Challenging the Status Quo – Innovations in RAS Design

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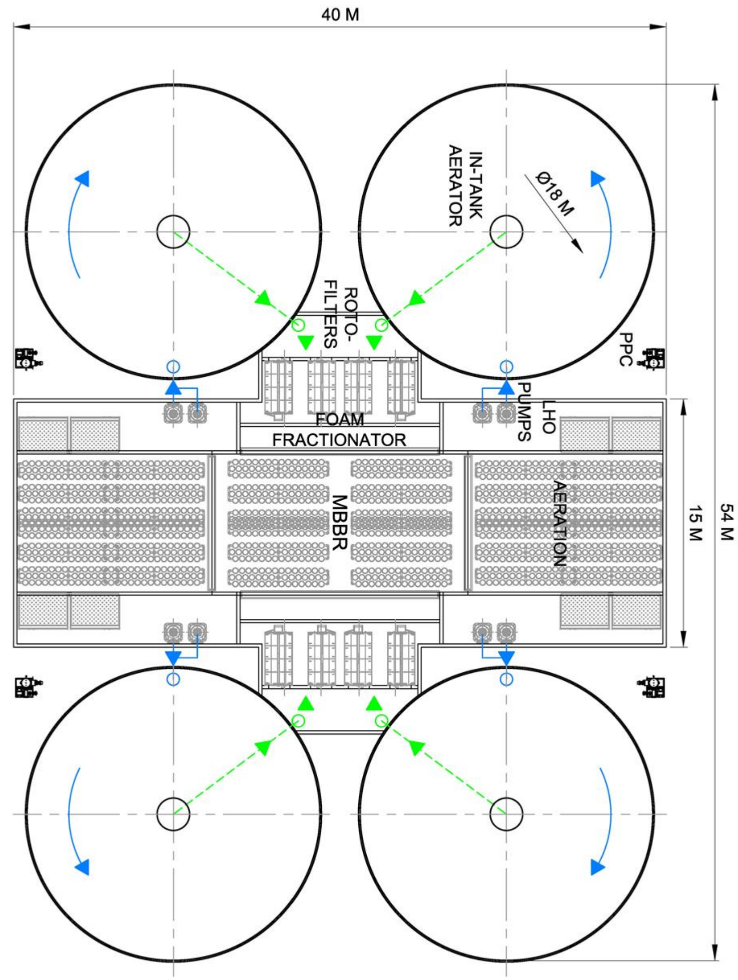
Revision A

Challenges

- Large systems (2000 - 4000 m3)
- Large fish culture tanks (500 – 1200 m3)
- Large flows (50k – 120k lpm)
- Large scale treatments
- Increasingly stringent water quality
- Brackish and saltwater culture conditions
- Minimize energy consumption while accommodating tighter temperature controls



Scale presents design opportunities!

RAS Processes

Design Criteria for Cold Water RAS

- Salinity: 0-15 ppt
- Temp: 10 – 15 deg C
- DCO_2 < 10 mg/L – 15 mg/L
- DN <100% Sat
- DO >90+% Sat, controlled per tank
- Large flow rates
- Minimize footprint and operating cost

Need processes that are scalable and flexible

Biofiltration

Bio-filtration Strategy

- Moving Bed Technology is used because:
  - Less dependent on flow rate
  - More scalable than other technologies
  - DO and CO2 neutral
- Sizing is critical
  - Understanding of impacts of salinity, temperature, dissolved oxygen, film thickness and bacterial species.
  - Control of heterotropic bacteria through effective organic carbon removal to optimize growth of autotrophic bacteria and limit oxygen requirements.
- Deep vessels are employed (>3m)
  - minimize footprint
  - maximize media movement with minimal air
  - deep injection of compressed air can result in unsafe Total Dissolved Gas Pressure

Method of integration is critical to success

Bio-filtration - Impacts of Salinity

For Post Smolt or Brackish Systems

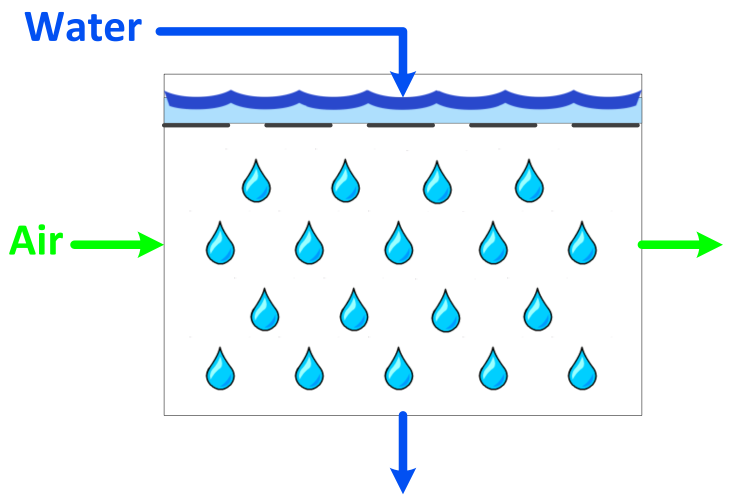
- Nitrification reaction constant at 35 ppt salinity is approximately 50% of that for freshwater.
- Biofiltration treatment process at 15 ppt will be approximately 26% larger than in freshwater
- Less available oxygen to the bioreactor due to lower solubility
  - Oxygen limited nitrification reaction can drive further increase in bioreactor size or increase aeration/oxygenation requirements

Treatments will be larger and/or flows will be larger

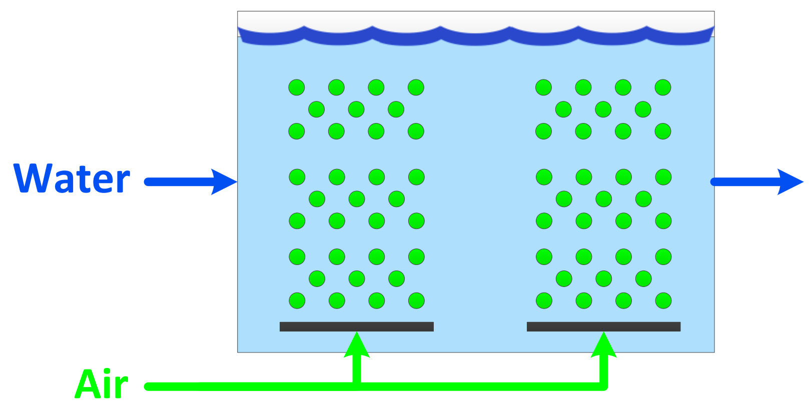
CO_2 Removal

Aeration Technology Comparison

Aeration Column



Diffused Aeration Basin



Aeration Column		Parameter		Diffused Aeration Basin
5 seconds	←	HRT	→	**5 minutes**
10:1	←	G:L Ratio	→	**3:1**
1 mBar (0.5 in WC)	←	Air Pressure	→	**180 mBar (6 ft WC)**
1.2-1.5 m (4-5 ft)	←	Water Head	→	**0 m (0 ft)**
40% per pass	←	Efficiency	→	**>65% per pass**

Process integration dictates technology selection

Aeration Strategy

Diffused Aeration Basin

- Air injection with membrane diffusers
- High efficiency due to high bubble contact time
- Gas: Liquid Ratio = 3:1 to 6:1
- 1.5 M Air injection depth
- >60% removal efficiency

Advantages

- Balances gases after bio-filtration
- Able to **turn down** during low biomass to conserve energy
- **Scalable** to meet specific performance independent of flow

Adaptable and scalable treatment

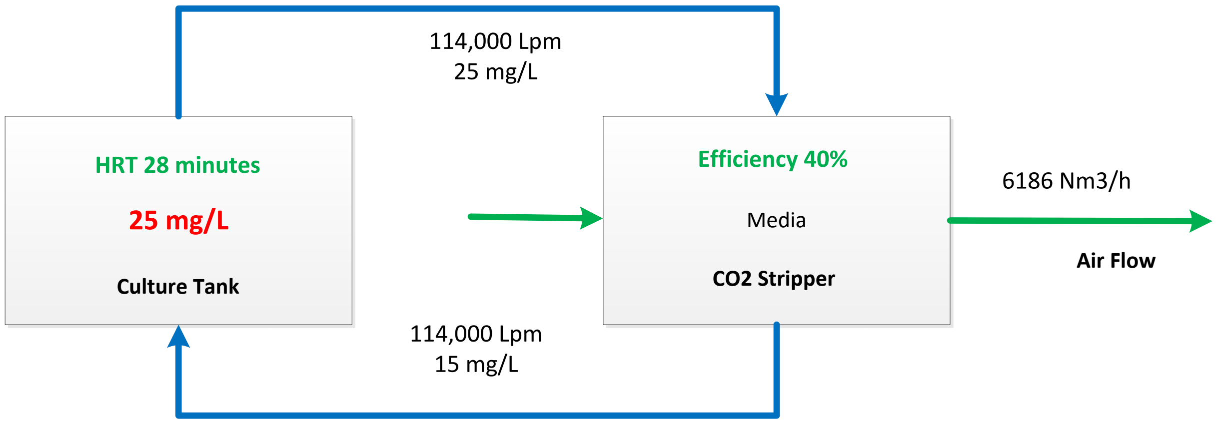
CO_2 Removal Performance

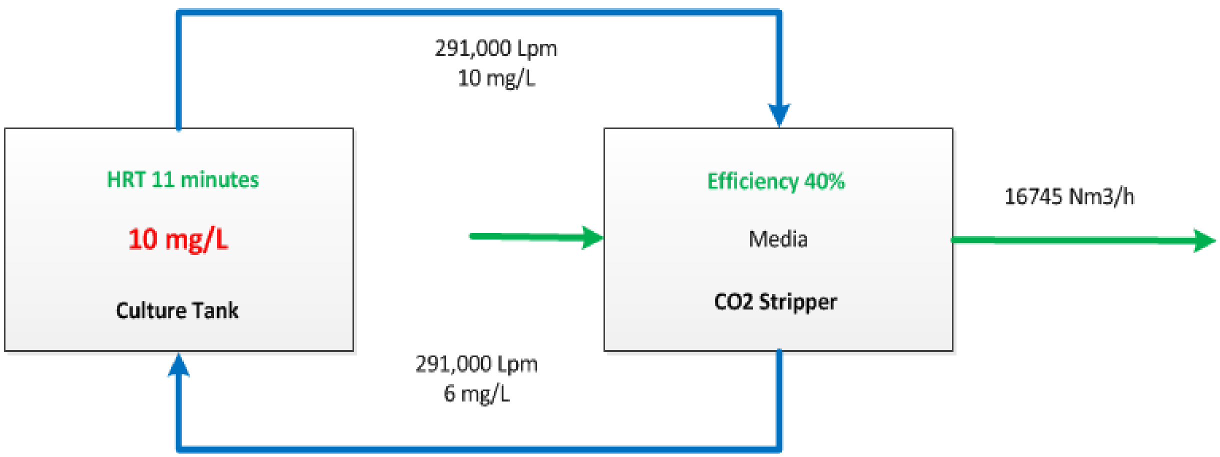
- **CO_2 removal is the key driver of flow in a RAS**

- **As systems get larger, we need scalable technologies that can be tuned to meet specific target concentrations**

- **Scenario Explored**
  - Post smolt production
  - 15°C
  - Peak stocking density of 75kg/m3 prior to ship out
  - 1kg feed/day/m3 volume
  - 500 g/kg feed oxygen consumption (high estimate)

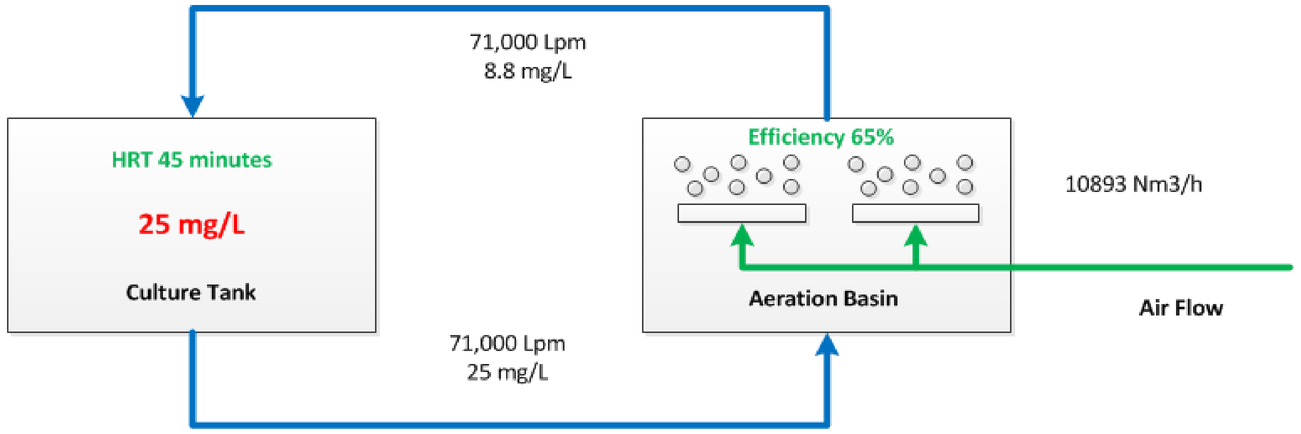
CO_2 Removal with Forced Air CO_2 Stripper

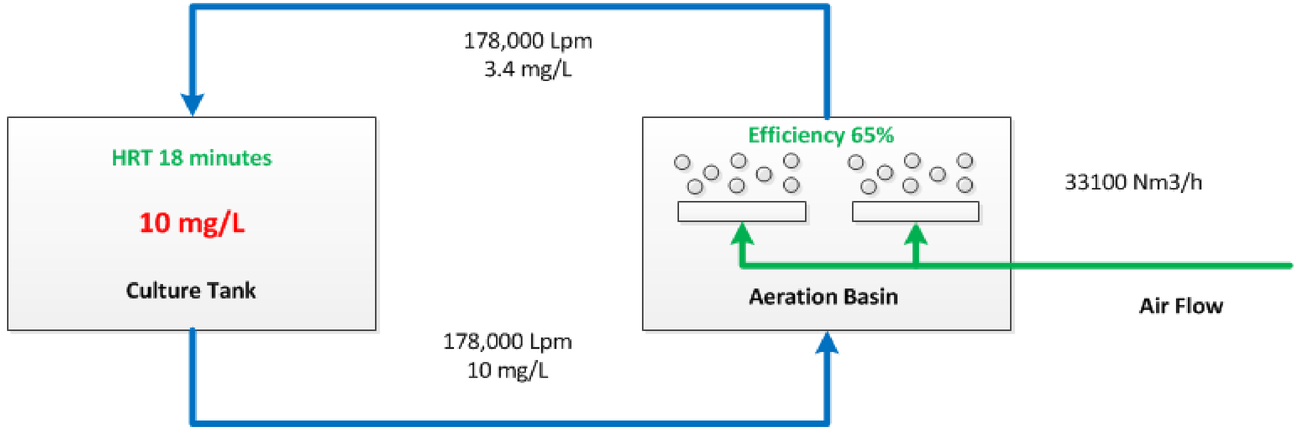




Extreme flow rates required using "conventional" equipment

CO_2 Removal with Aeration Basin





Water flow rates reduced using aeration basin; High air flow rates

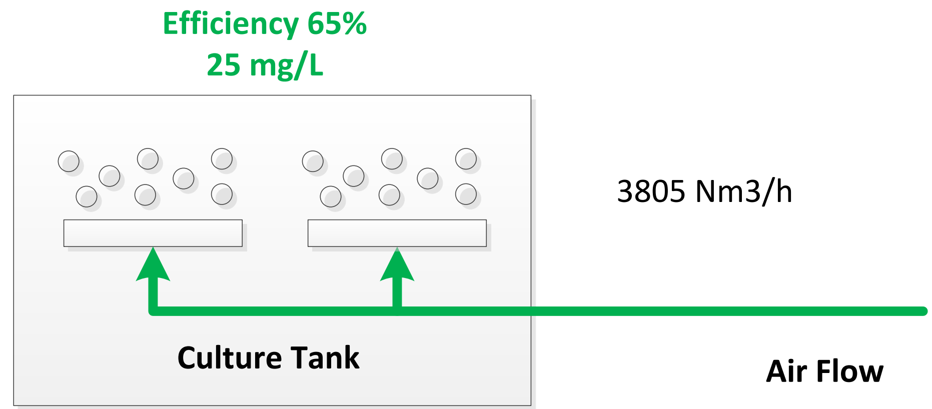
CO_2 Removal – In Tank Aeration

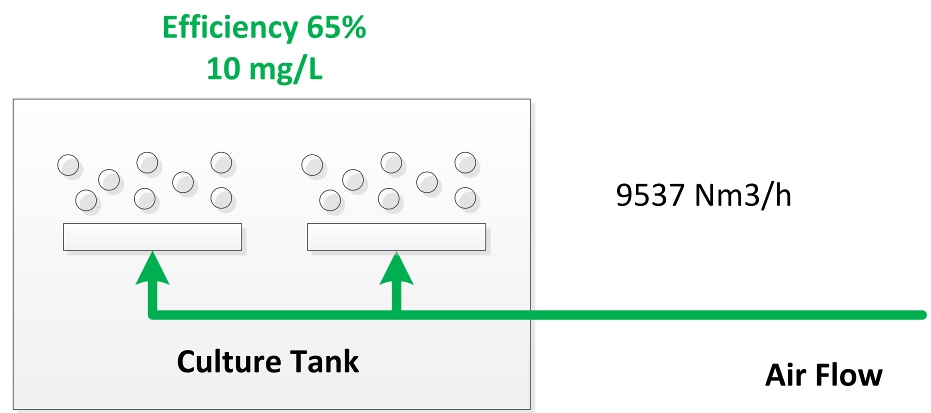
Treatment at the source

Independent of system flow

Maximum stripping efficiency due to culture tank concentration

Presents challenges for fish culture





High concentration delivers high efficiency

CO_2 Removal Technology Comparison

Parameter	Units	CO_2 Stripper with media	Aeration Basin	In-Tank Aeration
Target Concentration	mg/L	25	25	25
Water Flow Required	Lpm	114,286	71,111	0
Air Flow Required	m3/h	6,186	10,893	3,803
Target Concentration	mg/L	10	10	10
Water Flow Required	Lpm	290,909	177,778	0
Air Flow Required	m3/h	16,745	33,099	9,537

- Reduced target criteria drives increased flow rates
- CO_2 strippers require high water flow rates as CO_2 stripped per pass is low
- Aeration Basins can strip large amounts of CO_2 per pass which allows for reduced flow rates. Air can be increased independently to achieve low targets.
- In-Tank treatments operate at high efficiency and require no water flow, but place treatment equipment in the tank with the fish.

As scale increases and allowable concentration drops, impetus to treat in tank increases

Oxygenation

Oxygenation Strategy

Transition from Centralized O2 Over-supply to Multi-sourced Oxygenation designed to only supply oxygen where needed/as needed

Historical Approach

- **Common Oxygenation Equipment for all Supply to Culture tanks**
  - Usually LHO (diffuser backup)
  - Usually with Ozone
  - Distribute water flow between high demand tanks and low demand tanks

Current Approach

- **Multiple Oxygen Sources with Specific Purposes**
  - LHO, PPC, In-tank Diffusers
  - Baseline oxygen with LHO
  - Supplementary O2 on demand using PPC

Easier management, more turndown, reduced energy use

Oxygenation Strategy

Low Head Oxygenator (LHO)

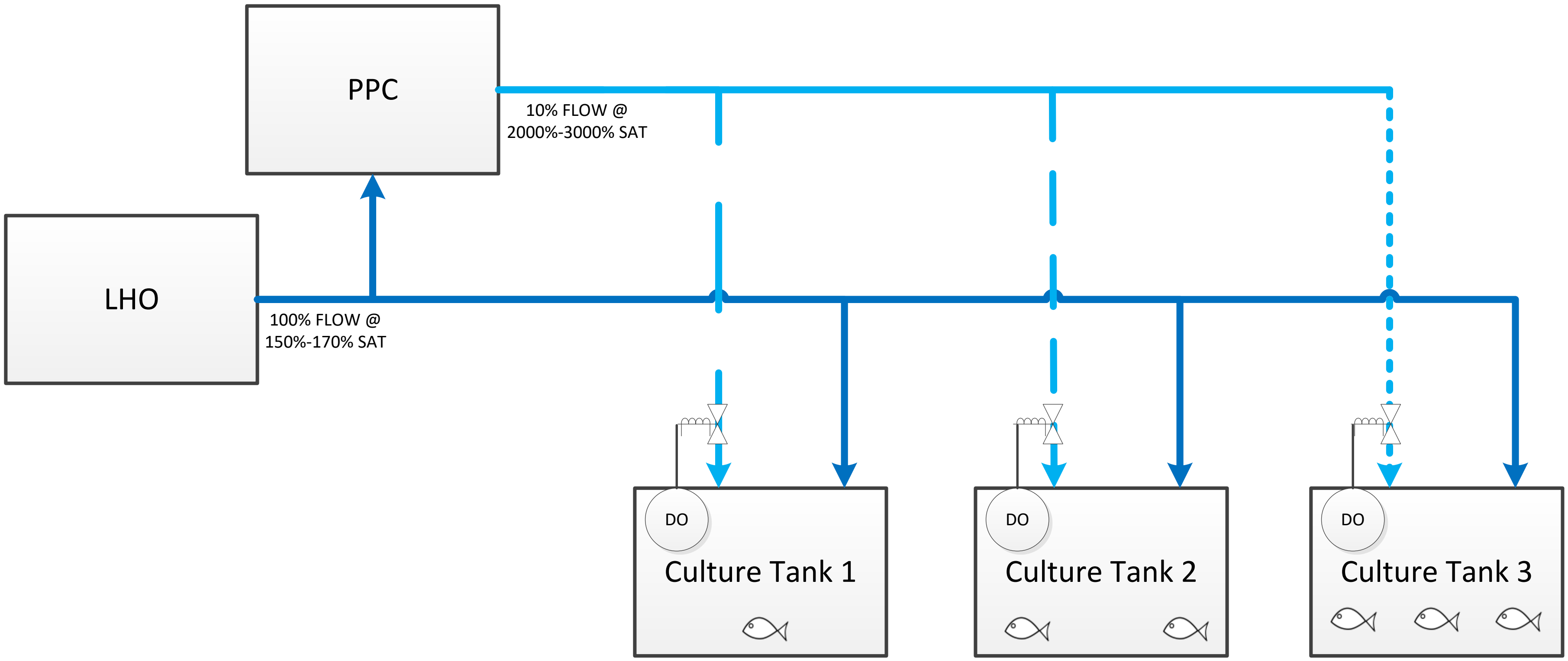
- Used to set **baseline oxygen concentration** and for ozone injection
- Reduces dissolved N2 after aeration basin
- May be used with generated oxygen
- Low capital and energy cost
- Oxygen Absorption Efficiency: 70-80%
- Head required = 0.61 M

Pressurized Packed Column (PPC)

- Used to **supplement oxygen on a tank-by-tank basis**
- High pressure allows for high DO in a small flow; allows for small distribution plumbing
- Automated valves at each culture tank operate based on DO
- Oxygen Absorption Efficiency: 98% +
- Pressure = 30-70 psi

Blend of low pressure and high pressure technologies

Oxygenation Strategy

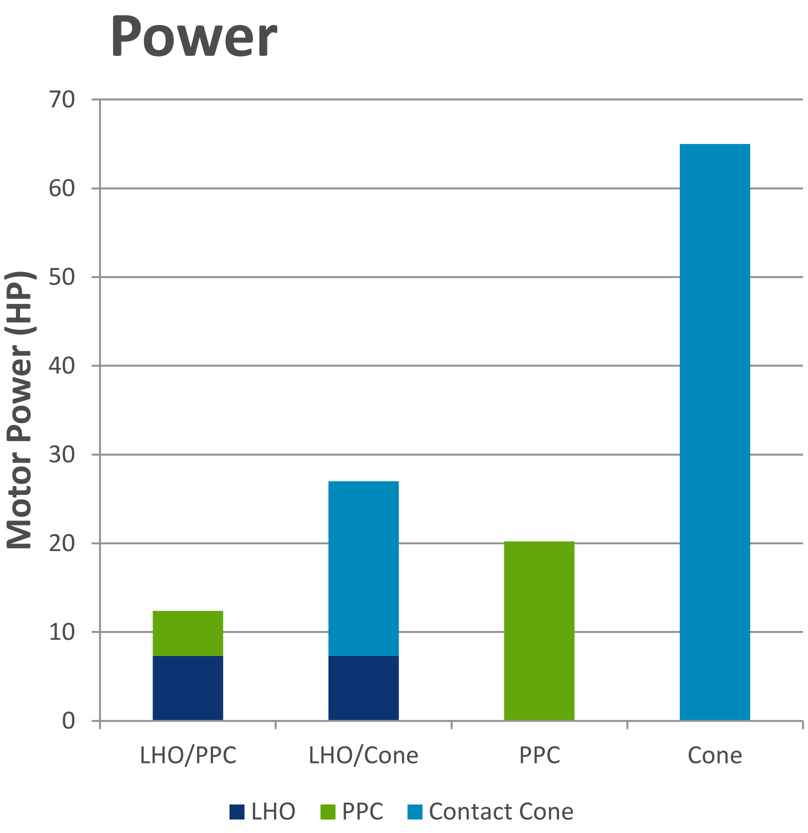


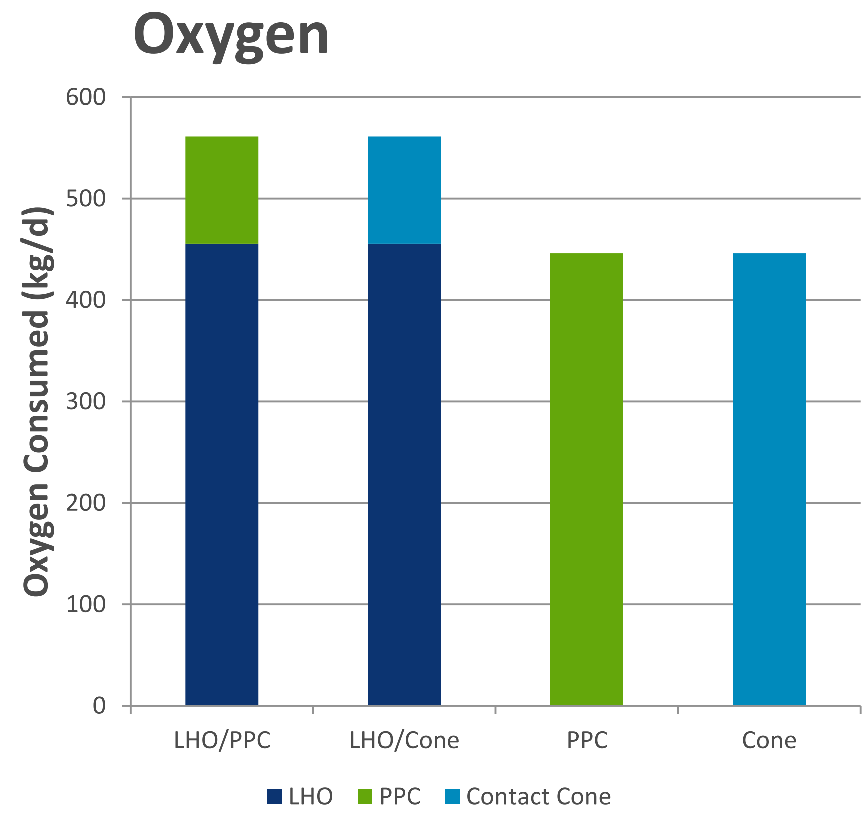
- Baseline oxygen (+ozone) set with LHO on full flow at low pressure
- Higher pressure PPC (65 psi typ.) is used to supplement oxygen only as needed
- Results in small PPC, small distribution lines, and small control valves

Optimize capital and operating cost

Oxygenation Technology Comparison

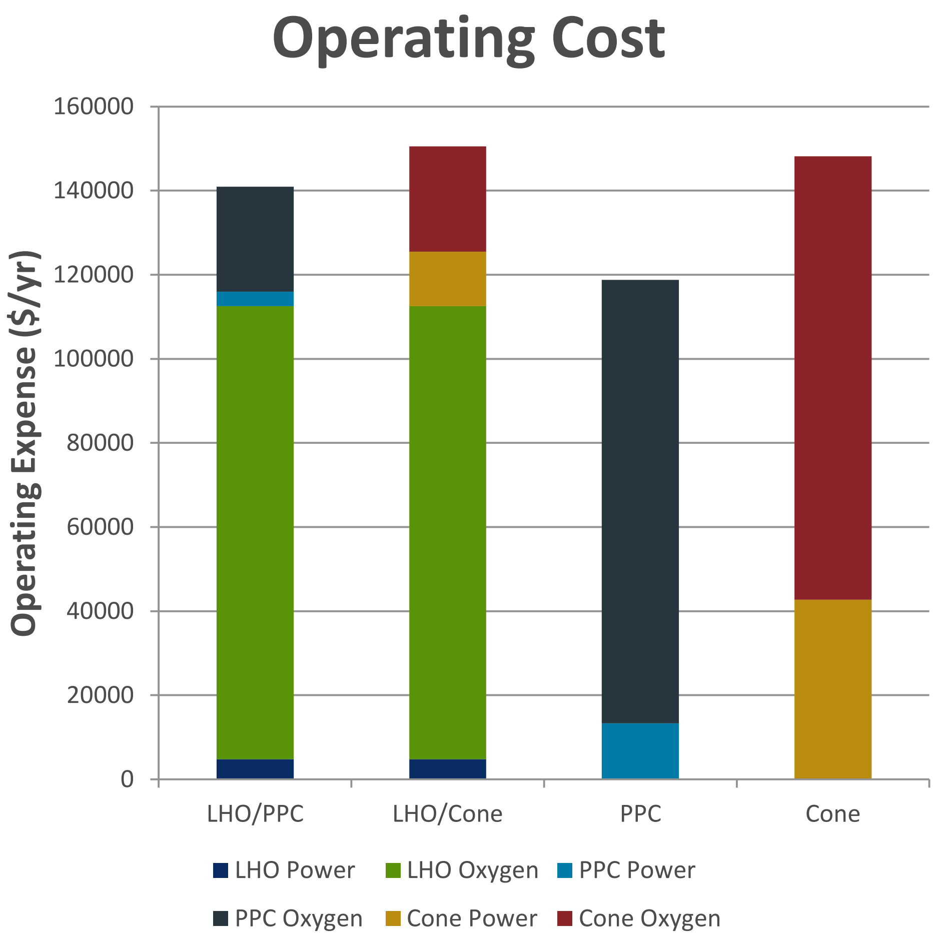
Cold Fresh Water Scenario
(15ºC, 0g/L salinity, 900m3, 30min HRT, 1kg/d/m3 feed, 0.5kgO2/kg feed)





Optimal energy use with incremental oxygen consumption

Oxygenation Technology Comparison



*Based on Vancouver Island rates; results may vary elsewhere

Assumptions:

- Electricity = $0.10/kWh (CAD)
- Oxygen = $0.65/kg O2 (CAD)

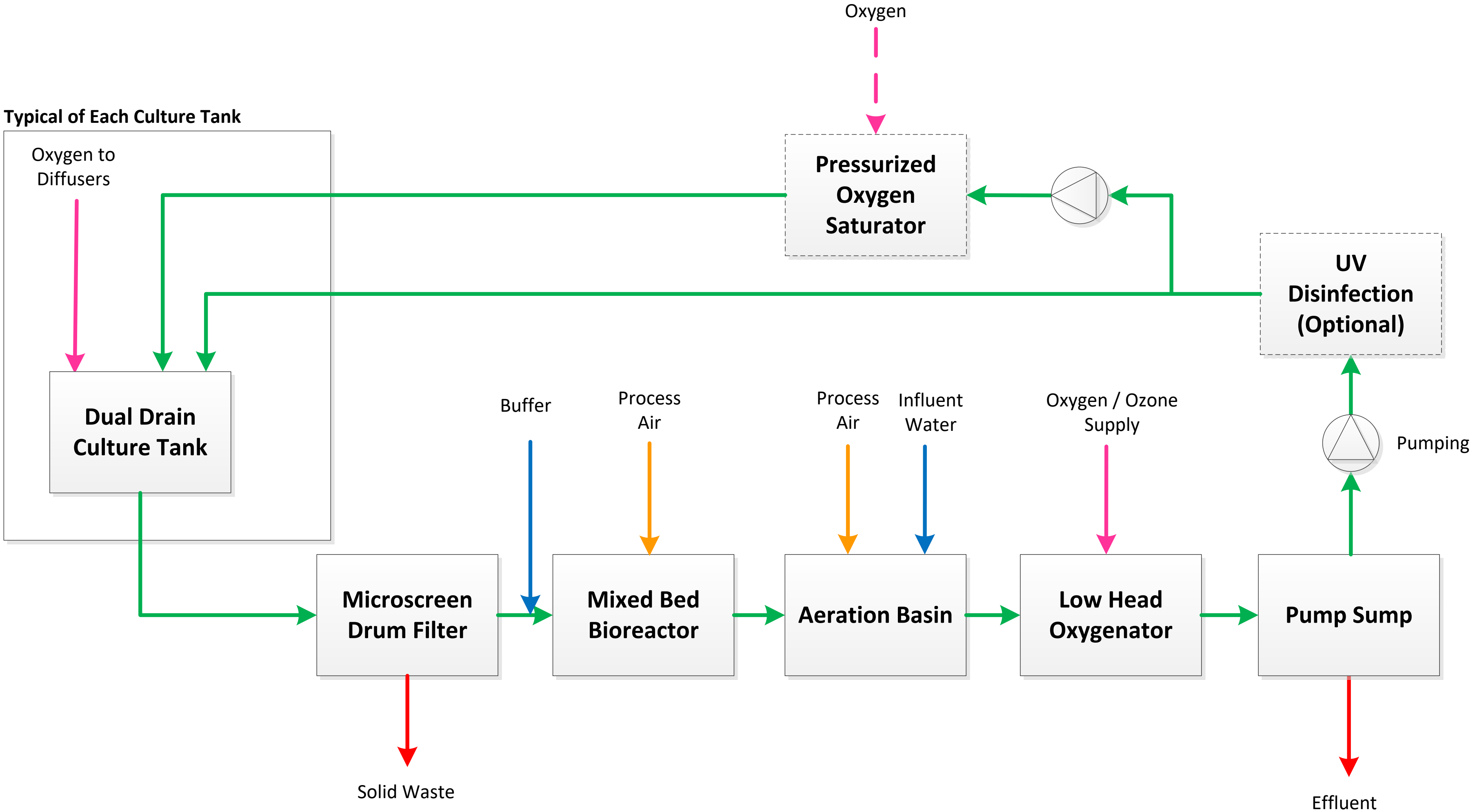
Conclusions:

- LHO with PPC is higher operating cost than PPC alone but it has additional benefits:
  - Nitrogen removal without active degassing
  - Ability to add ozone safely
  - LHO can be used with generated oxygen
- On a per unit flow basis, LHO with PPC is significantly less capital cost than PPC alone.

Integrating high/low pressure technologies to balance operating cost, capital cost, and operating flexibility

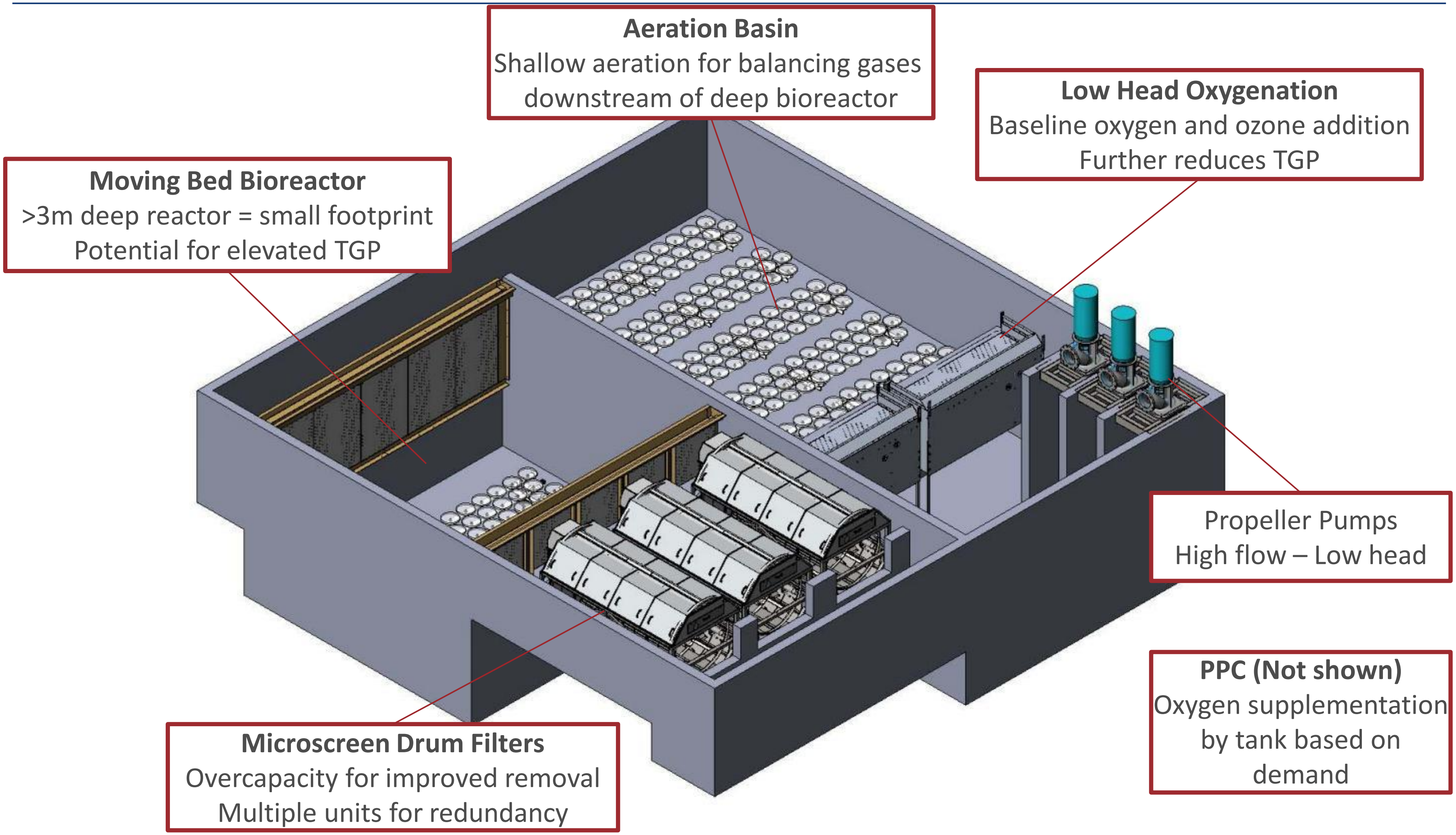
Process Integration

Typical Process



Simple-effective-scalable process

Putting It All Together



Simple-effective-scalable process

Emerging Opportunities

- Water consumption rates become performance limiting especially in applications where high quality influent is not readily available:
  - Saltwater systems not located near the ocean
  - Urban farming
  - Ambient temperature limited systems
  - Influent or Effluent limited sites

- Water recovery or water use reduction options:
  - Denitrification
  - Sludge concentration and water recovery
  - Aquaponics

Concentrate sludge and recover the water

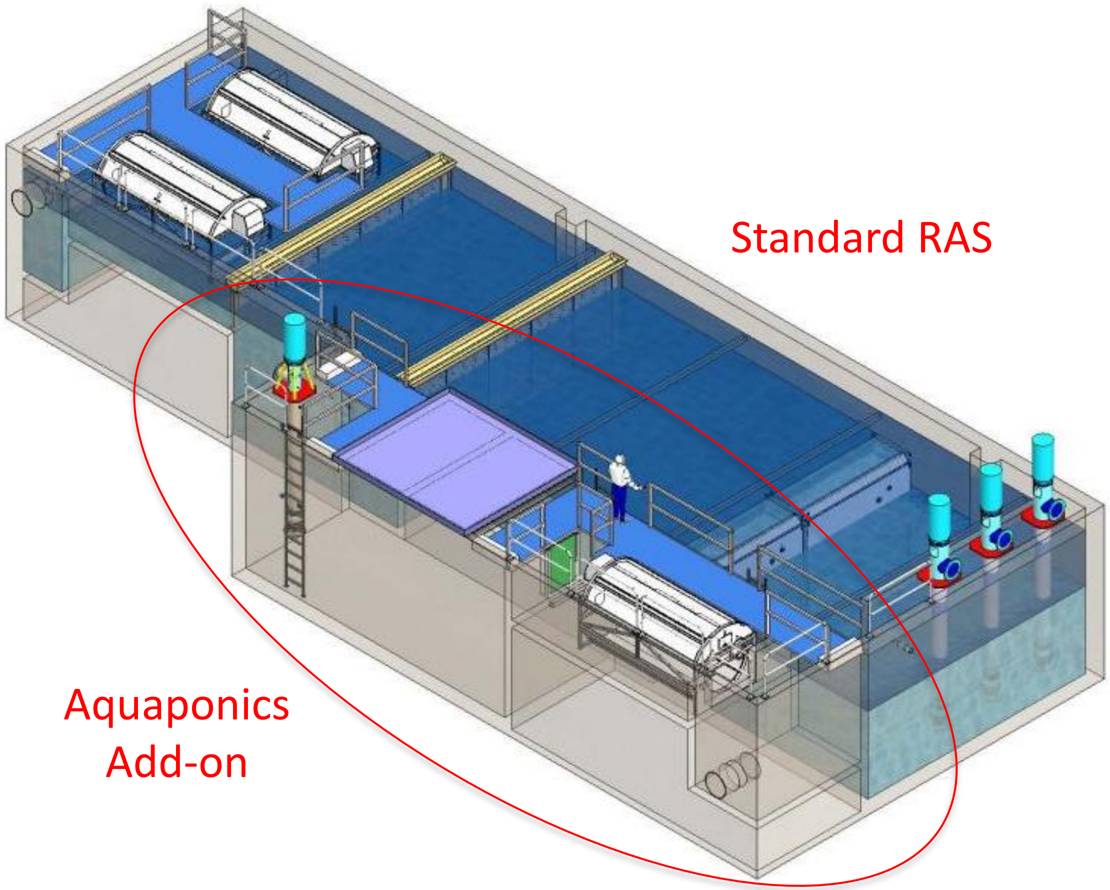
Aquaponics Integration with RAS

Decoupled Aquaponics / RAS

- Synergistic crop production
- Waste remediation
- Significant water use reduction
- Decoupled system allows hydroponics and RAS to work together or separately as needed.

Emerging opportunities

Aquaponics Integration with RAS



Nutrient recovery from RAS waste

Emerging opportunities

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Questions?