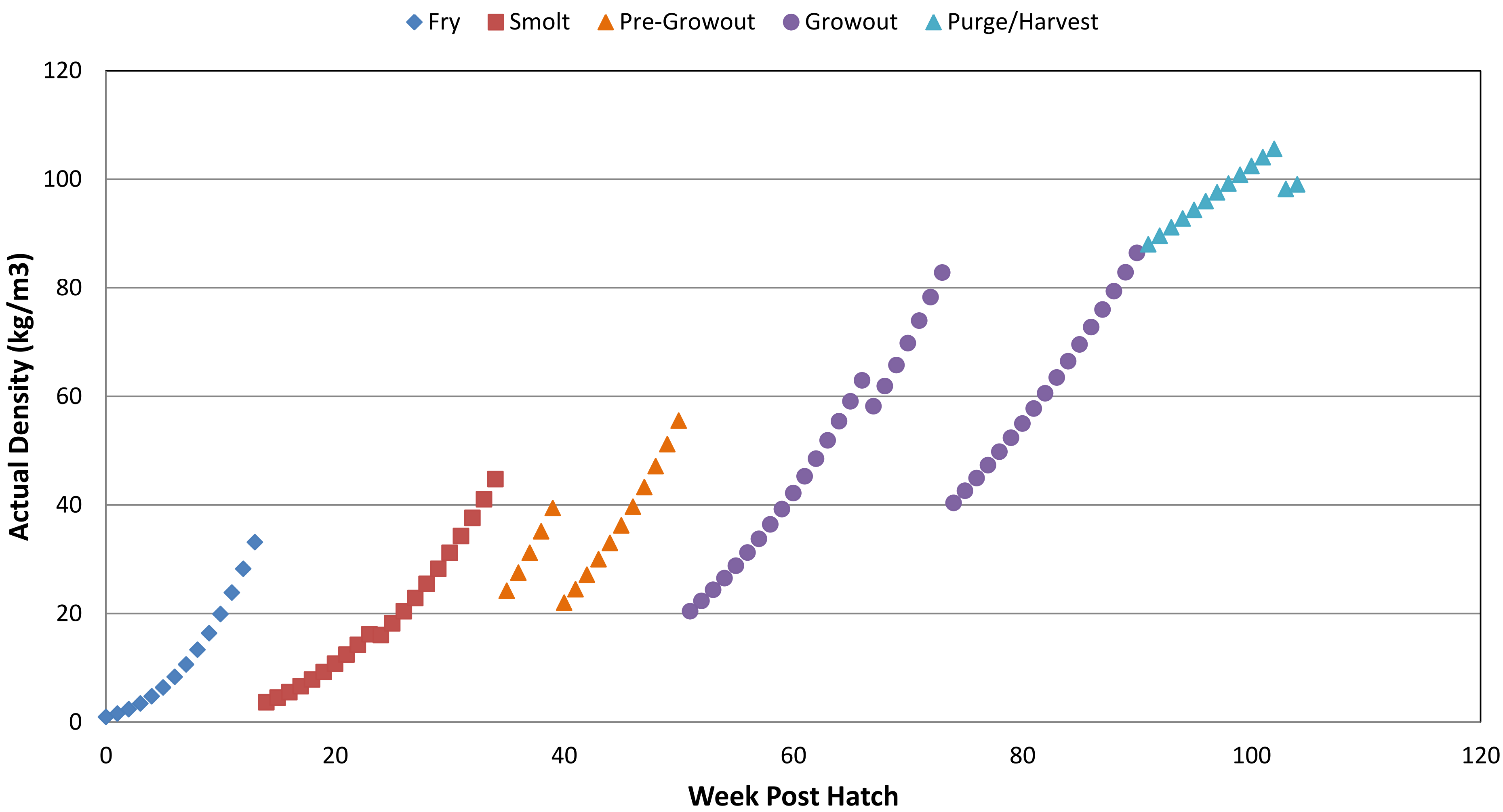
Totals

- RAS Culture Volume 39,791 m^3
  - *Fry Rearing* *57 m^3*
  - *Smolt Rearing* *1,018 m^3*
  - *Pre-Growout Rearing* *2,827 m^3*
  - *Growout Rearing* *34,180 m^3*
  - *Purge & Processing* *1,709 m^3*
- Buildings 28,191 m^2
  - *Fry, Smolt, Pre-Growout* *5,382 m^2*
  - *Growout* *21,320 m^2*
  - *Purge & Processing* *1,489 m^3*

Totals

- RAS Recirc Flow 233,800 gpm
  - *Fry Rearing* *400 gpm*
  - *Smolt Rearing* *6000 gpm*
  - *Pre-Growout Rearing* *17,400 gpm*
  - *Growout Rearing* *200,000 gpm*
  - *Purge & Processing* *10,000 gpm*
- Water Supply 2,015 gpm
  - *Fry, Smolt, Pre-Growout* *195 gpm*
  - *Growout* *1,520 gpm*
  - *Purge & Processing* *300 gpm*

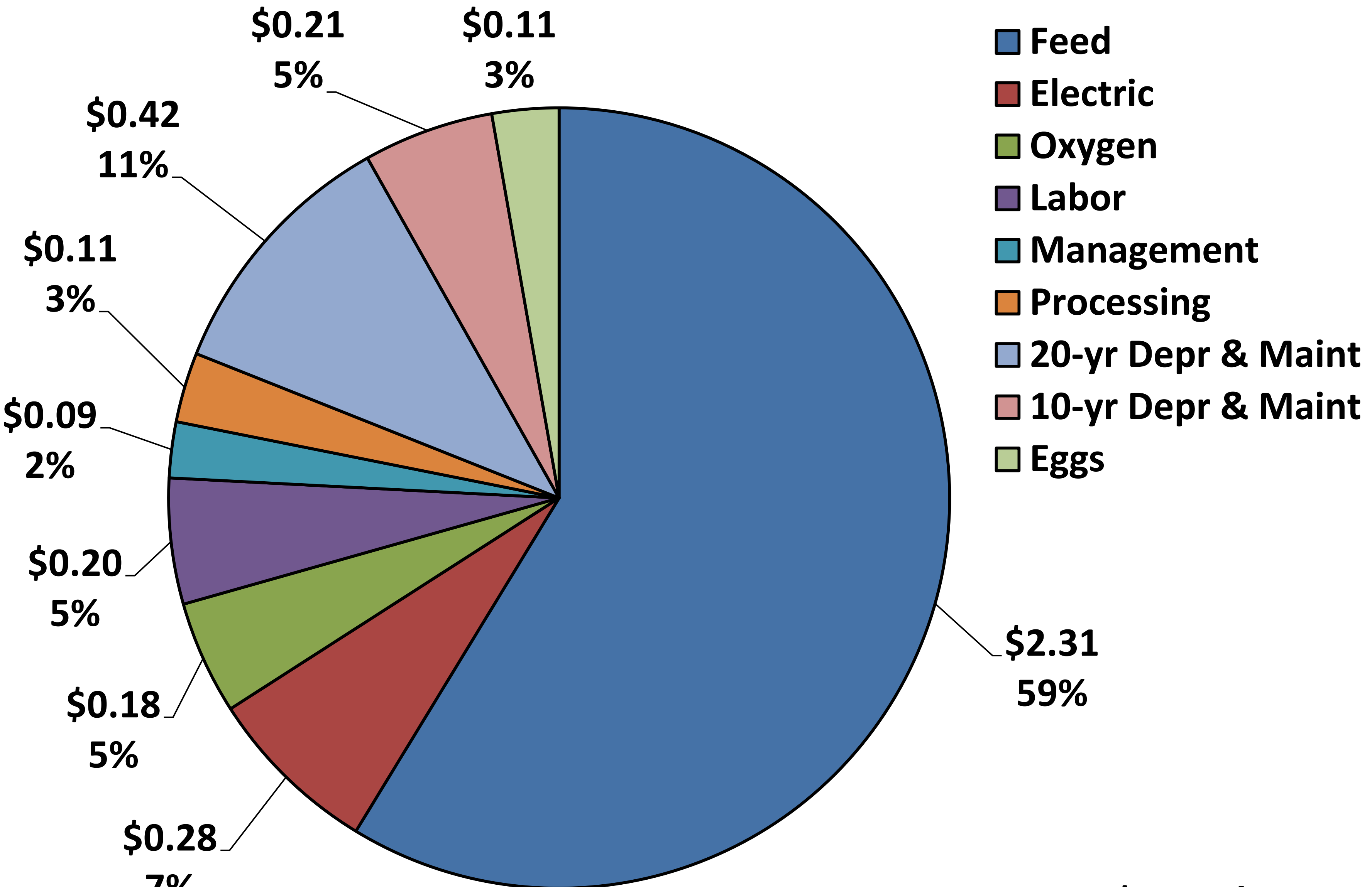
Revised Production-3,300 MT HOG



Cost Assumptions

- Feed: $1.50 per kg
- Electricity: $0.05 per kWh
- Oxygen: $0.20 per kg
- Labor & Processing: 25 FTEs
- Management Allowance: $300,000
- Eyed eggs at $0.30 per egg

Cost of Production



Cost of Production = $3.93/kg HOG

Energy & GHG Analysis

- Follows methods published by John Colt:
  - Colt et al. (2008). Energy and resource consumption of land-based Atlantic salmon smolt hatcheries in the Pacific Northwest
- Energy Analysis
  - Energy balance using densities from Tyedmers
- GHG Analysis
  - Factors based on Tyedmers

Energy Analysis

- Material Inputs
  - Feed
  - Pure Oxygen
  - Calcium Carbonate
- Energy Inputs
  - Electrical
  - Gas/Diesel/Natural Gas
- Fixed Capital
  - Concrete, Steel, Fiberglass, Plastic

Energy Analysis

- Direct Energy
  - Heat (ΔH) released when burned in a calorimeter
- Indirect Energy
  - Energy required to produce a component
- Transportation Energy
  - Energy required to transport material to/from

Energy Density

Component	Direct Energy	Indirect Energy	Transportation Energy
Feed	22.38 MJ/kg	48.08 MJ/kg	2.105 MJ/MT-km
Electricity	10.29 MJ/kWh	0.62 MJ/kWh	--
Steel	--	25 MJ/kg	--
Concrete	--	1 MJ/kg	--
Fiberglass	--	75 MJ/kg	--
Calcium Carbonate	--	0.046 MJ/kg	2.105 MJ/MT-km
LOX	--	0.240 MJ/kg	2.105 MJ/MT-km
Eggs	7.50 MJ/kg	--	--

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Inputs

Component	Units	Value
Eggs	kg/year	215
Feed	kg/year	5,072,047
Electricity	kWh/year	18,396,000
Steel in Concrete*	kg/20 year	337,676
Fiberglass/Plastic*	kg/20 year	704,700
Concrete*	kg/20 year	6,514,473
Calcium Carbonate	kg/year	760,807
Liquid Oxygen	kg/year	3,043,228
Steel in Building*	kg/20 year	801,060

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Energy Usage

Component	Direct Energy	Indirect Energy	Transport Energy	Total Energy
	MJ	MJ	MJ	MJ
Eggs	**1,612**	**--**	**--**	**1,612**
Feed	**113,512,412**	**243,864,020**	**7,665,131**	**365,041,563**
Electricity	**189,294,840**	**11,405,520**	**--**	**200,700,360**
Steel in Concrete*	**--**	**8,441,900**	**--**	**422,095**
Fiberglass/Plastic*	**--**	**52,852,500**	**--**	**2,642,625**
Concrete*	**--**	**6,514,473**	**--**	**325,724**
Calcium Carbonate	**--**	**34,997**	**153,303**	**188,300**
LOX	**--**	**730,375**	**1,226,421**	**1,956,796**
Steel in Building*	**--**	**20,026,500**	**--**	**1,001,325**

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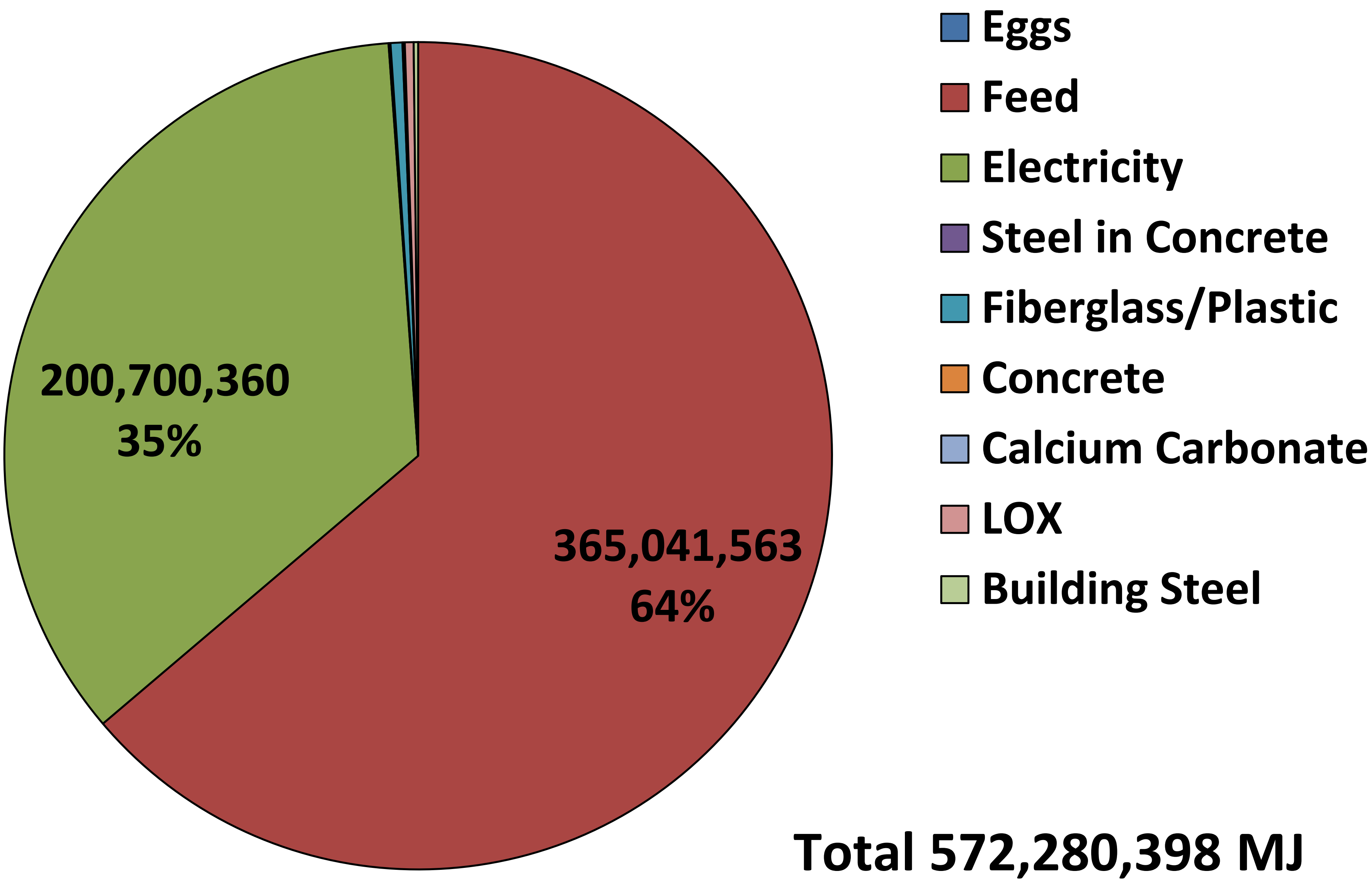
Energy Usage



Total 572,280,398 MJ

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Greenhouse Gas Assumptions

Component	Equivalent CO2 Production
Feed - Fish Respiration	450 g/kg
Feed – Manufacturing	3,300 g/kg
Electricity (90/10)	26.7 g/MJ
Steel	2500 g/kg
Fiberglass/Plastic	3000 g/kg
Concrete	150 g/kg
Calcium Carbonate	0.341 g/kg
Liquid Oxygen	1.78 g/kg
Gasoline	92.6 g/MJ
Natural Gas	57.9 g/MJ

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Greenhouse Gas Emissions

Component	Carbon Dioxide Equivalents
	MT/year
Feed – Fish Respiration	**2,282**
Feed – Manufacturing	**16,890**
Electricity	**5,359**
Steel in Concrete*	**42**
Fiberglass/Plastic*	**106**
Concrete*	**49**
Calcium Carbonate	**--**
LOX	**5**
Steel in Building*	**100**

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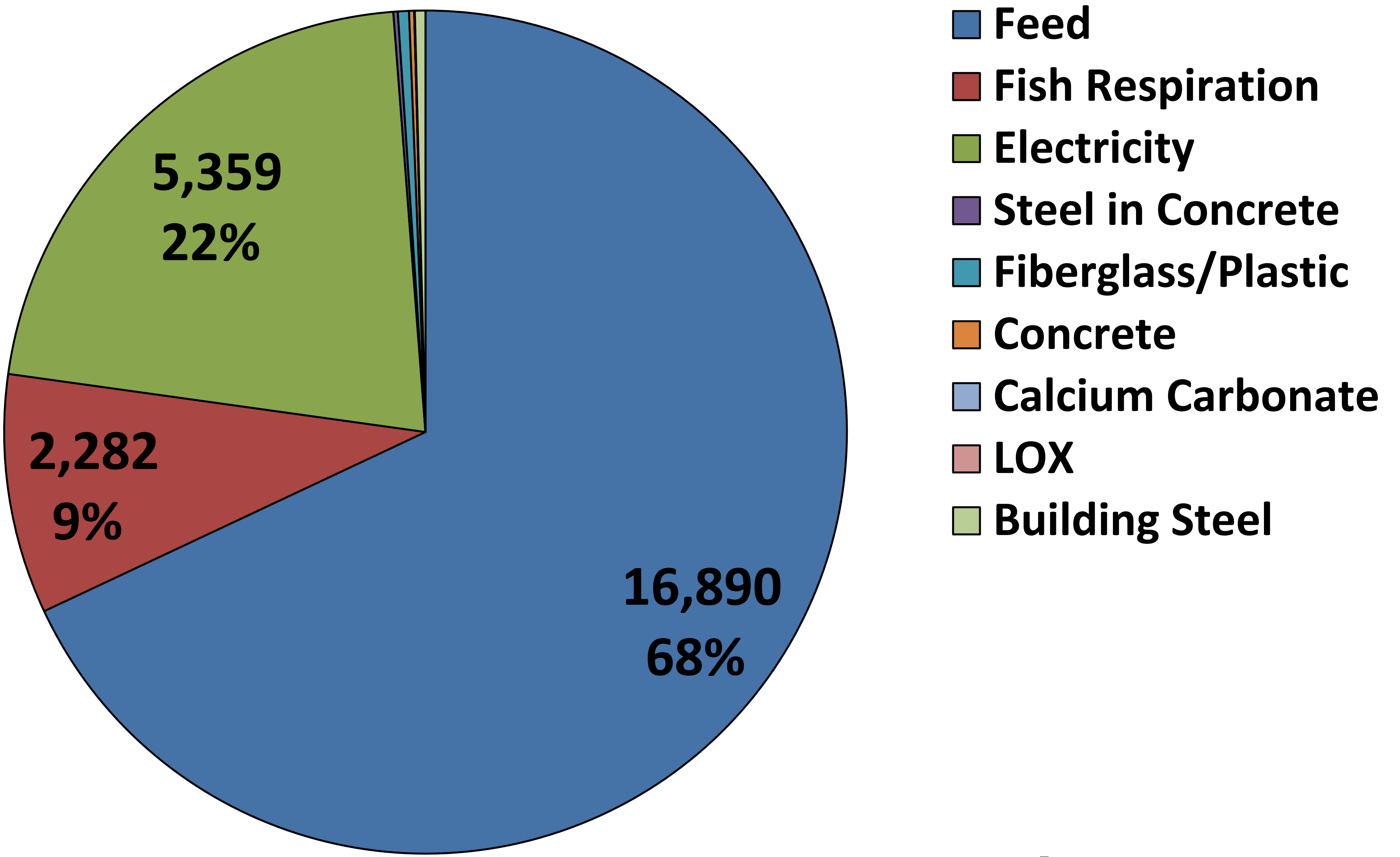
Greenhouse Gas Emissions



Total 24,834 MT

Energy Metric Comparison

Total Energy Consumption per kg of fish (whole, wet weight):

- This Study: 153 MJ/kg
- This Study (feed only) 97 MJ/kg
- Smolt in Recirc (Colt): 288 MJ/kg
- Salmon in Net Pens (Ayer): 27 MJ/kg
- Char in Recirc (Ayer): 233 MJ/kg

GHG Metric Comparison

Total GHG emissions per kg of fish (whole, wet weight):

- This Study: 6.6 kg/kg
- This Study (feed only) 4.5 kg/kg
- Smolt in Recirc (Colt): 11 kg/kg
- Salmon in Net Pens (Ayer): 2.1 kg/kg
- Char in Recirc (Ayer): 28 kg/kg

Thank You

- Thank You for Your Attention!
- Questions? Discussion?