Integrated Fixed Film Activated Sludge Enhanced Biological Phosphorus Removal

IFAS-EBPR

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CE 553

Raven Althouse, Serene Hayes, Marco Kleimans, Connor Sauceda, and Marella Schammel

Agenda

I. Enhanced Biological Phosphorus Removal (EBPR)
II. Integrated Fixed Film Activated Sludge (IFAS)
III. IFAS-EBPR Systems
IV. Full-Scale Study
V. Cost Effectiveness of IFAS-EBPR
VI. Application to OCSD

Enhanced Biological Phosphorus Removal (EBPR)

- Only ~20% of P is removed from wastewater, via conventional secondary biological treatment
  - Chemical precipitation
  - Biological treatment
- Chemical Precipitation
  - Removes up to 90% of influent P by adding either Fe (Fe^{2+}/Fe^{3+}) or Al (as chloride/sulfate salts) to form insoluble ferric phosphate or ferric hydroxide-phosphate complexes
  - Precipitate from the wastewater and are removed as sludge
  - Results in 95% more sludge

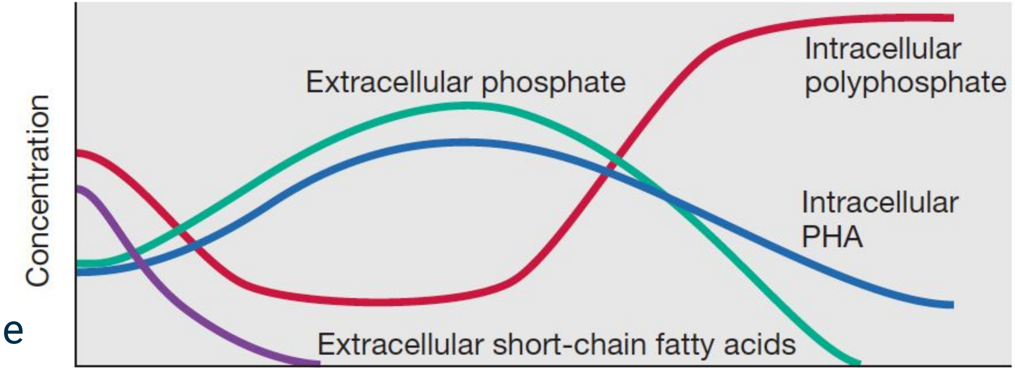
Enhanced Biological Phosphorus Removal (EBPR)

Biological Treatment: EBPR

- Growth of phosphorus accumulating bacteria can remove up to 90% P
- Two step process: Anaerobic + Aerobic

  - **Anaerobic phase**:
  - Phosphorus-accumulating organisms (PAOs) use energy from stored polyphosphate, producing intracellular polyhydroxyalkanoates (PHAs) and releasing soluble orthophosphate

  - **Aerobic phase**:
  - Stored PHAs used as energy and carbon source for cell growth. Intracellular polyphosphate is formed using energy and orthophosphate is removed from solution.
  - Polyphosphate storing biomass/sludge is collected, removing P

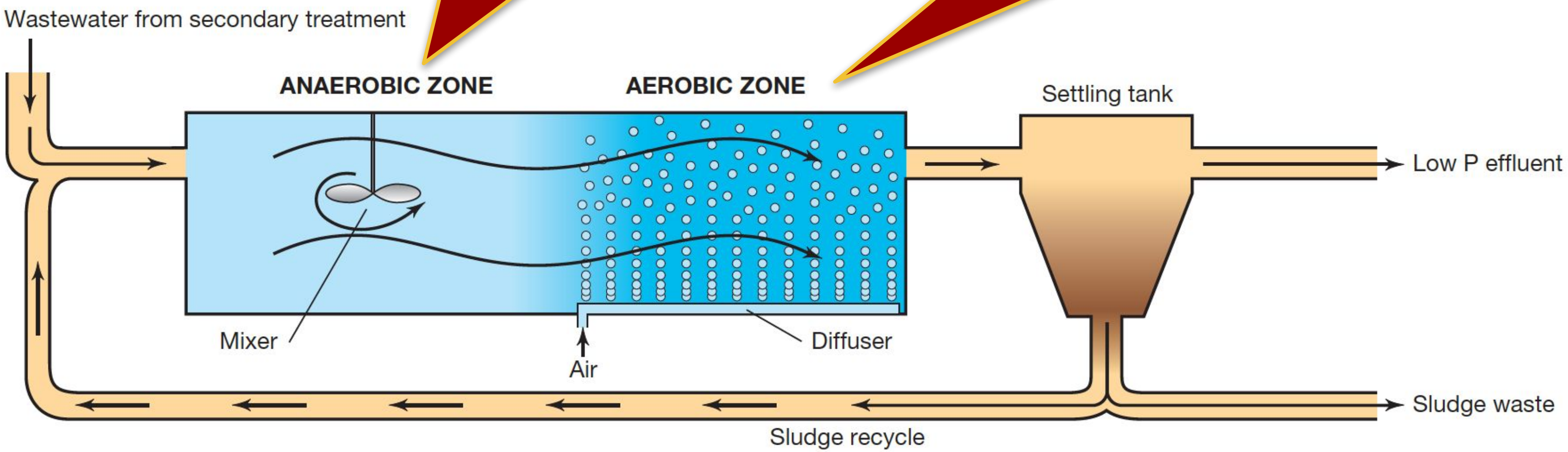


(Madigan et al., 2015)

Enhanced Biological Phosphorus Removal (EBPR)

Phosphorus-accumulating organisms (PAOs) use energy available from stored polyphosphate to assimilate short-chain fatty acids and produce intracellular pholyhydroxyalkanoates (PHAs), while releasing PO_4^{3-}.

Intracellular PHAs are metabolized and orthophosphate from the wastewater is taken up by the cell to be stored as Poly-P (removing P from WW)



(Madigan et al., 2015)

Integrated Fixed Film Activated Sludge (IFAS)

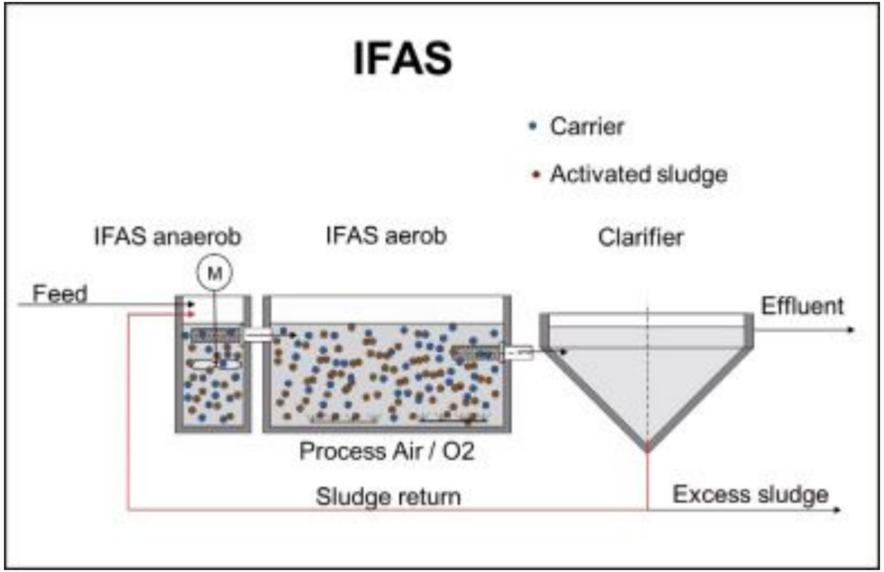
Integrated Fixed-film Activated Sludge (IFAS) (anaerobic/aerobic with returning activated sludge) has been gaining popularity as it enhances overall reactor performance of by creating suspended growth systems with biomass development attached to the solid media.

IFAS media can be plastic or fabric. The amount of biomass that grows on the media depends on a host of factors, including loading, dissolved oxygen concentration, temperature, mixing energy, suspended phase biomass concentration, and solids retention time.

Integrated Fixed Film Activated Sludge (IFAS)

Some benefits include:

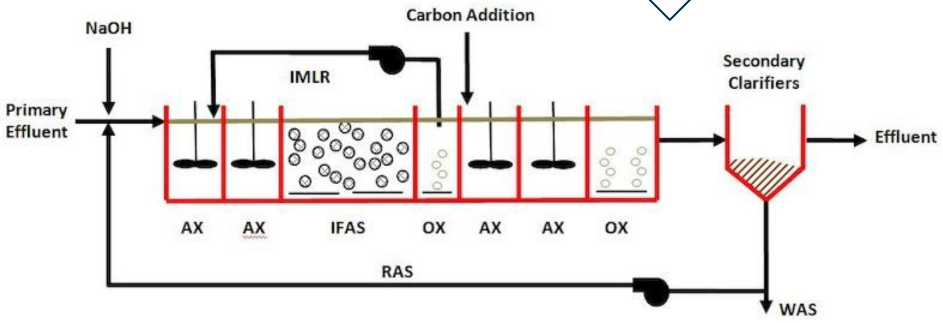
1. Decoupling of SRT (suspended biomass + attached biofilm growth)
2. Promote full nitrification - denitrification
3. Less footprint
4. Better removal of composites of anthropogenic origin



Integrated Fixed Film Activated Sludge (IFAS)

Considerations for IFAS systems:

- Mixing
- Turbulence
- Aeration
- Effluent Screens
- Foam removal
- Accumulation of debris



Field's Point Wastewater Treatment Facility (FPWWTF) in Providence, R.I

AnoxKaldnes IFAS: Meeting new limits. (2019, September 17).

Retrieved from https://www.wwdmag.com/channel/casestudies/providence-ri-removes-nutrients-saves-money-retrofit

Combining IFAS and EBPR

- Goal is simultaneous nitrification and P-removal
    - Competition for oxygen and organic carbon

- IFAS-EBPR: nitrifiers reside on biofilm, PAOs retained in suspended biomass

- SRT < 4 days
    - Favors PAOs over GAOs

Onnis-Hayden, A., Majed, N., McMahon, K.D., & Gu, A.Z. (2008). Phosphorus Removal and PAOs Populations at a Full-Scale Integrated Fixed-Film Activated Sludge (IFAS) Plant. *Proceedings of the Water Environment Foundation, 17*, 1-17. https://doi.org/10.2175/193864708788735484

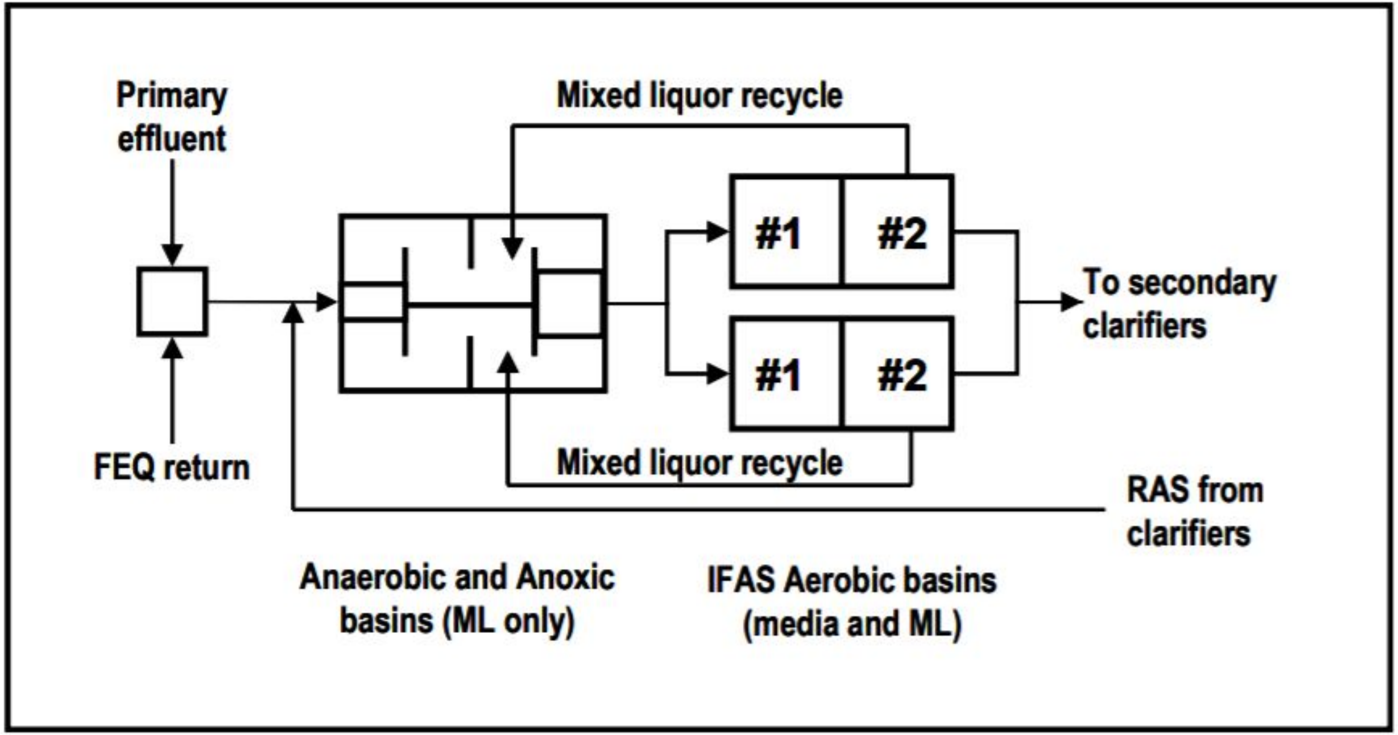


Figure 1. Process schematic of Broomfield BNR/IFAS facilities.

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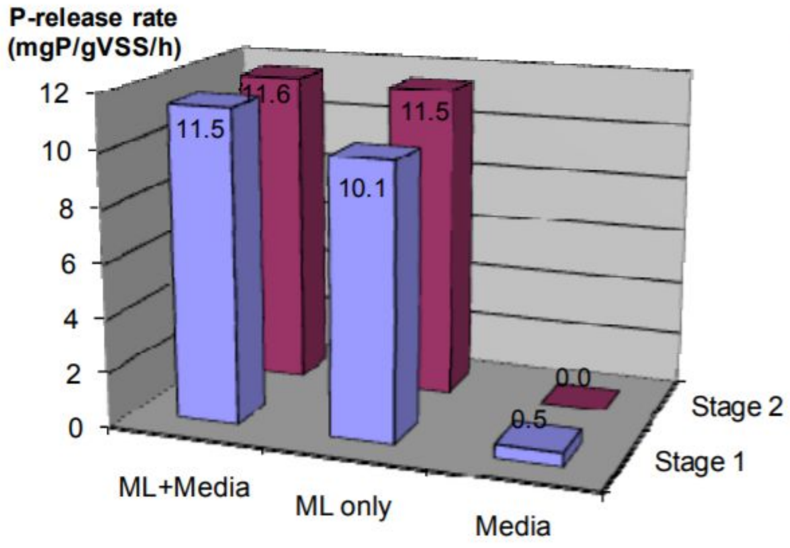
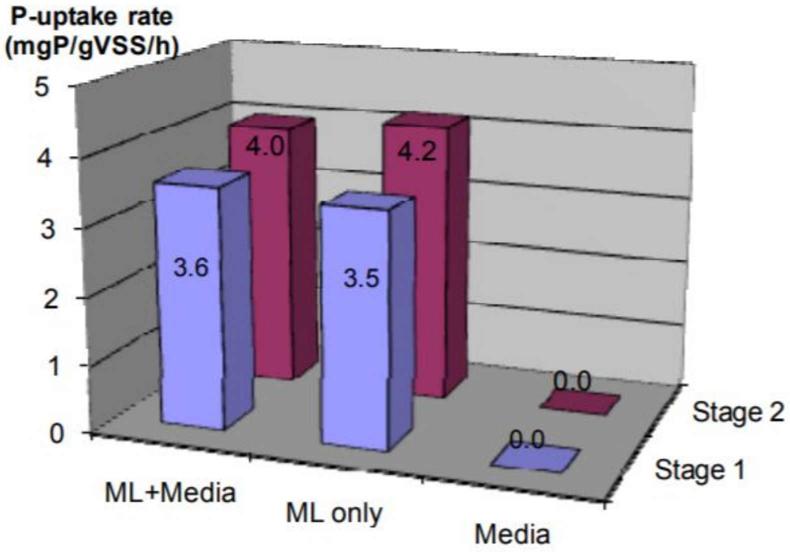
Combining IFAS and EBPR

- Aerobic P uptake rate = 3.5-4.2 mg P/VSS-h
- Anaerobic P release rate = 10.1-11.6 mg P/VSS-h





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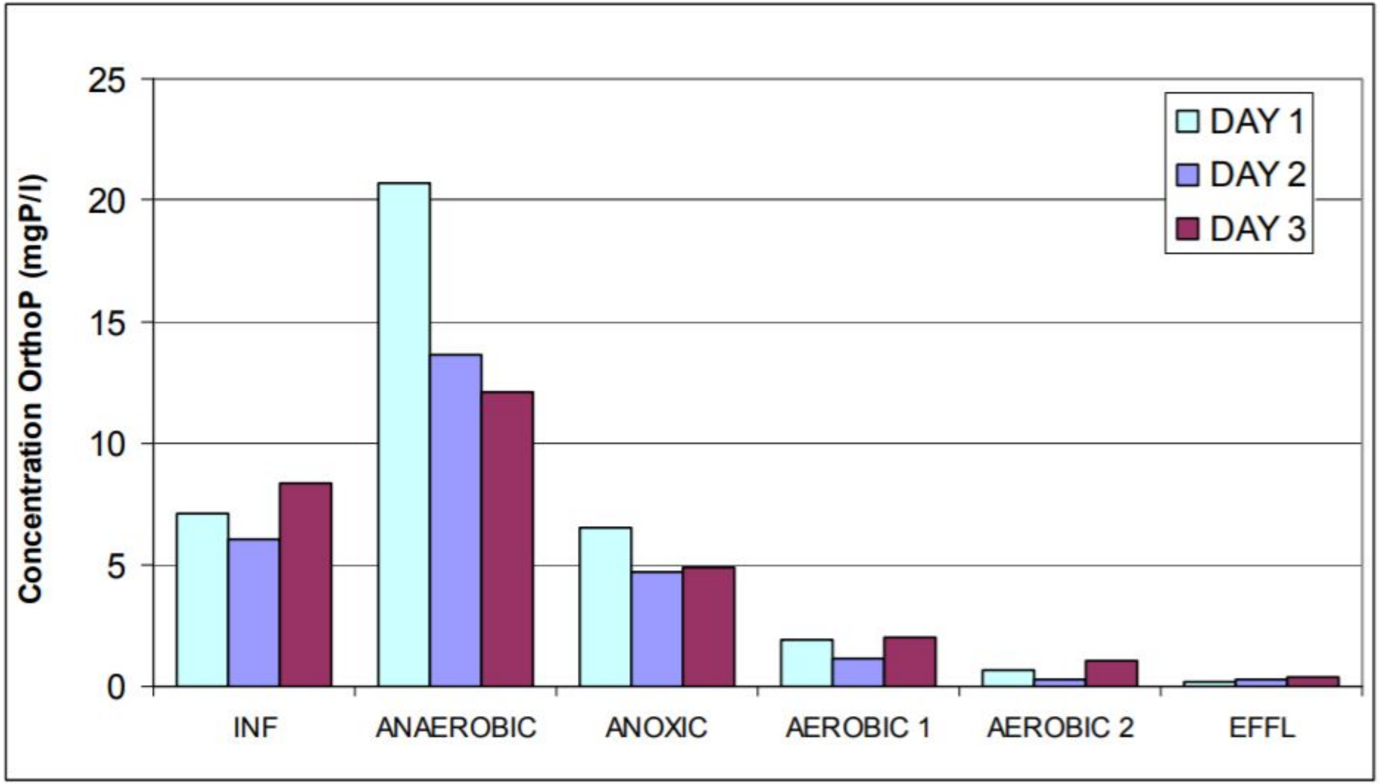

Figure 5. Profiles of Ortho-P along the plant, for the three days of sampling.

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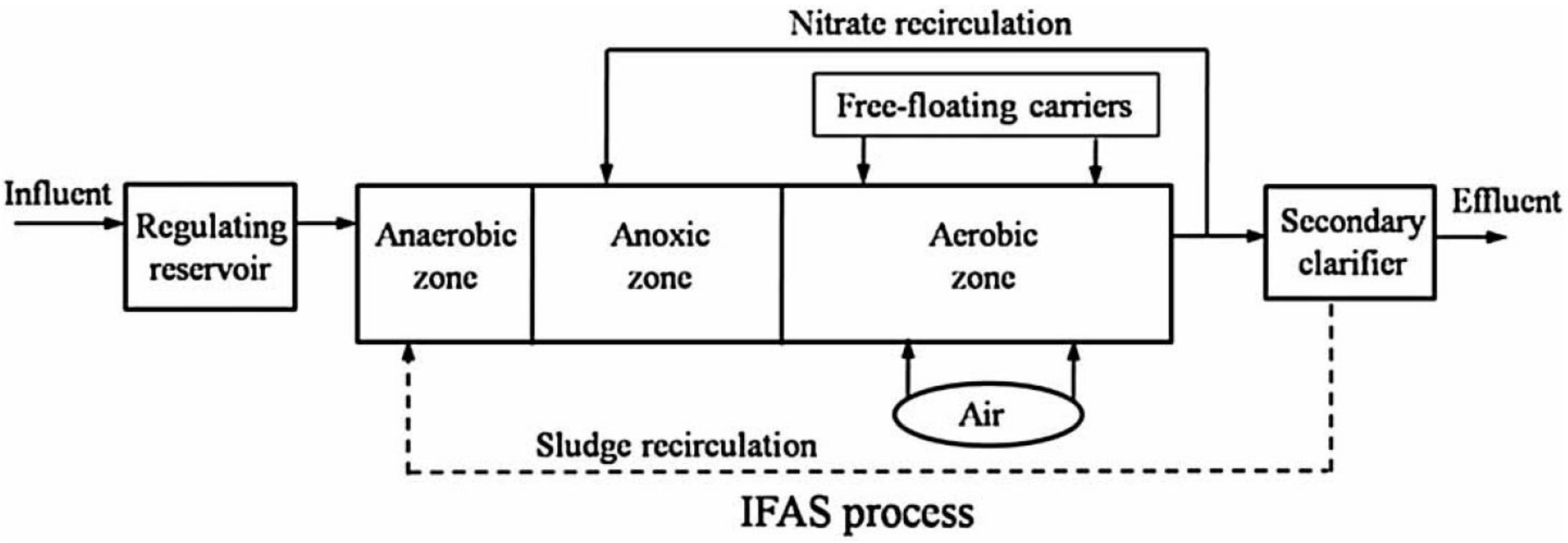
Full Scale IFAS-EBPR Performance (Bai et al)

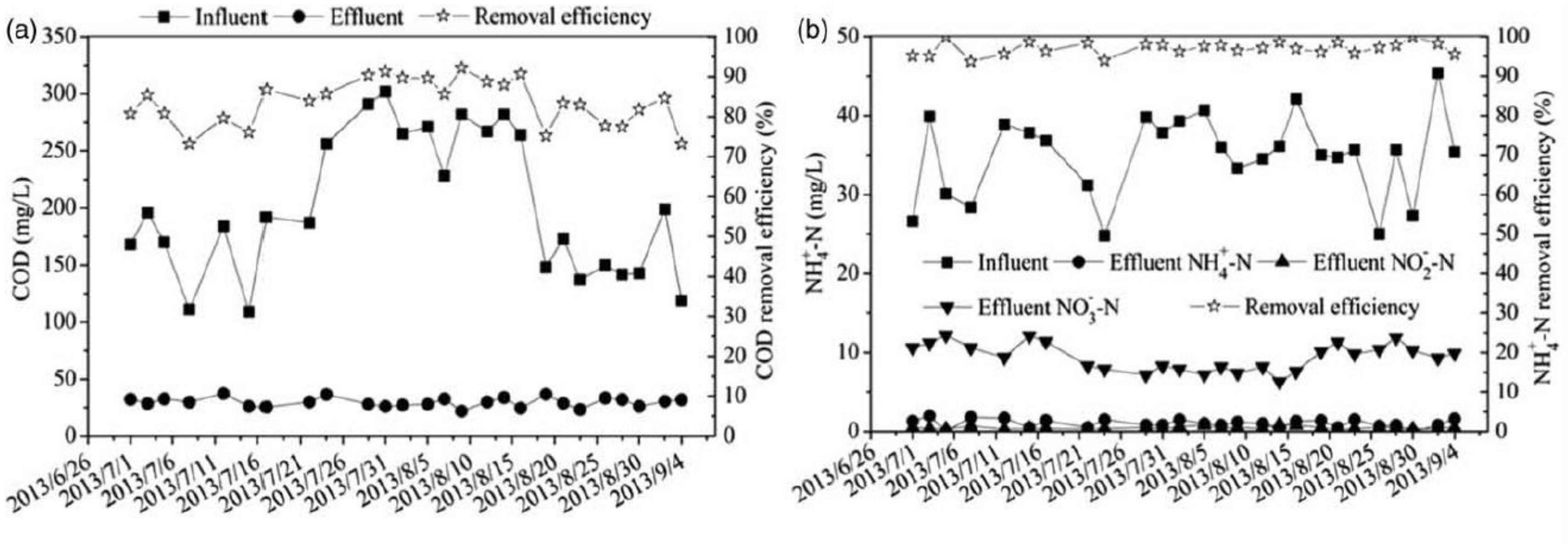
- 13 MGD wastewater treatment plant in Dalian, China
- 2 month study period with sampling every 5 days
- Monitored COD, NH4, NO3, NO2, Total N, Total P
- Microbial composition of biofilm and suspended biomass



Nutrient removal performance and microbial characteristics of a full-scale IFAS-EBPR process treating municipal wastewater (Bai et al, 2016)

Full Scale IFAS-EBPR Performance

COD and NH4 Removal



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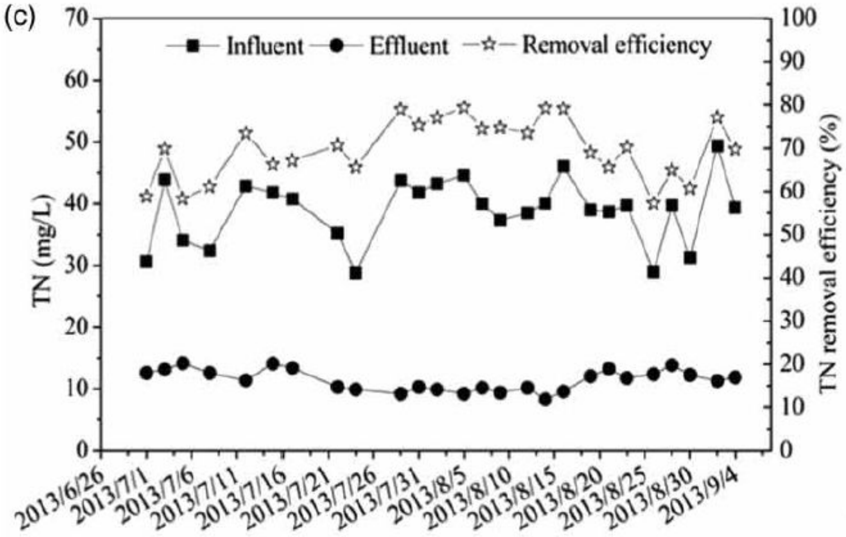
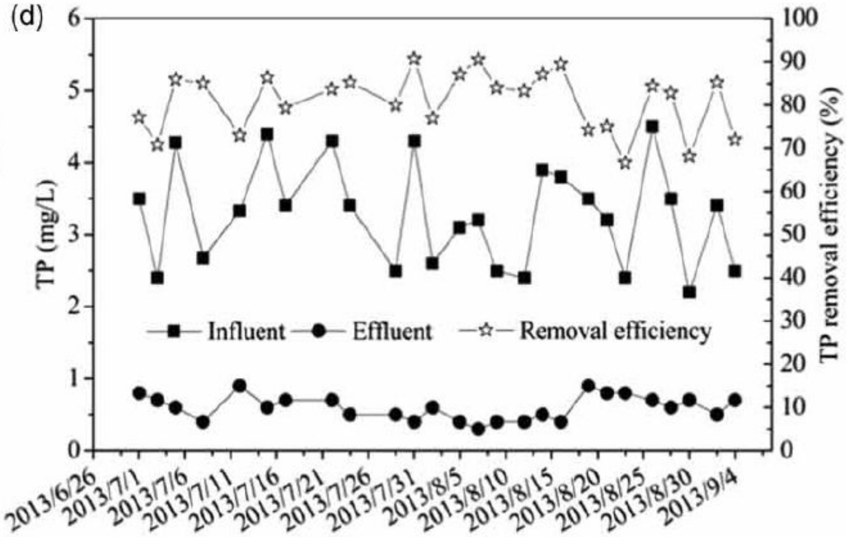
Full Scale IFAS-EBPR Performance

Total N and Total P





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Full Scale IFAS-EBPR Performance

- COD loading increasing in the middle of the study period
- During elevated COD loading, effluent COD was consistent, and nutrient removal was enhanced
  - 76% TN removal compared to 66.7% and 64.8% before and after, respectively
  - 85% TP removal compared to 80% and 76% before and after, respectively

	Jul 1-Jul 22	Jul 24-Aug 16	Aug 19-Sep 4
COD	160.4	283.8	157.1
TN	37.7	40.4	38.3
COD/TN	4.3	7.0	4.1

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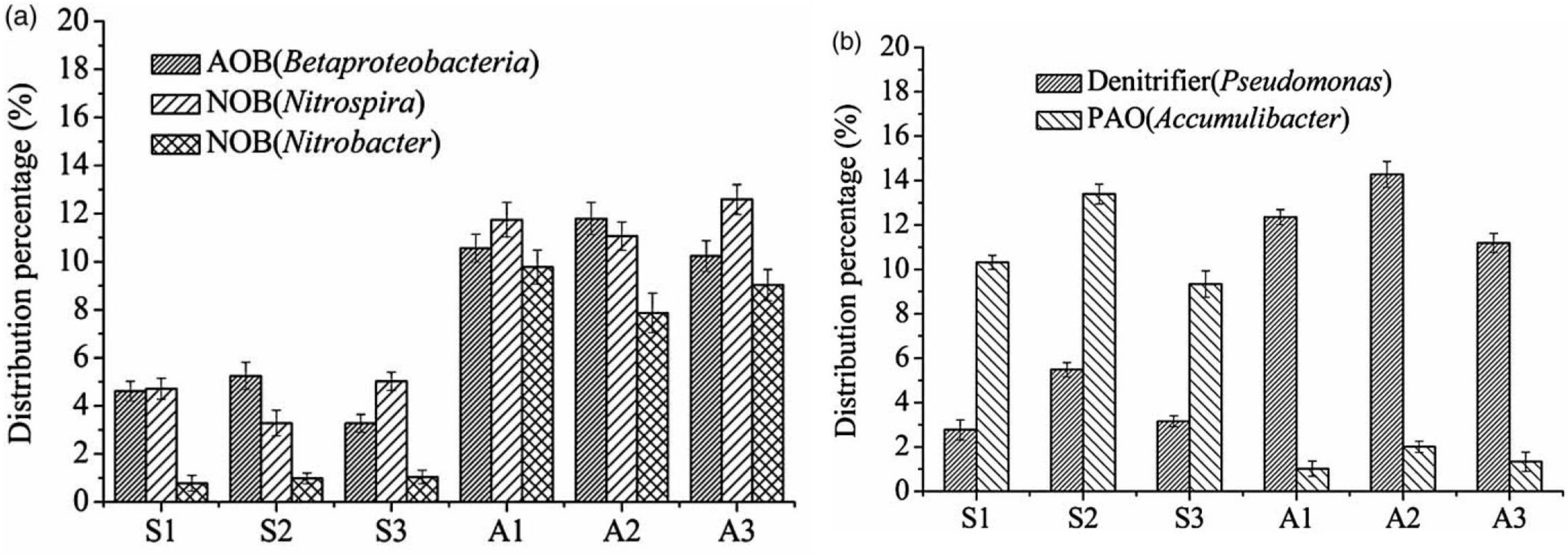
Full Scale IFAS-EBPR Microbial Composition



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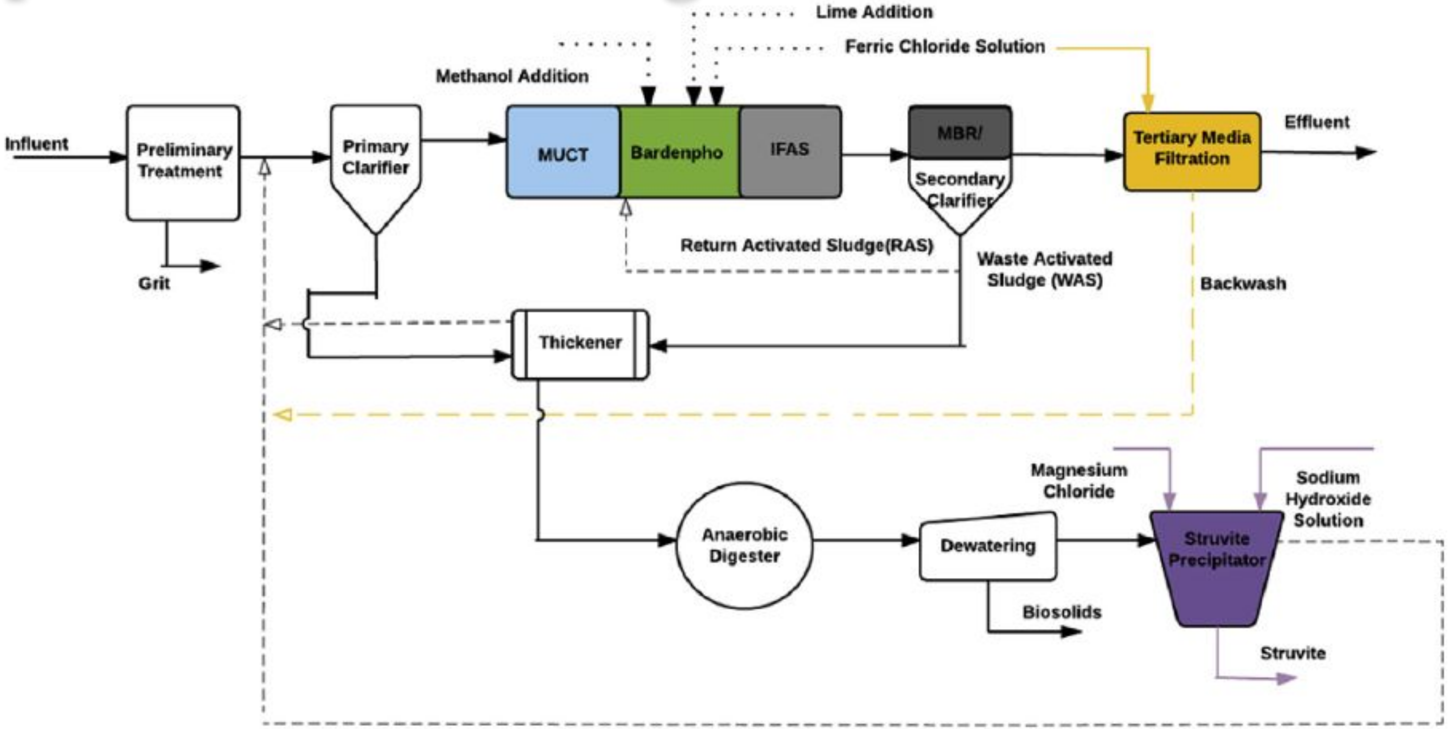
Cost Effectiveness of IFAS-EBPR

- Comparison between six (6) established and emerging technologies to show cost-effectiveness of phosphorus removal processes
- BioWin used as a tool to simulate 5 MGD full-scale plant with Phosphorus removal
- Operations & Maintenance Considered:
  - Energy
  - Chemical
  - Sludge Disposal
  - Maintenance & Insurance

Comparison of Technologies



- *Scenario 1 (S1):* MUCT BNR
- *Scenario 2 (S2):* Bardenpho five-stage BNR
- *Scenario 3 (S3):* MUCT BNR+ Membrane Bioreactor
- *Scenario 4 (S4):* IFAS-EBPR
- *Scenario 5 (S5):* MUCT BNR+ P recovery as struvite
- *Scenario 6 (S6):* MUCT BNR+ Tertiary reactive media filtration

Phosphorus Removal

Table 1
Influent operational data from Nine Springs Wastewater Treatment Plant, Madison, WI (N = 71).

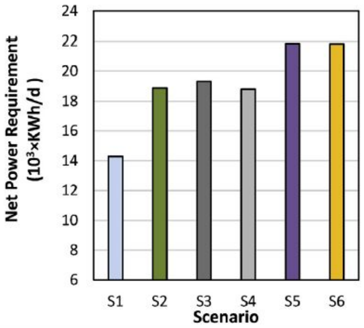
Parameter	Mean	Min	Max	SD	Typical range[a]
Flow, million gallons per day (MGD)	38.0	32.0	48.4	3.9	–
Chemical Oxygen Demand (COD), mg/L	507	450	540	28.2	250–800
Biochemical oxygen demand (BOD_5), mg/L	239.4	177.8	295.6	24.2	110–350
pH	7.5	7.3	9.6	0.3	7.0–8.0
Total Kjeldahl Nitrogen (TKN), mg/L	42.5	32.5	49.0	4.1	20–70
Total Phosphorus (TP), mg/L	5.7	4.6	6.7	0.5	4–12
Total Suspended Solids (TSS), mg/L	230.0	183.0	277.3	19.5	12–400
Calcium (Ca), mg/L	86.5	85.3	89.3	1.1	–
Magnesium (Mg), mg/L	45.6	44.8	46.8	0.6	–
NH_3-N, mg-N/L	26.8	20.1	32.7	3.1	20–75
Alkalinity, eqv/m^3	4.8	4.6	5.0	0.2	1–7

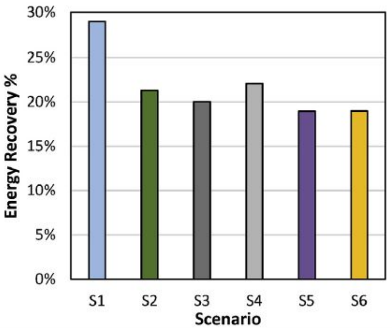
Min = Minimum, Max = Maximum, SD= Standard Deviation.
[a] Tchobanoglous et al. (2013).

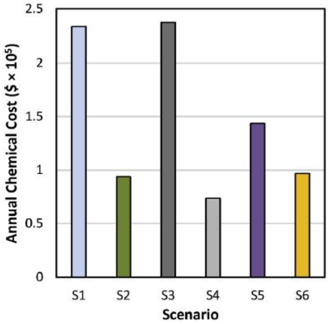
Table 2
Effluent quality for the six treatment scenarios evaluated in this study.

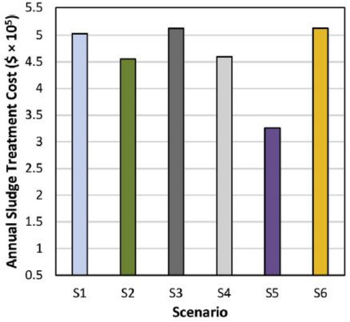
	S1 (MUCT)	S2 (Bardenpho)	S3 (MBR)	S4 (IFAS-EBPR)	S5 (P Recovery)	S6 (Tertiary Filtration)
Effluent						
Total BOD, mg/L	2.05	1.20	0.80	1.36	1.46	1.04
Total COD, mg/L	33.41	30.10	28.47	29.18	29.79	29.90
TSS, mg/L	2.87	1.24	<0.01	1.28	1.85	<0.01
Ammonia N, mg/L	0.62	0.06	0.08	0.35	0.31	0.62
NO_3-N, mg/L	7.04	5.29	6.99	7.36	7.15	7.05
NO_2-N	0.18	0.02	0.02	0.11	0.41	0.18
TIN, mg/L	7.84	5.37	7.09	7.82	7.87	7.85
TP, mg/L	0.90	0.95	1.02	0.82	0.58	0.05
TP Removal %	84.4	83.5	82.4	85.5	90.2	99.1
pH	6.99	7.04	7.10	7.02	7.02	6.95

O&M Cost Comparison









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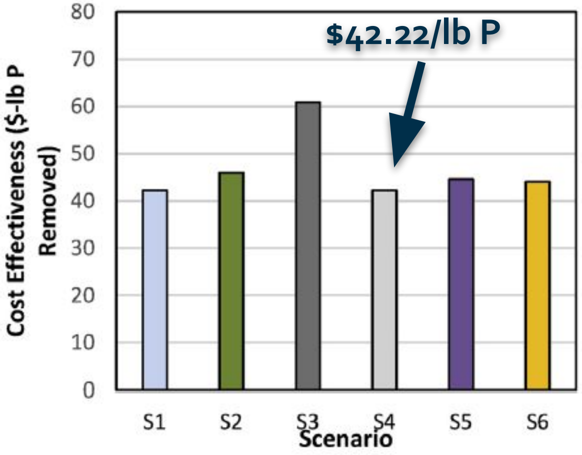
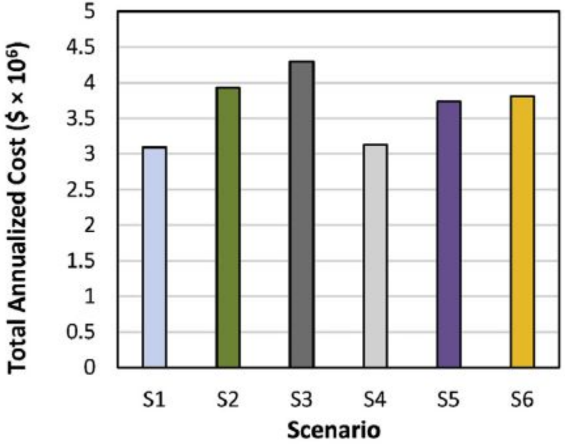
Cost Effectiveness & Total Cost





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OCSD Application of IFAS-EBPR

- Orange County Sanitation District NPDES Permit
    - No Phosphorus Limits
    - Ammonia-N effluent concentration is regulated at the closest ocean outfall (1.5 miles) for the protection of marine life
        - Maximum: 0.6 µg/L (6-month median)

- OCSD is not the best candidate for this technology based on its current regulatory requirements

OC SAN
ORANGE COUNTY SANITATION DISTRICT

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Any Questions?