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Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation

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Hinkley Center for Solid and Hazardous Waste Management

TAG Members

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Outline

- Background, Hypotheses and Objectives
- Research Plan
  - Lab-scale SBR
  - Pilot-scale CW
  - Reuse regulations
- Practical specific benefits for end users
- Timeline

Problems with Landfill Leachate

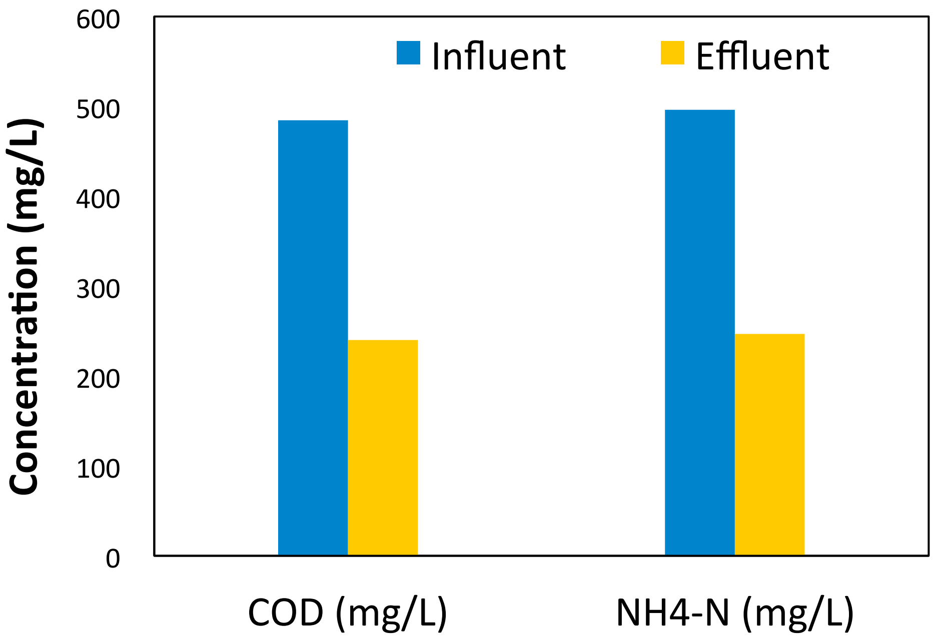
- Discharge to POTWs - common in Florida.
- High ammonia, recalcitrant organic matter and metal concentrations disrupt POTW processes.
- Hybrid vertical/horizontal subsurface flow constructed wetlands - cost-effective for onsite leachate treatment.

Douglas Road Landfill Leachate Treatment Wetland IN

(courtesy Jim Bays Jacobs Engineering)

CWs for Landfill Leachate Treatment

- Well documented for removal of organic compounds, nitrogen and trace metals.
- Reduces leachate volume by evapotranspiration.
- Year-round warm temperatures favor plant growth and biogeochemical processes that promote good performance.
- Hybrid Vertical Flow - Horizontal Flow Subsurface CWs enhances nitrification/denitrification.



Source: case study based on (Bulc, 2006)

Questions from Hinkley Research Agenda

- What innovative technologies are available to engineer wetlands capable of treating landfill leachate?
- What cost-effective pretreatment processes should the leachate undergo to meet secondary drinking water standards?
- What processes, chemicals, or plants are best suited to mitigate the negative impact of humic acids as a pretreatment process at a landfill?

Guiding Hypotheses

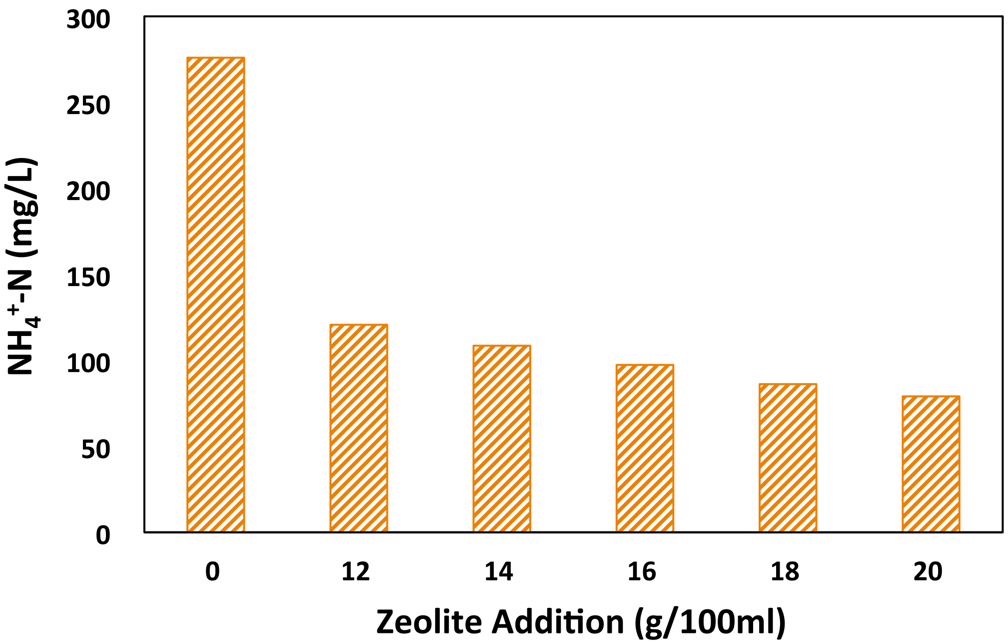
- Addition of zeolite, a natural mineral with a high NH_4^+ affinity, to VF-CW media reduces free ammonia toxicity to microorganisms and enhances biological nitrogen removal.
- Addition of biochar, a low-cost material produced from organic feedstocks such as wood chips, to HF-CW media enhances plant growth and retains recalcitrant organic matter, such as humic acids, to enhance its heterotrophic biodegradation.
- Adsorbent amended hybrid CWs can provide a cost-effective and low complexity landfill leachate treatment method compared with conventional onsite leachate treatment systems.

Research Objectives

1. Design lab-scale sequencing batch reactors with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design.
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model that can be used to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics; and
4. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Natural Zeolite Minerals

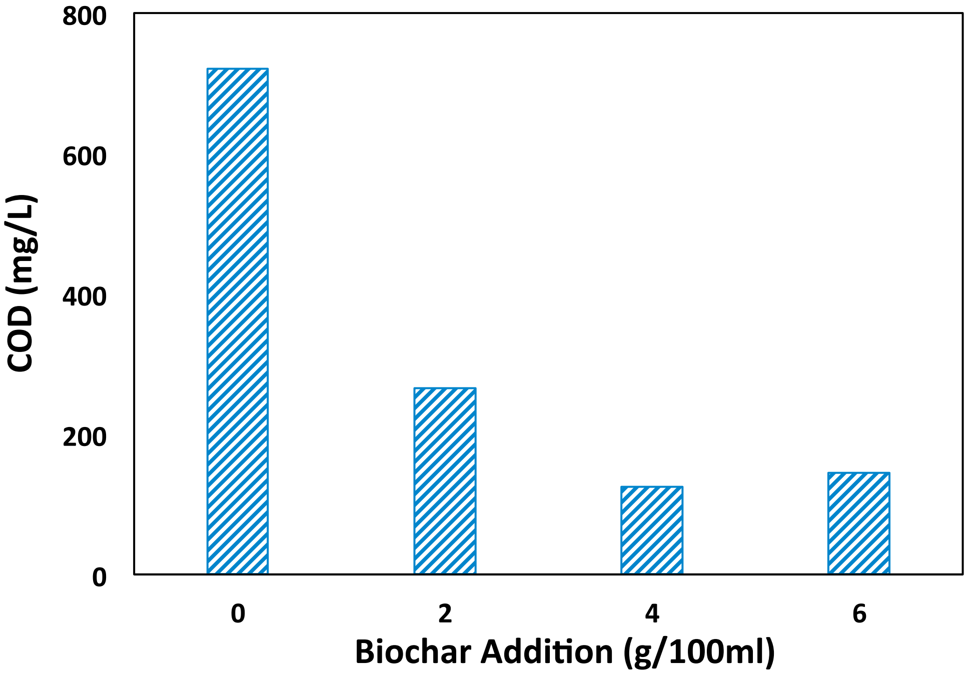
- Porous aluminosilicate minerals.
- High cation exchange capacity and selectivity for NH_4^+ and K^+.
- Clinoptilolite - most abundant and commonly used zeolite.
- Chabazite - more expensive but higher NH_4^+ capacity.
- Widely used as chemical sieve, food and feed additive, odor control (cat litter).



Ammonia removal in landfill leachate by clinoptilolite

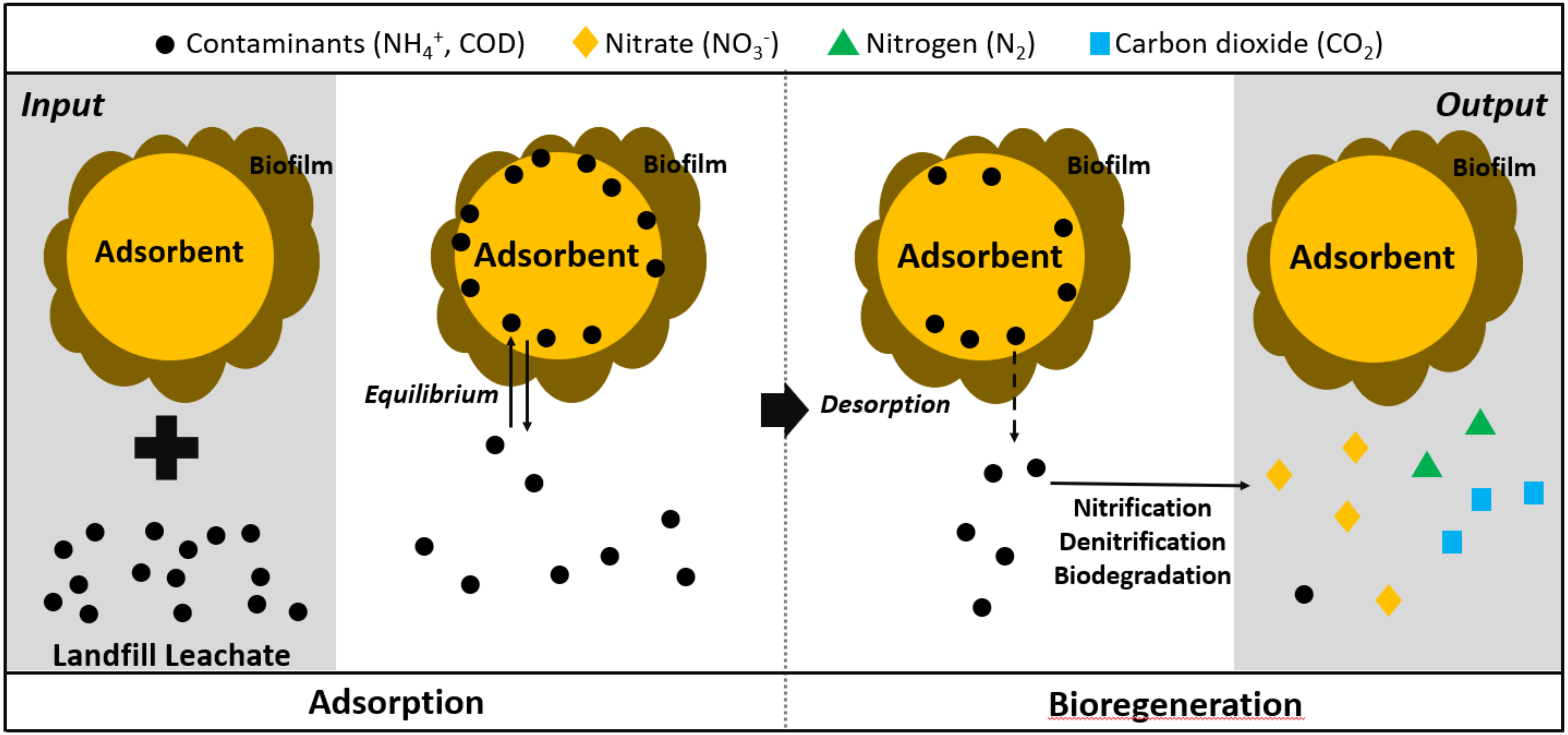
Biochar

- Low-cost material produced by pyrolysis of organic feedstock (e.g., wood chips) at high temperature under O_2 limitations.
- High surface area, cation exchange capacity, moisture holding capacity.
- Improves productivity of agricultural soils.
- Enhances growth of beneficial microorganisms.



COD removal in landfill leachate by biochar.

Adsorption and bioregeneration



Hillsborough County's Southeast Landfill

- Class 1 landfill, waste tire processing, & composting operations.
- Partial onsite leachate treatment by activated sludge BNR with glycerol addition.
- Leachate hauled to county POTW.
- Pilot CWs will be housed in containment area adjacent to the leachate treatment.
- County interested in the potential implementation at adjacent wetlands.
- Operations staff enthusiastic about project.

Parameter		Units	Untreated Leachate	Treated Leachate
pH		mg/L	7.6-7.9	7.2-8.2
Cond.		umhos/cm	12,700-15,300	14,200-16,200
COD		mg/L	450-1500	600-2000
BOD_5		mg/L	50-70	2-44
Ammonia		mg/L	300-450	NP
Metals	Sb	µg/L	40-430	3
	As	µg/L	8-80	7
	Ba	µg/L	50-1300	57
	Cu	µg/L	30-190	12
	Pb	µgL	15-160	0.52
	Zn	µg/L	40-100	21

NP: data not provided.

Lab-scale experimental design

LECA

LECA
Zeolite

LECA
Zeolite
Biochar

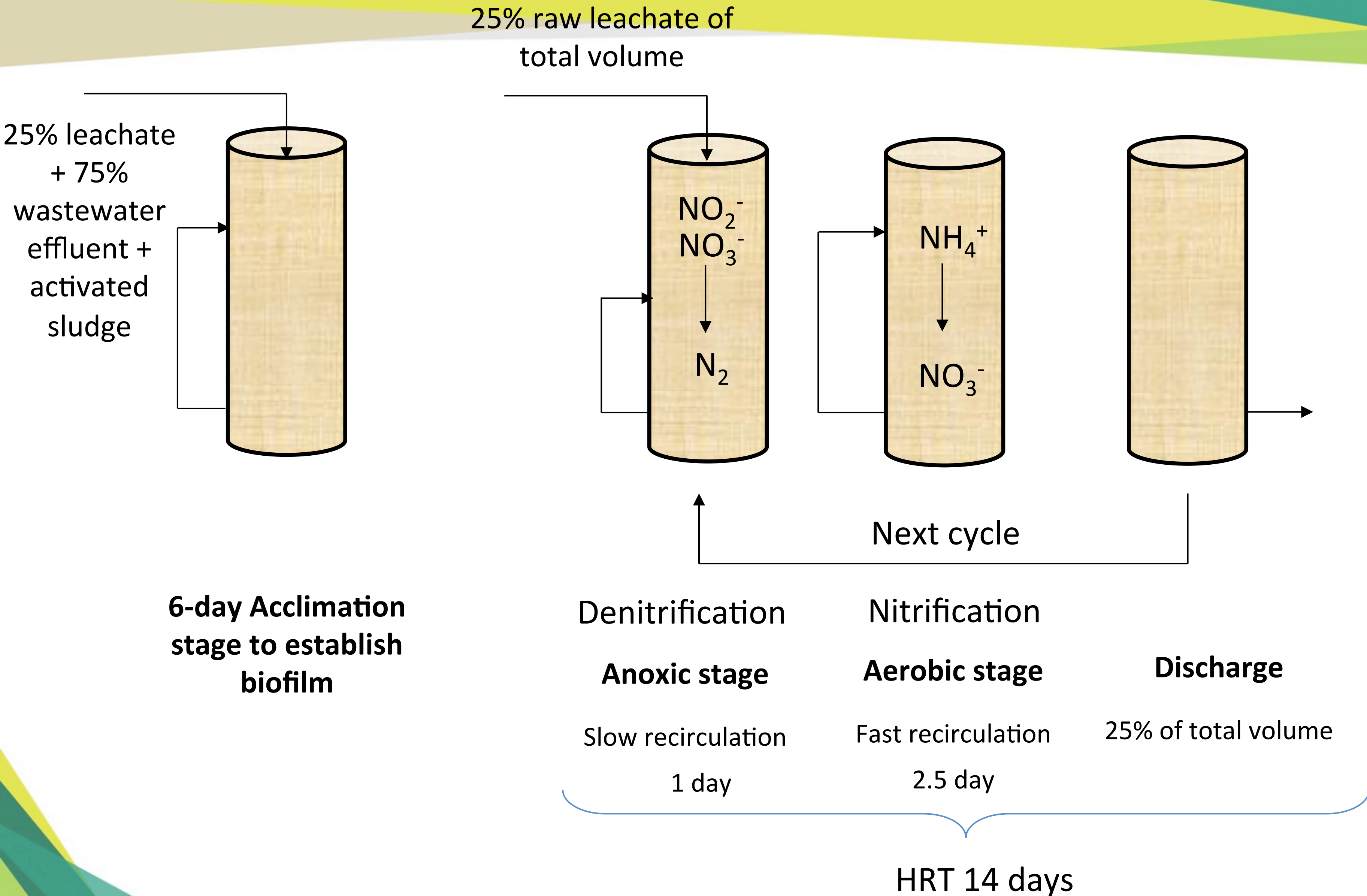
Different wetland substrates for microbial growth

LECA

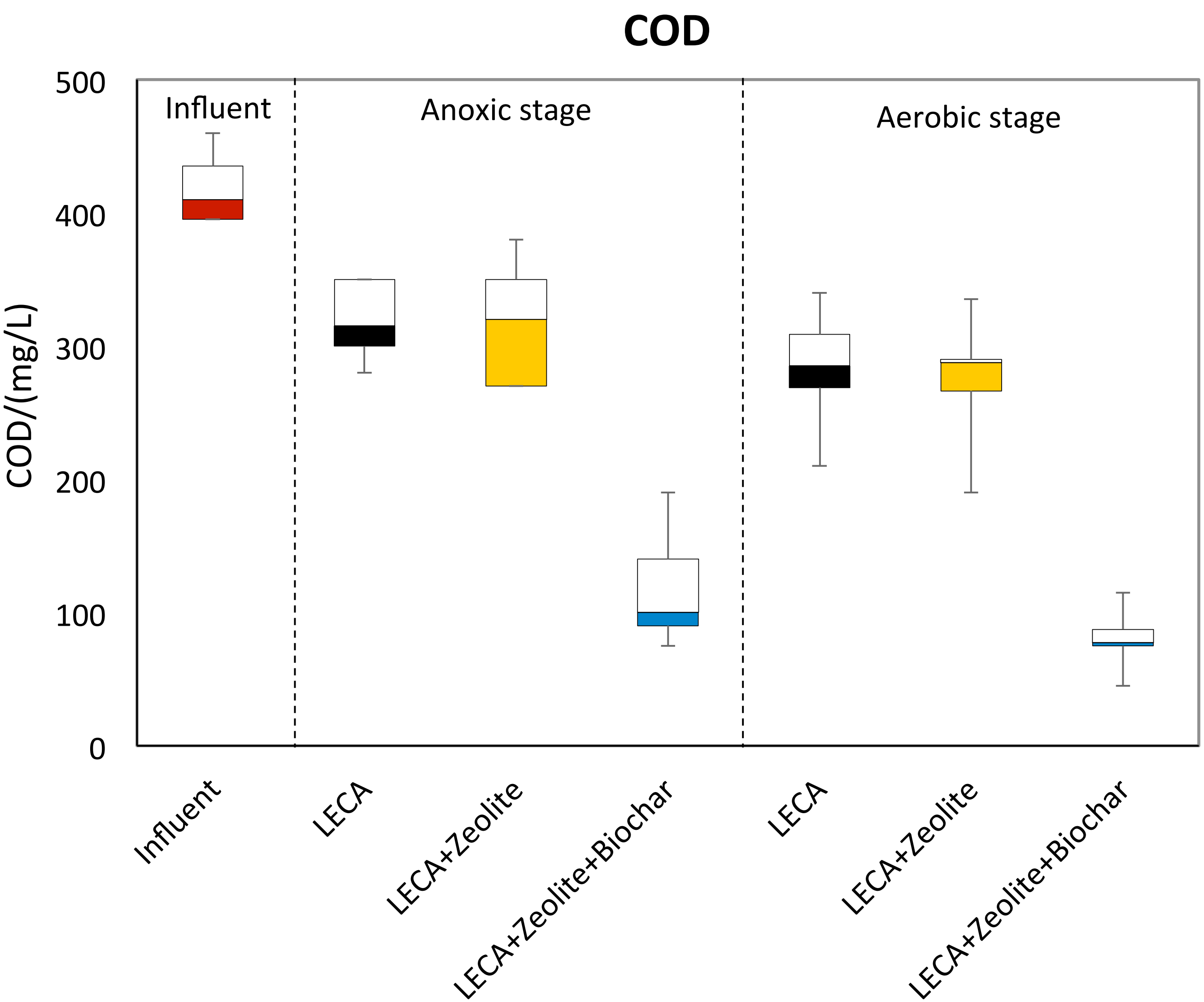
Zeolite

Biochar

Lab-scale sequencing batch reactor operation

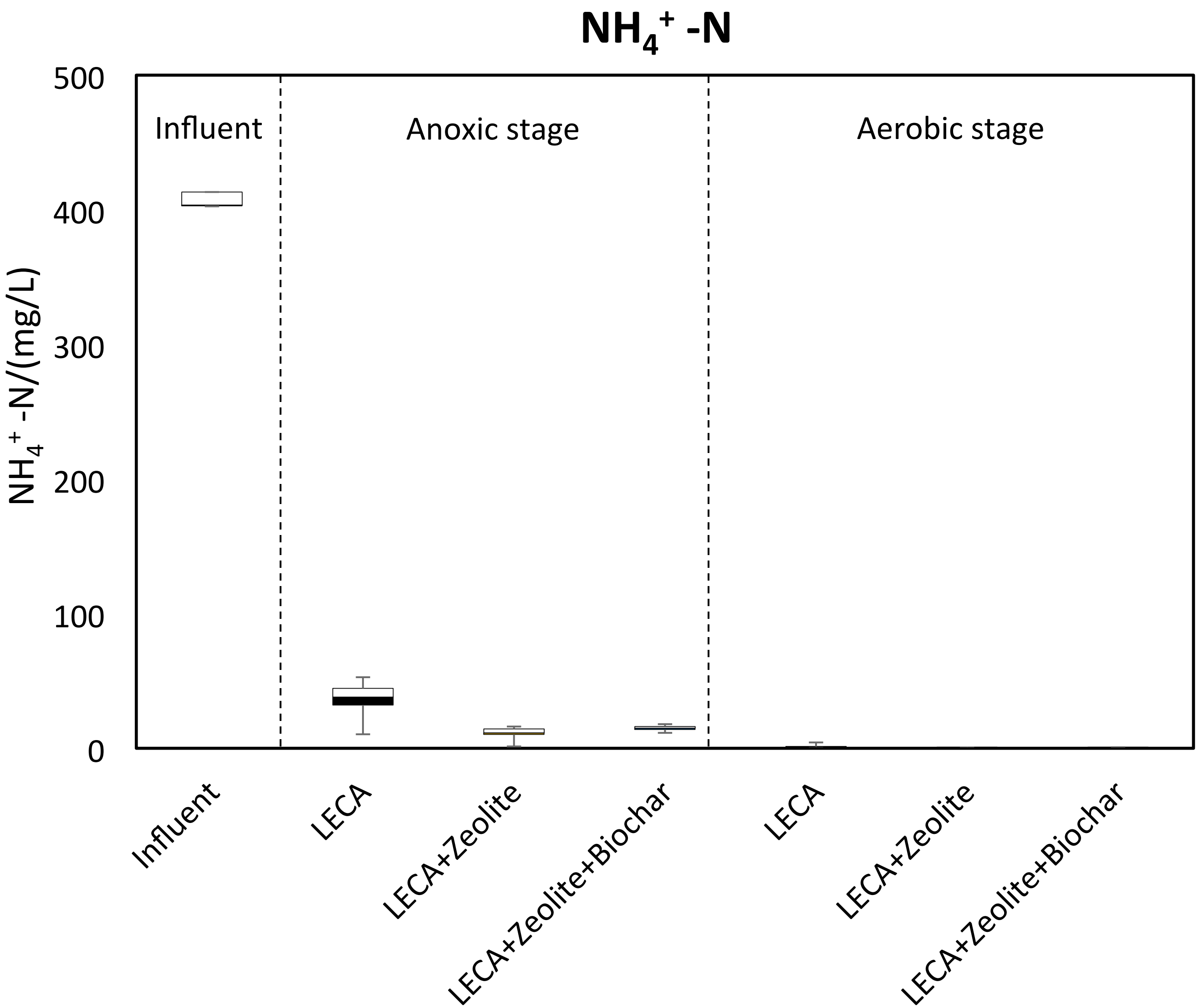


Lab-scale experimental results --- COD



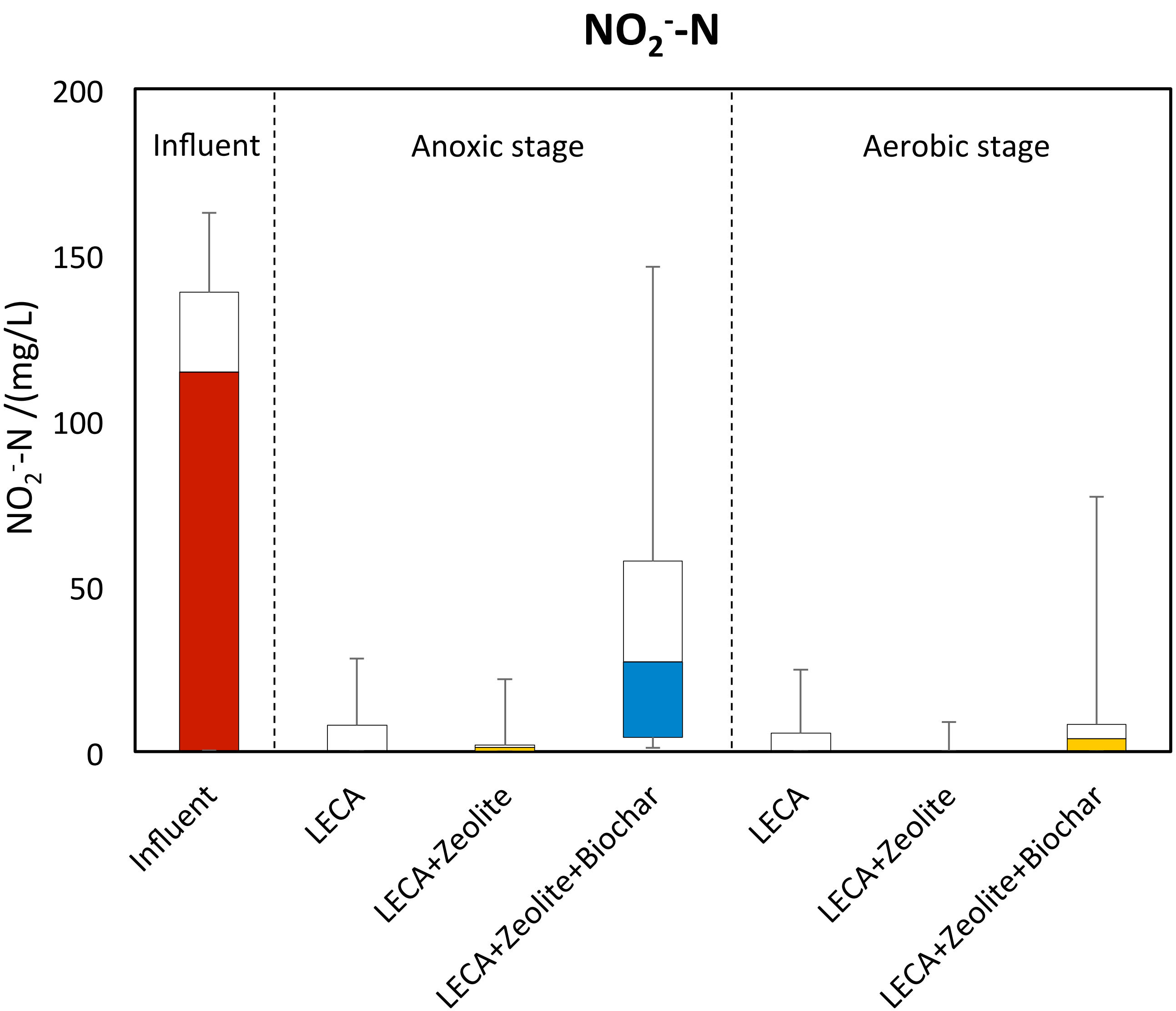
- Biochar column has highest COD removal efficiency.
- The addition of zeolite does not improve the COD removal.

Lab-scale experimental results --- NH_4^+-N



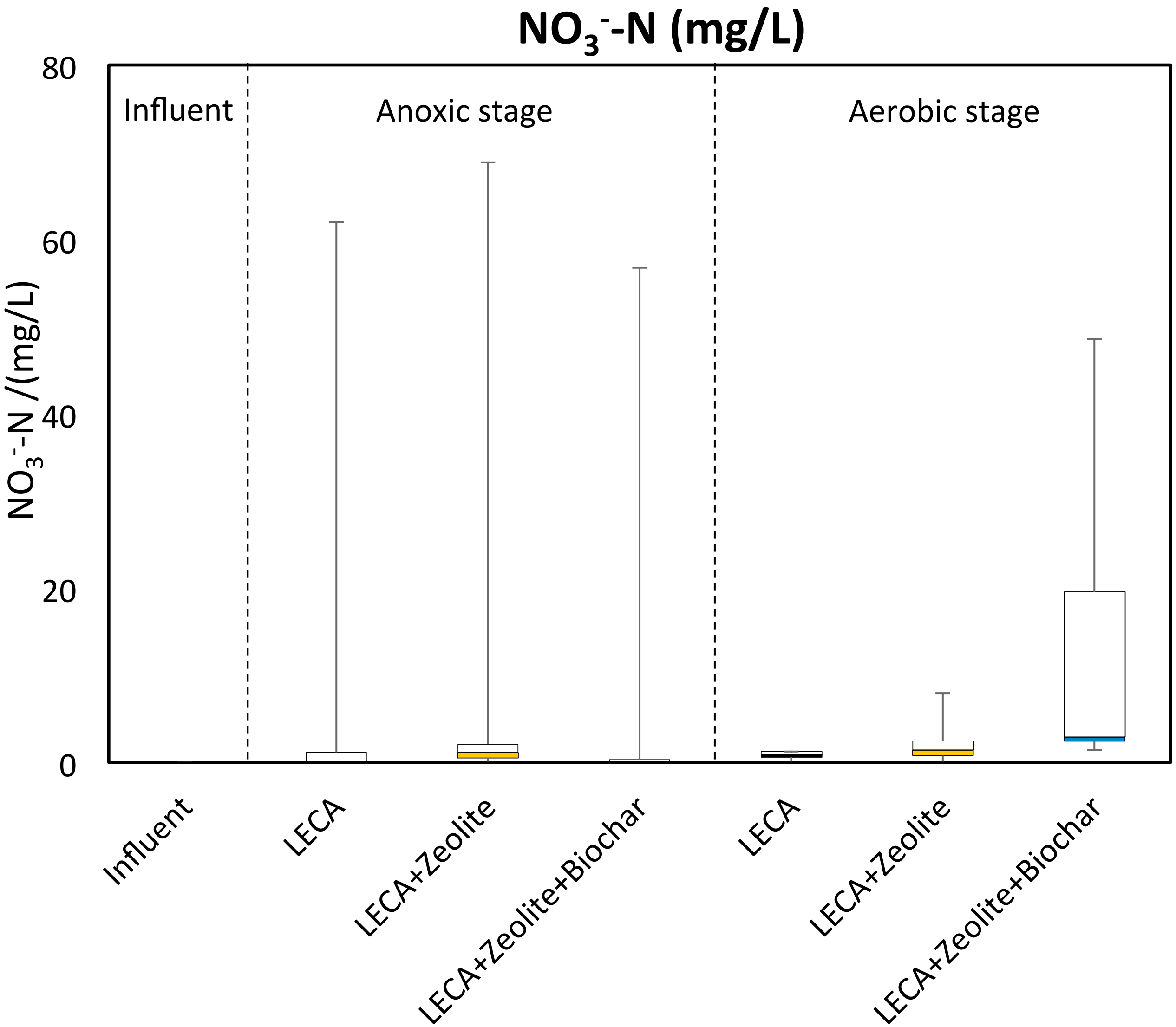
- All three columns have high ammonia removal, indicating good nitrification efficiency.

Lab-scale experimental results --- NO_2^--N



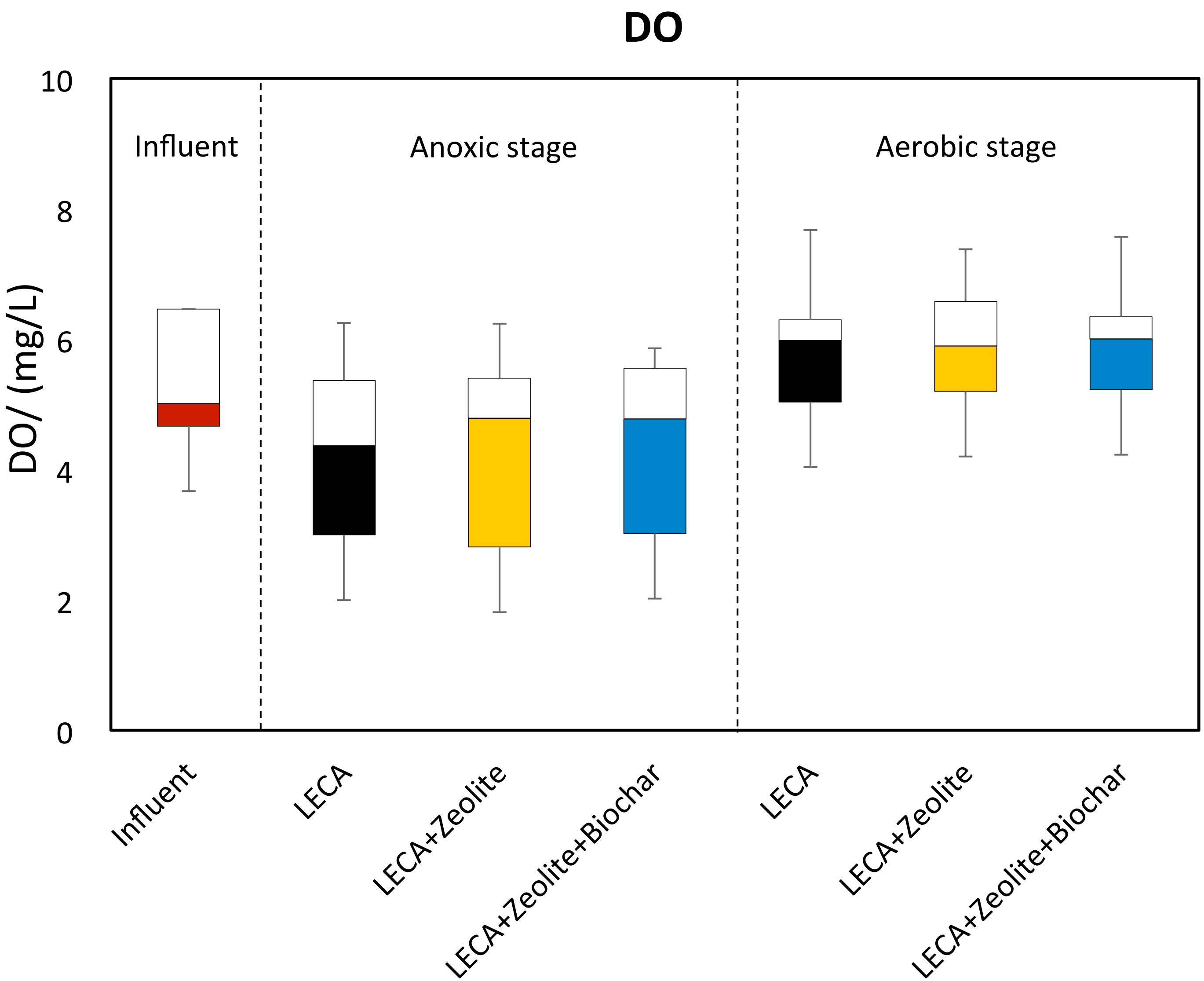
- In biochar column, in anoxic phase, nitrite concentration is higher due to lack of available carbon source.

Lab-scale experimental results --- NO_3^--N



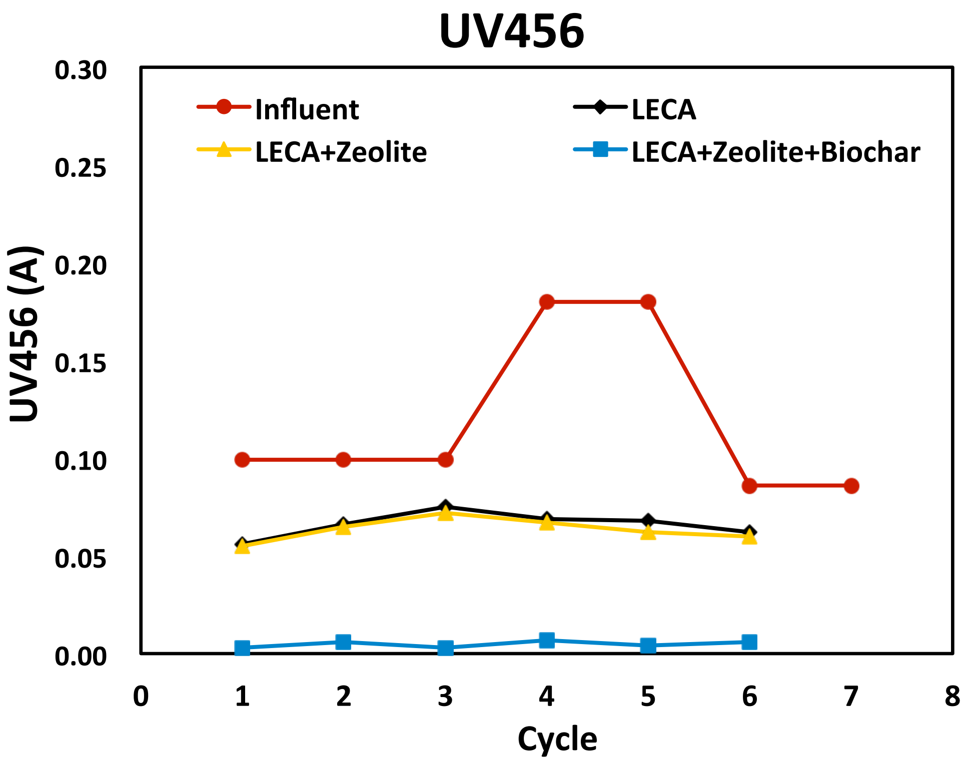
- In biochar column, in aerobic phase, lack of COD causes higher NO_3^-.
- In clay column, clay and zeolite column, the N species conc. are similar, zeolite addition does not make significant difference.

Lab-scale experimental results --- DO



- In anoxic phase, DO in three columns are high due to recirculation, nitrification might occur along with denitrification.

Lab-scale experimental results --- Color



Raw Leachate | LECA Effluent | LECA Zeolite Effluent | LECA Zeolite Biochar Effluent

- Biochar column has highest color removal.
- In biochar column, bioregeneration of biochar may occur but not release COD into the effluent.

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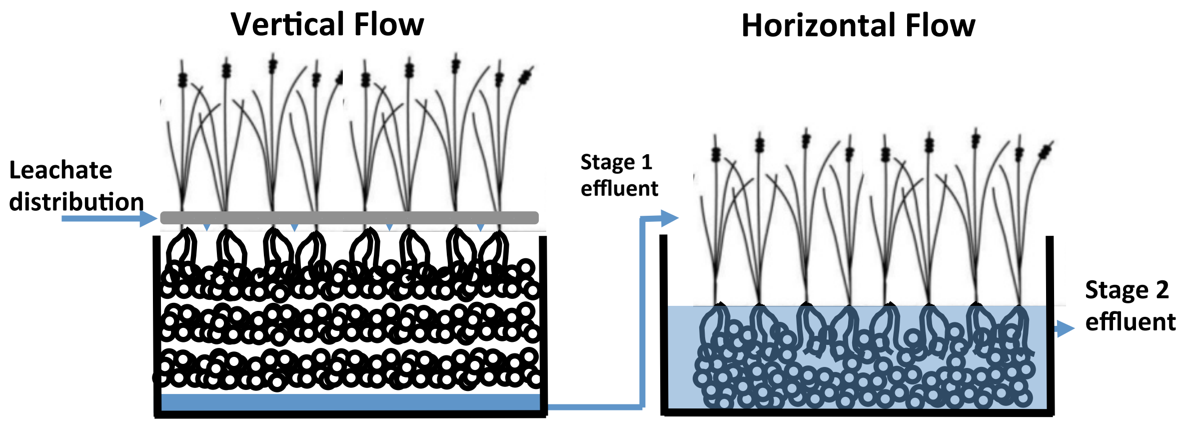
Pilot-scale CW design

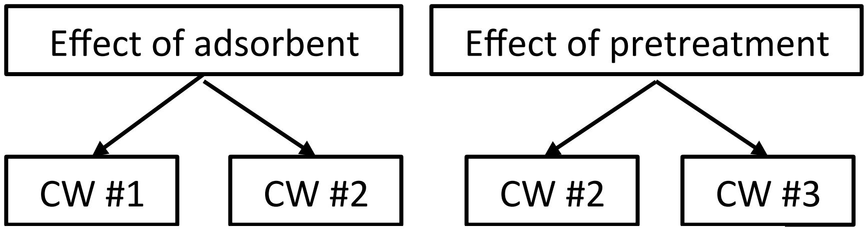
- Adsorption isotherm studies - to determine zeolite & biochar fractions with expanded clay.
- 3 pilot-scale hybrid VF-HF CWs.
- Planted with low cost, low maintenance, leachate tolerant plants



Pilot system schematic (not to scale).

CW	V-CW medium	HF-CW medium	Feed
CW#1	LECA	LECA	Raw
CW#2	LECA + zeolite	LECA + biochar	Raw
CW#3	LECA + zeolite	LECA + biochar	Treated

LECA= lightweight expanded clay aggregate

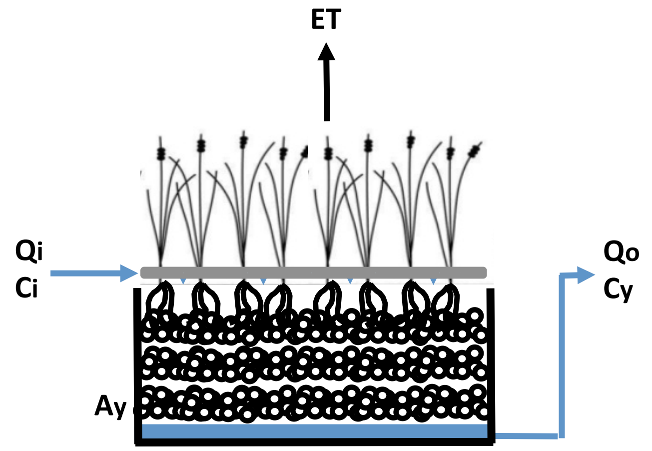


Pilot CW Monitoring & Modeling

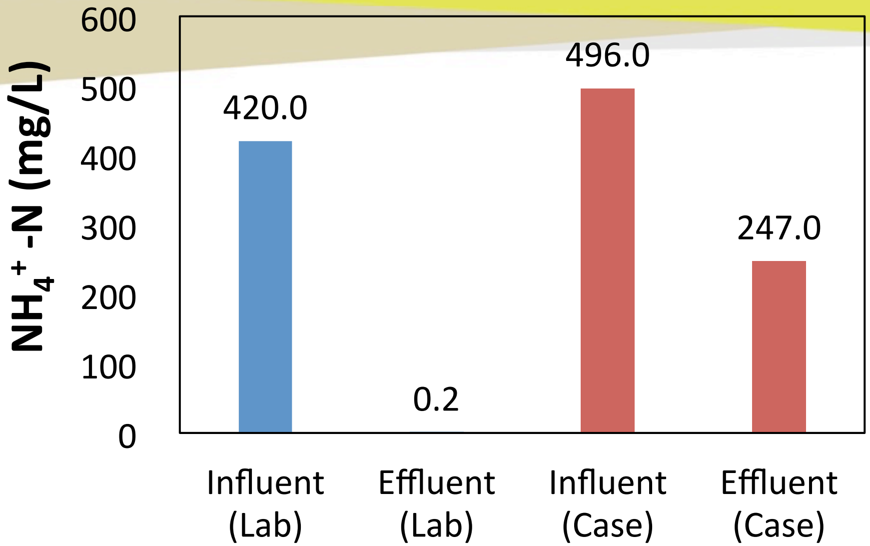
- Biweekly measurements of pH, alkalinity, TSS/VSS, N and P species, sCOD, BOD5, UV254, full wavelength scans, metals.
- Logging sensors for water level, temperature and conductivity at hourly time steps.
- CW numerical process model to predict daily and long term N and organic carbon performance under varying operational, media and leachate characteristics.

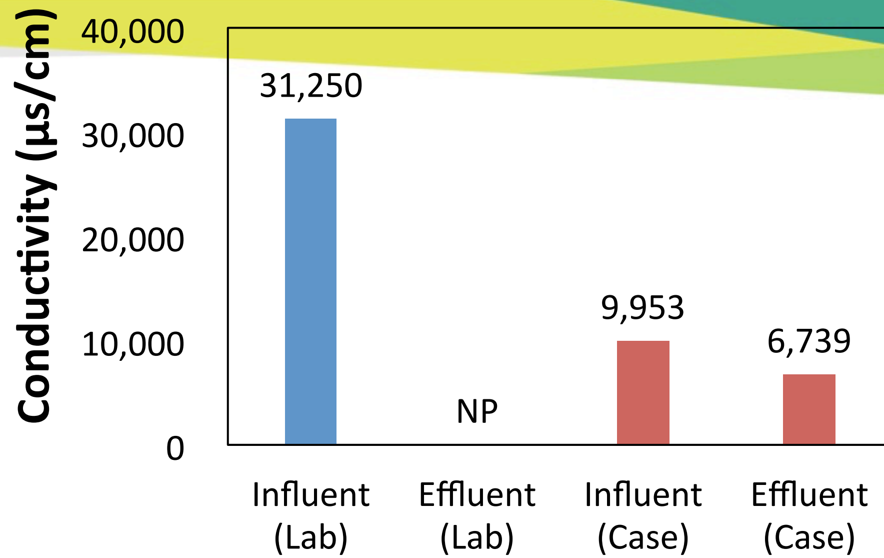
Pollutant Mass Balance

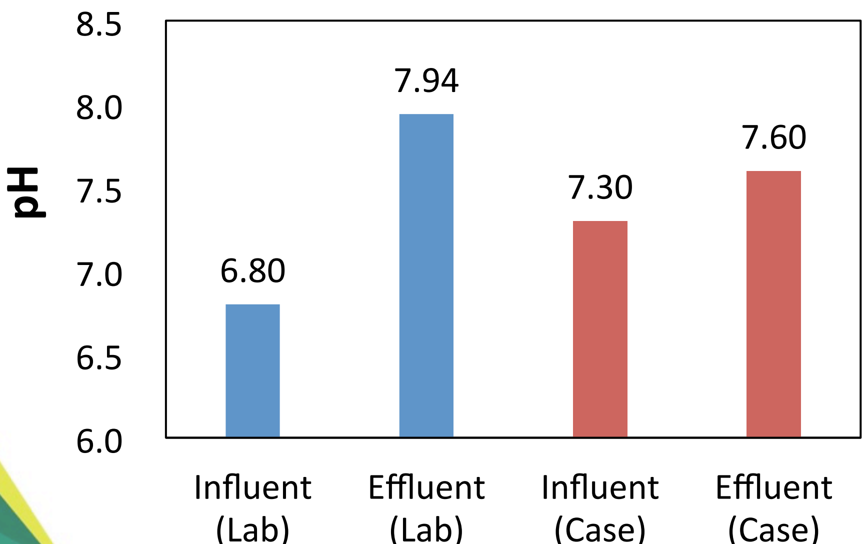
$$\frac{\Delta M_y}{\Delta t} = Q_i C_i - (Q_o C_y) - (\alpha ET x A_y C_y) - (k A_y (C_y - C^*))$$

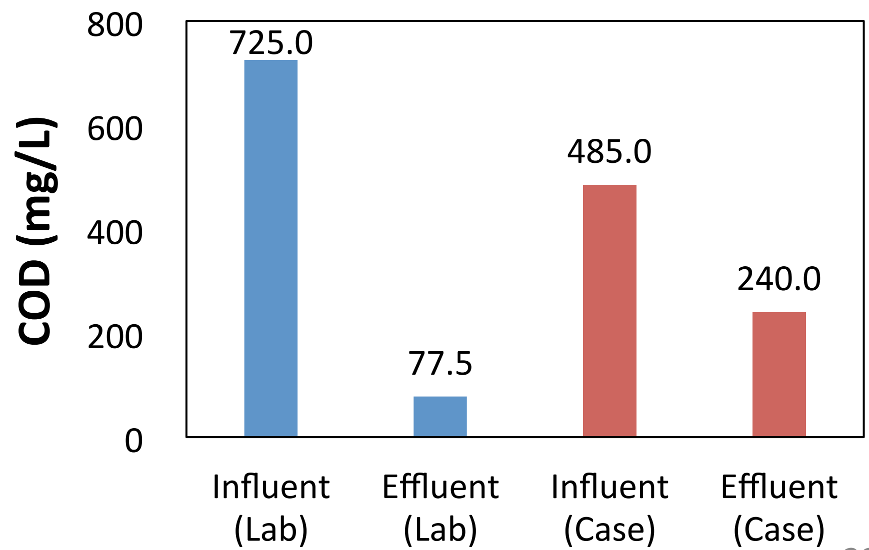


CW performance comparison









Sources: Lab results (LECA + Zeolite + Biochar); Case study based on (Bulc, 2006)

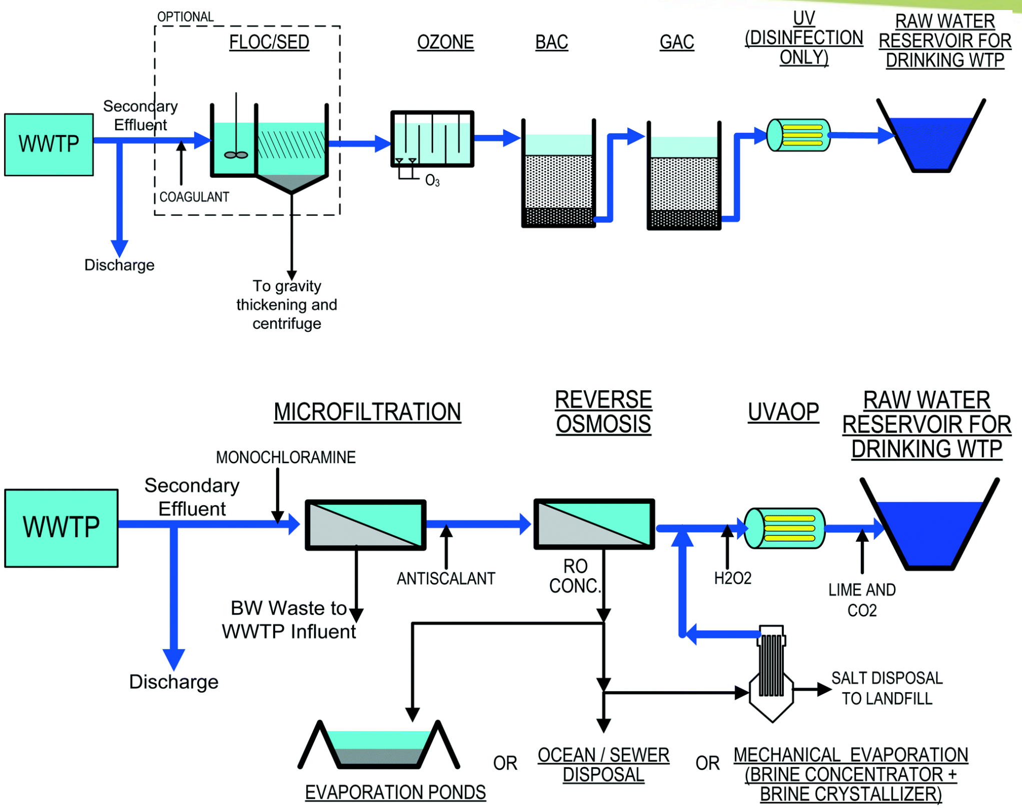
Regulations and recommendations of water reuse

Water Quality Parameter		Urban reuse	Agricultural reuse	Industrial reuse	Aquifer recovery
Example		Municipal irrigation	Agricultural irrigation	Cooling	Groundwater recharge
BOD_5 (mg/L ann avg)		20	20	20	20
pH		NS	7 ~ 8	7.9 ~ 8.7	6.5 ~ 9.2
Conductivity (µs/cm)		NS	< 1,360	< 1,120	< 1,000
Total N (mg/L)		< 10	NS	< 2.3	NS
NO_3 – N (mg/L)		NS	< 9.34	< 0.1	< 15
NH_4 – N (mg/L)		NS	< 0.02	< 0.25	< 1.5
Heavy metals	As (mg/L)	< 0.1	NS	< 0.006	NS
	Cu (mg/L)	< 0.2	< 0.003	< 0.003	< 0.1
	Pb (mg/L)	< 5	NS	< 0.003	< 0.02
	Zn(mg/L)	< 2	NS	< 0.021	< 0.2

Notes: NS= not specified by the Florida state's reuse regulation; avg = average; ann = annual.

Post Treatment Requirements for Reuse

- Preliminary assessment of post-treatment requirements for reuse.
- Consider irrigation, industrial (*e.g.,* cooling water), aquifer recharge, surface water augmentation, direct & indirect potable reuse.
- Post-treatment requirements - coagulation-flocculation-sedimentation-filtration, DAF, AOP, biofiltration, IX, GAC and membrane processes.



From Schimmoller *et al.* (2015) Triple bottom line costs for multiple potable reuse treatment schemes, *J. Royal Society Chem*.

Practical Specific Benefits for End Users

"The treatment of landfill leachate is a big issue both economically and environmentally for most landfills and wastewater treatment plants."

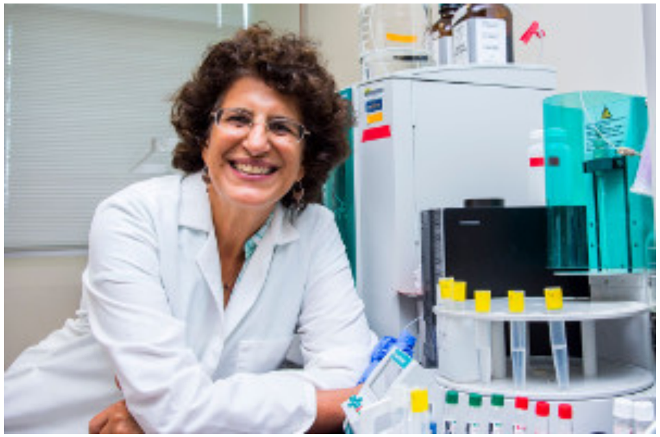
- Hinkley Center Research Agenda

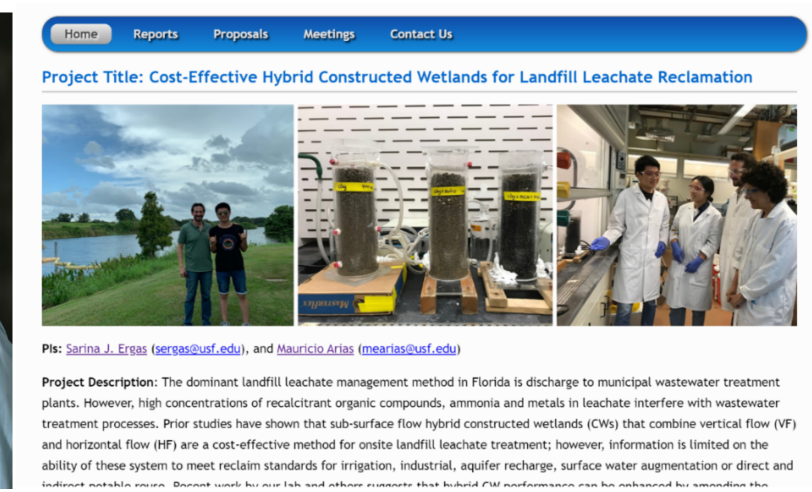
- Hybrid CWs for onsite treatment have low complexity, low capital and O&M costs and proven long-term performance for removal of organic matter, nutrients and metals from landfill leachate.
- Addition of low-cost adsorbent materials, clinoptilolite and biochar, can reduce system land requirements and improve effluent quality.
- Effluents from the proposed CWs can be safely discharged to POTWs or treated further to meet reclaim water standards.

Project Timeline and Milestones

Task	Q1	Q2	Q3	Q4	Deliverable
Lab scale SBR design & operation					Three SBRs
Isotherm studies					Data for CW studies
CW construction & start up					Three pilot CWs
Pilot operation & modeling					Process model, Journal publication
Reuse assessment					Journal publication
Education & outreach					K-12 and USF students, professionals & community members
Quarterly & final reports	■	■	■	■	Reports for Hinkley and USF websites

Research Team

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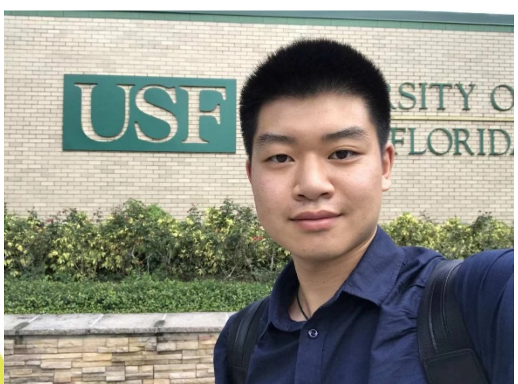
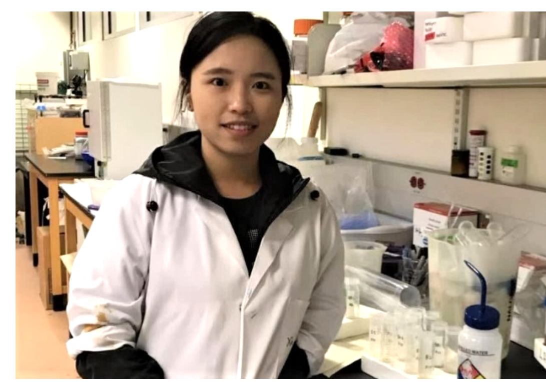
Project Title: Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation

PIs: Sarina J. Ergas (sergas@usf.edu), and Mauricio Arias (mearias@usf.edu)

Project Description: The dominant landfill leachate management method in Florida is discharge to municipal wastewater treatment plants. However, high concentrations of recalcitrant organic compounds, ammonia and metals in leachate interfere with wastewater treatment processes. Prior studies have shown that sub-surface flow hybrid constructed wetlands (CWs) that combine vertical flow (VF) and horizontal flow (HF) are a cost-effective method for onsite landfill leachate treatment; however, information is limited on the ability of these system to meet reclaim standards for irrigation, industrial, aquifer recharge, surface water augmentation or direct and indirect potable reuse. Recent work by our lab and others suggests that hybrid CW performance can be enhanced by amending the





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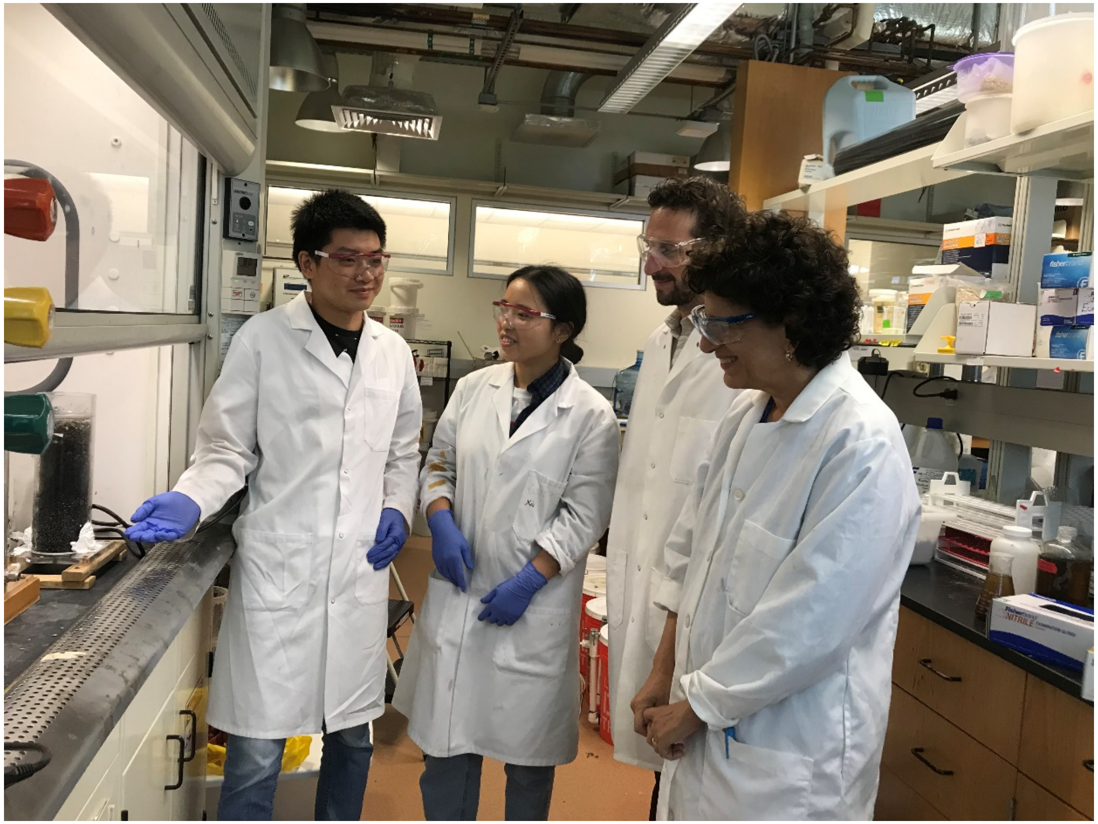
Questions?

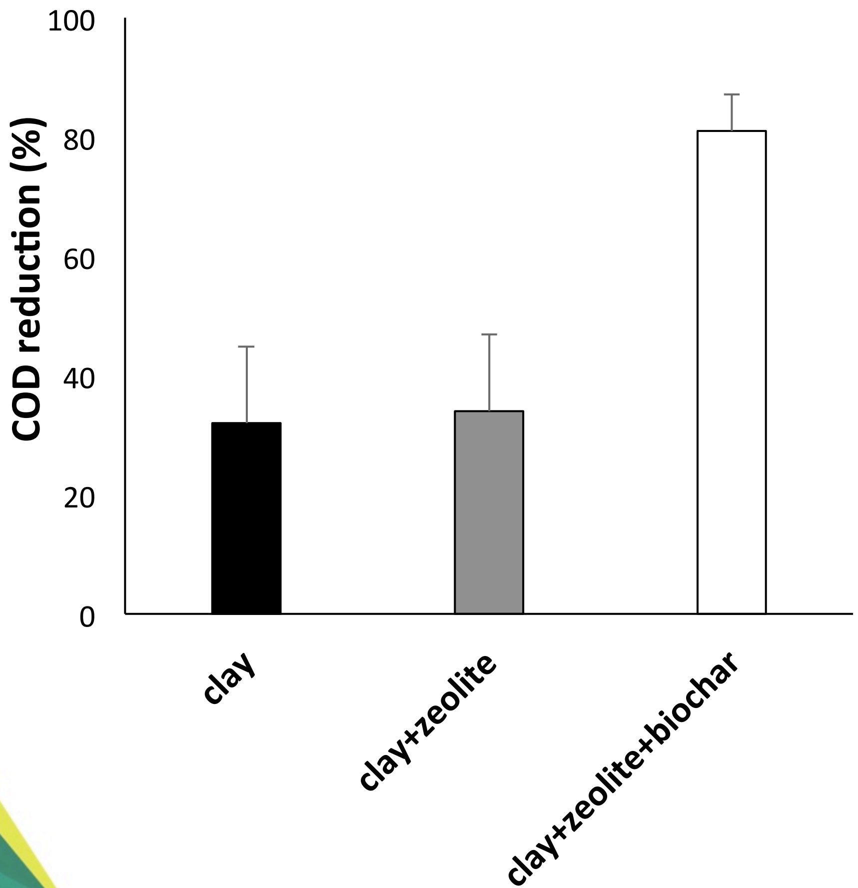
reclaim

water • nutrients • energy

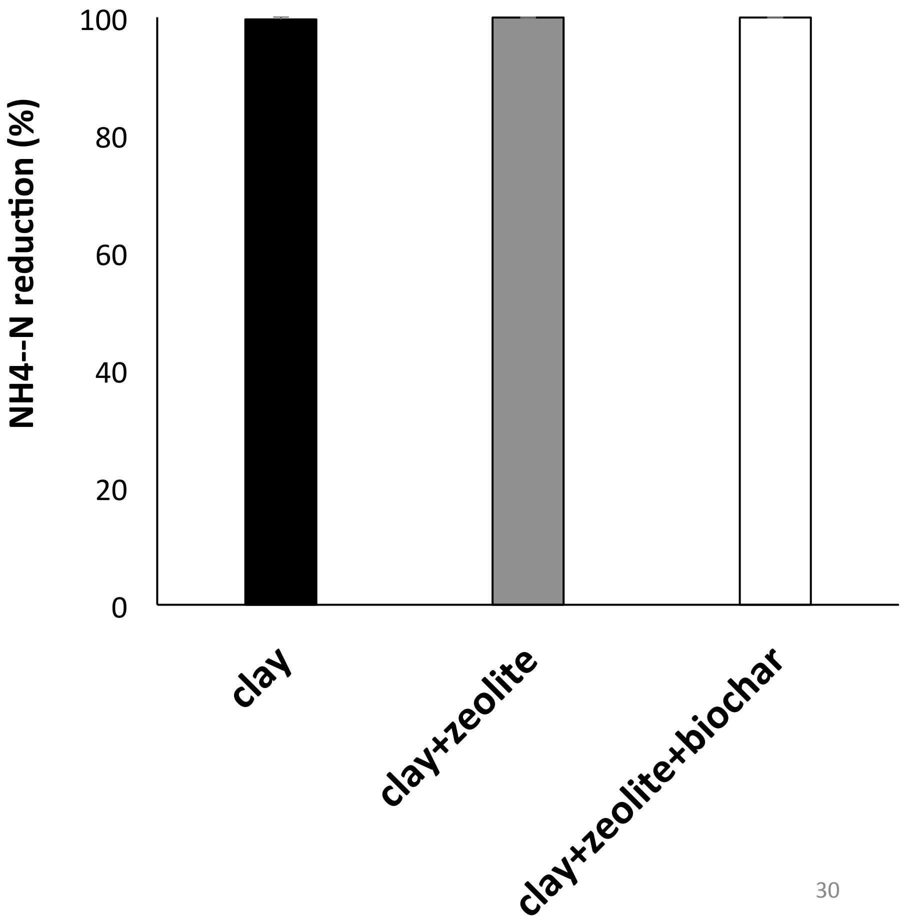
usf-reclaim.org

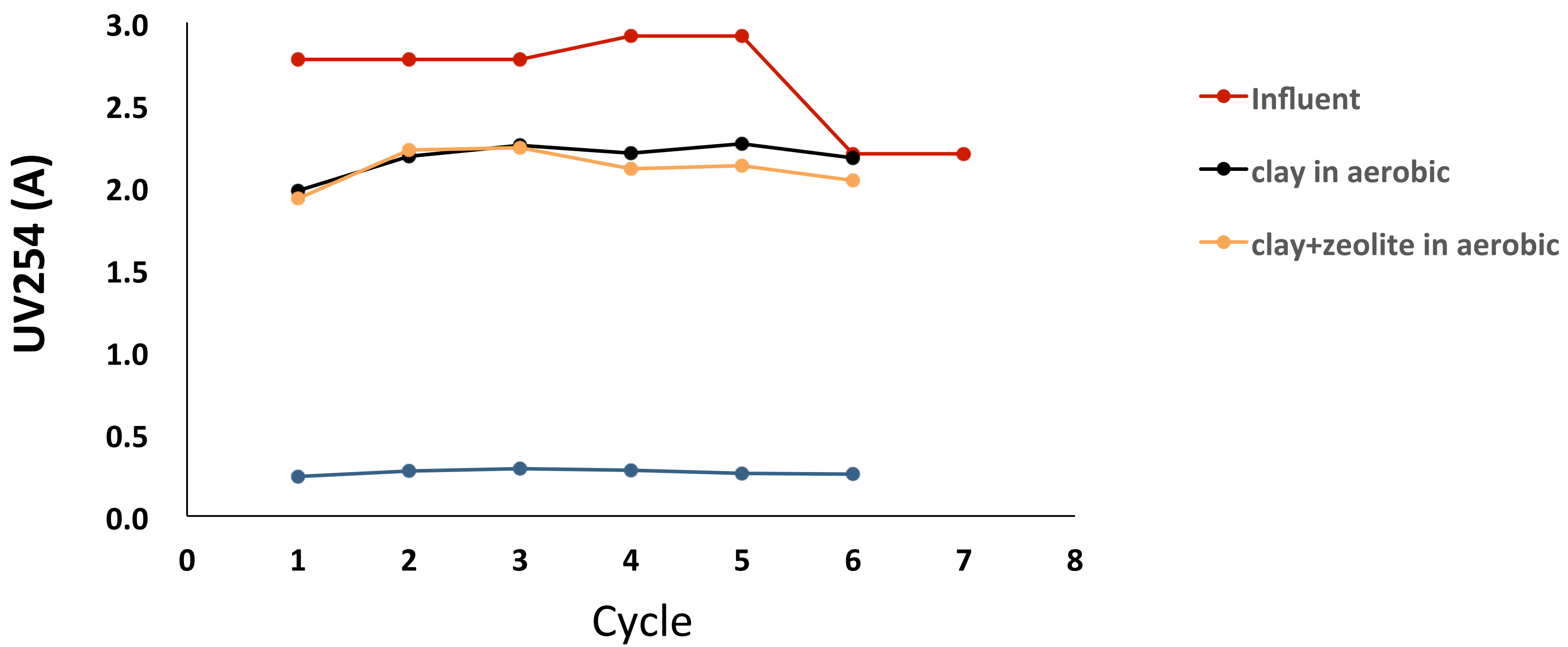


Overall COD reduction



Overall NH_4^- -N reduction

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UV254 (A)
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1
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3
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5
6
7
8
Cycle
Influent
clay in aerobic
clay+zeolite in aerobic