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Nutrient Removal Operations – A Compilation of Lessons Learned Over 30 Years of Practice

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OTCO's Class III & IV Workshop and 60th Anniversary

Presentation Agenda Summarizes Nutrient Removal Experience

- Summary of nutrient removal
- Nutrient removal fundamentals and drivers for success
- Conventional nutrient removal processes
- New and emerging technologies for nutrient removal
- Lessons learned
- Final thoughts

Phosphorus (P) is a Limiting Nutrient for Algae Growth and Therefore is Limited by NPDES Programs

- “Nutrient pollution is one of America’s most widespread, costly and challenging environmental problems”
  – *USEPA*
- Research in Canada in the1960s and 1970s revealed P to be the limiting nutrient in freshwater
- Limits vary from state to state but principles discussed today apply broadly to phosphorus removal facilities

Source: IISD Experimental Lakes Area

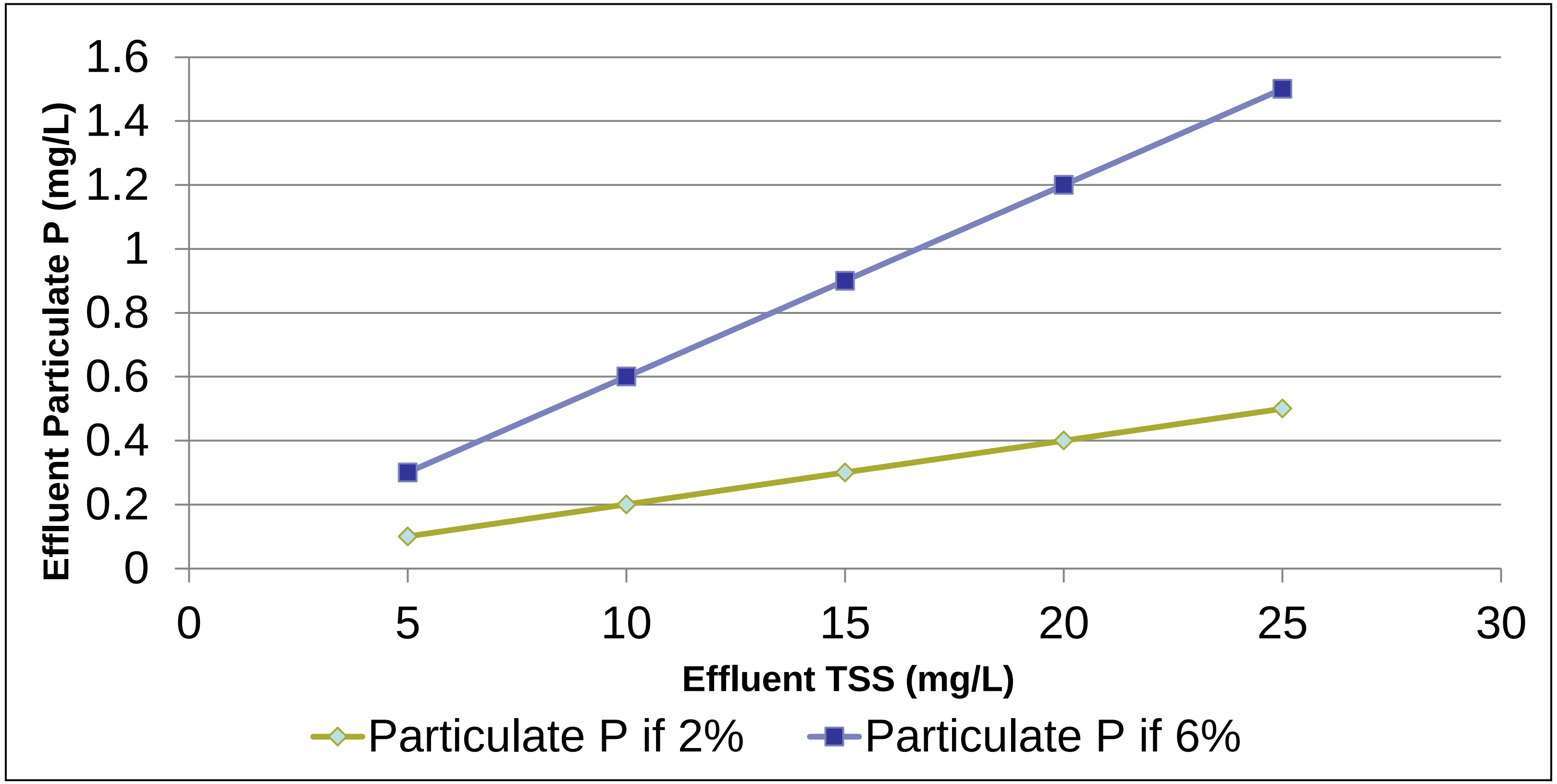
Experience Includes More Than 30 Years of Nutrient Removal

- **Great Lakes Dischargers**
  - Phosphorus (limit 1 mg/L since 1970s)
- **Wisconsin**
  - 1992 - Implemented phosphorus limits ~ 1 mg/L
  - 1994 – 1st BPR design (Strand)
  - 2010 – State significantly lowered P limits to <0.1 to 0.2 mg/L
- **Illinois, Indiana, Kentucky, Ohio**
  - Currently implementing P limits ~ 0.5 to 1 mg/L
- **Iowa**
  - 2012 nutrient strategy ~ 10 mg/L TN and 1 mg/L P

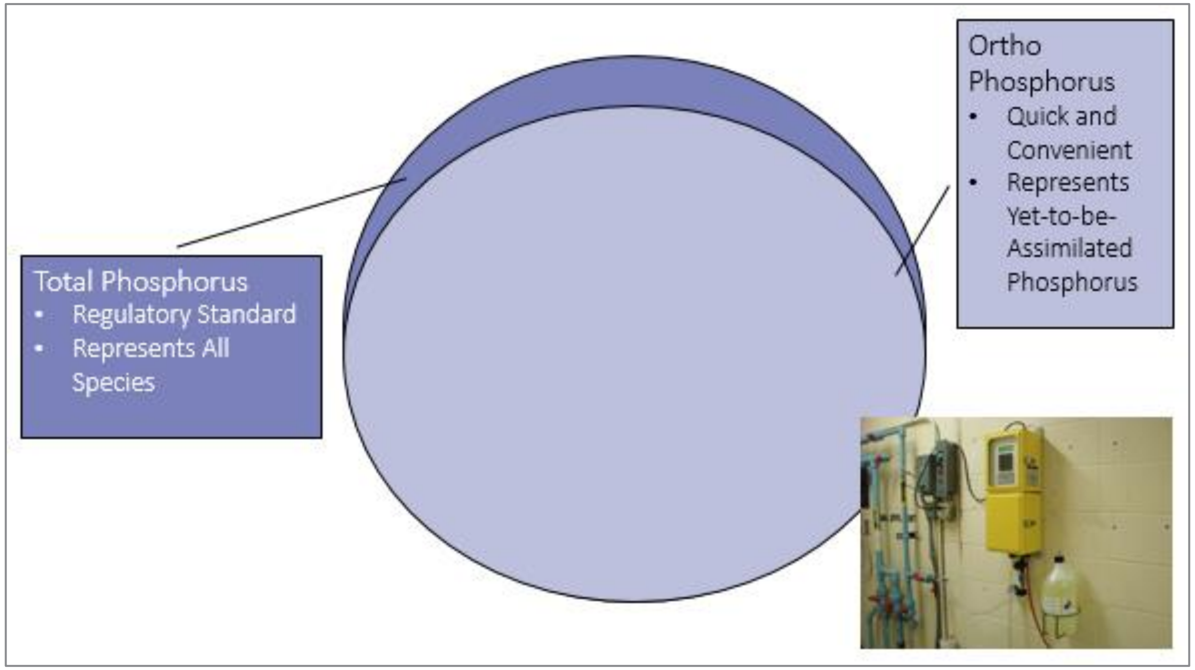
Understanding Nutrient Removal Fundamentals are Key Drivers for Successful Treatment Performance

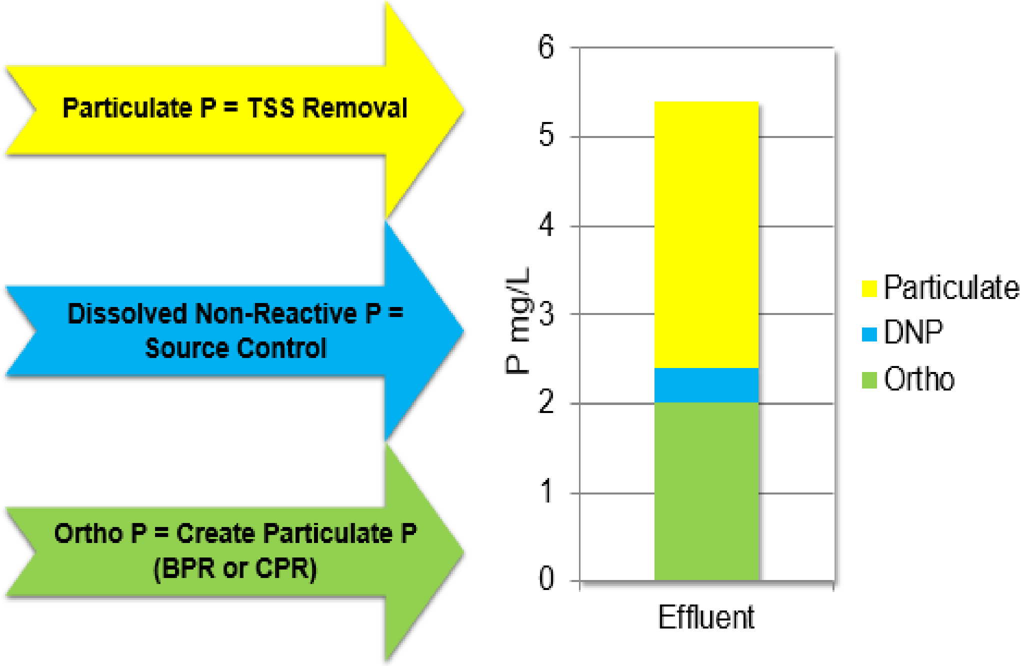
- Fundamental 1: Convert dissolved phosphorus into particulate phosphorus

Fundamental 2: Remove Phosphorus-laden Solids from the Effluent Stream



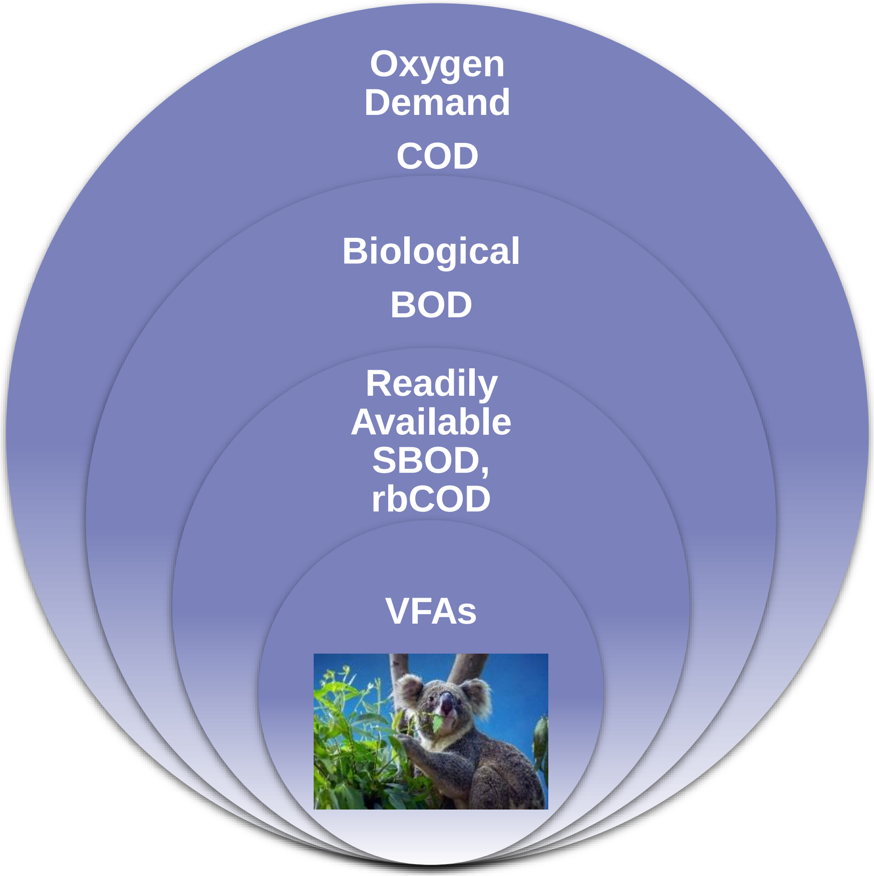
Fundamental 3: Understand Composition of Your Phosphorus





Fundamental 4: PAOs Require a Simple Food Source

- Volatile fatty acid (VFA) sources might include:
  - Sewer fermentation
  - Fermenter
  - In-line fermentation
  - S2EBPR solids fermentation
  - Purchased substrate



What is Fermentation?
A metabolic process by which an organism converts BOD into an acid.

Fundamental 5: Operational Choices Impact BPR Success

- BPR systems require a strategically located anaerobic zone and anaerobic conditions need to be maintained – that means:
  - No dissolved Oxygen (O_2)
  - No Nitrate (NO_3)
  - No Nitrite (NO_2)
- Oxygen introduction to the Anaerobic Zone needs to be monitored and controlled!

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Fundamental 5, Continued: Nitrate Control Impacts Anaerobic Zones and Soluble Substrate Quantities

Nitrate Control Options

- Limiting nitrification
  - Not an option if facility also has ammonia limit
- Controlling quantity of nitrate returned
  - RAS and Internal Recycle Control
- Denitrification
  - Process configurations limit options
  - Avoid use of best substrate

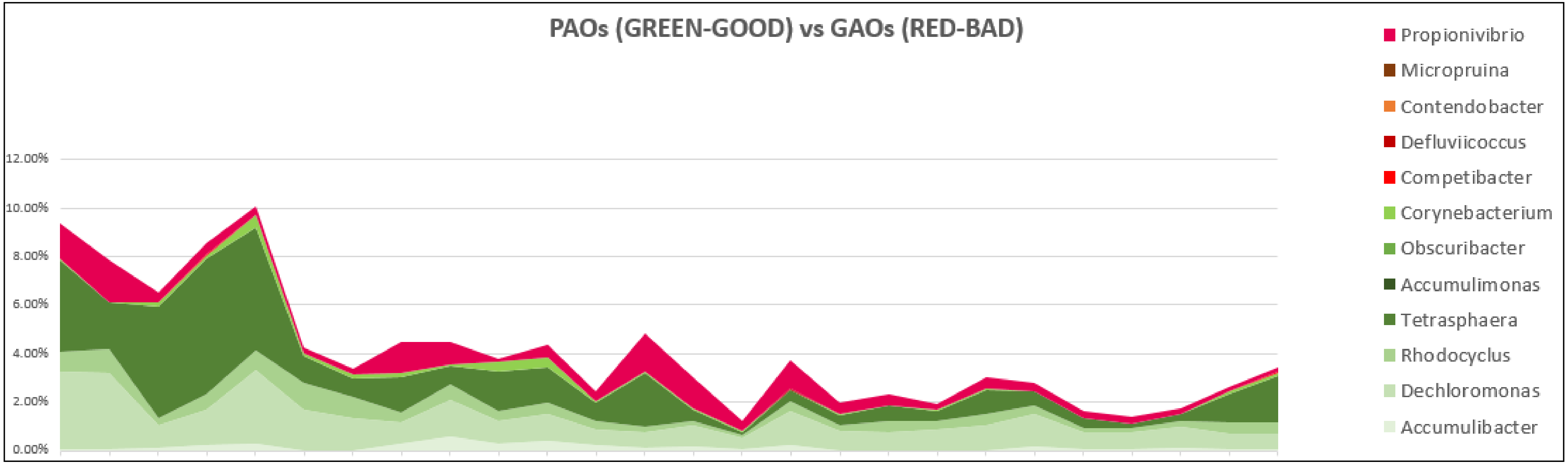
Aerobic Zone
- Substrate= NH_4^+
- Energy Source = DO

Anoxic Zone
- Substrate = BOD
- Energy Source = NO_2/NO_3

Nitrification			De-Nitrification
NH_3-N →	NO_2 →	NO_3 →	N_2
ammonia	nitrite	nitrate	nitrogen gas

Fundamental 5, Continued: Managing Conditions to Favor Phosphorus Accumulating Organisms is Key to Successful BPR

- DNA analysis can help determine conditions that select for productive PAOs



Conventional Nutrient Removal Processes

- **Phosphorus removal:**
  - Chemical removal (chemical sludge)
  - Biological removal (incorporated into the bugs)
  - **P is removed with the sludge**
- **Nitrogen removal:**
  - Biological process – Nitrification and denitrification

    ($NH_3 \rightarrow NO_2 \rightarrow NO_3 \rightarrow N_2$)
  - Simultaneous nitrification/denitrification
  - Shortcut nitrogen removal
  - **N_2 gas is discharged to the atmosphere**

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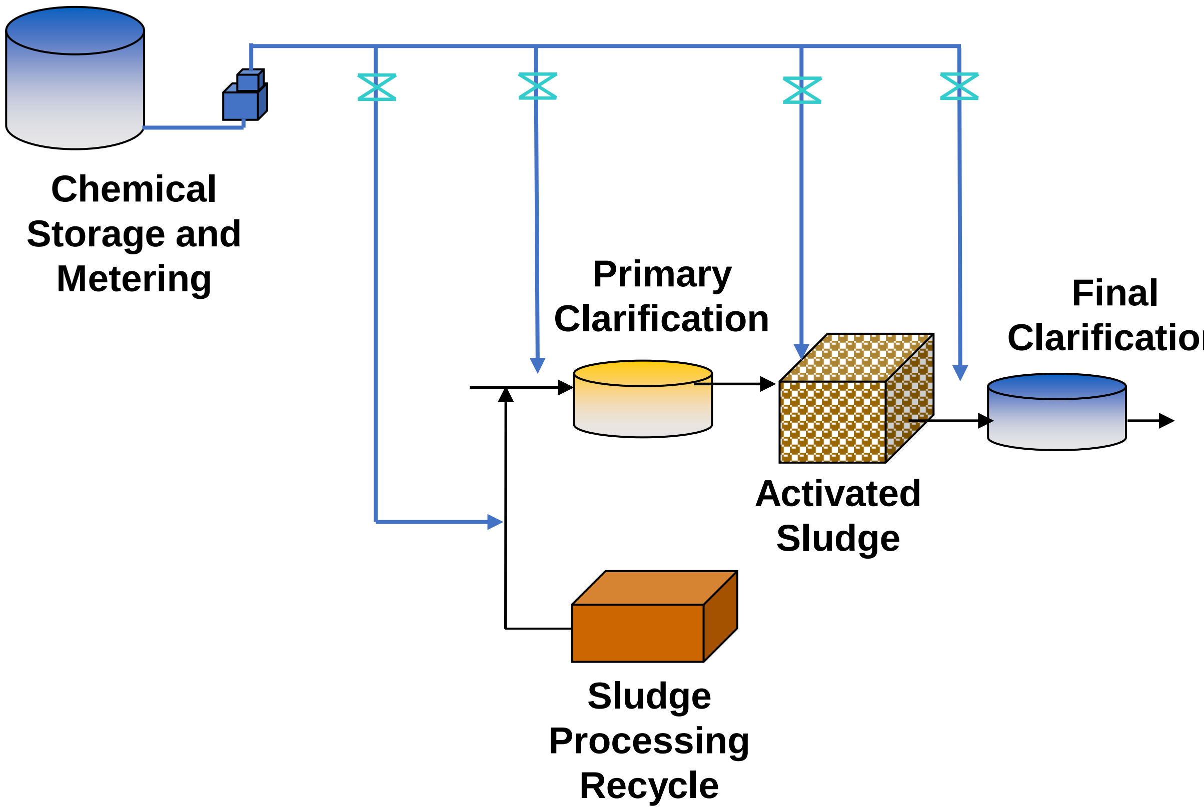
Typical Chemical P Removal Schematic

- In use in the US since the 1970s or longer
- Provides reliable P removal



Conventional BNR Activated Sludge: Status in Industry

- Developed in the ~1970s and used throughout the world
- Provides reliable P removal, nitrification, and denitrification in dedicated zones

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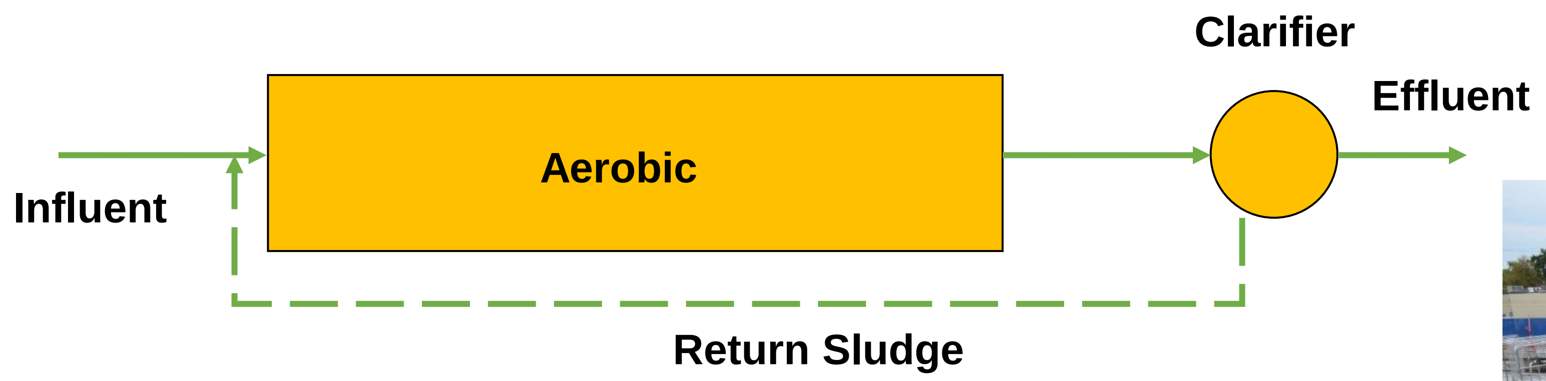
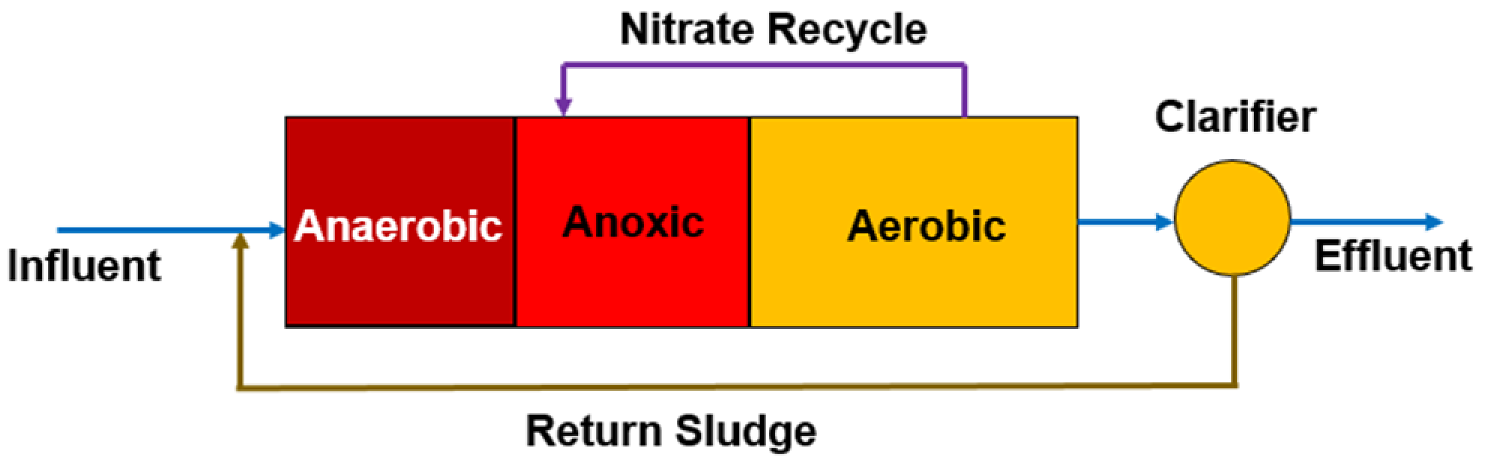
Conventional Biological Nutrient Removal Schematic





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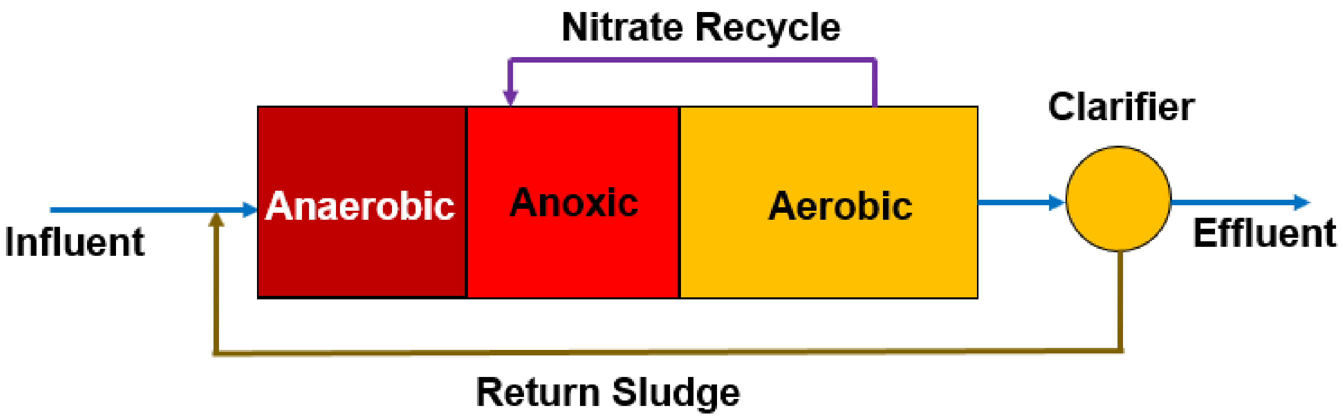
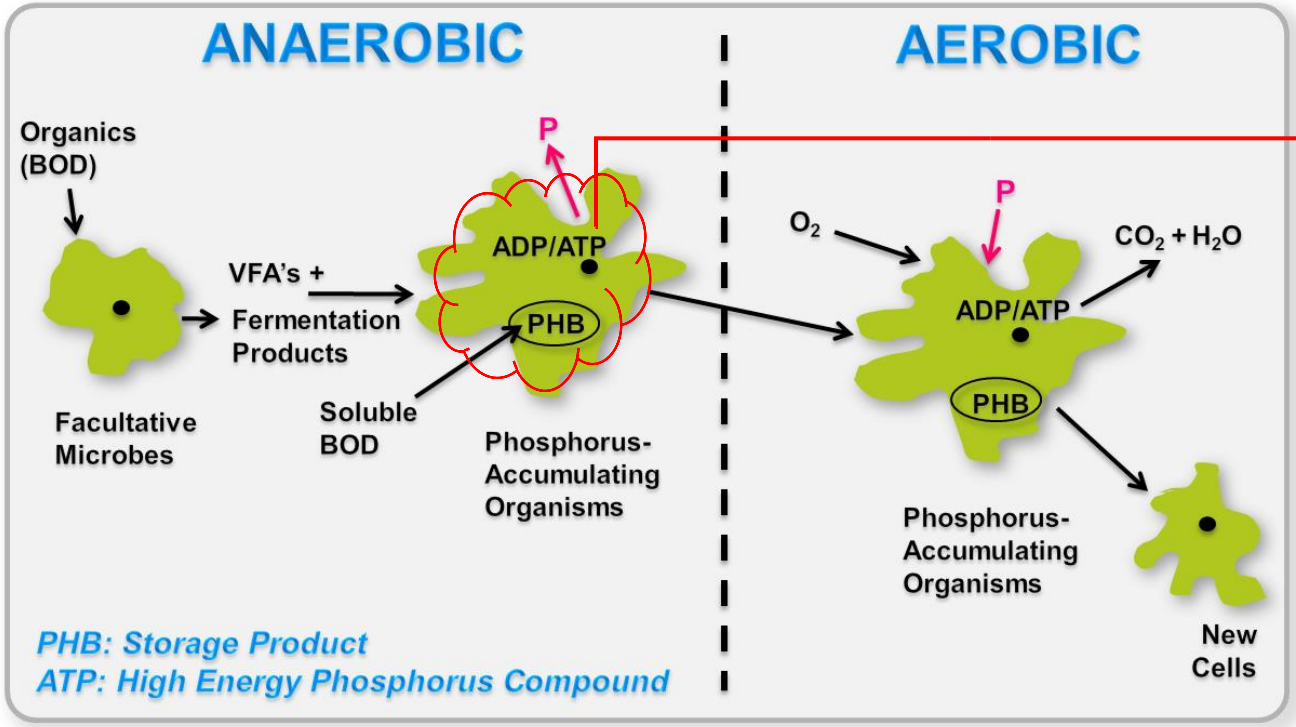
Conventional BNR Activated Sludge

- Dedicated Anaerobic Zone to enhance BPR (BOD/VFA uptake and P release)
- Dedicated Anoxic Zone for denitrification
- Aerated Zone for BOD removal, P uptake, and nitrification
- Numerous configurations



Production of PAOs is First Objective in Effective BPR

- Facilitate growth of PAOs



Source: Strand Associates, Inc.®

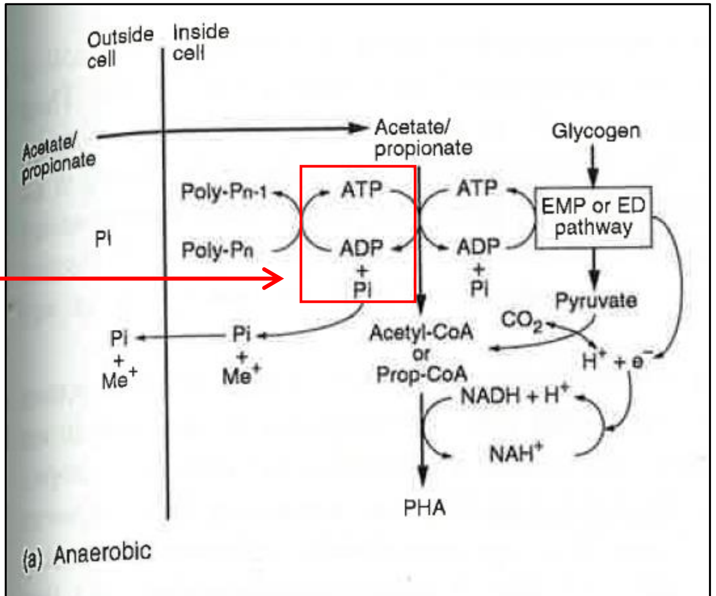


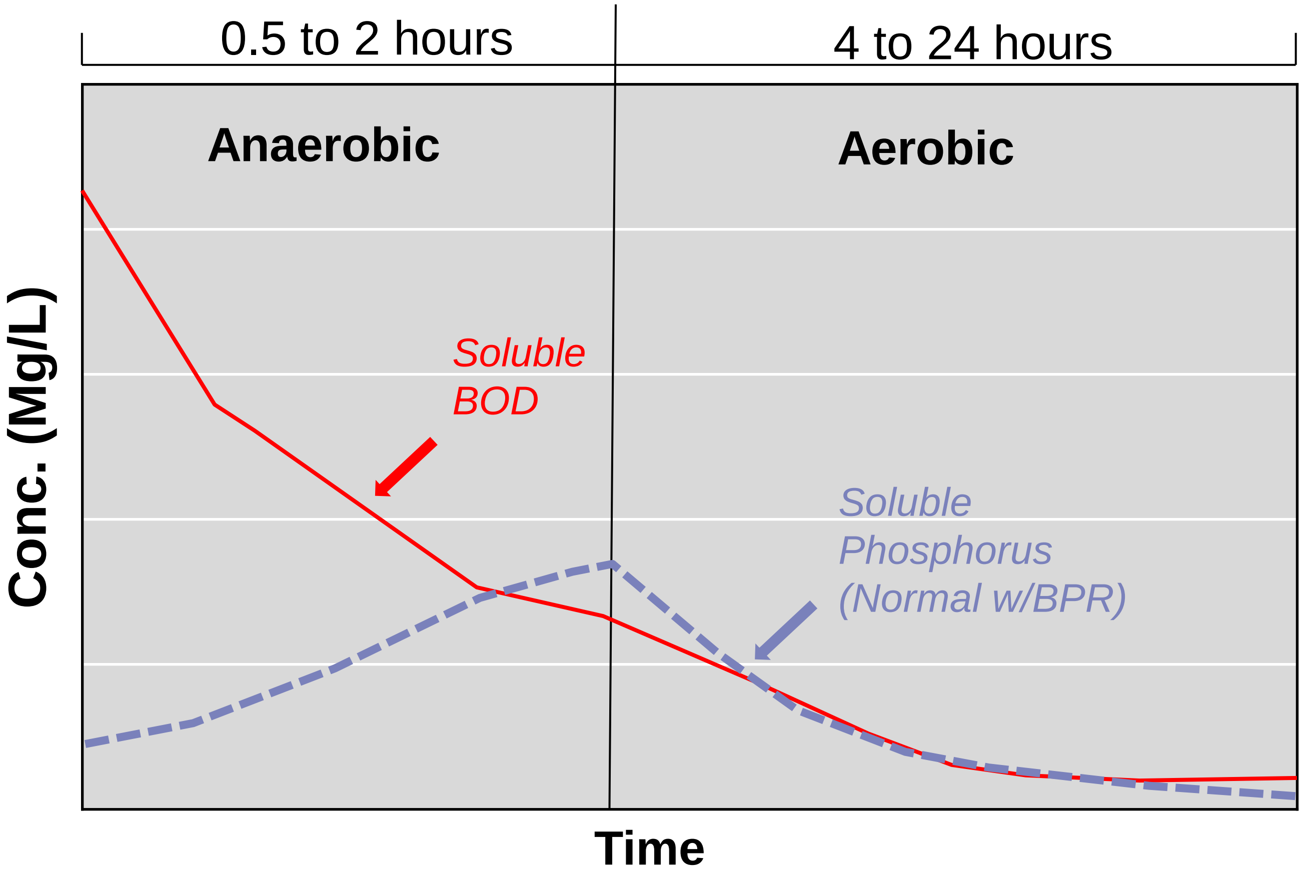
Figure 7–25

Biochemical model for phosphorus release and removal
(b) under aerobic conditions.

Source: Wastewater Engineering – Treatment and Resource Recovery - Metcalf and Eddy/AECOM

Two-Stage BOD Removal is the Essence of Traditional BPR

- Phosphorus cycle involves release in anaerobic zone, “luxury” uptake in aerobic zone



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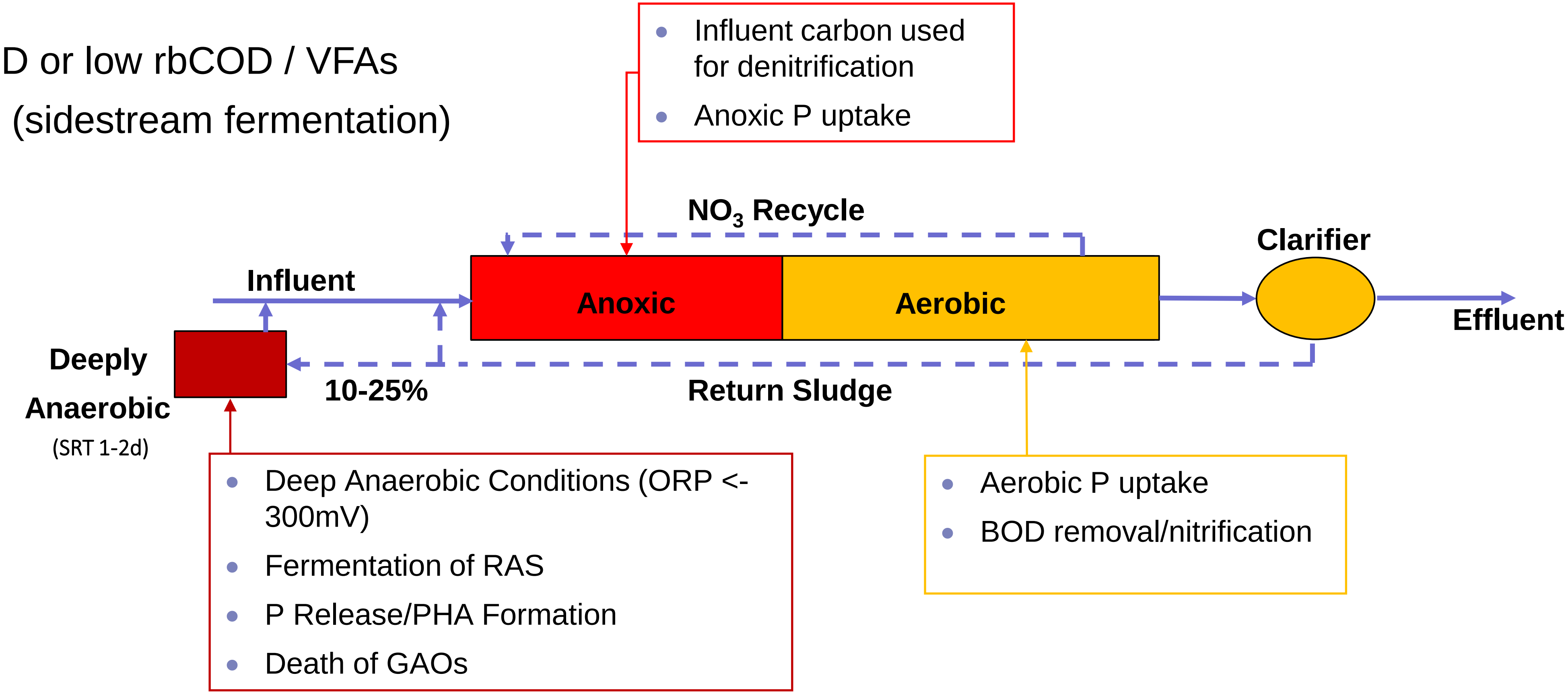
Fermentation Began to be Used for VFA Production About 10 Years Ago (Our Experience)

- Volatile Fatty Acids (VFAs) are needed to drive bio-P removal
- VFA sources:
  - Sludge fermenter (typically primary sludge)
  - Carry higher primary sludge blankets
  - Recycle primary sludge (activate your primaries)

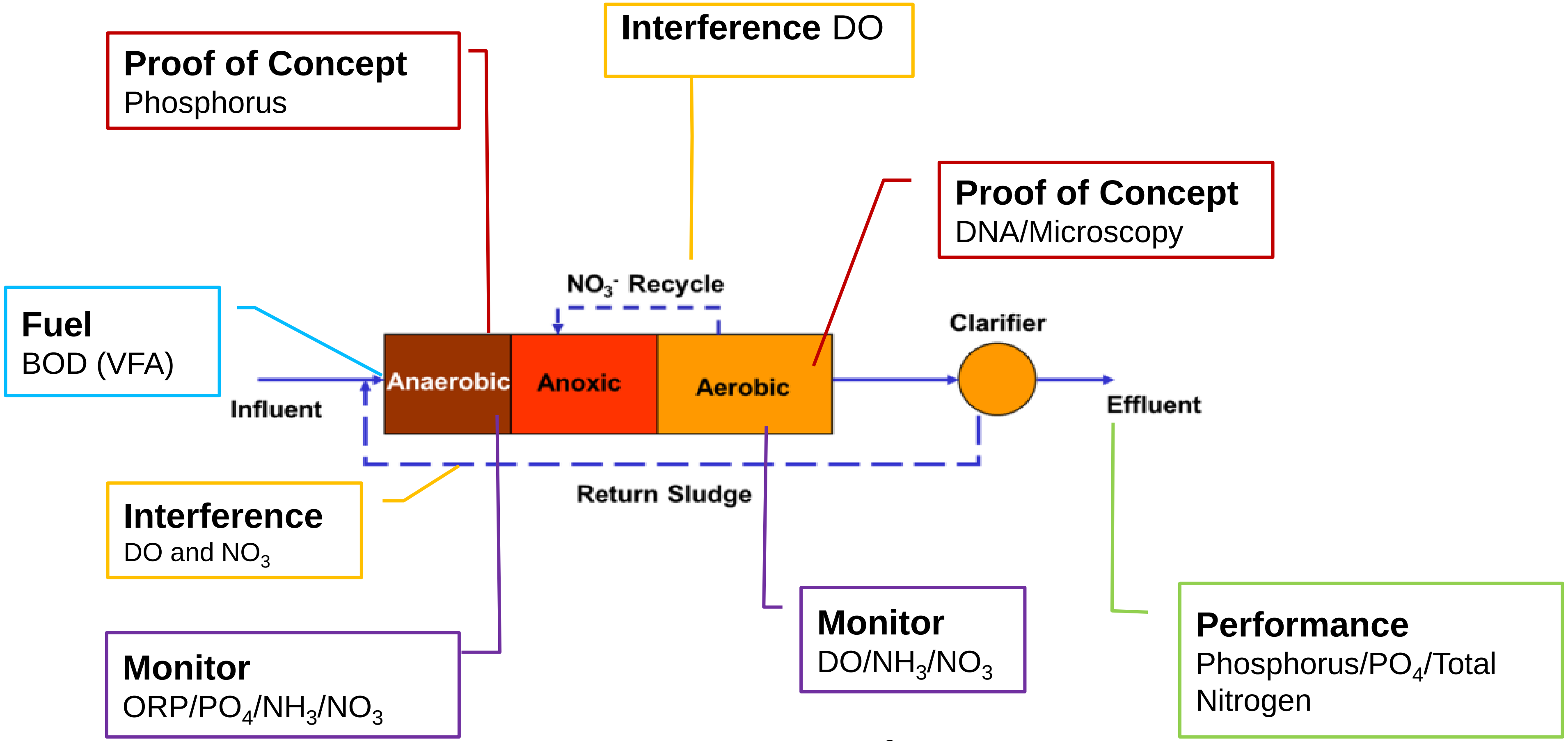
Source: Westech

Recent Innovation in BNR Activated Sludge: S2EBPR (RAS Fermentation)

- Uses fermentation to produce VFAs from RAS
- When to Use:
  - Low influent BOD or low rbCOD / VFAs
  - High peak flows (sidestream fermentation)



Biological Nutrient Removal Requires Additional Monitoring and Controls Depending on Limits



Conventional BPR (A^2O)

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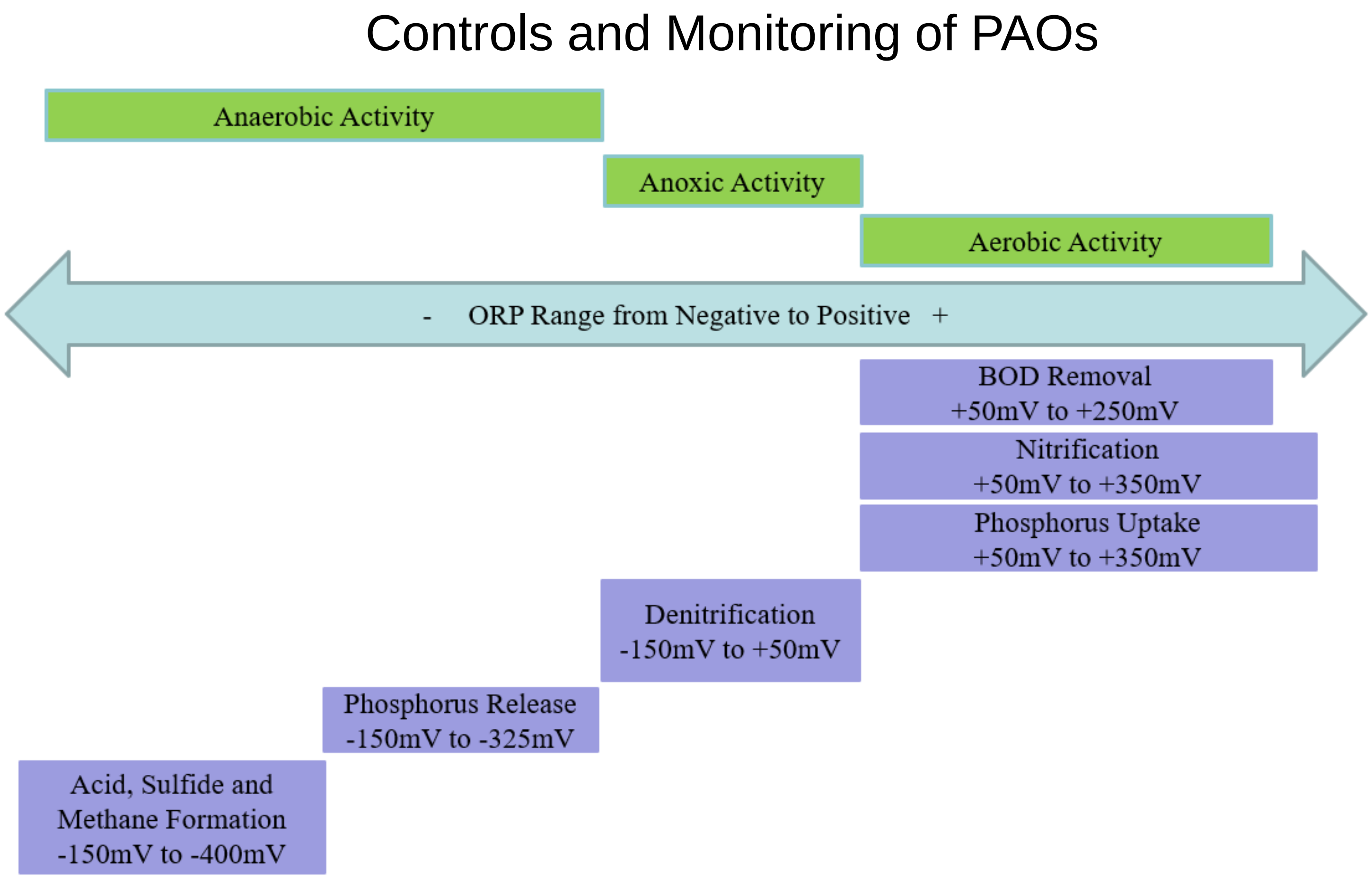
ORP Probe use with PAO Control and Monitoring in Anaerobic Zone



Oxidation reduction potential values and corresponding biochemical reactions

New and Emerging Technologies for Nutrient Removal Within the Past 5 years (+/-)

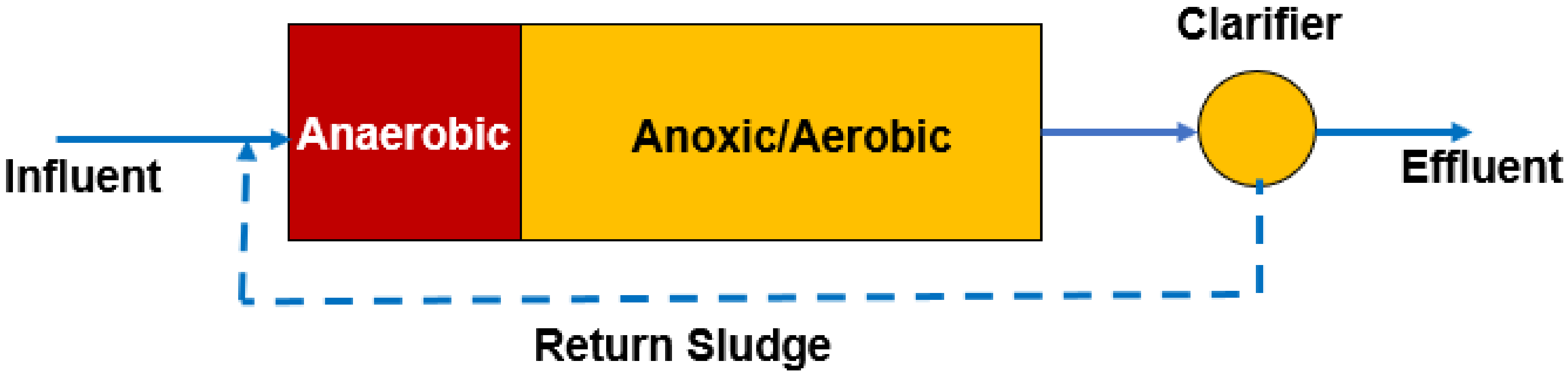
- Low D.O. BNR to drive simultaneous nitrification-denitrification (SNDN)
- Sludge densification processes (to improve settling)
- Aerobic granular sludge processes

Others:

- Chemical polishing with filtration (for very low effluent P limits)
- Membrane aerated biofilm reactors (MABR)
- Sidestream and mainstream Anammox processes
- Sidestream phosphorus recovery or sequestration

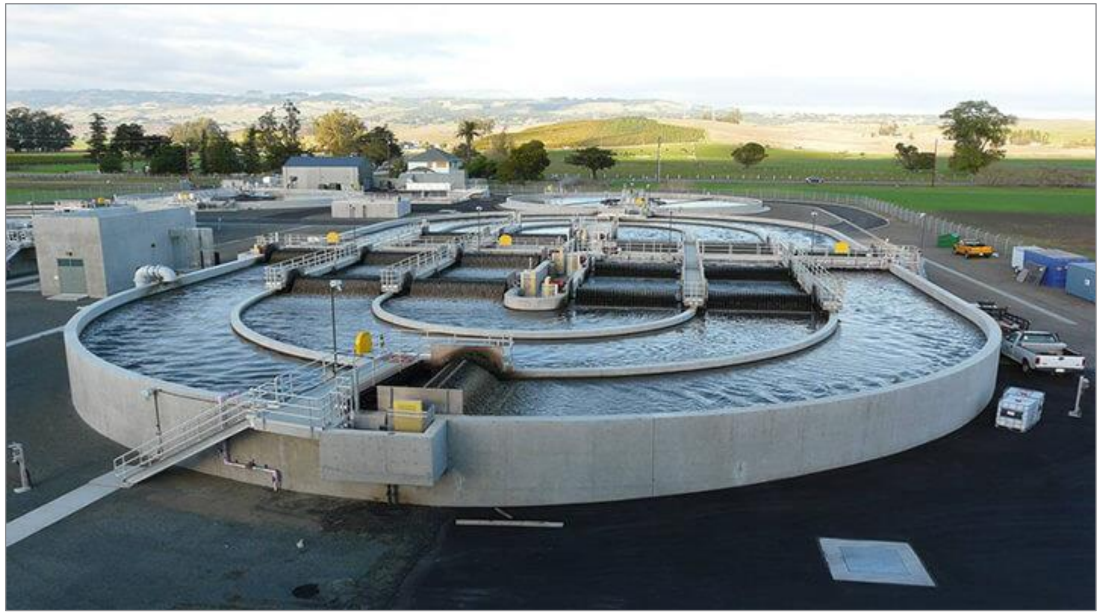
BPR + Simultaneous Nitrification and Denitrification Activated Sludge

- Dedicated anaerobic zone for enhancing bio P
- Aerated zone operated at **Low DO (0.2 to 0.7 mg/L)**
- Nitrification and denitrification occurs in one reactor simultaneously
- Requires more monitoring/instrumentation
- Control aeration using ammonia or DO, or both



BPR + SNDN Activated Sludge: Status in Industry

- Many plants perform SNDN to some extent (e.g., oxidation ditches)
- Very few conventional plants operate entire system at low DO (<0.7 mg/L)
- Area of significant ongoing research and application
- Design for conventional but provide ability to operate at low DO



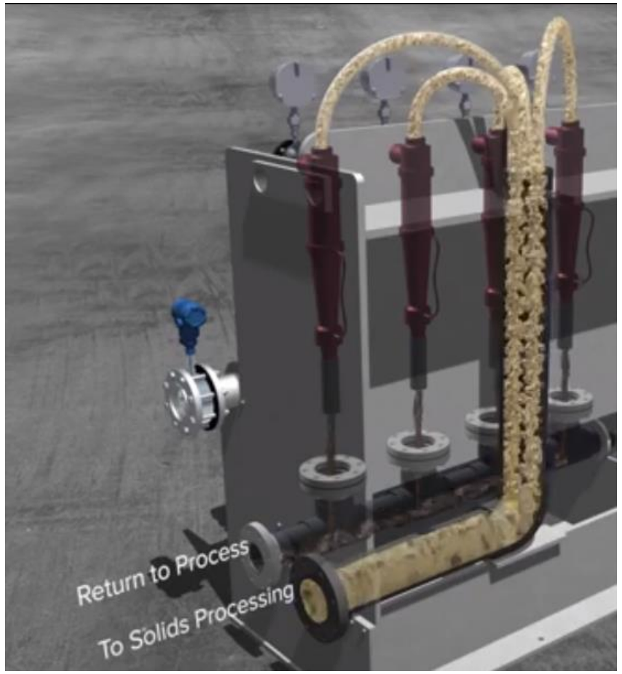
Source: Evoqua

Source: City of Chico, California

Sludge Densification Often Coupled with SNDN Activated Sludge

- Low DO operations can lead to poorer settling sludge
- Hydrocyclones have been used to improve SVI
- Metabolic selectors can also drive densification

Source: World Water Works, Inc.



Source: World Water Works, Inc.

BPR + SNDN Activated Sludge Process: Pros/Cons

Pros

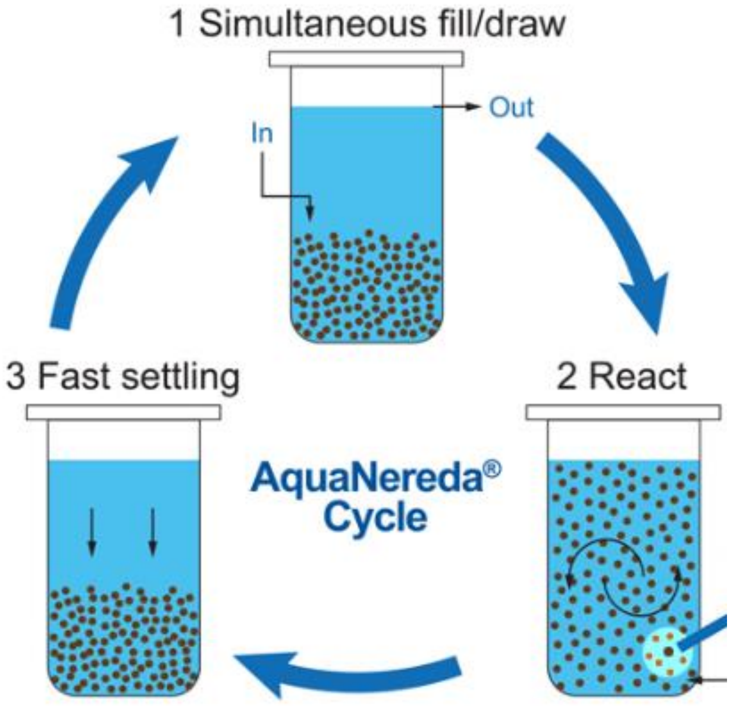
- Lower energy requirements than conventional BNR (~25-35%)
- Less equipment than conventional BNR (recycle pumps, mixers)

Cons

- Emerging process
- Greater potential for poor settling sludge
- Might not be viable with very low ammonia limits (< 1 mg/L?)

Aerobic Granular Sludge: Background

- AquaNereda® Upflow SBR by Aqua-Aerobic Systems



Source: Aqua-Aerobic Systems, Inc.

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Aerobic Granular Sludge

- Sludge volume index (SVI) comparison with conventional activated sludge
  - 5-minute SVI is similar to 30-minute SVI at higher MLSS concentration

Source: Aqua-Aerobic Systems, Inc.

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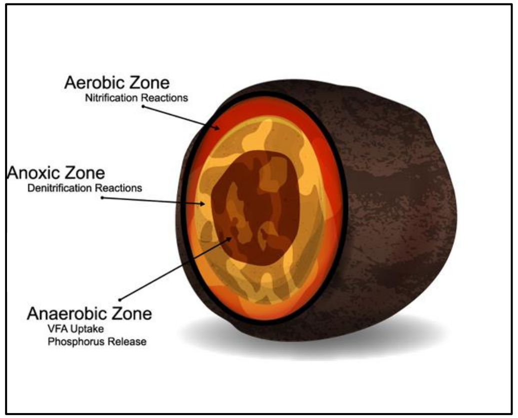

Source: Aqua-Aerobic Systems

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Aerobic Granular Sludge (AGS): Status in Industry

- Research and development in the Netherlands in 1990s through 2000s
- In 2016, Aqua-Aerobics became the exclusive licensee in the US
- 55 full-scale operating Nereda plants in the world (approximately within the last 10 years)
- 6 operating plants in US, approx. 20+ plants in construction or design

AQUA-AEROBIC SYSTEMS, INC.
A Metawater Company

AquaNereda®

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AGS: Pros/Cons

Pros

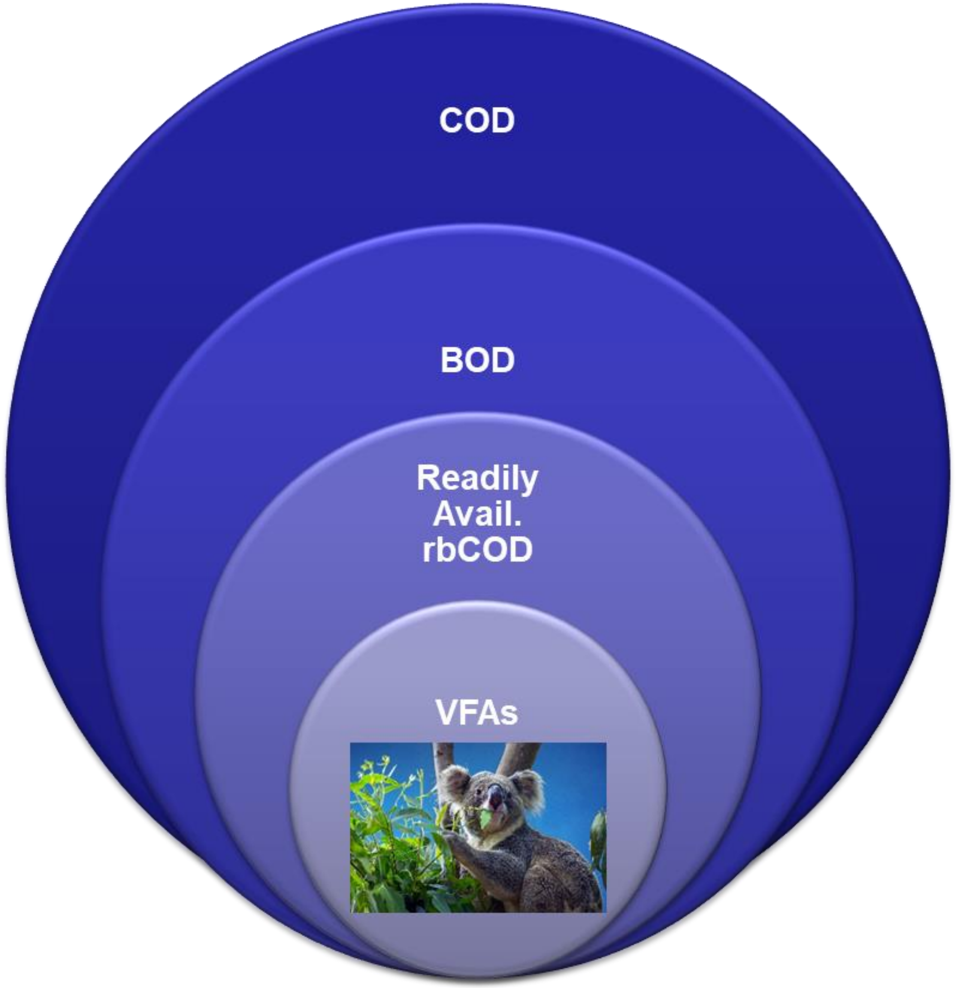
- Process guarantee provided by equipment manufacturer
- Case studies demonstrate nutrient removal and nitrification
- Less energy than conventional BNR
- Fewer processes (no clarifiers, RAS pumping)

Cons

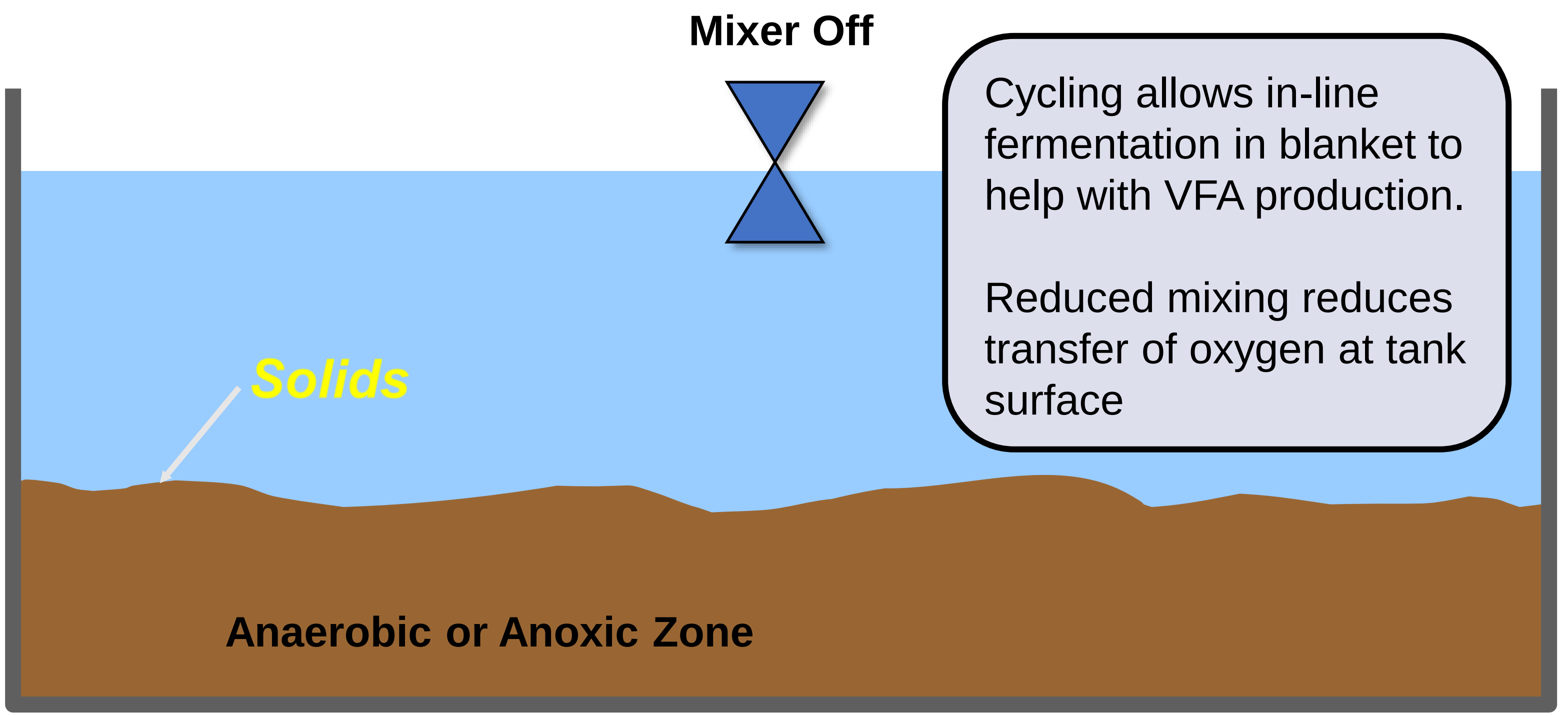
- Emerging technology in US with only a few operating facilities
- More instrumentation
- Possibly more complex to operate, especially at smaller plants and during wet weather events

Lessons Learned – The Right Kind of Food is Critical

- If adequate food is not available, consider:
  - In-line fermentation
  - Sludge fermentation
  - S2EBPR
  - Adding carbon (methanol, industrial wastes)



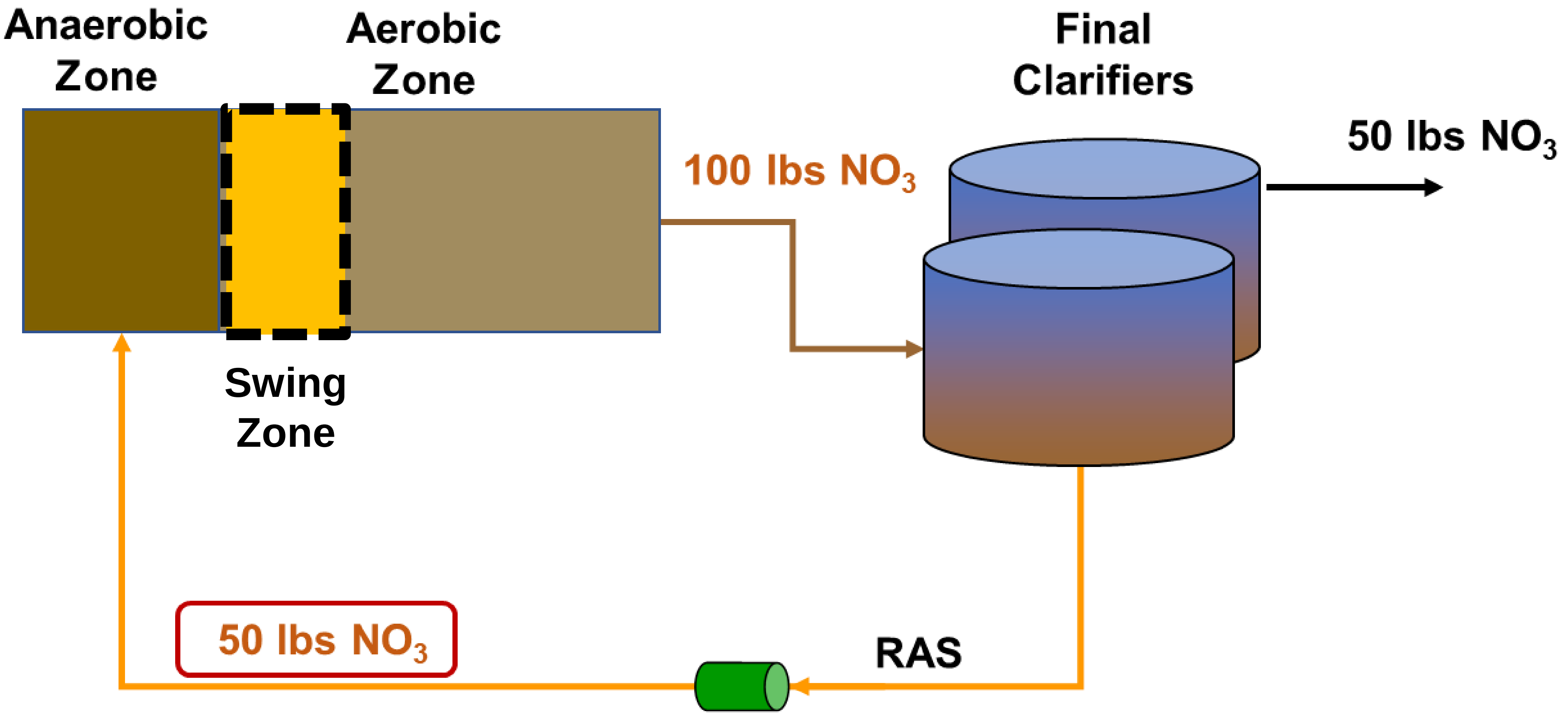
Cycling Mixers Stimulate Anaerobic Activities (In-Line Fermentation)



Cycling allows in-line fermentation in blanket to help with VFA production.

Reduced mixing reduces transfer of oxygen at tank surface

Lessons Learned – Design Flexibility is Important



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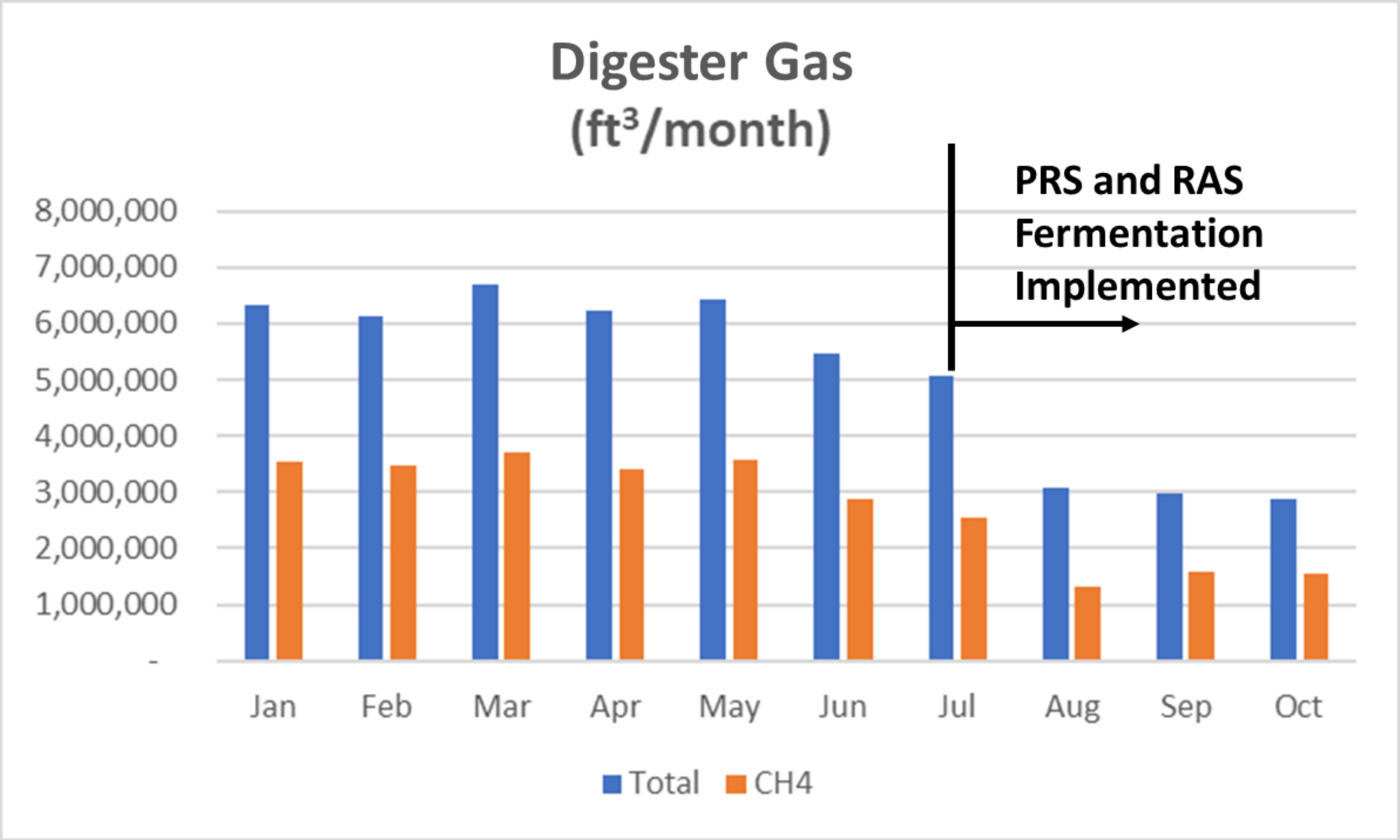
Unintended Consequences of Sludge Fermentation to Drive BNR



Final Thoughts

- Influent characterization is critical to determine how well a BNR system might operate
- Nutrient removal systems require more operator attention
- Real-time monitoring is essential for very low limits and for many innovative approaches
- Give yourself as much flexibility as possible
- BNR systems continue to evolve

Source: © marish – vectorstock.com

Thank you!
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