NITROGEN AND PHOSPHORUS: TREATMENT CONCEPTS

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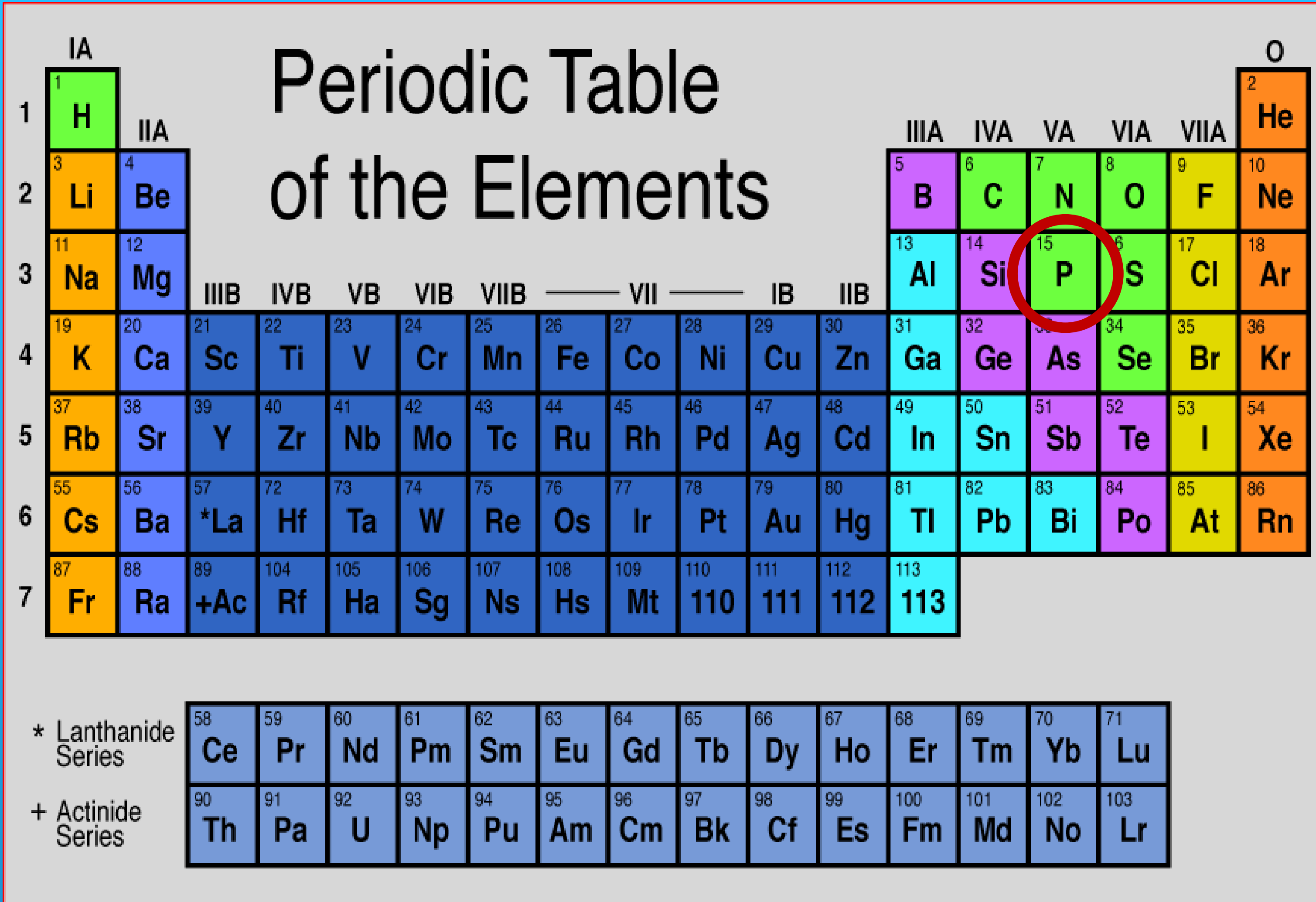
Part II: Phosphorus



Phosphorus Topics

- **Problems:** why remove?
- **Forms:** what is found in wastewater?
- **Removal concepts:** how is P removed from wastewater?
- **Process considerations:** what design and operational factors influence removal?
- Tying N & P removal together

Why Remove Phosphorus?

- Ecological consequences:
  - Phosphorus may stimulate excess algae growth (eutrophication)
  - If nitrogen loading to water body decreased, phosphorus can become limiting

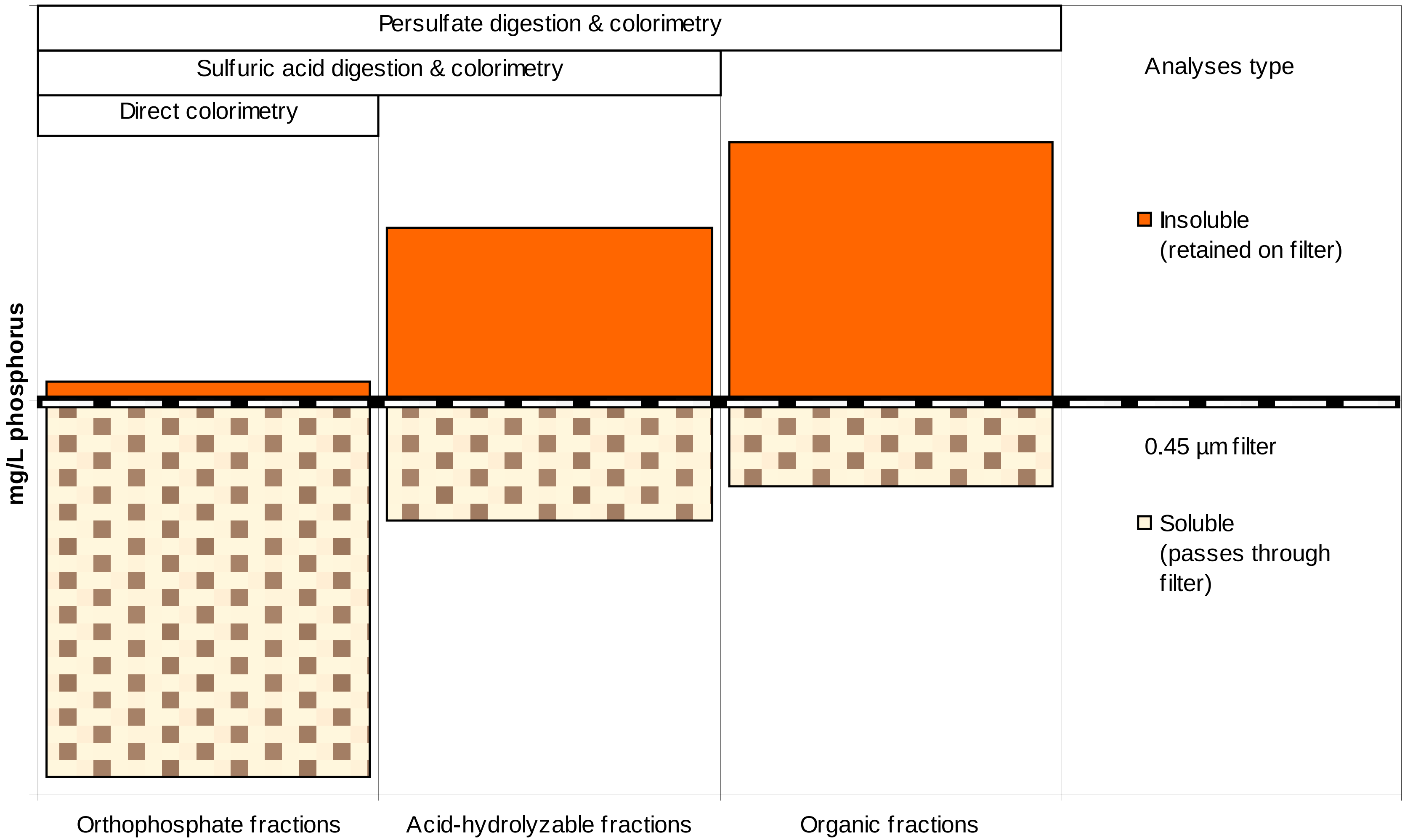
Forms: Basic Categories

- Dissolved vs. particulate
- Organic vs. inorganic
- *No gas phase*

Forms: Operational Definitions

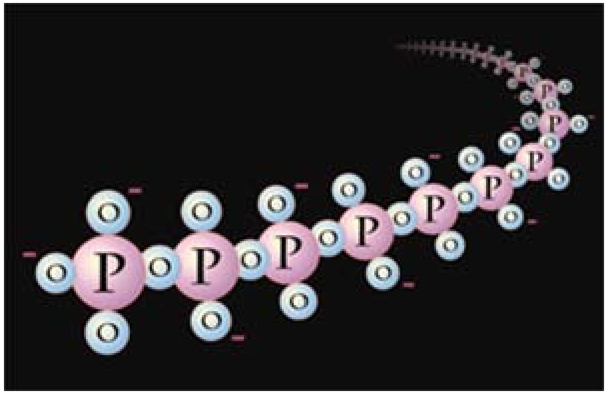
- Defined by analytical method, not by chemical structure
- Two common methods:
  - EPA Method 365.2
  - Standard Methods 4500-P
- Three common colorimetric analyses:
  - Direct colorimetry
  - Sulfuric acid digestion/colorimetry
  - Persulfate digestion/colorimetry
- Filtered and unfiltered (typically 0.45 µm)

Forms: Six P Fractions

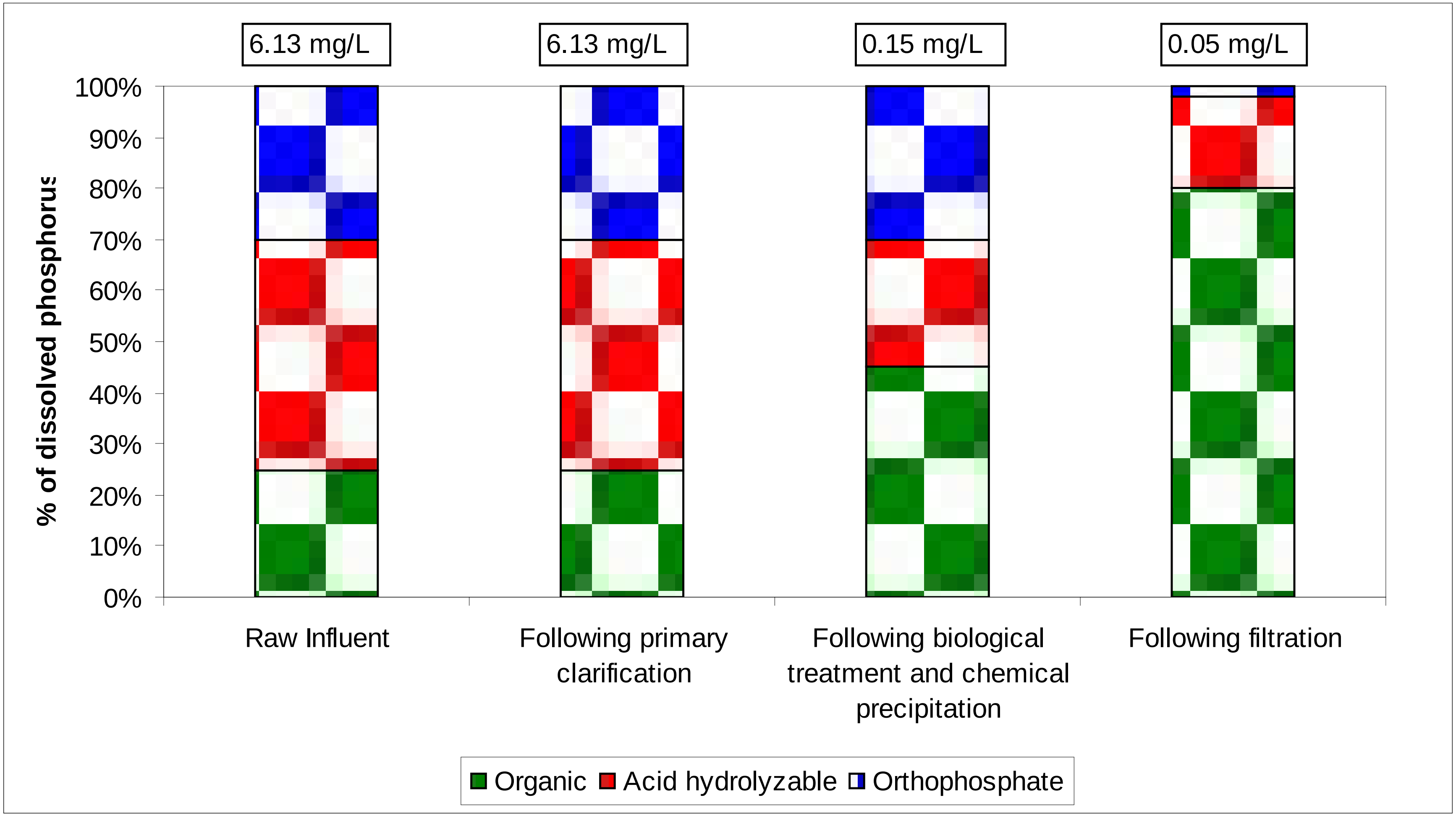


Forms: Operational Definitions

- "Orthophosphate"
  - Mostly orthophosphate ("ortho-P"; H2PO4- and HPO42-)
  - Mostly dissolved
  - Highly reactive
- "Acid-hydrolyzable"
  - Mostly "condensed" phosphates: polyphosphates and metaphosphates
  - Dissolved and particulate
  - Somewhat reactive
- "Organic"
  - Phospholipids, nucleotides
  - Mostly particulate
  - Least reactive



Forms: Dissolved P in WWTP



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Forms: Total and Soluble Reactive P

- Total (TP) = total, unfiltered, persulfate-digested result

- Soluble Reactive (SRP) = ortho-P
  = filtered, direct colorimetry result

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Forms: Typical Concentrations in Raw Domestic Wastewater

	Wastewater Strength		
Form	**Strong**	**Medium**	**Weak**
Total	12	7	4
Organic	4	2	1
Inorganic	8	5	3
Ortho-P	6	4	2

Ortho-P ~ 50% of TP

(Metcalf & Eddy)

Removal Concepts: Basic Ideas

- What comes in must go out
  - Water
  - Solids
- Everything must be converted to solid form to be removed
  - Biological (biomass)
  - Chemical
- Remove solids
  - Sedimentation
  - Filtration
  - Membrane separation

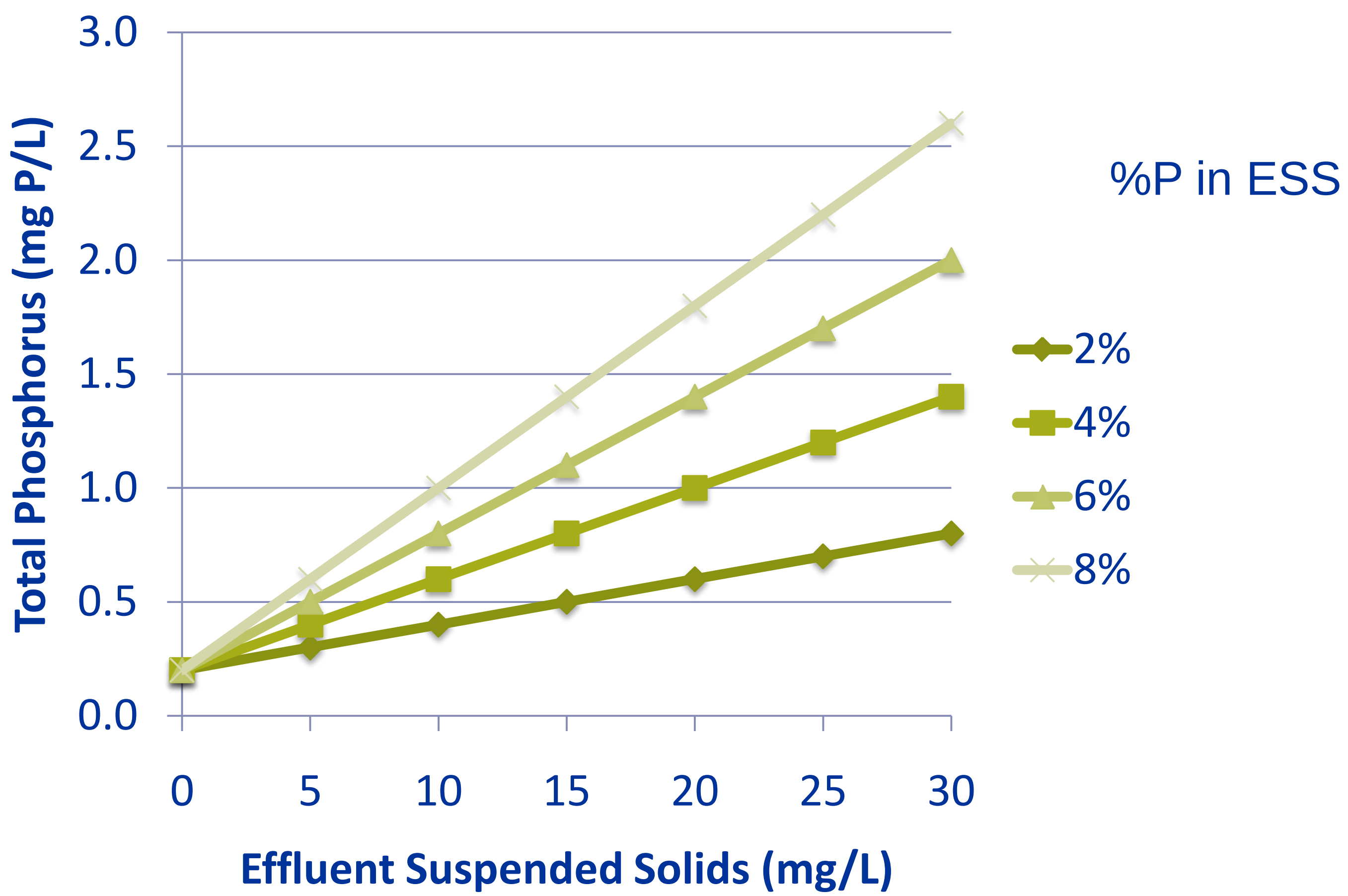
Removal Concepts: Overview

- Inorganic, non-ortho-P converted to ortho-P: **hydrolysis**
- Ortho-P incorporated into biomass: **assimilation**
  - ➔ Increase P content in biomass with P storage with Bio-P
- Ortho-P removed by reaction with metal salts: **chemical precipitation**

Removal Concepts: Incorporation into Biomass

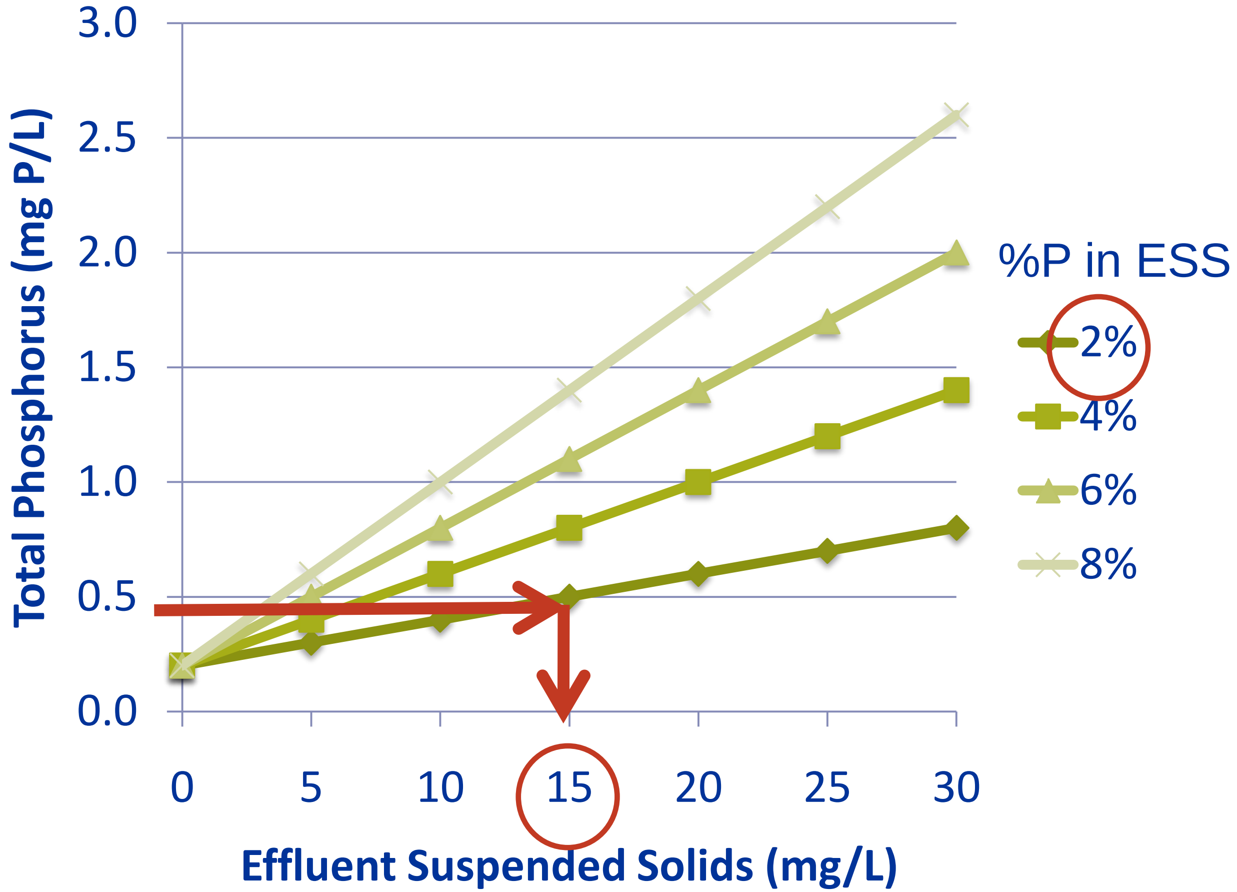
- All biological processes
- Incorporation of ortho-P into biomass during growth: $C_{12}H_{87}O_{23}N_{12}P$
- Waste biomass P % depends on whether conventional activated sludge or Bio-P is used

Removal Concepts: Incorporation into Biomass



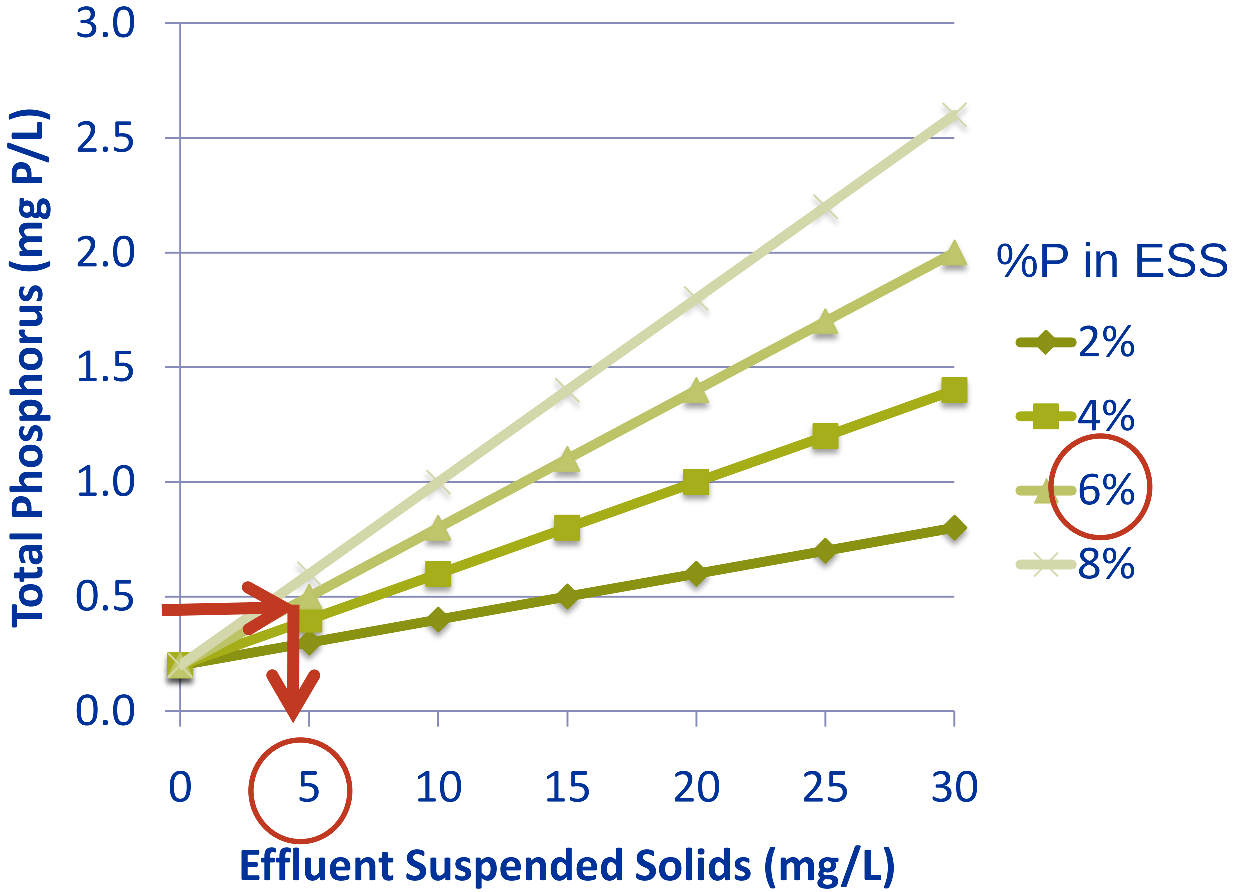
Removal Concepts: Incorporation into Biomass

ESS needed for < 0.5 mg/L TP with conventional activated sludge
Assumes ortho-P = 0.2 mg P/L



Removal Concepts: Incorporation into Biomass

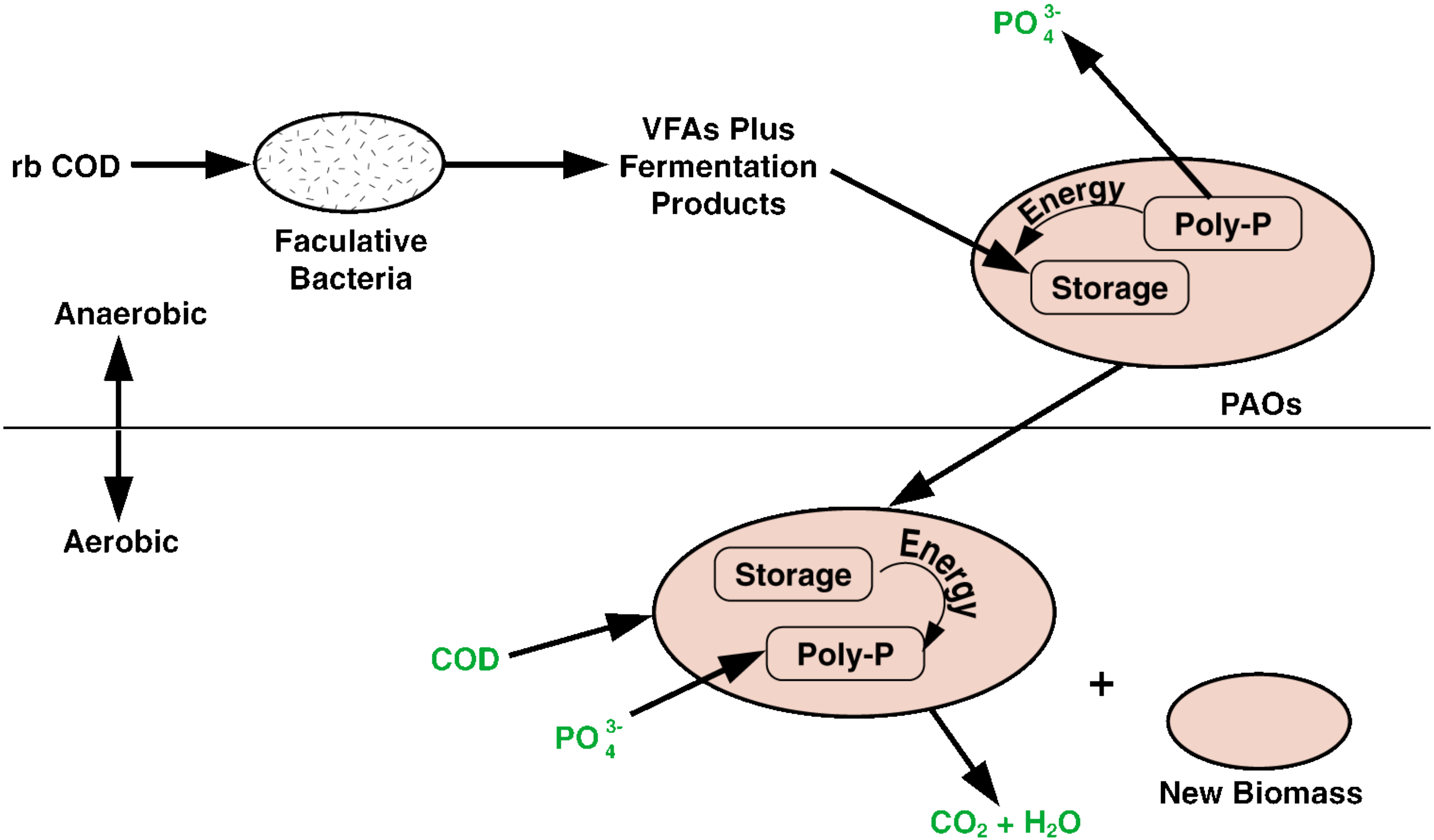
ESS needed for < 0.5 mg/L TP with Bio-P
Assumes ortho-P = 0.2 mg P/L



Removal Concepts: Bio-P

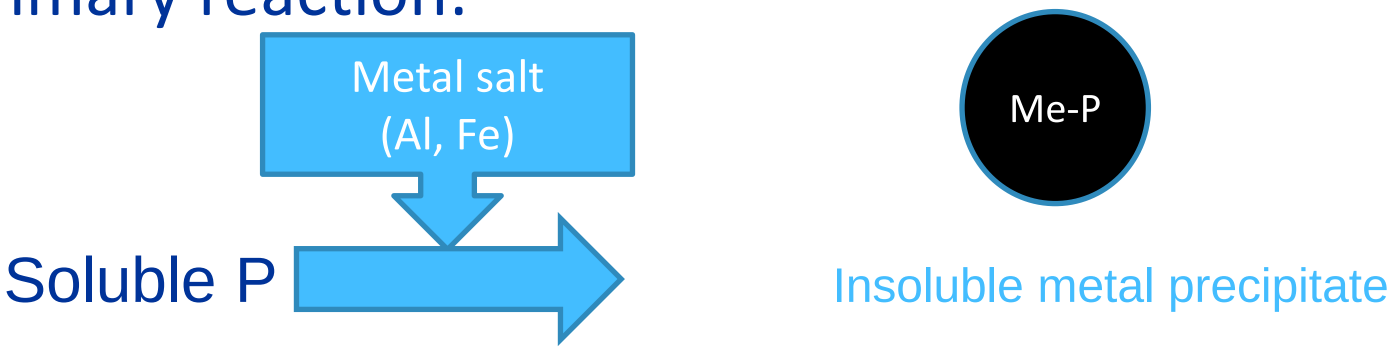
- Anaerobic ("no air" = no nitrate): release ortho-P
- Aerobic: take up more ortho-P than originally released
  - → Performed by P-accumulating organisms or PAOs, distinct from "ordinary" heterotrophs

Removal Concepts: Bio-P

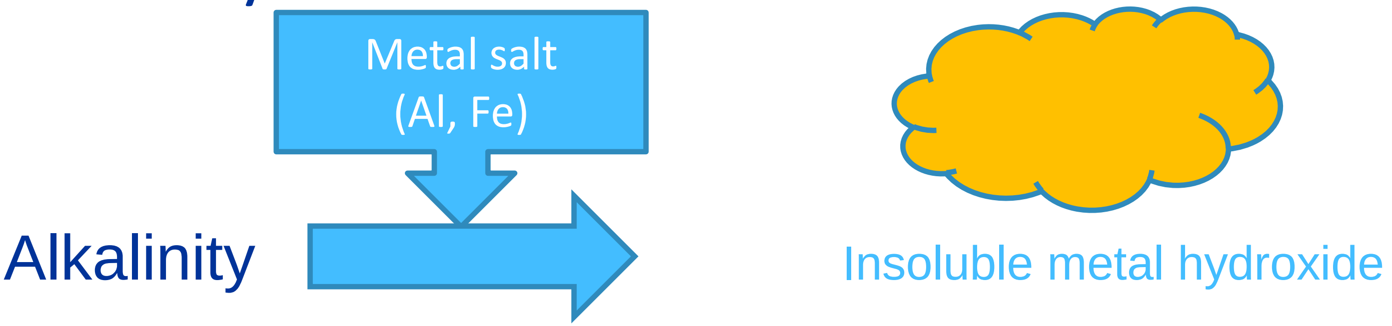


Removal Concepts: Chemical Precipitation

- Primary reaction:

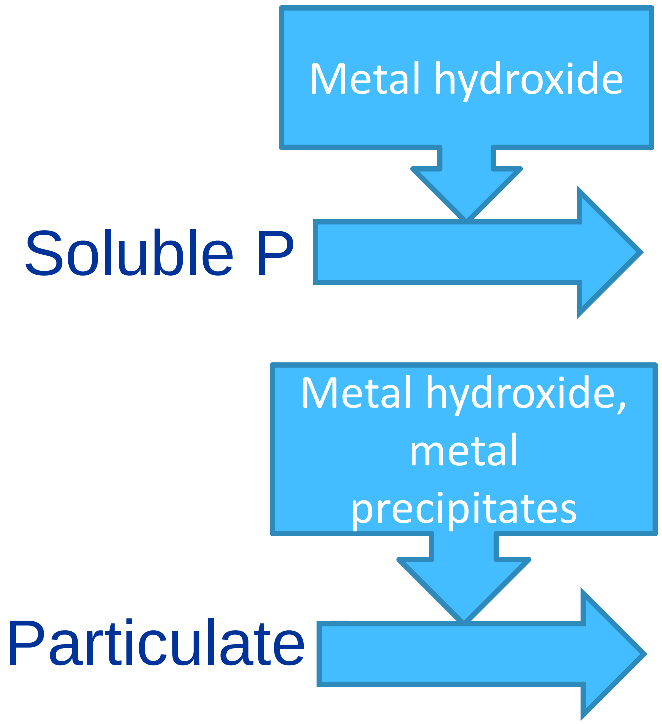


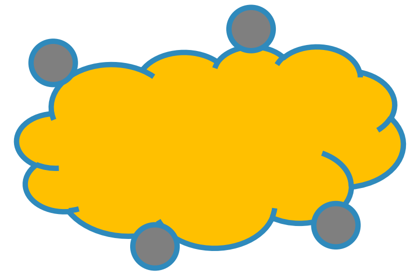
- Secondary reaction:



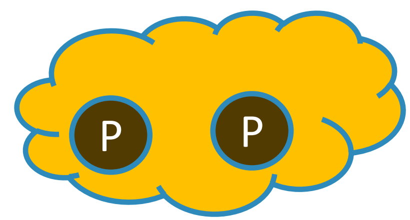
Removal Concepts: Chemical Precipitation

- Additional reactions:





P adsorbed to insoluble metal precipitate



Particulate P enmeshed in precipitates and hydroxides

Removal Concepts: Typical Chemicals

- Iron salts
  - Ferric salts
  - Ferrous salts
- Aluminum salts
  - Alum
  - Sodium aluminate
  - Poly-aluminum chloride (PACl)
- Lime
- Polymers

Process Considerations: Conditions for Bio-P

- Anaerobic/aerobic cycling
- Adequate carbon
  - VFAs (acetate, propionate)
  - Readily biodegradable COD (rbCOD) that can be fermented to VFAs by ordinary heterotrophs
- Minimization of anaerobic re-release of P
- Minimization of competition from glycogen-accumulating organisms

Process Considerations: Carbon Required

Ratio	Minimum to Achieve 1 mg/L TP with Bio-P
BOD:P	20:1
COD:TP	45:1
VFA:TP	10:1
rbCOD:TP	15:1

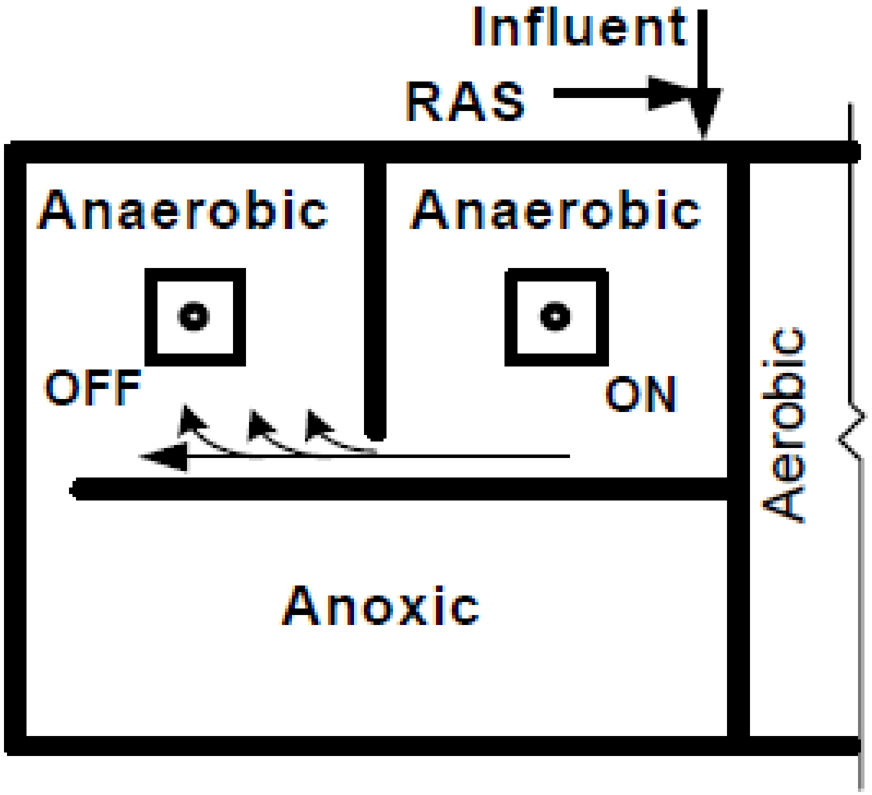
Process Considerations: Carbon Sources

- Increase carbon with:
  - Sidestream fermentation of primary sludge
  - Carbon addition
  - Unmixed, inline fermentation (UMIF)
- Consider variability in VFA supply from:
  - Variable/high BOD removal in primary clarifiers
  - Wet weather flows
  - High/variable recycle loads

Process Considerations: UMIF

- Pinery, CO
- 1.5 mgd
- 5-stage Bardenpho
- Limited bio-P

→ Switched off 2nd anaerobic mixer
→ Allow MLSS to settle and ferment
→ Influent TP = 9 mg/L
→ Secondary effluent TP = 0.5 mg/L



Barnard et al. 2010. "Fermentation of mixed liquor for phosphorus removal" Presented at WEFTEC.

Removal Concepts: Re-Release of P

- Re-release of stored P from Bio-P
- P assimilated into biomass or removed chemically does not release
- Re-release of P can occur:
  - In anoxic zone that becomes anaerobic
  - When aerobic digester is decanted after air turned off over night
  - When solids become anaerobic during thickening/dewatering
  - In anaerobic digester

Process Considerations: Avoiding Re-Release

- Consider converting portion of initial anoxic zone to swing zone to avoid anaerobic conditions
- Consider conversion of second anoxic zone to aerobic
- Avoid carrying a deep clarifier sludge blanket
- Evaluate effects of P-rich sidestream and consider avoiding:
  - Unaerated sludge storage
  - Co-settling of primary sludge and WAS in primary clarifier
  - Anaerobic digestion

Process Considerations:
Avoiding GAO Competition

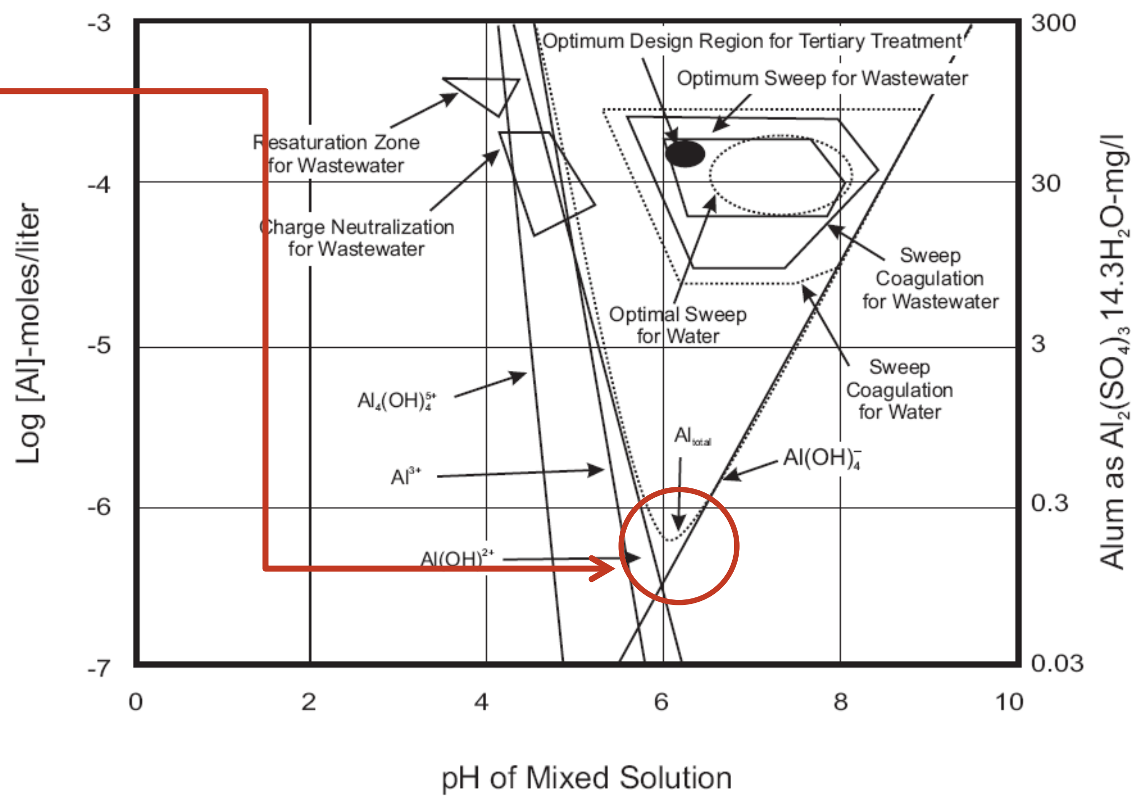
	Anaerobic	Aerobic
PAOs	✓ VFA uptake and storage ✓ P release	✓ Excess P uptake ✓ Stored food oxidized
GAOs	✓ VFA uptake and storage <u>No P release</u>	<u>No excess P uptake</u> ✓ Stored food oxidized

Process Considerations:
Avoiding GAO Competition

- GAO conditions:
  - Warm temperatures
  - Long SRT
  - Long anoxic and anaerobic HRTs
  - Variable supply of VFAs
  - Ongoing use of acetic acid
  - pH < 7

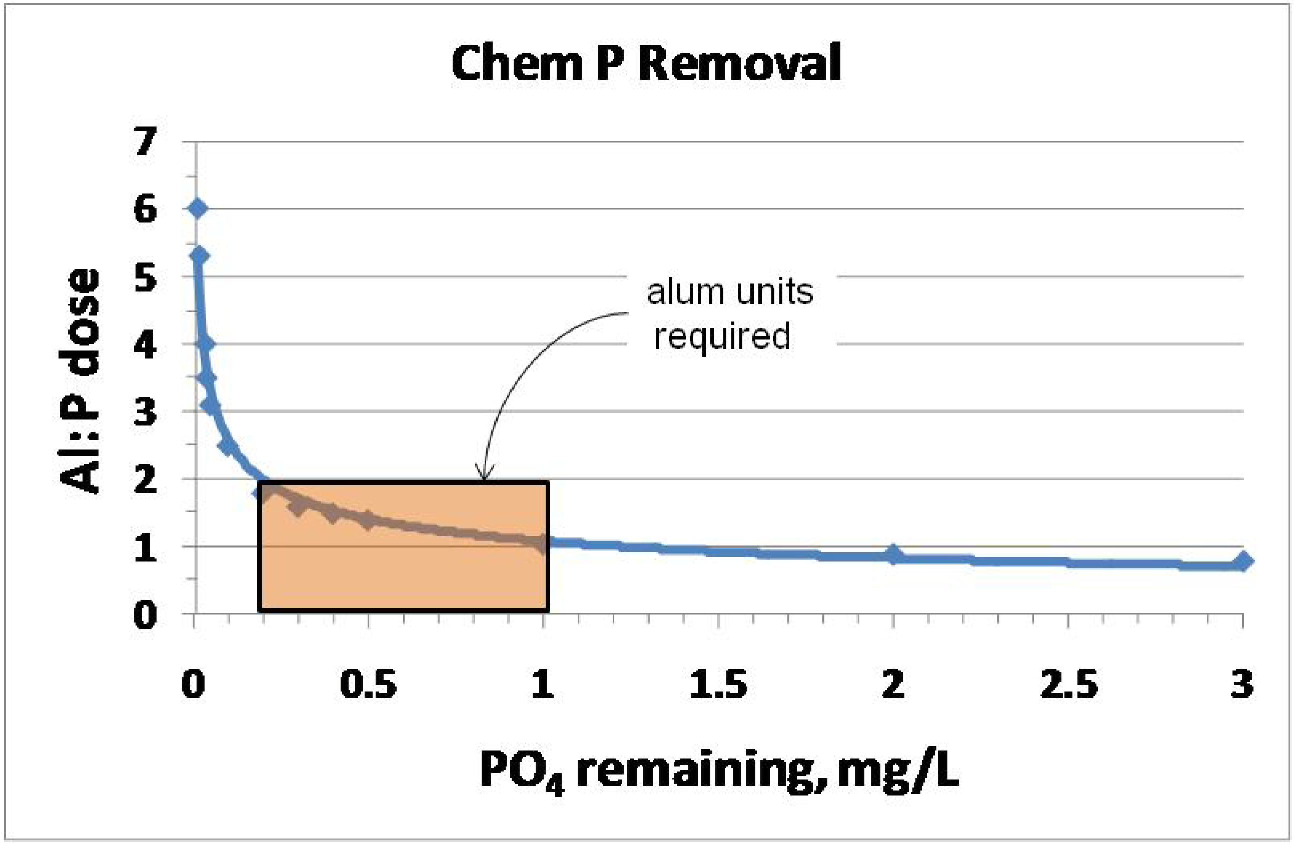
Process Considerations:
Conditions for Chemical P

- Optimal pH
- Adequate mixing
- Multiple addition points



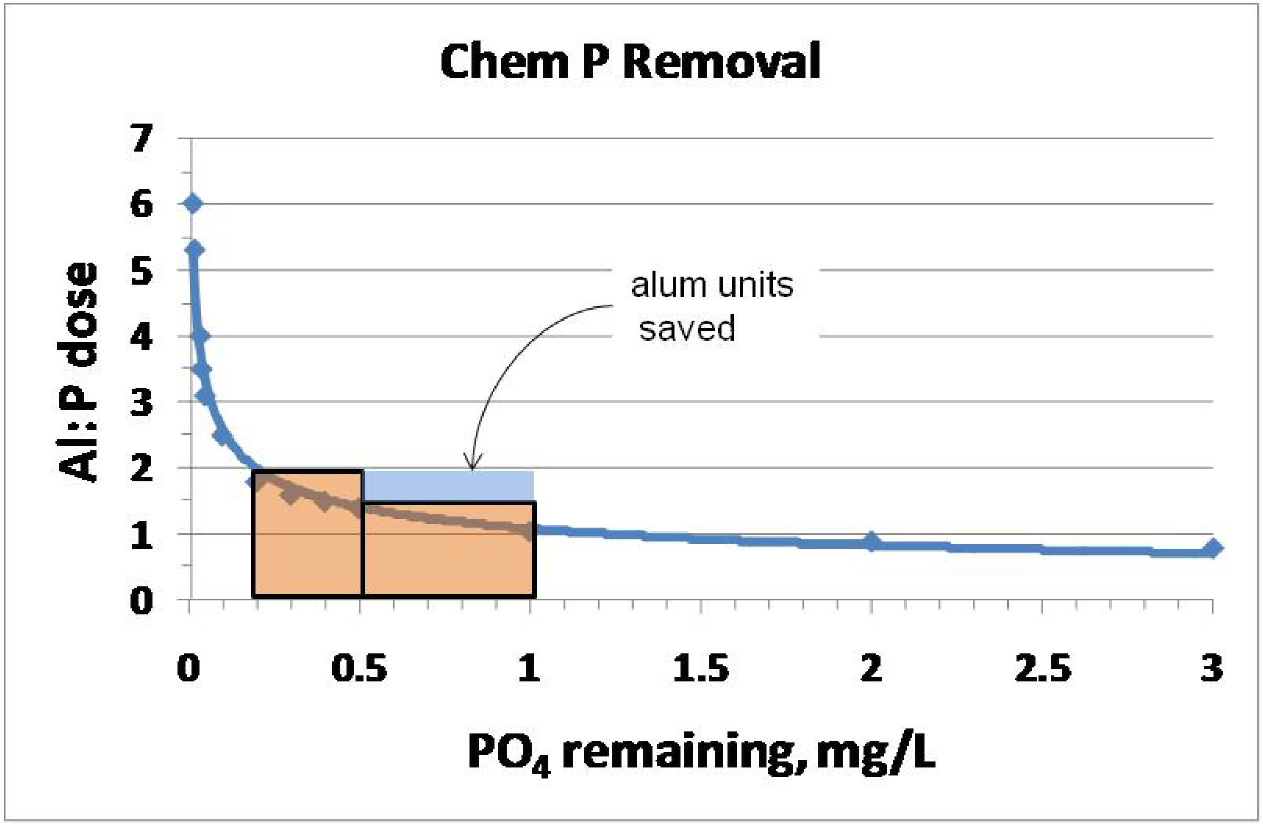
Process Considerations:
Single-Point Addition

- 1 mg/L to 0.2 mg/L
- Dose = 1.6 units alum



Process Considerations:
Dual-Point Addition

- Stage 1:
  - 1 mg/L to 0.5 mg/L
- Stage 2:
  - 0.5 mg/L to 0.2 mg/L
- Dose = 1.35 units alum



2-stage dosing reduces alum demand by 16% in this example

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Process Considerations:
Dual-Point Addition

- Example 1: Single feed removal
  - 1 mg/L to be reduced to 0.2 mg/L
  - 0.8 mg/L reduction requires 2.0:1 Al:P ratio
- Example 2: Dual feed removal
  - Stage 1: 1 mg/L reduced to 0.5 mg/L
  - 0.5 mg/L reduction requires 1.5:1 Al:P ratio
  - Stage 2: 0.5 mg/L reduced to 0.2 mg/L
  - 0.3 mg/L reduction requires 2.0:1 Al:P ratio
- 16% less chemical using dual feed

Process Considerations:
Effluent TP with Bio-P

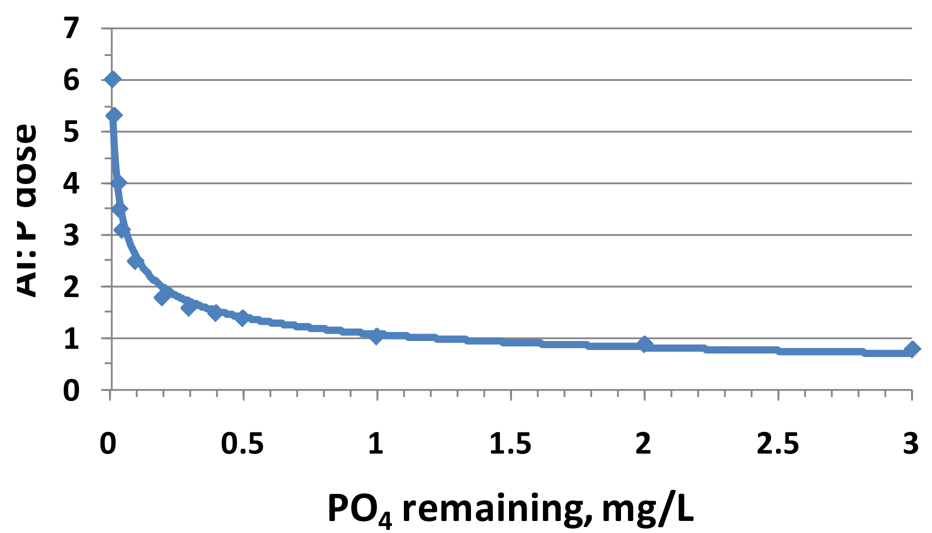
- From Randall:
  - 0.16 mg/L at Bowie Creek, MD
  - ESS ~ 2 mg/L
- From Barnard:
  - 0.11 mg/L at Kalispell, MT
- Conventional wisdom:
  - 1 mg/L
  - Need filters

Process Considerations:
Effluent TP with Chemical P

- Precipitation before/with secondary treatment: 0.1 to 0.4 mg/L
- Tertiary clarification/filtration: 0.05 mg/L

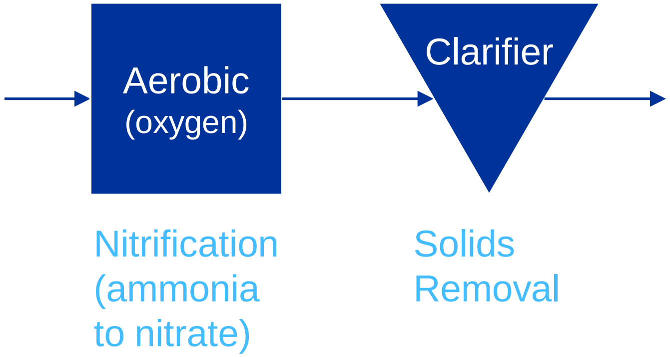
Process Considerations:
Balancing Bio-P and Chemicals

- Very difficult to avoid releasing P taken up during Bio-P
- Bio-P may reduce chemical use, but chemicals likely still needed
- Decision for chemicals is:
  - Treat large, dilute flow?
  - Treat small, concentrated flow (digester decant, filtrate)?



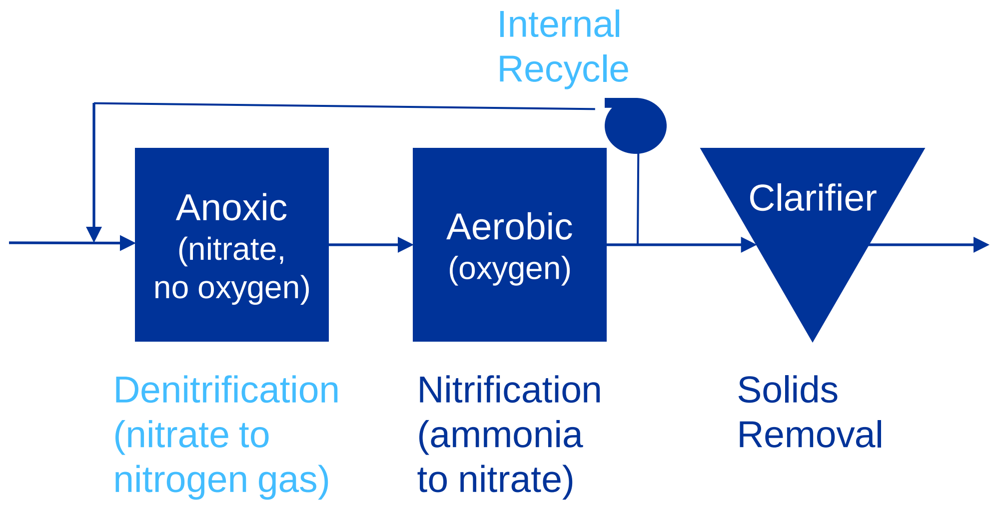
N & P Removal: Combined Nutrient Removal

- **Nitrification (ammonia to nitrate)**



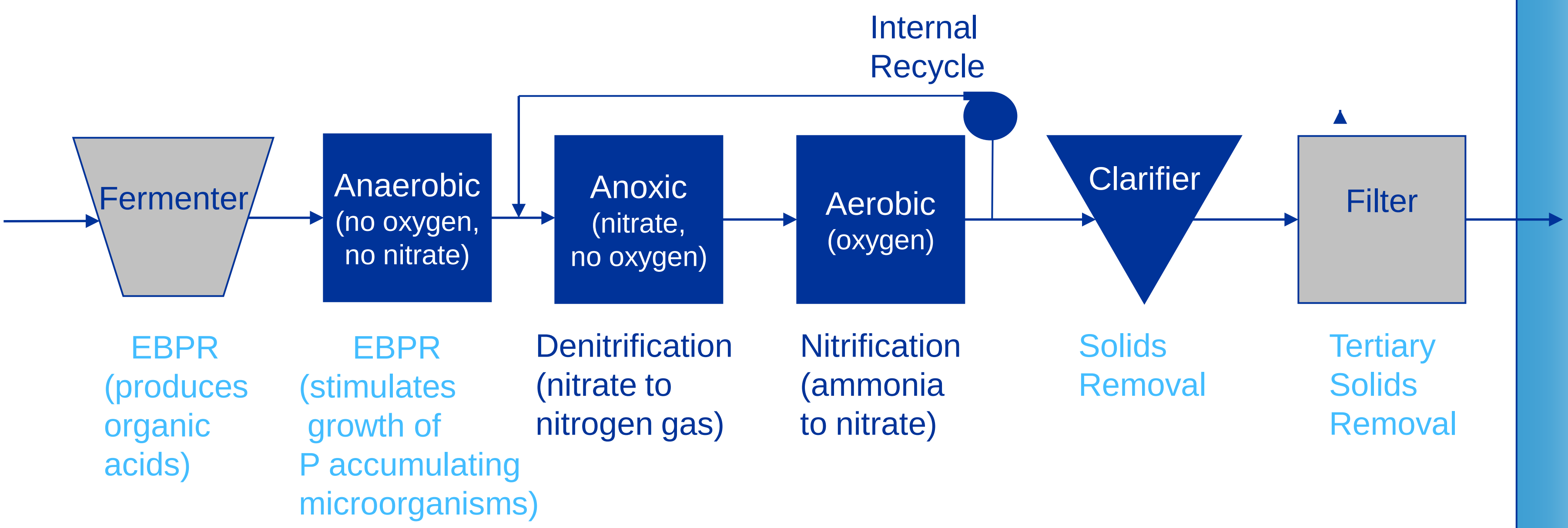
N & P Removal: Combined Nutrient Removal

- Nitrification (ammonia to nitrate)
- **Denitrification (nitrate to nitrogen gas)**



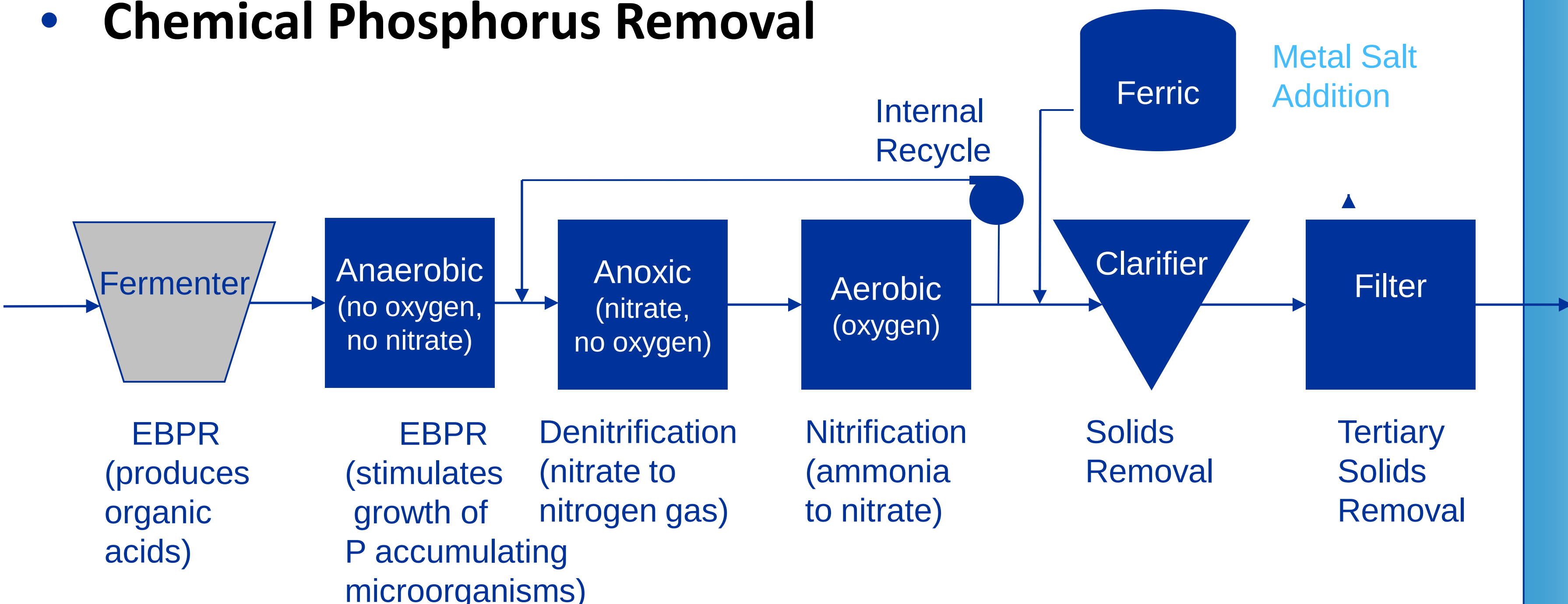
N & P Removal: Combined Nutrient Removal

- Nitrification (ammonia to nitrate)
- Denitrification (nitrate to nitrogen gas)
- **Enhanced Biological Phosphorus Removal (EBPR)**



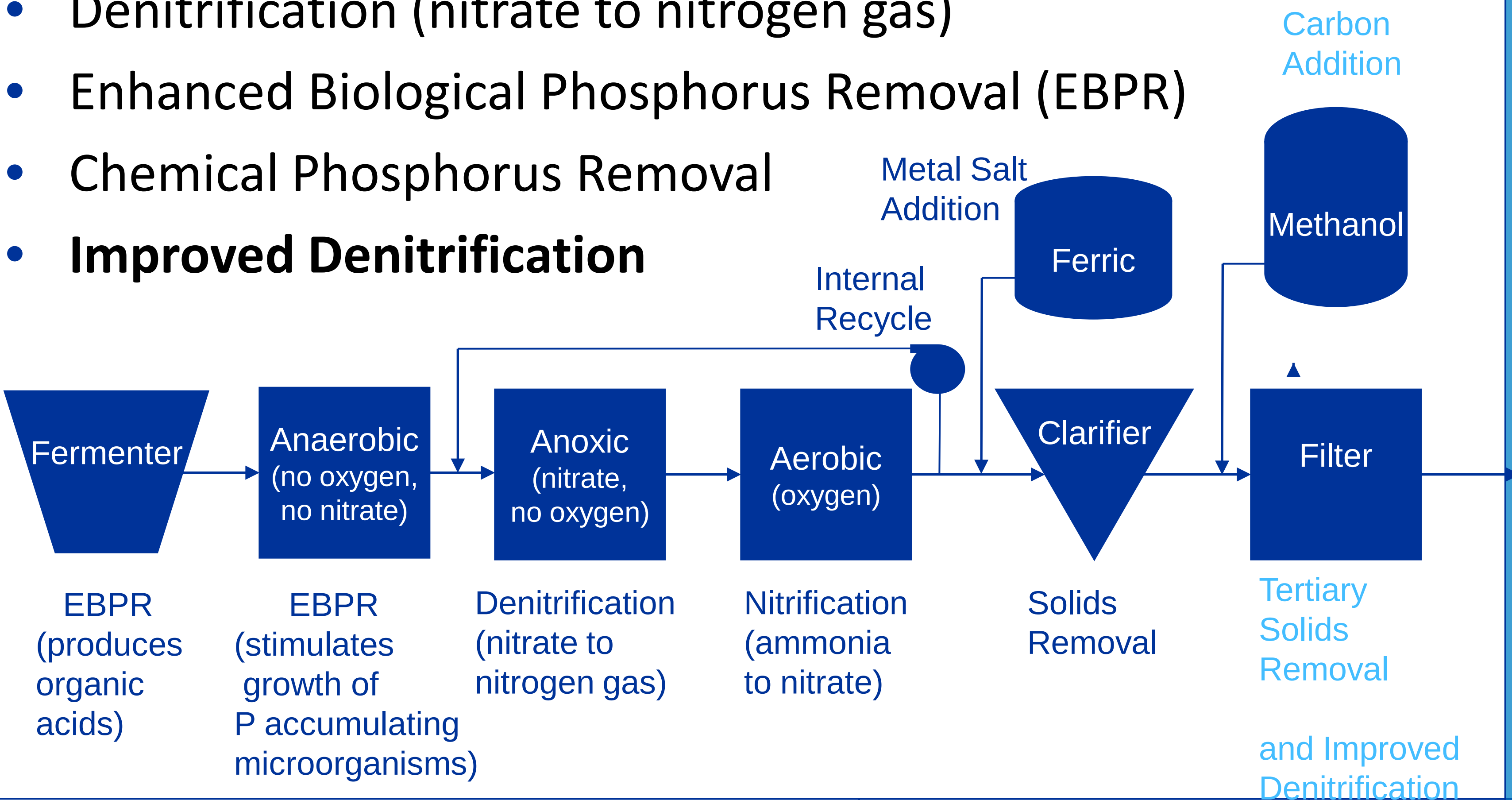
N & P Removal: Combined Nutrient Removal

- Nitrification (ammonia to nitrate)
- Denitrification (nitrate to nitrogen gas)
- Enhanced Biological Phosphorus Removal (EBPR)
- **Chemical Phosphorus Removal**



N & P Removal: Combined Nutrient Removal

- Nitrification (ammonia to nitrate)
- Denitrification (nitrate to nitrogen gas)
- Enhanced Biological Phosphorus Removal (EBPR)
- Chemical Phosphorus Removal
- **Improved Denitrification**



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