PENTAIR

CO_2 REMOVAL

UPDATE ON CHALLENGES, EXPERIENCES, AND SOLUTIONS DEVELOPED FOR LAND BASED CLOSED CONTAINMENT AQUACULTURE SYSTEMS

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Shepardstown, W. Virginia

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Presentation Objectives

- **Review experiences and challenges related to CO_2 removal at the Kuterra Closed Containment facility**

- **Provide a summary of analysis performed, conclusions drawn, and solutions developed to improve carbon dioxide levels**

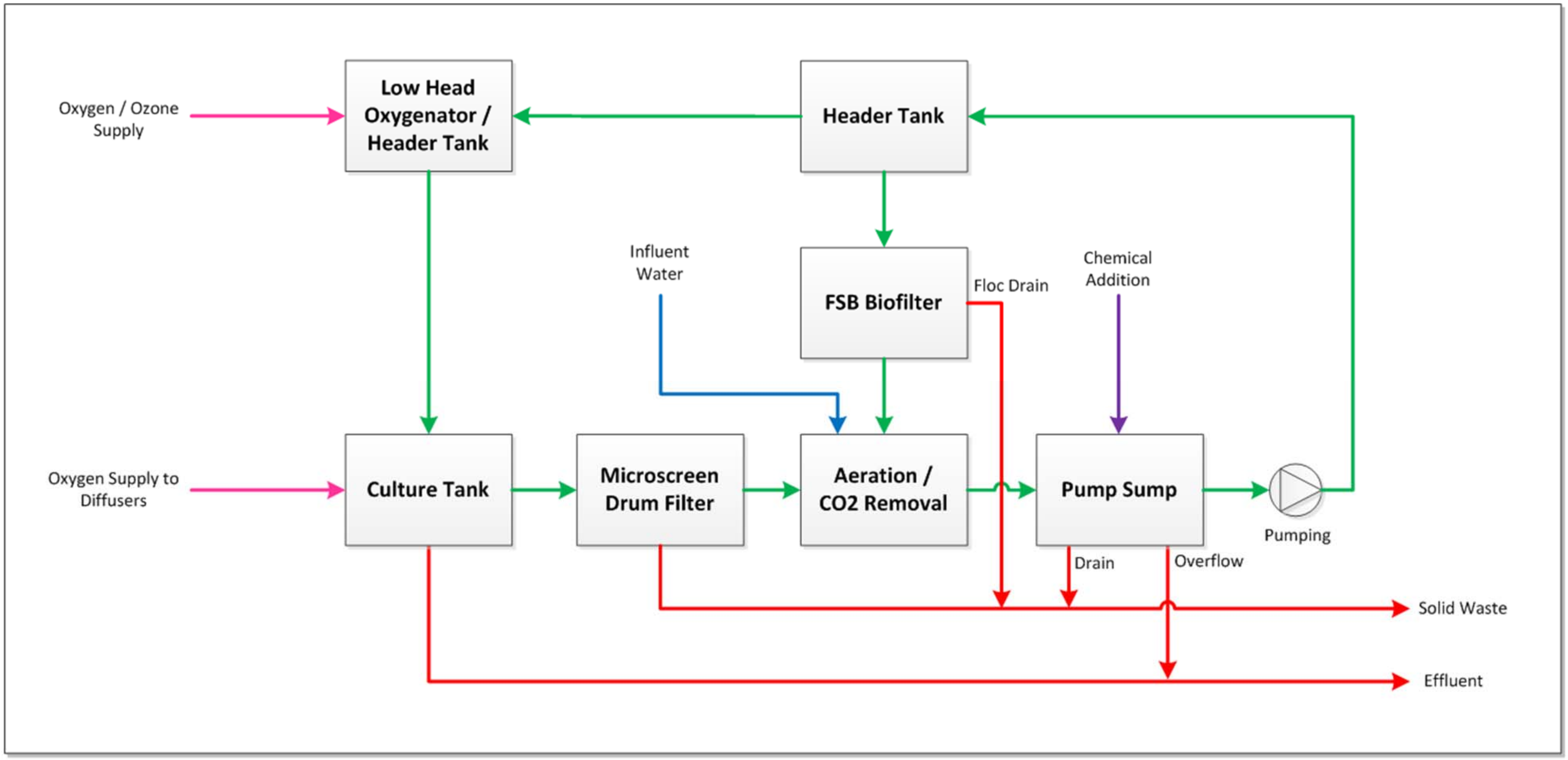
- **Comment on potential design methodology for CO2 removal in large-scale, land based closed containment projects in the future.**

Project Background: Kuterra Closed Containment

- **Located near Port McNeil on Vancouver Island, BC, Canada**
- **Target production of 390 mT/year of 6 kg Atlantic Salmon**
- **Smolt entry every 17 weeks**
- **Three modules:**
  - Quarantine (360 m3)
  - Growout (2500 m3)
  - Purge (360 m3)
- **RAS: 540 L/kg feed influent use**
- **Began production in 2013**

First land based Altantic Salmon grow-out in North America

Process Overview



Two process loops through a centralized, forced-air CO2 stripper

Design Criteria Overview (Grow-out Module)

- **Culture tank design criteria**
  - Target CO_2 concentration <12mg/L at tank outlet
  - Culture tank HRT = 45 min
  - Maximum density (per tank) = 50 kg/m3 with 1.5 safety factor
  - Oxygen consumption rate = 330 g O2 / kg feed
  - CO2 production rate = 1 kg CO2 / 1 kg O2
  - Feeding 24 hour/day

- **CO2 stripper design**
  - HLR = 35 gpm / ft2
  - G:L ratio = 10:1 maximum
  - Orifice plate with crown nozzles
  - No gas transfer media

Changing Operating Conditions

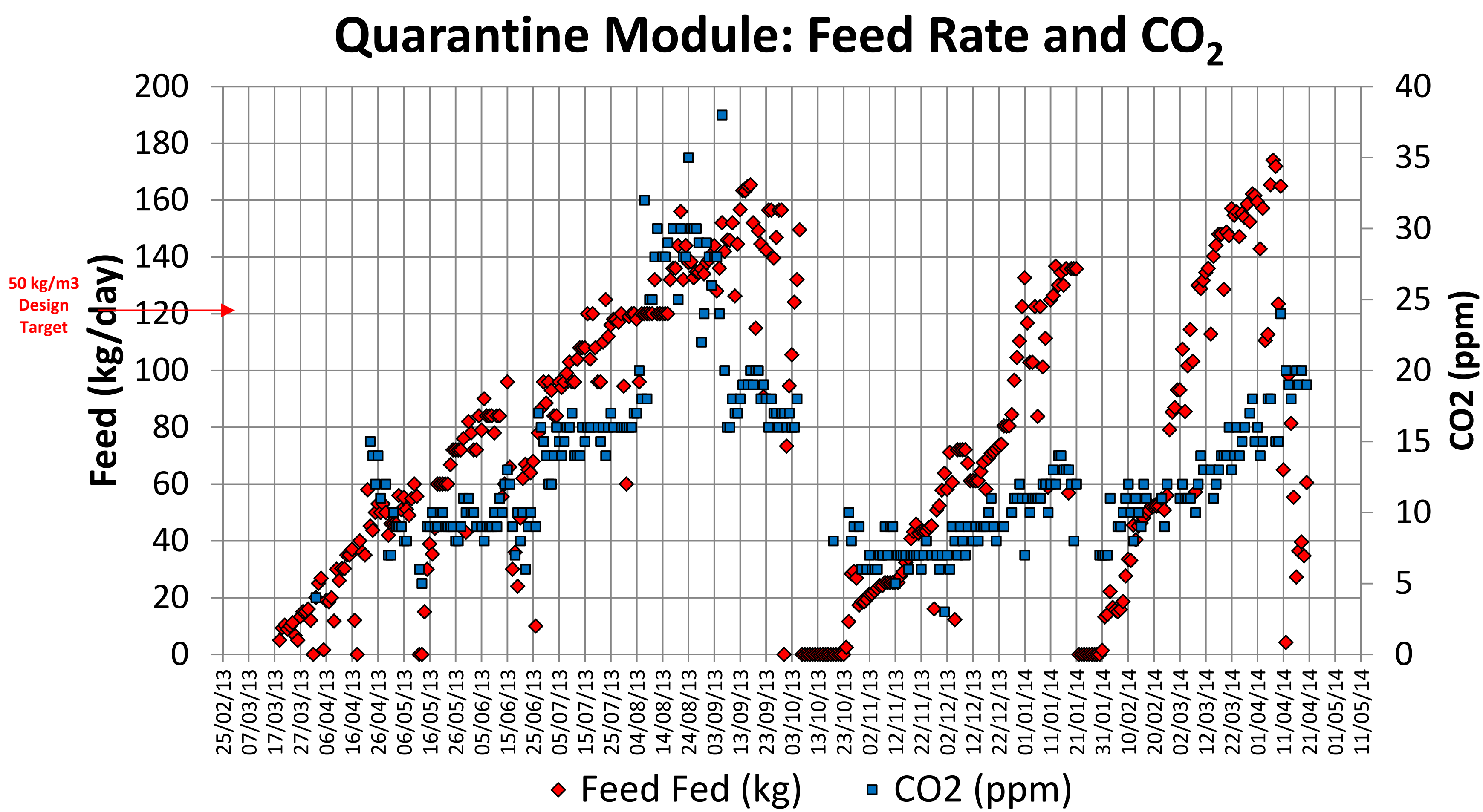
- **Increased maximum density**
  - Design = 50 kg/m3 (+1.5x safety factor)
  - New Target = 90 kg/m^3
- **Feeding over a shortened day**
  - Design = 24 hr feeding
  - Actual = 10-24 hr feeding (variable)
- **Alkalinity reduced**
  - Design = 100 mg/L as $CaCO_3$ minimum
  - Actual = 20-30 mg/L as $CaCO_3$
- **CO_2 concentration target relaxed**
  - Design = 12mg/L
  - New Target = 18 mg/L Grow-out, 17 mg/L Quarantine

Challenges Encountered

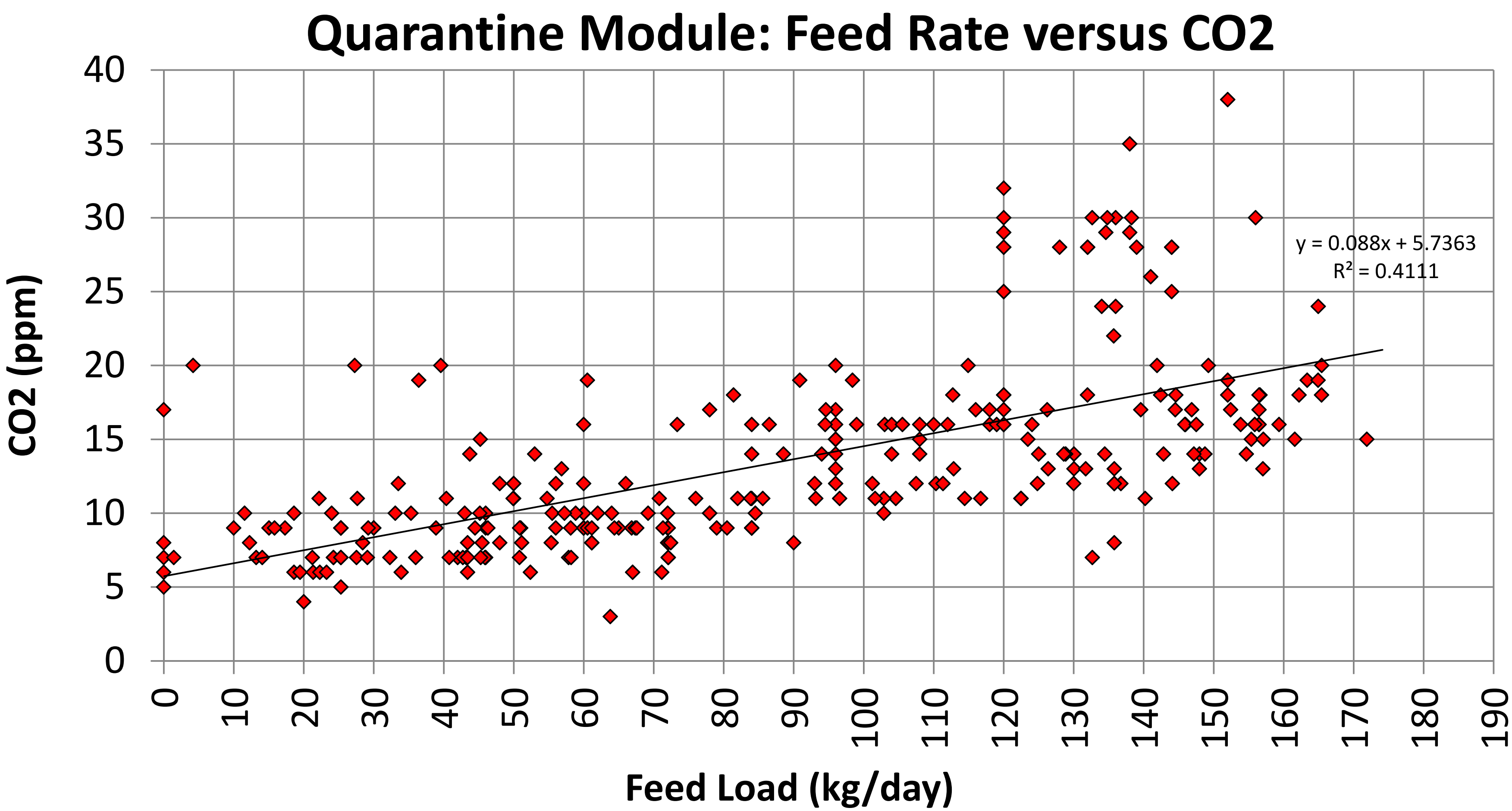
- **CO_2 concentrations consistently higher than 12 mg/L target despite lower than target design density and feed load**

- **Issue is exacerbated by the desire to increase production by 20% over the safety factor design value (80% over design value)**

Data Measurement and Validation



Data Measurement and Validation



Wide variation in CO2 readings due to measurement uncertainty

Root Cause Analysis: Potential Causes

- Measurement Issues
- Insufficient flow rate
- Reduced Stripping Efficiency
- Increased CO_2 Production Rate

Potential Cause: Increased CO_2 Production Rate

- **March 2014 data:**
  - 640 - 1000 g CO_2 / kg feed

- **Aug-Sept 2014 data:**
  - 550 g O2 consumed/kg feed
  - 0.87:1 kg CO2 produced per kg O2 consumed
  - therefore 480 g CO2/kg feed

- **High delta CO_2 across culture tank**
  - Requires very low CO_2 leaving treatment system to address most heavily loaded culture tank

Root Cause Analysis: Conclusions

- Accurate, real-time measurement of CO_2 is challenging
- Low flow rate to culture tanks due to high flow rate to biofilters
- Central CO_2 stripper efficiency requires media to maximize removal
- Oxygen consumption by the fish is much higher than assumed in design (68% higher)

Options Evaluated

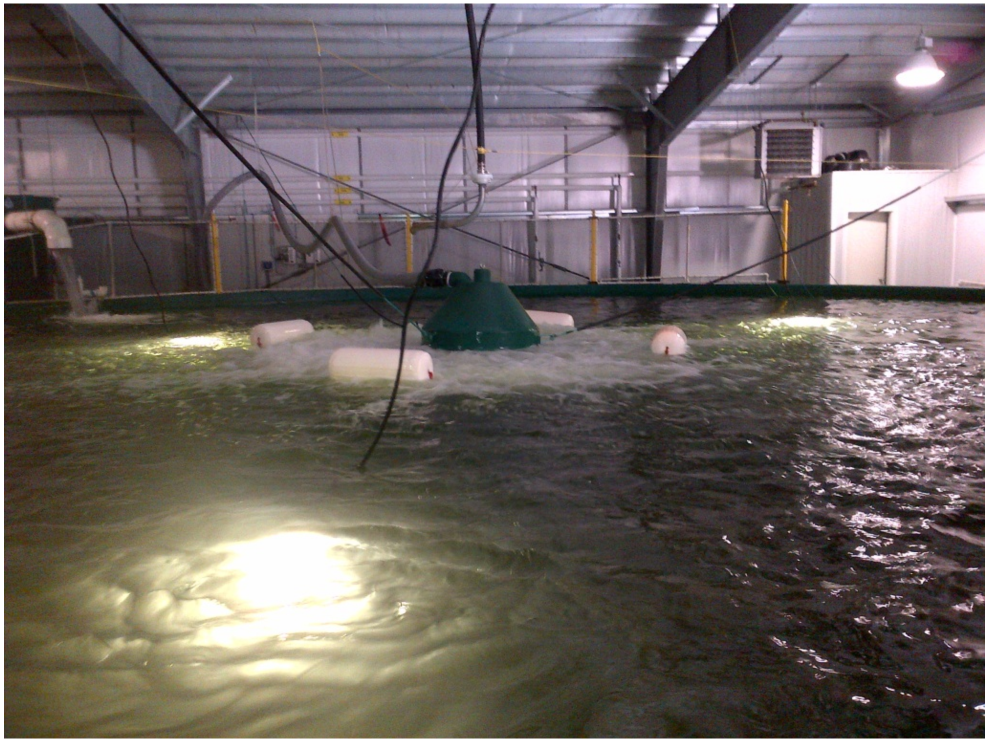
- **Flow Rate Increase (reduce delta CO_2 at tank): Rejected**
  - Limitations of existing piping
- **Centralized CO_2 treatment: Rejected**
  - 90 kg/m3 loading (351kg/d feed peak tank) (1323kg/d feed system)
    - 12.2mg/L across the peak tank requires 5.8mg/L CO_2 inlet condition
    - Requires 61.5% CO2 removal efficiency at central treatment (does not include FSB CO2 production)
  - Can't shut down flow to make modifications
- **Decentralized CO_2 treatment beside tank: Rejected**
  - large flow and footprint required
  - major tank modifications required (screened inlet / outlet)

Options Evaluation

- **In-tank aeration: Selected**
  - Advantages:
    - Strips CO_2 at source
    - More stripping on highest loaded tanks
    - Minimal infrastructure change
    - No additional footprint
  - Disadvantages:
    - Potential disruption to tank hydrodynamics
    - Potential for suspension and shearing of solid waste
    - Operational challenges

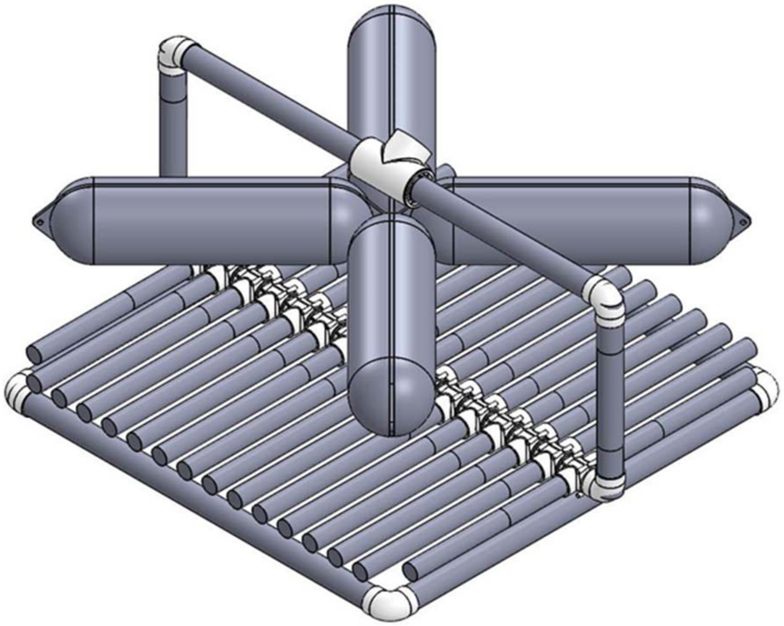
In-tank Aeration: Alpha Pilot

- Located in top 1/3 of tank depth
- Occupy <4% of tank volume
- Low rise velocity, minimal solids entrainment
- Central float design
- Minimized hard edges and flat surfaces
- 10 HP regenerative blower

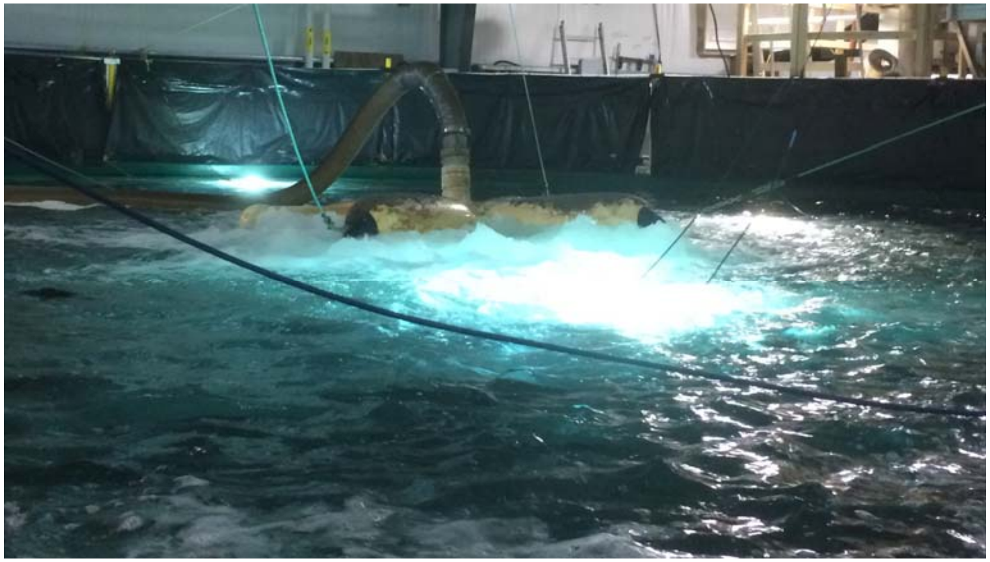


Central float made balancing difficult

In-tank Aeration: Beta Pilot



- Alternate float design to address balancing
- Increased number of diffusers in a square arrangement



Continued balancing issues; tank operability concerns

In-tank Aeration Pilot: Results

- **Effectively removes CO_2 (up to 5 mg/L delta achieved)**
- **CO_2 removal efficiency less than small scale testing suggested (approx. 50%)**
  - possible cause includes geometry, water impurities, salinity
- **No observable solids entrainment or increase in turbidity**
- **No observable negative reaction from fish**
- **No observable impact to tank hydrodynamics**
- **Scalable performance = flexibility**
- **Cumbersome for operators during fish handling**

In-tank aeration determined to be a viable solution

Implementation Phase

- **Decision was made to proceed with a full scale implementation on all Quarantine and Grow-out Tanks**

- **Product Design Considerations**
  - Fish friendly
  - Removable
  - Adjustable air flow
  - Adjustable deployment depth
  - Minimal above-water exposure
  - Minimal impact on water temperature

Improve user and fish friendliness

Implementation Phase: Process Air Supply

Redundant Air Supply

- Four 15 hp Regenerative Blowers, 2300 SCFM Air (@ 60" WG)
- Provides all of the air required for both Grow-out and Quarantine modules

Redundancy to mitigate mechanical risk

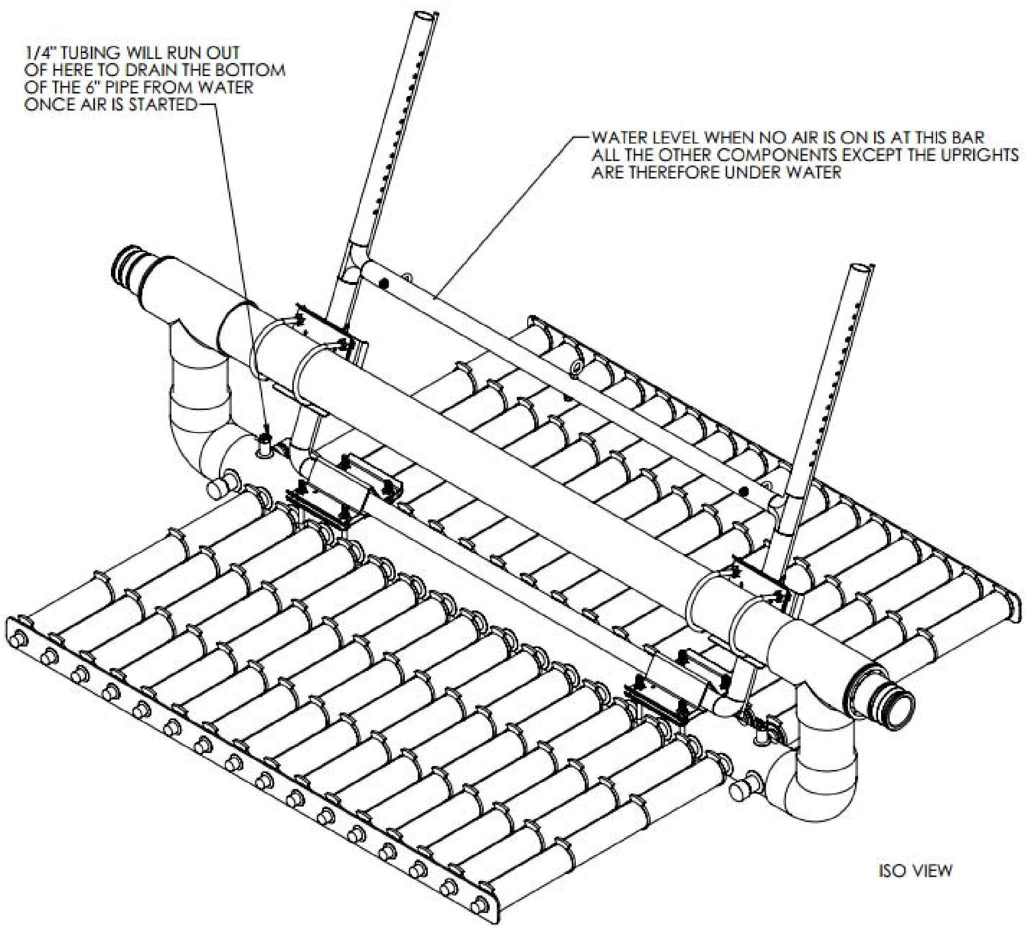
Implementation Phase: Air Temperature Control

Water cooled heat exchanger

- 60 deg C (140 F) In
- 18 deg C (65 F) Out
- 2300 SCFM (10,177 lb/hr) Air flow
- 27.4 gpm (13,678 lb/hr) Water flow

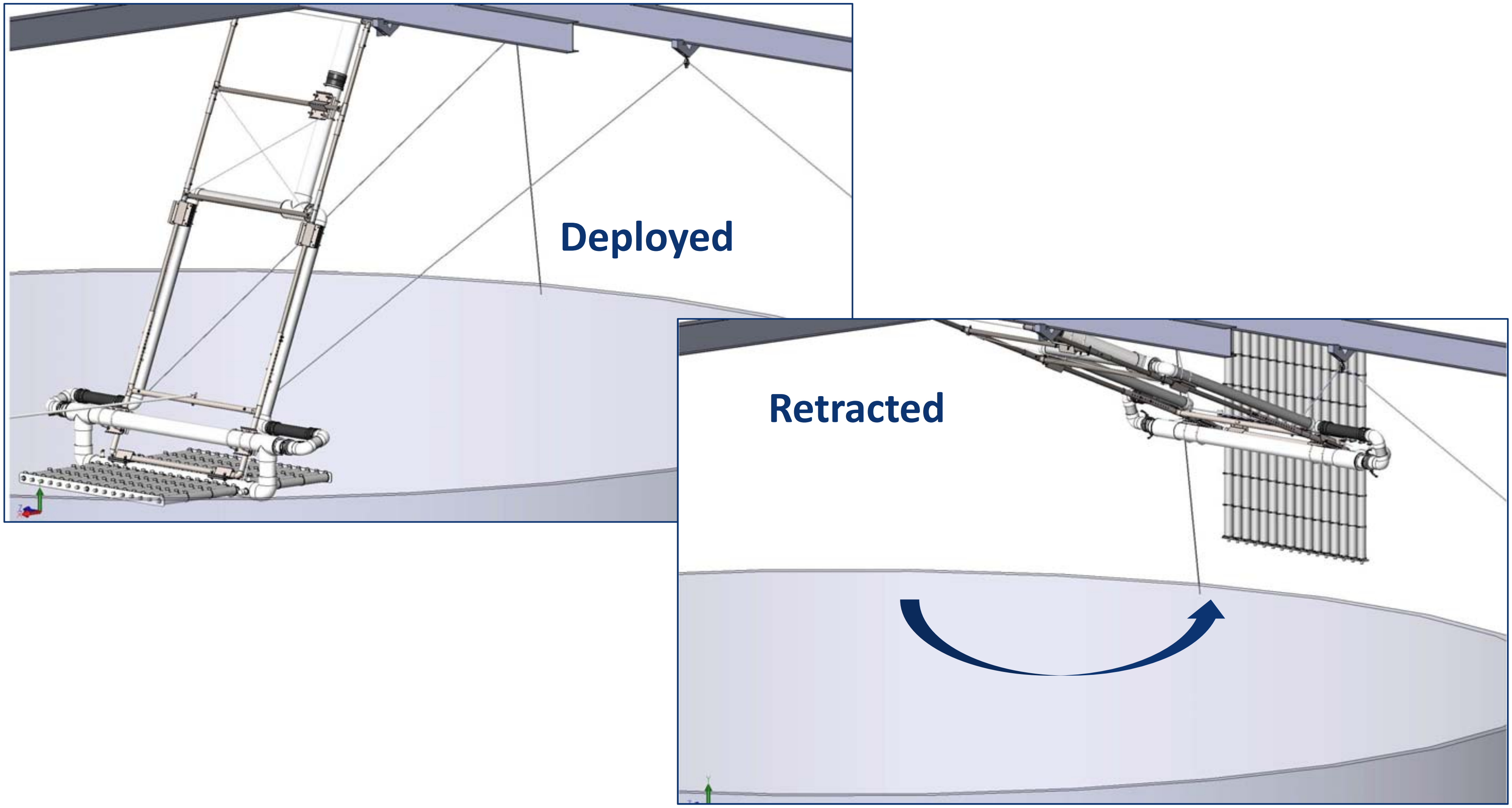
Prevents culture temperature gain due to air injection

Implementation Phase: In-Tank Aeration Device



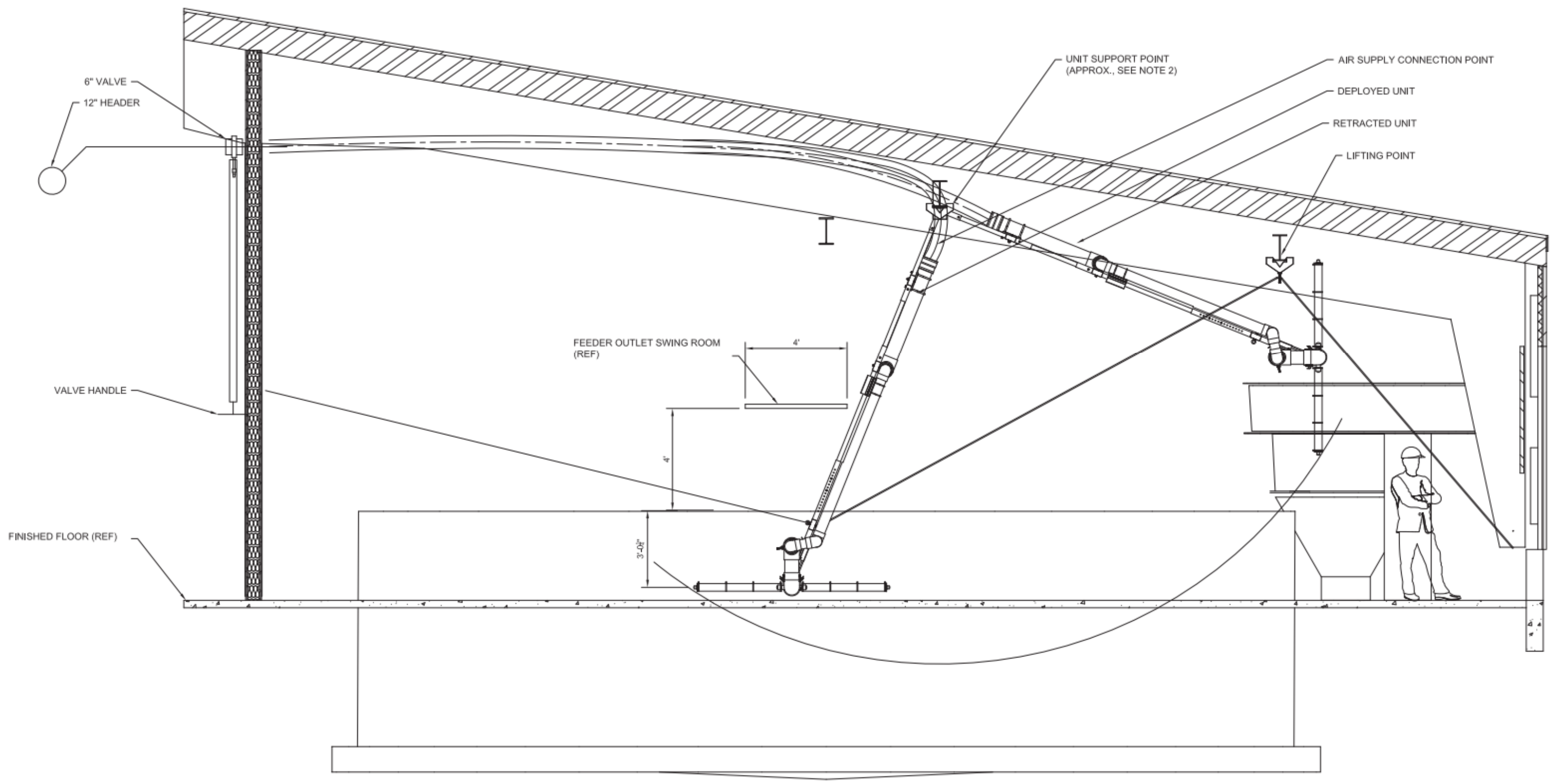
Scaled based on pilot performance

Implementation Phase: In-Tank Aeration Device



Device is suspended and retractable

Implementation Phase: In-Tank Aeration Device



Device is suspended and retractable

Aeration Device Deployed

Aggressive shallow aeration at tank center

Aeration Device Retracted

Retracted during fish handling or for maintenance

Performance Metrics (CO_2)

Description	***Units***	***No Aeration***	***In-Tank Aeration***	***Change***
System				
Feed Load (to culture field)	kg/d	743	1200	62%
Flow Rate (to culture field)	lpm	46500	56850	22%
Peak Tank				
Feed Load (to peak tank)	kg/d	294	415	41%
Flow Rate (to peak tank)	lpm	10620	11370	7%
CO2 conc. (side drain)	mg/L CO2	18	18	0%
CO2 conc. (bottom drain)	mg/L CO2	21	20	-5%
CO2 Conc. Weighted Average	mg/L CO2	18.9	18.6	-2%

- **Flow to culture tanks was increased; flow to FSB Biofilter reduced**
- **Flow balanced between all culture tanks**

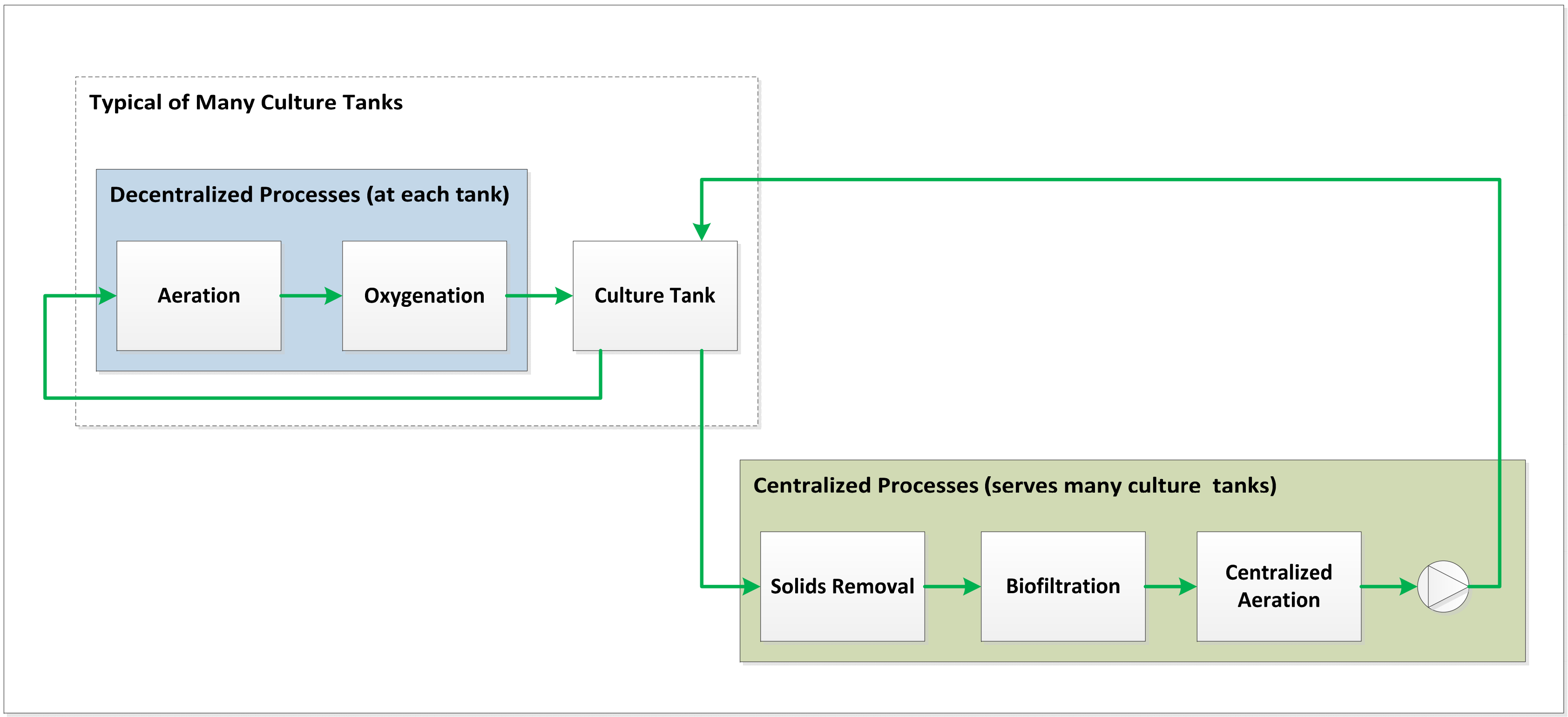
Similar outlet conditions despite 62% increase in feed load

Impacts to Future Design Methodology

- **Centralized treatment strategy:**
  - System flow rates (for all processes) are driven by the needs of one limiting water quality criteria
  - At high density culture, and at low CO_2 design concentrations, CO_2 is likely to be the limiting factor setting tank HRT

- **Combination of centralized and decentralized treatment makes sense:**
  - Allows for peaks to be dealt with at highest loaded tank
  - Allows “right-sizing” of flows for other treatment processes
  - Reduces flows that need to be conveyed to centralized treatment
  - Longer actual tank HRT with shorter effective HRT
  - Redundancy of process

Impacts to Future Design Methodology



Combination of centralized and decentralized treatment

Future Work Required

- **Improve understanding of the factors impacting oxygen consumption and CO_2 production rates**
  - Quantify impacts of swim speed, lighting, stress, and feed composition & loads
- **Determine optimal design limits for CO_2**
  - Balance between production optimization and cost
- **Continue to develop distributed treatment solutions for carbon dioxide removal**
  - Develop designs to mitigate impacts to tank operation
  - Performance testing proceeding at Kuterra facility

Questions?

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