Metropolitan Water Reclamation District of Greater Chicago

Welcome to the May Edition of the 2023 M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

- Remote attendees' audio lines have been muted to minimize background noise. For attendees in the auditorium, please silence your phones.

- A question and answer session will follow the presentation.

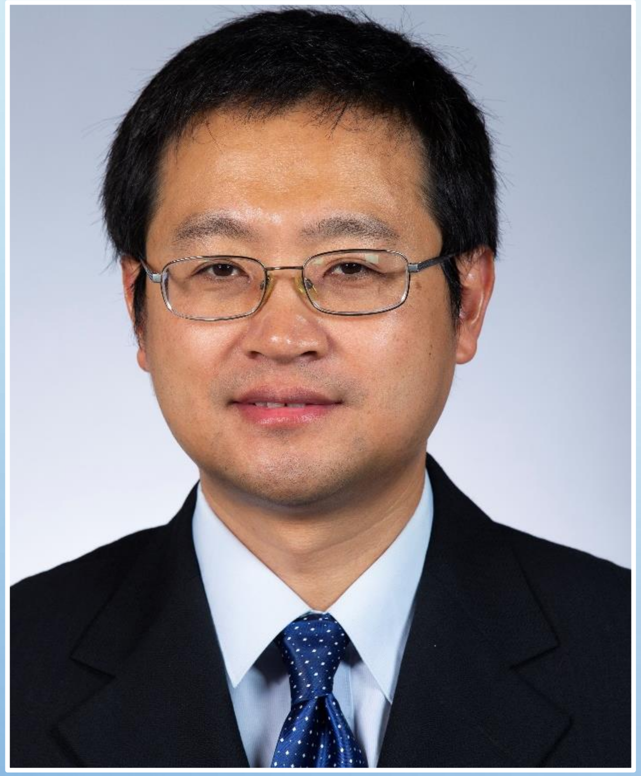
- For remote attendees, Please use the "**Chat**" feature to ask a question via text to "Host". For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question.

- The presentation slides will be posted on the MWRD website after the seminar.

- This seminar has been approved by the ISPE for one PDH and is pending approval by the IEPA for one TCH. Certificates will only be issued to participants who attend the entire presentation.

Dr. Zhiyou Wen

William K. Deal Agricultural Innovation Professor
College of Agricultural and Life Sciences
Iowa State University, Ames, Iowa



Dr. Zhiyou Wen is a professor of Food Science and Human Nutrition and William K. Deal Agricultural Innovation Professor at the College of Agricultural and Life Sciences, Iowa State University. He is Director of the Center for Crops Utilization Research, a multidisciplinary research, development and technology transfer program at Iowa State University with a focus on exploring new food, feed and nonfood industrial uses for agricultural materials. His research focuses on green and sustainable food, fuel and biomaterials processing technologies. In 2015, Dr. Wen co-founded Gross-Wen Technologies Inc., an Iowa-based company that uses algae to mitigate water pollution and produce high-value products such as fertilizers and bio-based plastics from algal biomass. The company co-owns the intellectual property with Iowa State University Research Foundation on a novel Revolving Algal Biofilm (RAB) system, which is an innovative and extremely effective microalgae cultivation system.

Revolving Algal Biofilm (RAB) System for Wastewater Treatment: A Journey from Lab Study to Commercialization

Zhiyou Wen, PhD

Professor, Iowa State University

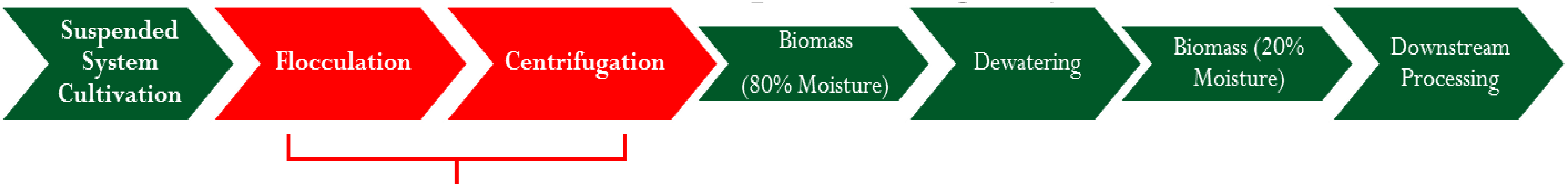
Co-founder, Gross-Wen Technologies, Inc.

Traditional algal cultivation systems

➢ High water content in suspended cultures

- Open pond (0.5-1 g/L cell dry weight, 99.9-99.95 % water)
- Closed photobioreactors (1-4 g/L cell dry weight, 99.4-99.8 % water)

➢ Separating microscopic algal cells from water is costly

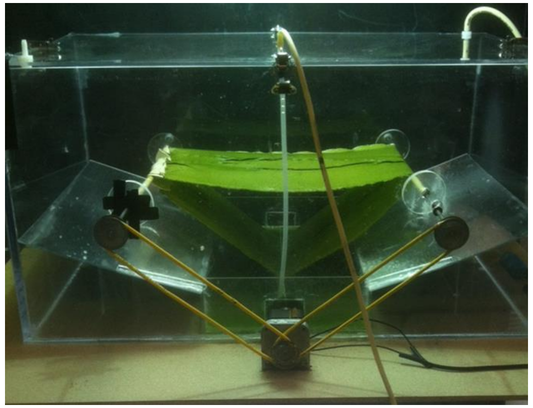


~30% of total capital and operation costs

Attached algal growth

- Algal cells are allowed to grow on a surface of a material to form a biofilm
- Harvesting can be done simply by scraping algae off attached surface
- Harvested algae has similar water content as algae post centrifugation

2009

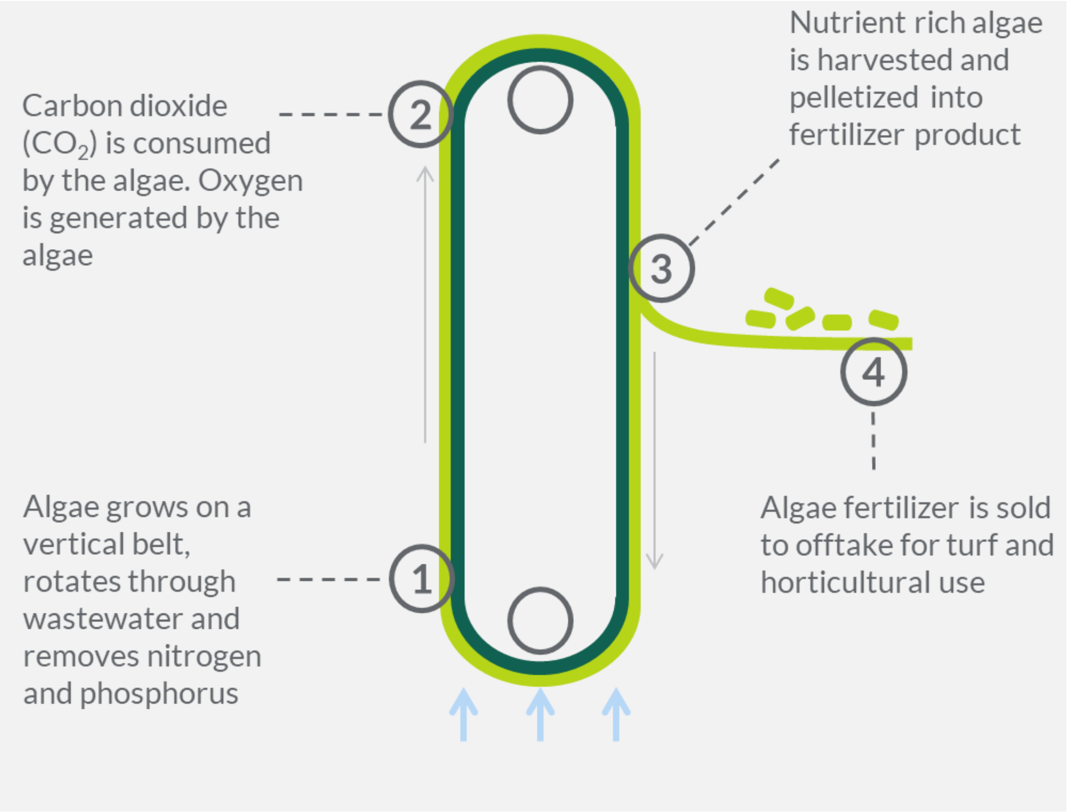


2011

2013

2013

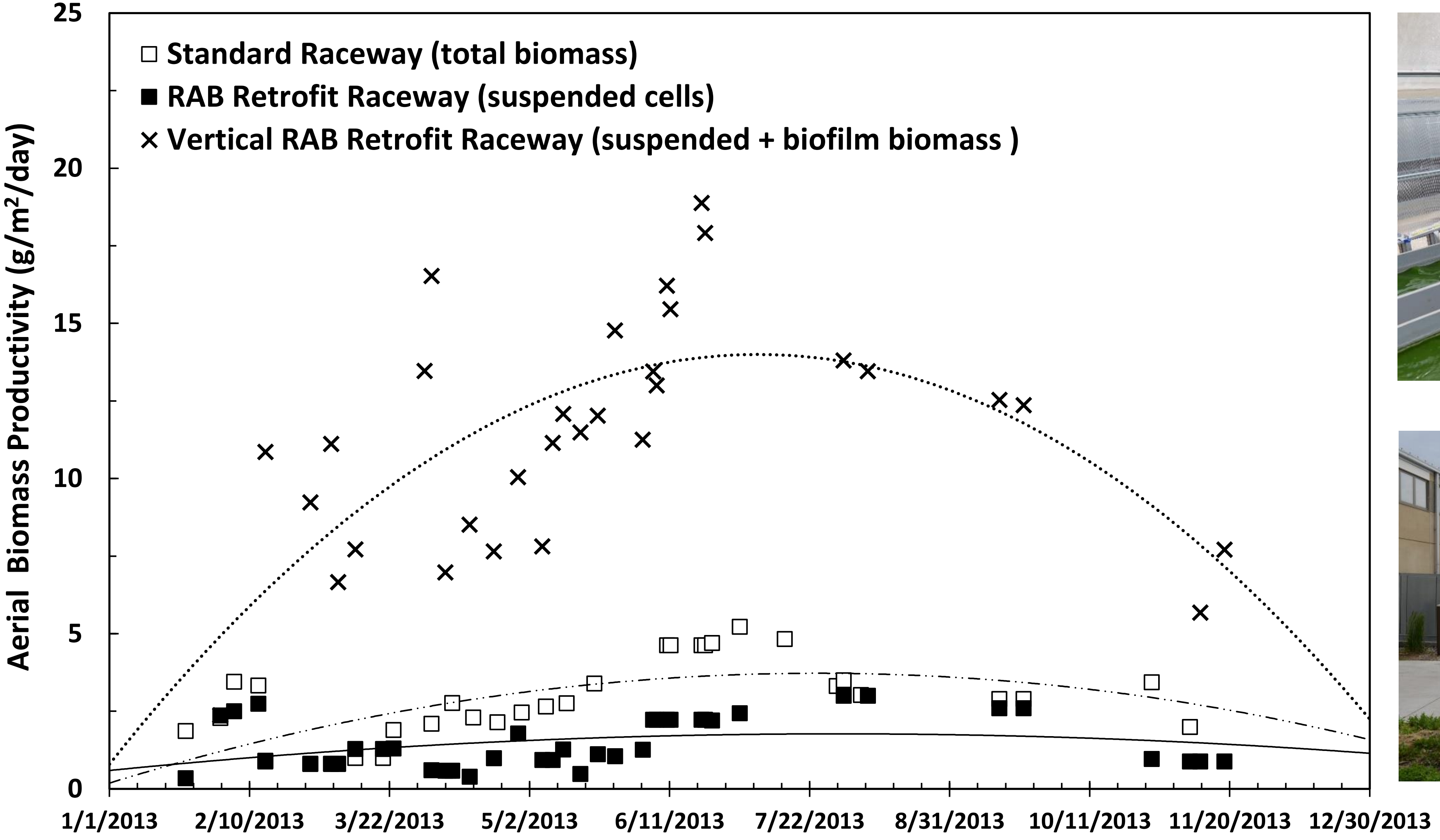
Revolving Algal Biofilm (RAB™) Technology



Advantages of RAB system:

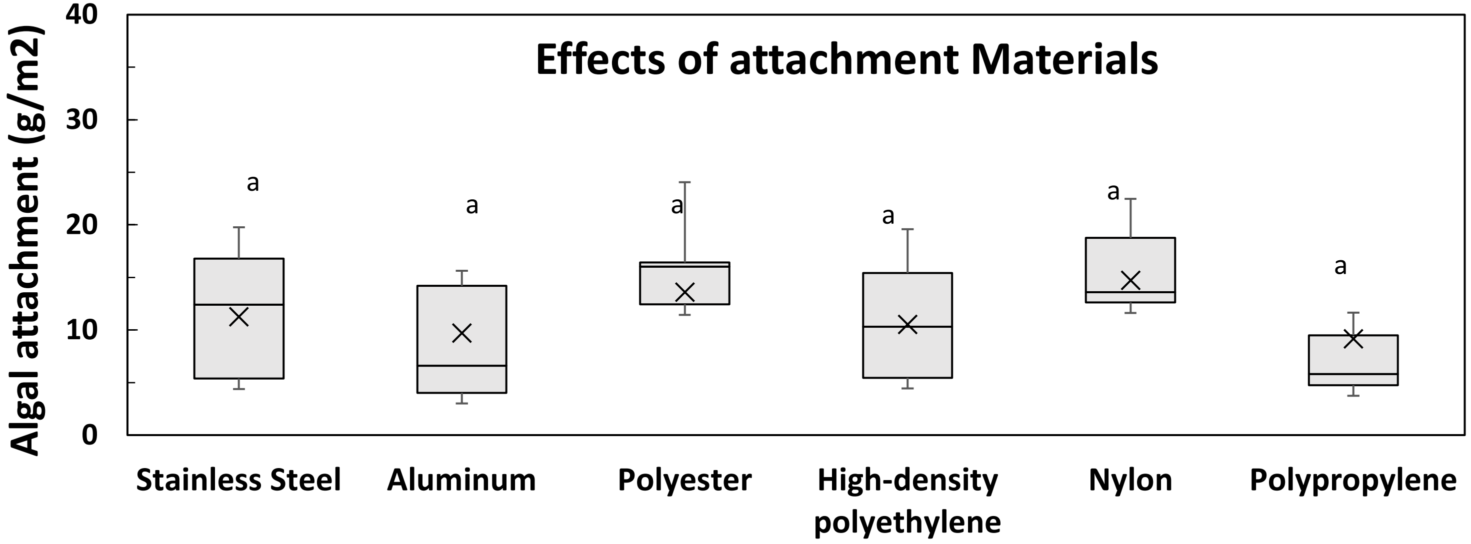
- Simple and low cost harvest
- Enhanced delivery of light and CO2
- High productivity with low footprint
- Nature separation of HRT and SRT

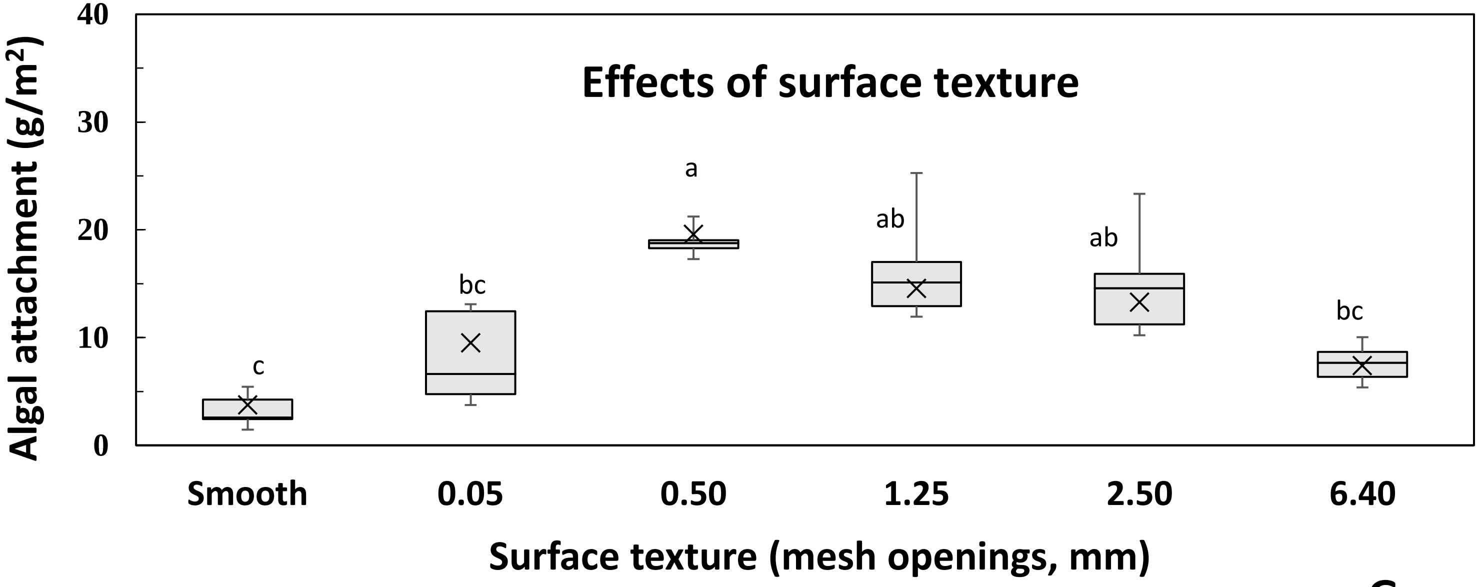
Algae production in RAB system – yearlong biomass productivity



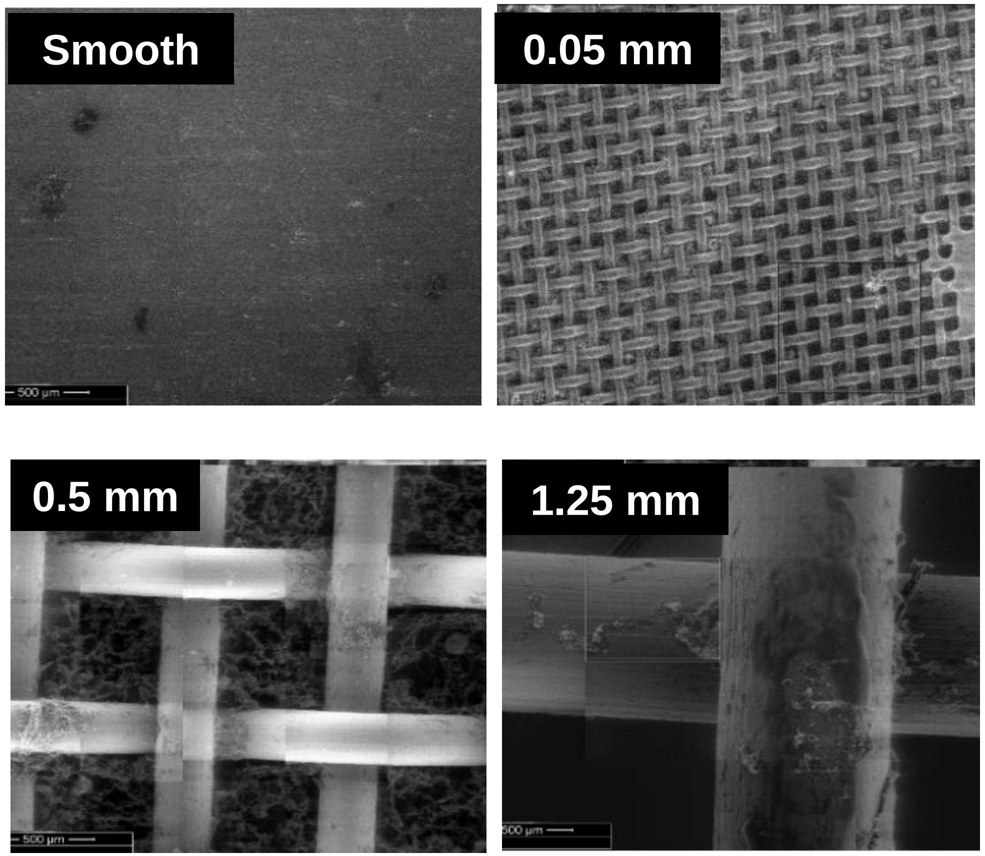
Gross and Wen (2014) Bioresource Technology 171: 50-58

Algae production in RAB system – Effects of attaching materials and surface texture





Cell attachment as a function of mesh size openings of nylon materials



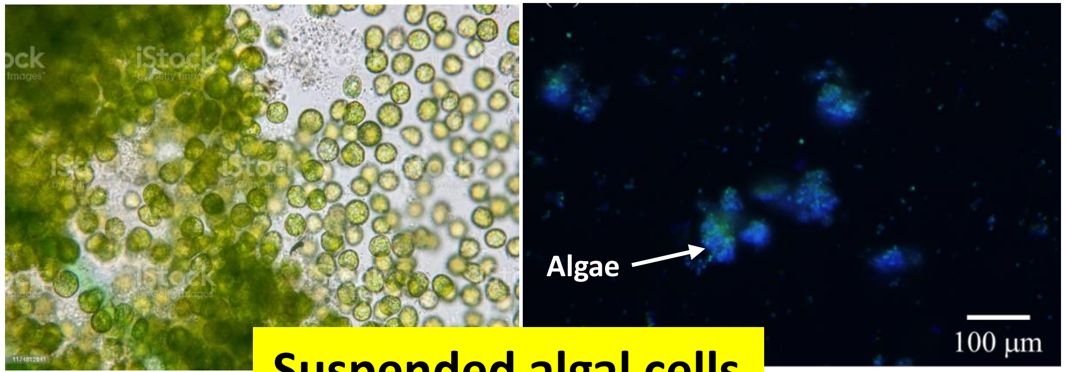
Gross et al., (2016). *Biotechnology for Biofuels.* 9: 38.

Algae Based Wastewater Treatment

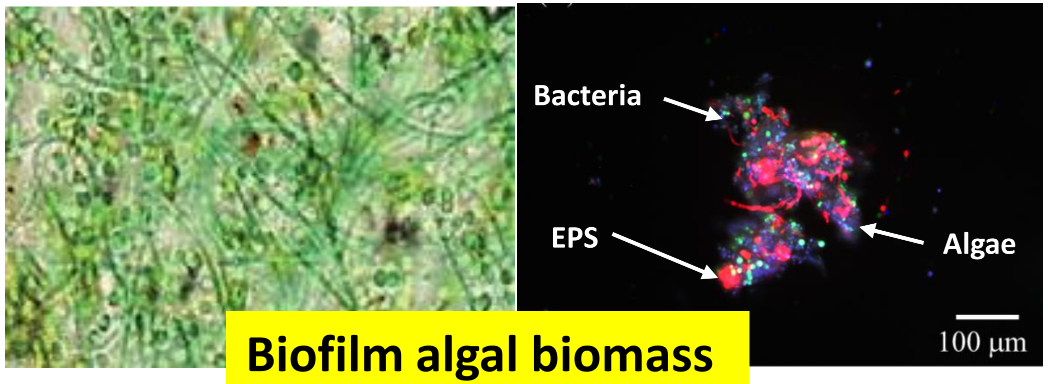
- Capable of removing N/P/COD/metals simultaneously in wastewater
- Production of valuable algal biomass.
- Algal treatment is photosynthetic and consumes CO_2
- Algal treatment generally has a low energy requirement

Uniqueness of RAB systems

- Smaller footprint than other algal systems
- Cost-effective harvesting and dewatering of algae
- Removing pollutants by Extracellular Polymeric Substances (EPS) secreted by algal biofilm

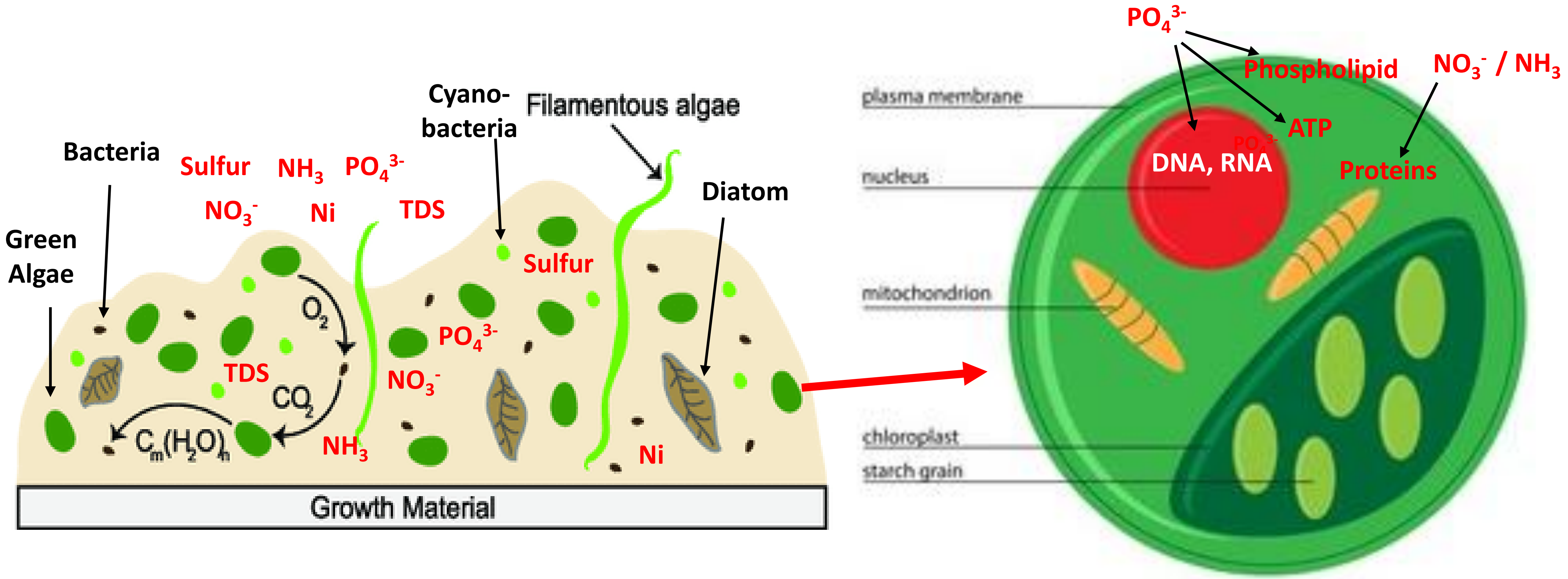


Suspended algal cells



Biofilm algal biomass

Fates of nutrients, heavy metals, TDS in RAB system



Algal Biofilm

Algal cell

Schnurr and Allen (2015). *Renewable and Sustainable Energy Reviews*. 52: 418-429.

RAB for Wastewater Treatment (i): Nutrients removal in MWRD-O'Brien facility

Treatment Objective: TN, TP removal

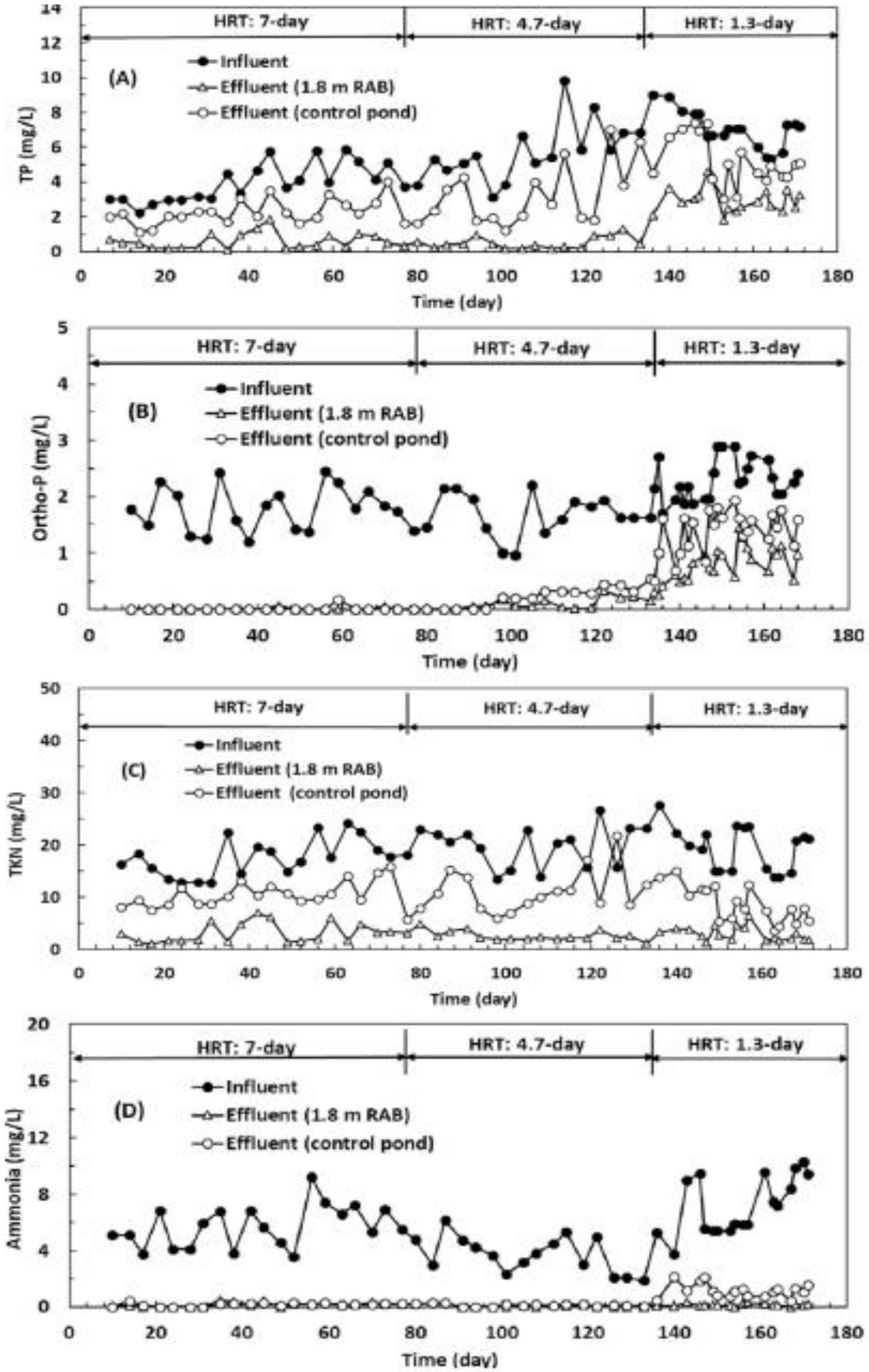
Treatment Location: Sludge thickening supernatant

Pilot Size (4x): 200-2,000 gal/day; 8-40 m^2 of belt area





Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres



Evaluation of revolving algae biofilm reactors for nutrients and metals removal from sludge thickening supernatant in a municipal wastewater treatment facility

Xuefei Zhao [a], Kuldip Kumar [b], Martin A. Gross [a, c], Thomas E. Kunetz [b], Zhiyou Wen [a, c, *]

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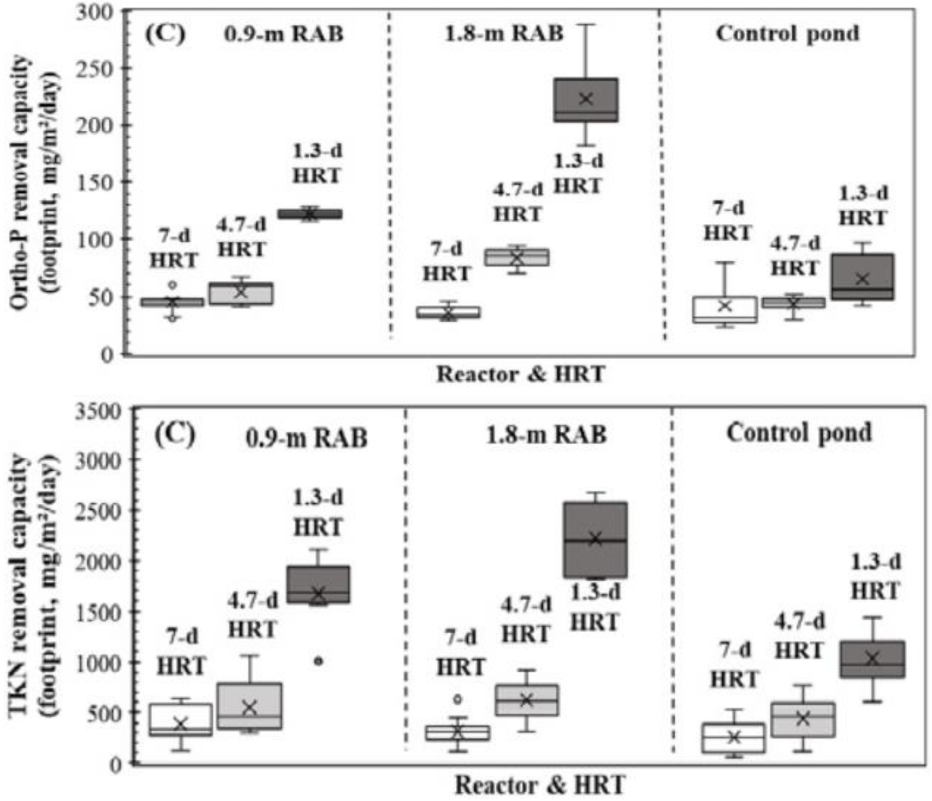
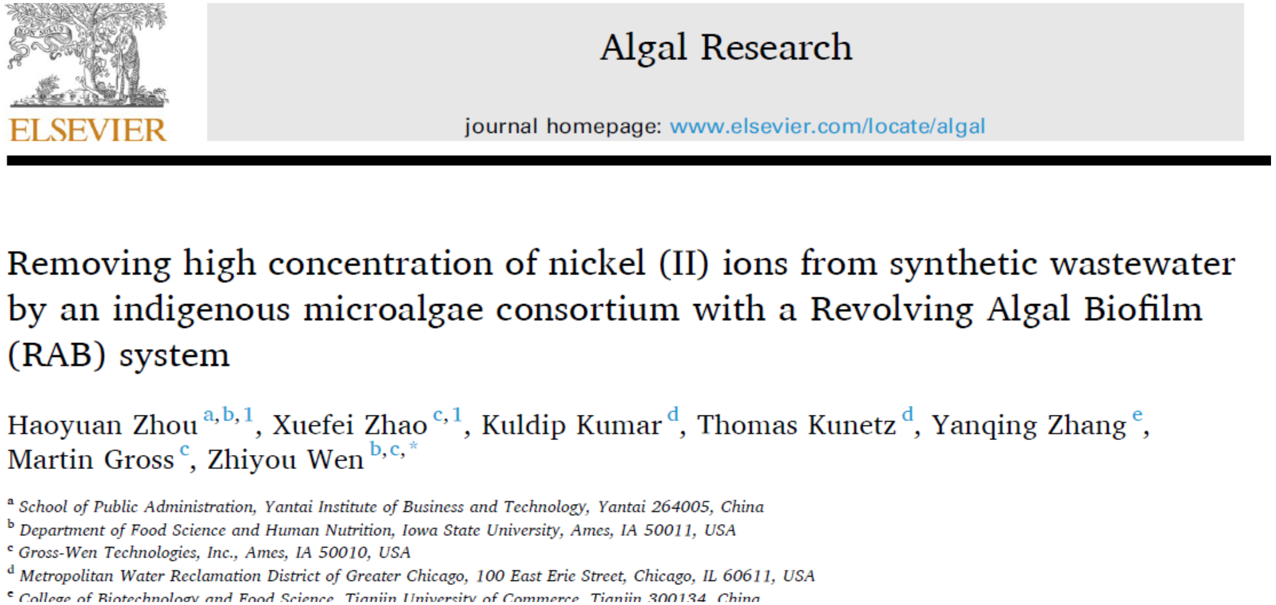
[b] Metropolitan Water Reclamation District of Greater Chicago, 100 East Erie Street, Chicago, IL, 60611, USA
[c] Food Science and Human Nutrition, Iowa State University, 536 Farmhouse Ln, Ames, IA, 50011, USA



RAB for Wastewater Treatment (ii):
Nickel (II) ions removal from wastewater



Algal Research

journal homepage: www.elsevier.com/locate/algal

Removing high concentration of nickel (II) ions from synthetic wastewater by an indigenous microalgae consortium with a Revolving Algal Biofilm (RAB) system

Haoyuan Zhou[a,b,1], Xuefei Zhao[c,1], Kuldip Kumar[d], Thomas Kunetz[d], Yanqing Zhang[e], Martin Gross[c], Zhiyou Wen[b,c,*]

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[b] Department of Food Science and Human Nutrition, Iowa State University, Ames, IA 50011, USA
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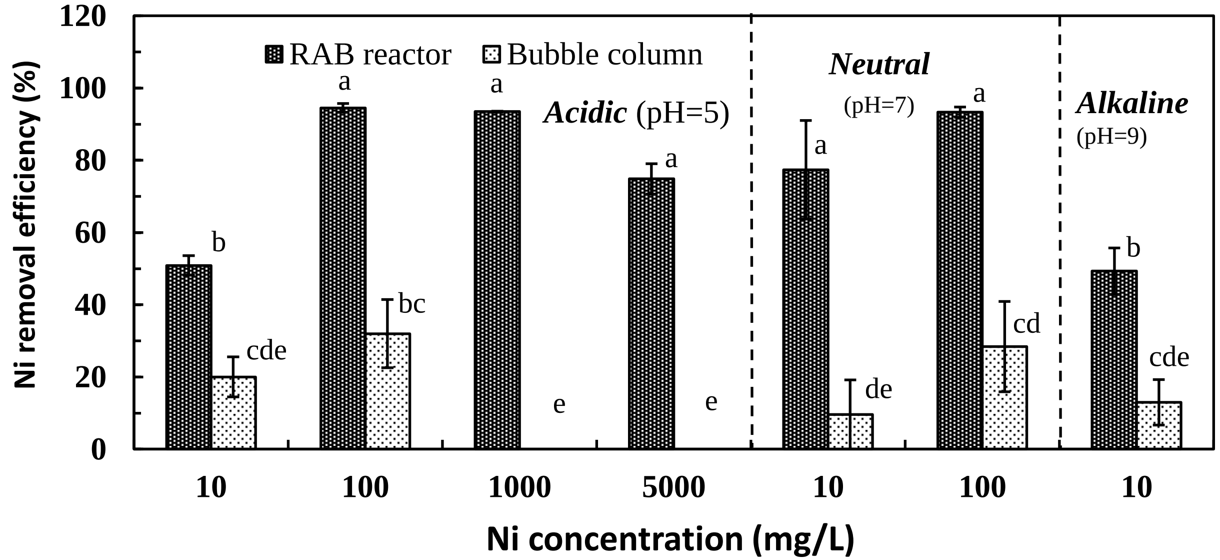
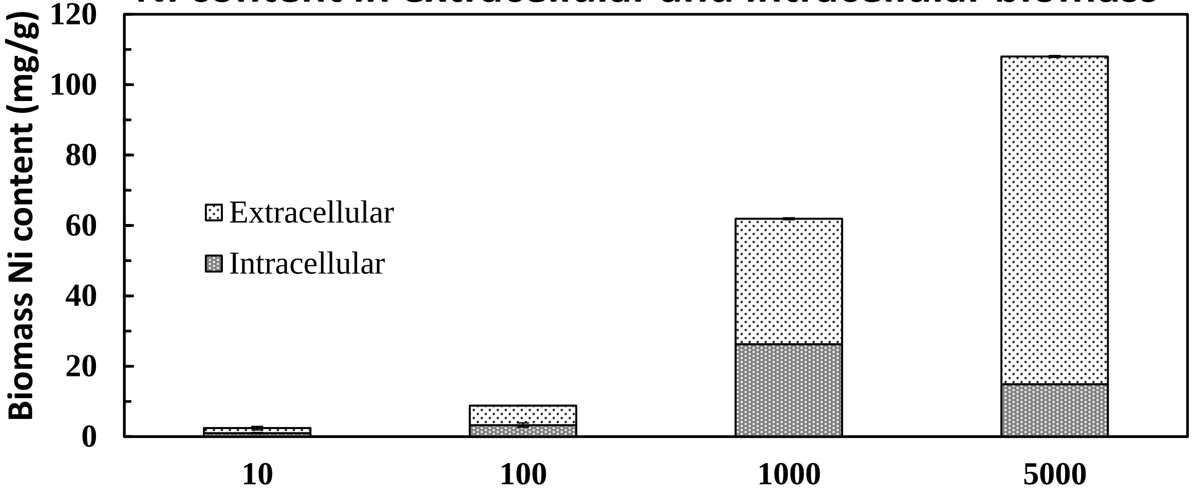
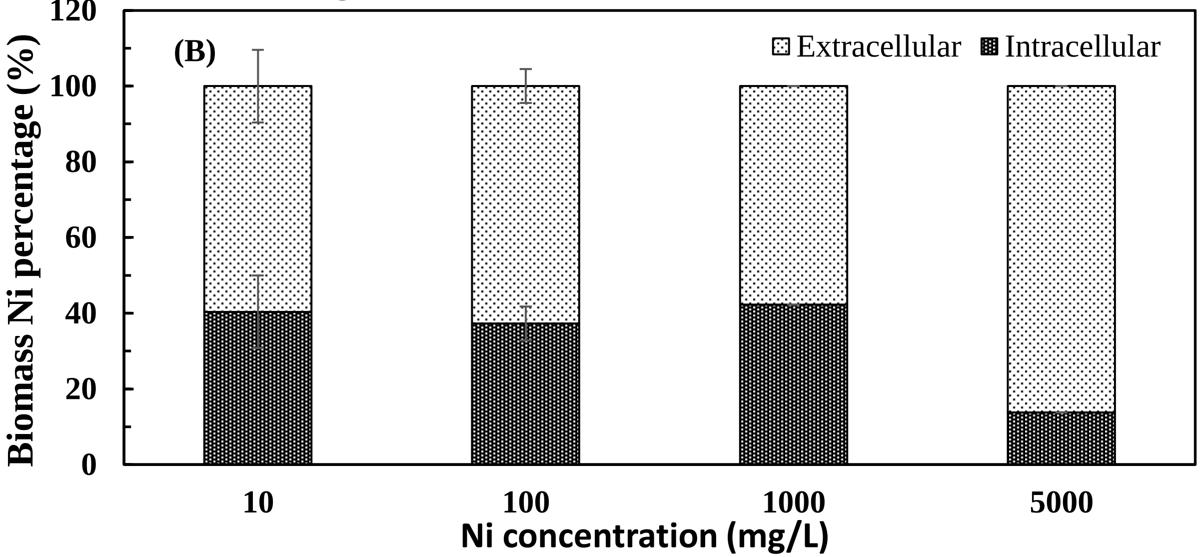
[d] Metropolitan Water Reclamation District of Greater Chicago, 100 East Erie Street, Chicago, IL 60611, USA
[e] College of Biotechnology and Food Science, Tianjin University of Commerce, Tianjin 300134, China



Ni content in extracellular and intracellular biomass



Percentage of extracellular and intracellular Ni



RAB for Wastewater Treatment (iii): Total dissolved solids (TDS) removal from wastewater

Water Environment Federation
the water quality people

Removal of total dissolved solids from wastewater using a revolving algal biofilm reactor

Juan Peng,[1,2] Kuldip Kumar,[3*] Martin Gross,[4*] Thomas Kunetz,[3*] Zhiyou Wen[2,4,*]

[1]Guangdong Provincial Key Laboratory of Marine Resources and Coastal Engineering, School of Marine Sciences, Sun Yat-Sen University, Guangzhou, China
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[4]Gross-Wen Technologies Inc., Ames, Iowa

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DOI: 10.1002/wer.1273

• **Abstract**

Total dissolved solids (TDS) comprising inorganic salts and organic matters are pollutants of concern to aquatic systems and water for human use. This work aimed to investigate the use of revolving algal biofilm (RAB) reactors as a sustainable and environmental friendly method to remove TDS from industrial effluents and municipal wastewaters. The wastewaters contained chloride, sodium, potassium, calcium, magnesium, and sulfate as the major components. The RAB reactors fed with synthetic industrial effluent with high TDS level demonstrated the best algal growth, with the highest TDS removal efficiency (27%) and removal rate (2,783 mg/L-day and 19,530 mg/m^2-day). A suspended algal culture system only removed 3% TDS from the same wastewater. The TDS removal by the RAB reactors was considered due to several mechanisms such as absorption by the algae cells, adsorption by extracellular polymeric substance of the biofilm, and/or precipitation. Collectively, this research shows that the RAB reactors can serve as an efficient system in wastewater remediation for TDS removal. © 2019 Water Environment Federation

• **Practitioner points**

- Total dissolved solids (TDS) in wastewater are pollutants of concern.
- The RAB reactors can remove TDS from various types of wastewater.
- The RAB reactors removed TDS by adsorbing ions elements such as Cl, Na, K, Ca, Mg, and S.
- The algal biomass absorbs ions through extracellular polymeric substance.

• **Key words**

chloride; extracellular polymeric substance; revolving algal biofilm; total dissolved solids

(19) **United States**
(12) **Patent Application Publication**
Wen et al.

(10) **Pub. No.: US 2020/0231477 A1**
(43) **Pub. Date: Jul. 23, 2020**

(54) **SYSTEMS AND METHODS FOR REDUCING TOTAL DISSOLVED SOLIDS (TDS) IN WASTEWATER BY AN ALGAL BIOFILM TREATMENT**

(71) Applicants: **Iowa State University Research Foundation, Inc.**, Ames, IA (US); **Metropolitan Water Reclamation District of Greater Chicago**, Chicago, IL (US)

(72) Inventors: **Zhiyou Wen**, Ames, IA (US); **Juan Peng**, Ames, IA (US); **Martin A. Gross**, Ames, IA (US); **Kumar Kuldip**, Chicago, IL (US); **Thomas Kunetz**, Chicago, IL (US)

(21) Appl. No.: **16/748,211**

(22) Filed: **Jan. 21, 2020**

Publication Classification

(51) **Int. Cl.**
C02F 3/08 (2006.01)
C02F 1/66 (2006.01)

(52) **U.S. Cl.**
CPC . *C02F 3/08* (2013.01); *C02F 1/66* (2013.01)

(57) **ABSTRACT**

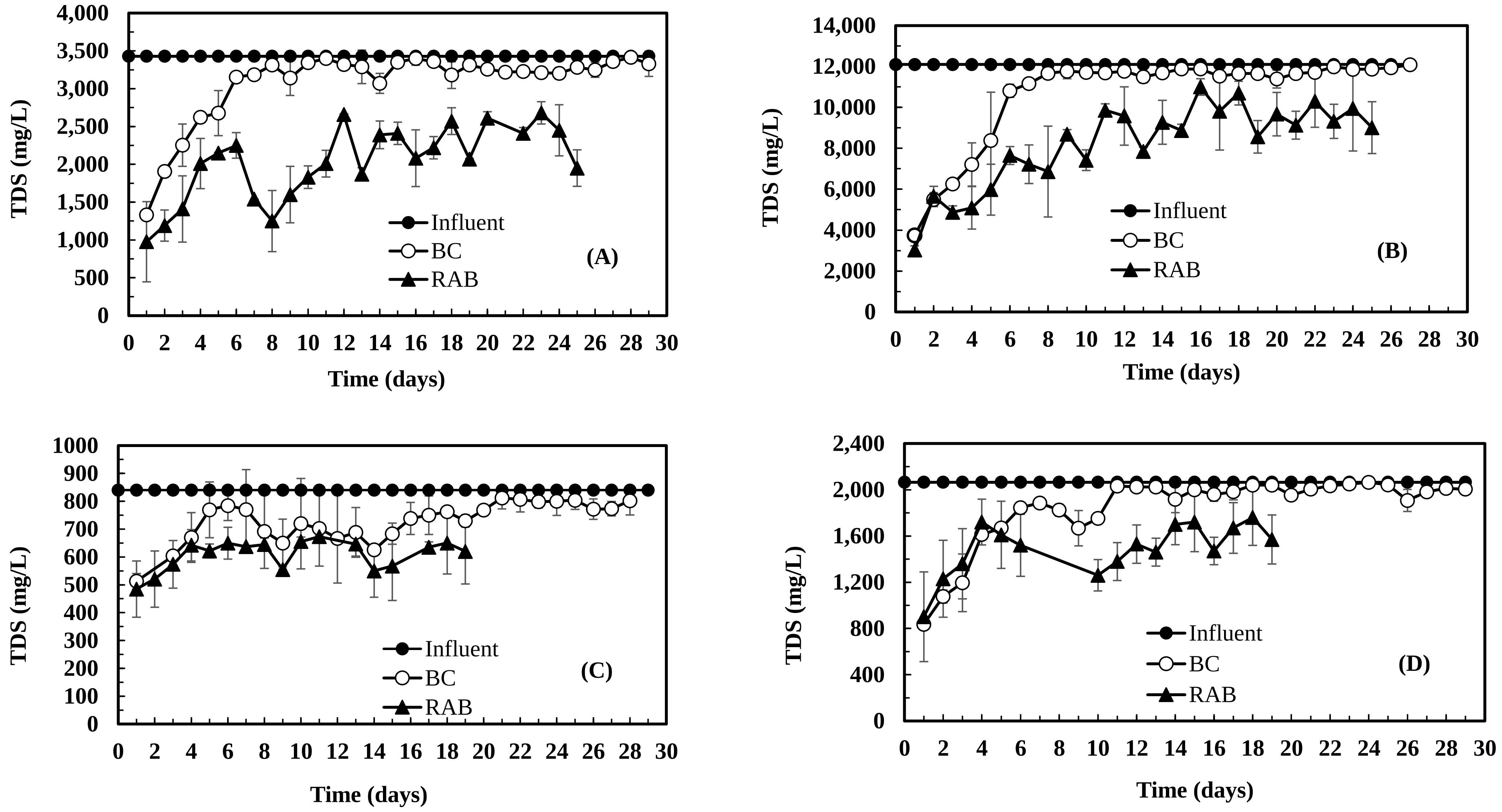
A system for reducing total dissolved solids in wastewater can include a vertical reactor that can include a flexible sheet material, where the flexible sheet material can be configured to facilitate the growth and attachment of an algal biofilm. The vertical reactor can include a shaft, where the shaft can be associated with and can support the flexible sheet material, and a drive motor, where the drive motor can be coupled with the shaft such that the flexible sheet material can be selectively actuated. The system can include a fluid reservoir containing a portion of wastewater through which the flexible sheet material is configured to pass as well as a stressor operably configured to stimulate the algae to produce an

USPTO Updates (May 16, 2023): claims allowed and its official issuance will happen in the next month

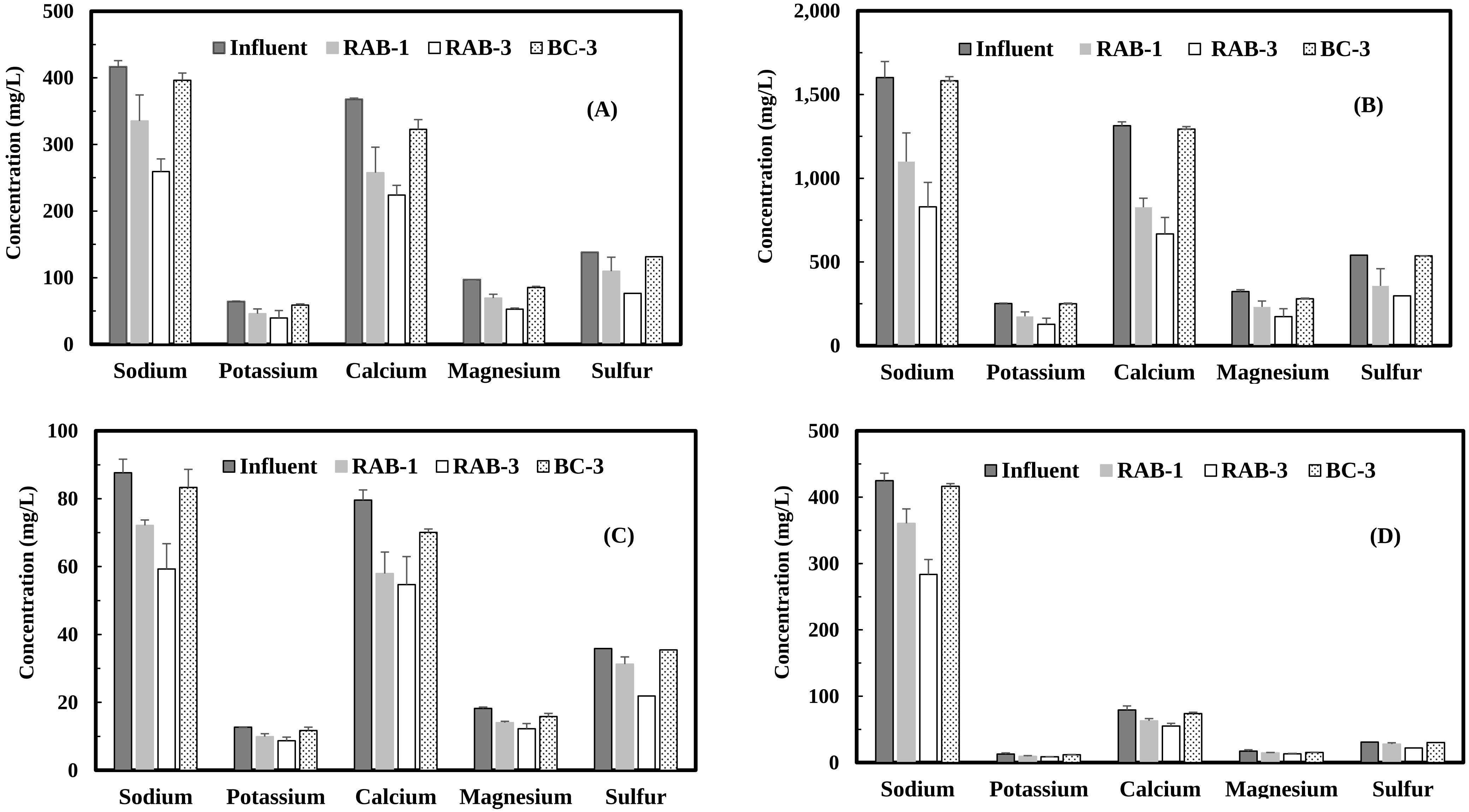
Four types of wastewater with different TDS levels

Components (mg/L)	Wastewater (WW) sources			
	Industrial WW – low TDS (A)	Industrial WW – high TDS (B)	Ames WW (C)	Ames WW +NaCl (D)
Sodium	417	1,601	88	425
Potassium	64	252	13	13
Calcium	368	1,359	80	79
Magnesium	97	324	17	16
Chloride	1,250	4,500	175	781
Sulfur	138	540	33	37
Nitrogen	14	56	26	26
Phosphorus	9	36	12	13
Silicon	23	92	Not added	Not added
BBM trace metals	10 mL/L	10 mL/L	Not added	Not added
TDS	3,430	12,100	840	2,065
pH	9.60	9.80	7.89	7.92

TDS concentrations in the influent and effluent of RAB systems



Salt concentrations in the influent and effluent of the RAB systems



RAB for Wastewater Treatment (iv): Pharmaceutical and Personal Care Products

US EPA definition: any product used by individuals for personal health or cosmetic reasons or used by agribusiness to enhance growth or health of livestock.

Concerns of PPCPs in environment:

- Persistence
- Bioaccumulation
- Acute toxicity
- Feminization of male fish

Model PPCP compounds used

- Ibuprofen (painkiller drug)
- Oxybenzone (cosmetic product)
- Bisphenol A (antimicrobial agent)
- Triclosan (plasticizer)
- DEET (insect repellent)

Individual home

Hospital

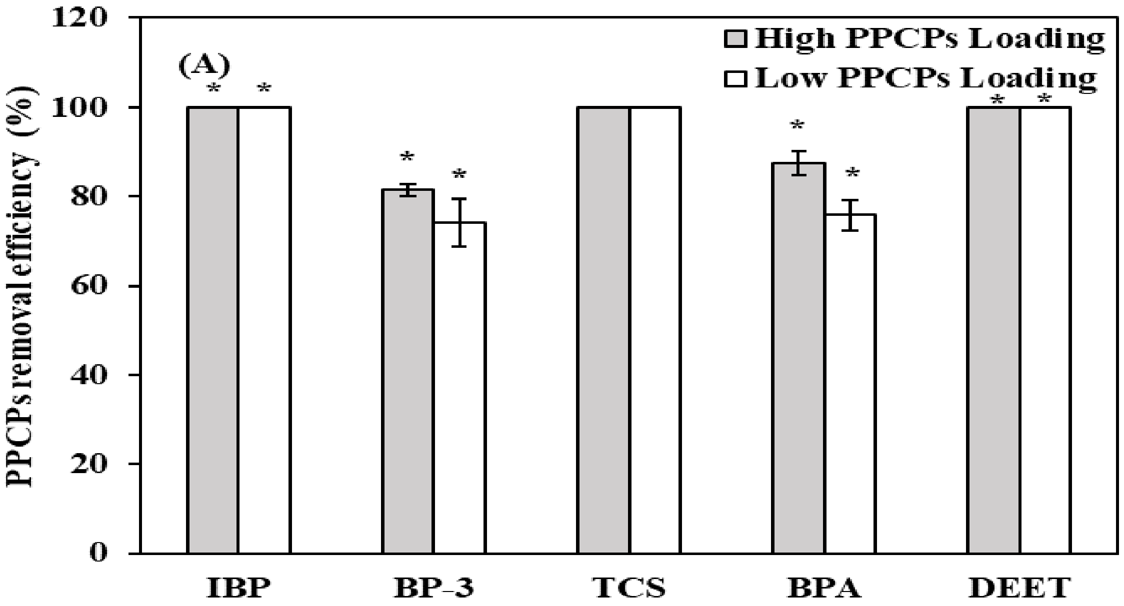
Contents lists available at ScienceDirect
Journal of Hazardous Materials
journal homepage: www.elsevier.com/locate/jhazmat
ELSEVIER

Research Paper

Removal of pharmaceutical and personal care products (PPCPs) from waterbody using a revolving algal biofilm (RAB) reactor

Si Chen [a], Jiahui Xie [a], Zhiyou Wen [a,b,*]

[a] Department of Food Science and Human Nutrition, Iowa State University, 536 Farmhouse Lane, Ames 50011, Iowa, USA
[b] Gross-Wen Technologies Inc., 404 Main Street, Slater 50244, Iowa, USA



Fate of PPCPs: Accumulation vs. Degradation?

PPCP compound	Accumulation rate (μg $L^{-1}day^{-1}$)		Degradation rate (μg $L^{-1}day^{-1}$)	
	High loading	Low loading	High loading	Low loading
Ibuprofen	0.00 ± 0.00 **(0%)**	0.00 ± 0.00 **(0%)**	20.08 ± 0.00 **(100%)**	9.14 ± 0.00 **(100%)**
Oxybenzone	0.06 ± 0.01 **(2%)**	0.05 ± 0.01 **(6%)**	2.24 ± 0.10 **(98%)**	0.87 ± 0.05 **(94%)**
Triclosan	0.05 ± 0.00 **(7%)**	0.04 ± 0.00 **(7%)**	0.64 ± 0.00 **(93%)**	0.55 ± 0.00 **(93%)**
Bisphenol A	0.00 ± 0.00 **(0%)**	0.00 ± 0.00 **(0%)**	0.79 ± 0.00 **(100%)**	0.42 ± 0.04 **(100%)**
DEET	0.00 ± 0.00 **(0%)**	0.00 ± 0.00 **(0%)**	27.03 ± 0.00 **(100%)**	12.80 ± 0.00 **(100%)**

Commercialization of using RAB system for wastewater treatment

Regulatory approvals to treat wastewater and sell algae fertilizer

11
Issued Patents

2012
RAB Invented at Iowa State University

$16 million
In equity/grant funding to date

20 Employees
World leading algae wastewater team

>35
Projects at WWTP's

10,000+
Treatment data points

$14 million
in commercial projects under construction

$17 million
Projects in design

Modular design of the RAB system

10

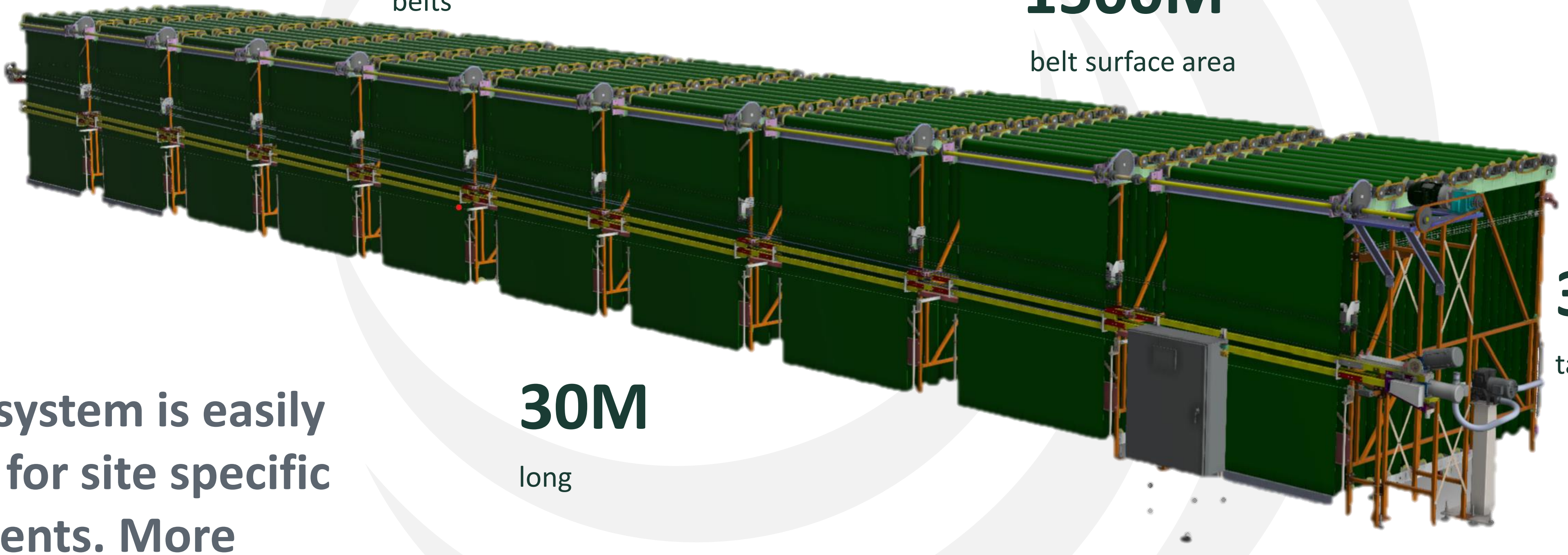
belts

1500M^2

belt surface area

3.2M

wide



3M

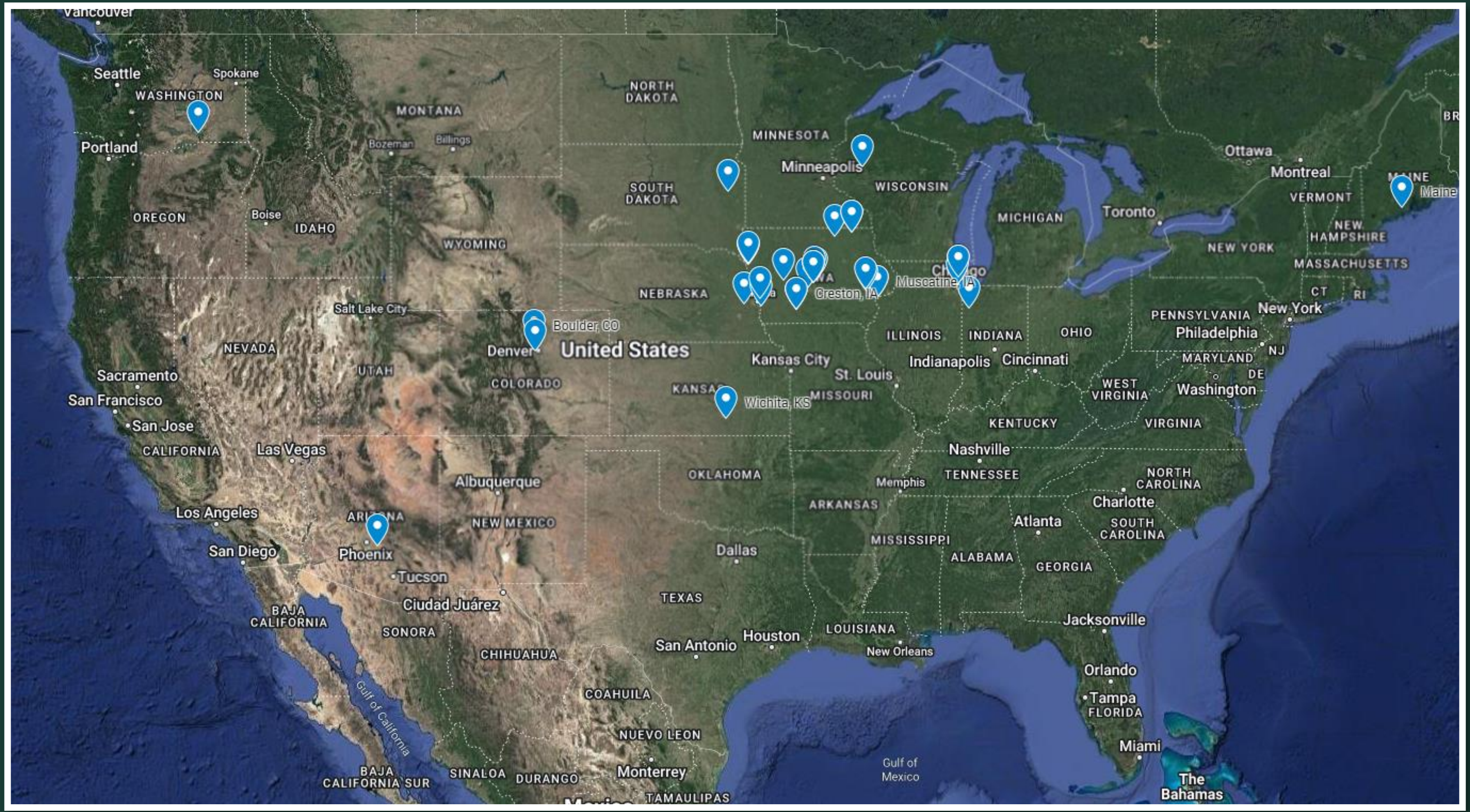
tall

30M

long

The RAB system is easily modified for site specific requirements. More treatment is achieved by adding additional modules.

Where has the RAB been?



35 Projects across the United States

1 Project in Japan

1 Project in Singapore

GWT's Target Markets

GWT has validated the RAB system is a cost-effective treatment solution in our four target markets

Anaerobic Digestors	Fixed Film Plants
GWT Customer Example: Pasco WA	GWT Customer Example: Creston, IA

Lagoon Plants	Industrial (Food/Beverage)
GWT Customer Example: Slater, IA	GWT Customer Example: CHBC Beef Processing

TARGET MARKET (i):
SIDE STREAM TREATMENT OF ANAEROBIC DIGESTER EFFLUENT AT WWTP

Project Qualifiers:

1. WRRF has anaerobic digesters.
2. Additional nutrient treatment capacity is needed for new nutrient permit.
3. Benefit of simultaneous N and P removal.
4. Benefit of lowering operating costs and reduced carbon intensity

Anaerobic Digestor Side Stream Treatment

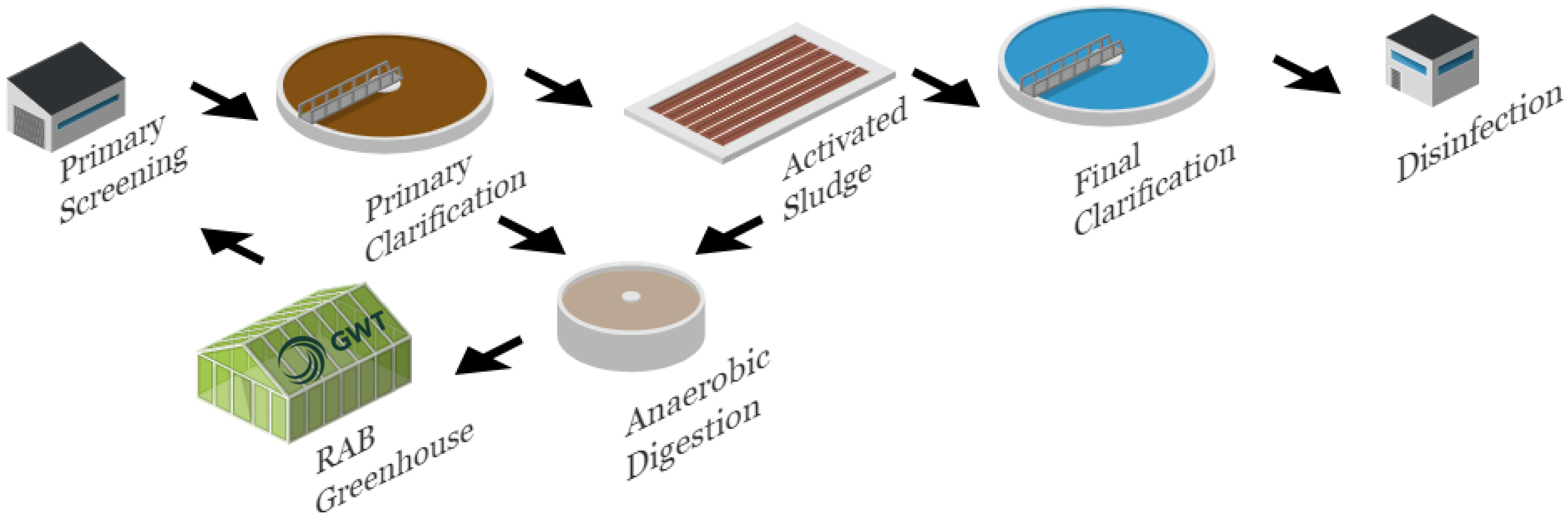
04

TARGET APPLICATION: MUNICIPAL WWTP WITH AD

WWTP's that need additional TKN, TN or TP capacity often expand their secondary treatment process. An alternative is to install side stream treatment to reduce the total plant loading. The RAB system can be used as an alternative means to expand plant capacity.

ADVANTAGES

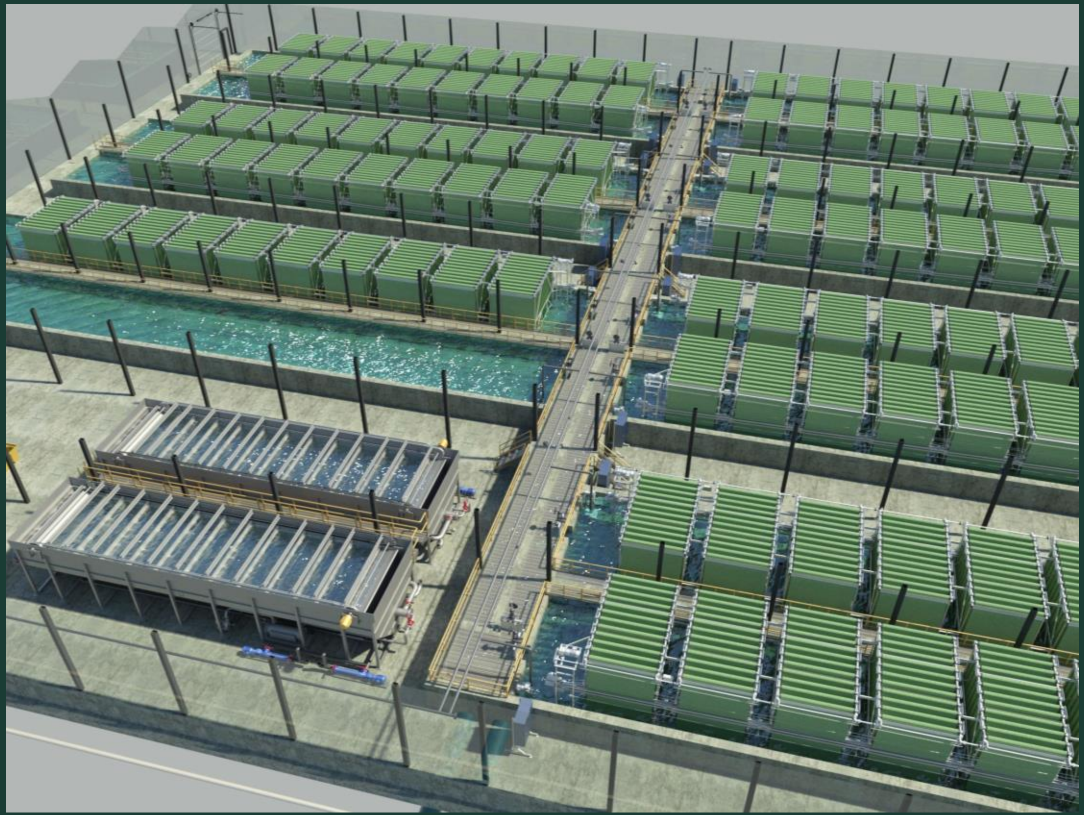
- Simultaneous treatment of both nitrogen and phosphorus
- Simple to operate and maintain
- Reduced total energy use of WWTP
- Lower carbon footprint



Case study: Sioux City, IA – Side Stream Treatment of Anaerobic Digester Effluent

Project Started	**6/15/2020**	**Project Description:** RAB system treating anaerobic digester effluent to remove both nitrogen and phosphorous simultaneously before recycling water to the headworks of the treatment plant.			
Project Ended	**10/8/2020**				
# of Data Points	**749**				
Parameter	**RAB Influent mg/L**	**RAB Effluent mg/L**	**Removal Efficiency**	**SALR g/m2/day**	**SARR g/m2/day**
Ammonia	173.4	103.7	40.2%	39.8	13.1
Total Nitrogen	228.3	197.0	13.7%	53.6	3.9
Total Phosphorous	12.8	10.6	17.1%	2.9	0.5
COD	535.6	398.5	25.6%	119.9	32.1
TKN	223.1	156.2	30.0%	52.4	13.5
sTP	11.1	9.3	16.7%	2.6	0.4

Case study: Pasco, WA – Food Processor Digestor Effluent (2023 Commercial System)



- 4.0 MGD Wastewater
- 13 RAB Modules (10 Belts / Module)
- 2,250 lbs N removed /day
- 140 M.T. Algae Produced / year
- 5,300 M.T. CO_2e Offset / year
  - 5,830 Equivalent Acres of Forests
- 1.1 Acres of Land Required
- Under construction
- Summer 2024 start up

TARGET MARKET (ii):
SECONDARY TREATMENT AT LAGOONS

Project Qualifiers:

1. Lagoon WWTP (controlled or continuous discharge)
2. Needs to meet stricter N, P, or ammonia permits (all three preferred)
3. Benefits from additional BOD capacity

Secondary Treatment with Nutrient Removal at Lagoons

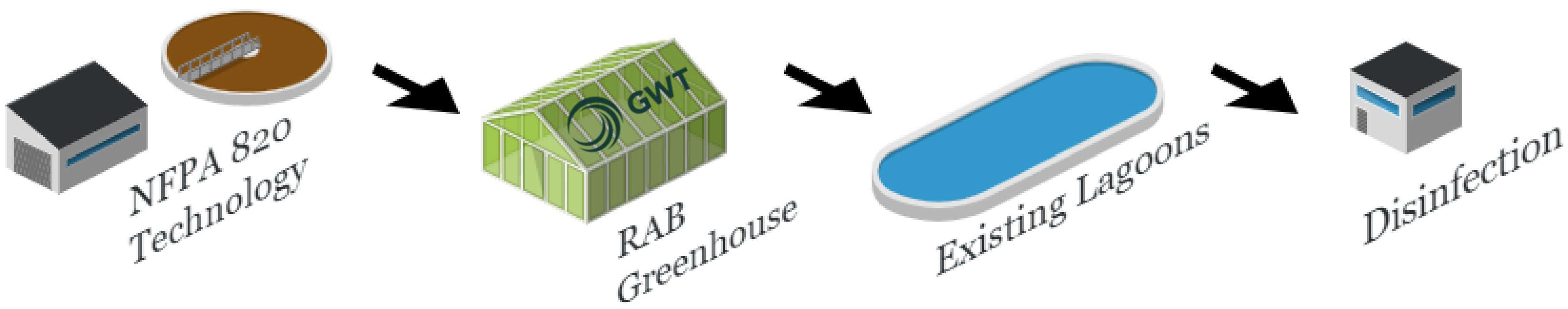
01

TARGET APPLICATION: LAGOON FACILITIES

Lagoon facilities that need to be upgraded to meet new NH3, TN or TP permits. If a client is considering abandoning a lagoon for a mechanical treatment plant, the RAB is a simple retrofit alternative

ADVANTAGES

- Lower energy use compared to aeration-based technologies
- Simple operation, low operator grade requirement
- Easy to maintain, with off the shelf components
- Allows for retrofit vs completely new treatment plant



Case study: Slater, IA – Secondary Treatment at Lagoons

Project Started	9/1/2019	**Project Description:** Data collected from demonstration facility in Slater, IA treating primary effluent after coarse screening			
Project Ended	**Current**				
# of Data Points	**2,889**				
Parameter	**RAB Influent mg/L**	**RAB Effluent, mg/L**	**Removal Efficiency**	**SALR, g/m2/day**	**SARR, g/m2/day**
Ammonia	29.3	19.0	35.0%	16.9	3.9
Total Nitrogen	39.9	30.7	23.1%	21.2	4.2
Total Phosphorous	4.4	3.4	21.7%	2.3	0.5
COD	243.0	134.2	44.8%	111.5	37.2
TKN	33.6	25.8	23.2%	8.1	2.3
sTP	3.3	2.6	22.0%	0.6	0.2
BOD5	143.1	69.4	51.5%	32.1	18.9
TSS	97.5	76.2	21.8%	24.8	14.7
Alkalinity	479.5	440.5	8.1%	109.8	13.0

GWT GROSS-WEN TECHNOLOGIES

SIDE TANGENT #1:

RAB Treatment Modeling

RAB Treatment Modeling

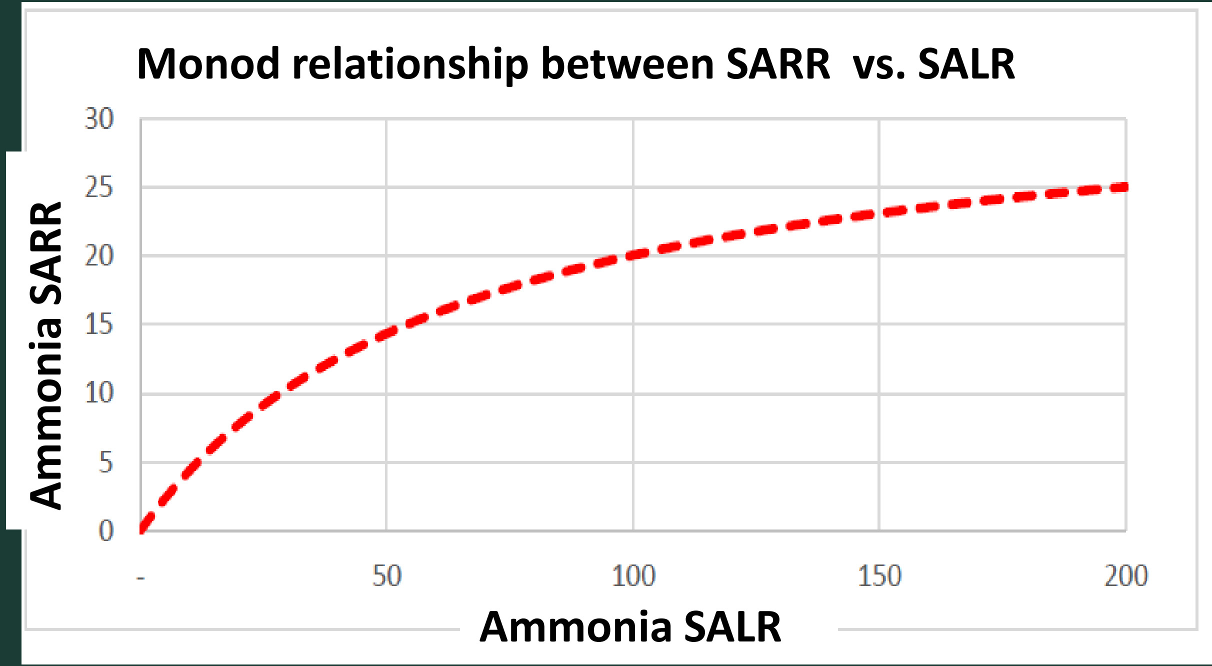
General Overview

RAB MODEL OVERVIEW

- Over the past 10 years, we have collected >10,000 data points from 25 projects deployed at real wastewater plants
- Developing RAB treatment model to predict future RAB treatment capability based on the real world data, so the RAB size can be determined.
- Separate models are used based on application.
    1. Iowa Lagoon Treatment
    2. Primary/Secondary Treatment
    3. Tertiary Treatment
    4. Anaerobic Digester Treatment

RAB Treatment Modeling

General Overview



RAB MODELING APPROACH

- To establish relationship between the loading rate (SALR) and removal rate (SARR).
- The curve is based on Monod growth kinetics and is trained based on imperial observations from RAB systems .

RAB Treatment Modeling

Series Model Concept

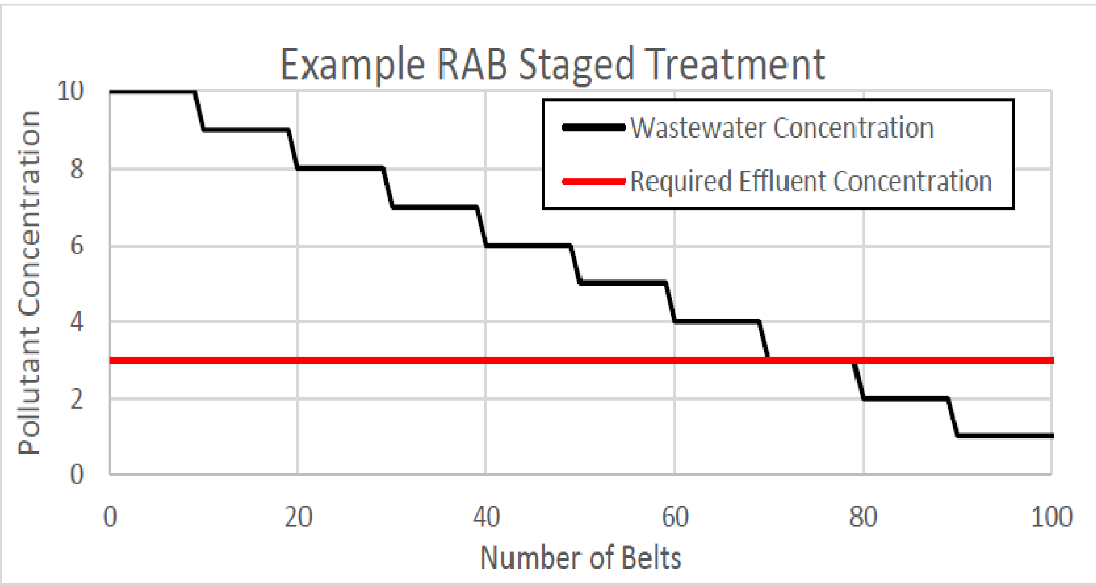


Figure 2 - Example Series Based Treatment Model

RAB SERIES MODEL CONCEPT

- Influent flows sequentially from one module (stage) to the next of a commercial RAB system.
- RAB removes nutrients based on a series stages to achieve the required mass removal.
- Each stage achieves a small percent removal; Multiple stages are combined together to achieve the overall mass removal target.

GWT GROSS-WEN TECHNOLOGIES

SIDE TANGENT #2

Sustainability: Carbon Footprint and Waste Reduction

GWT GROSS-WEN TECHNOLOGIES

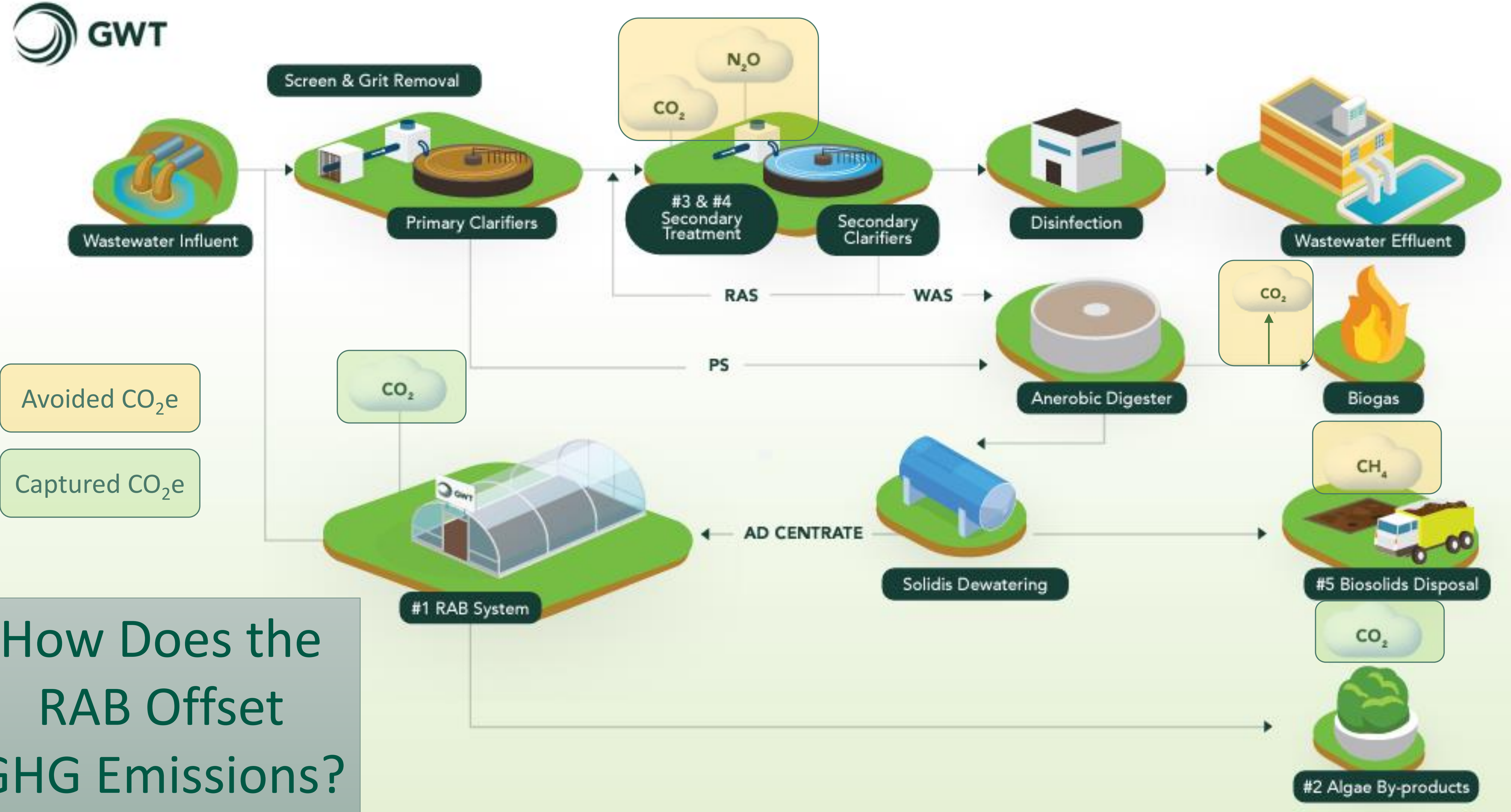
PUB (Public Utilities Board) Singapore: Winer of the Carbon Zero Grand Challenge

Carbon Footprint Reduction by Algae in the Context of Wastewater Treatment

WHAT IT IS:

- PUB Singapore held a global competition for technologies that could be used to make their utility carbon neutral.
- S$6.5M in potential prize winnings
- GWT/Xylem Singapore are 1 of 2 winners among 460 applicants

PUB SINGAPORE'S NATIONAL WATER AGENCY

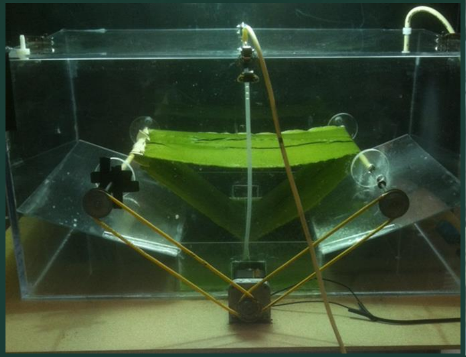


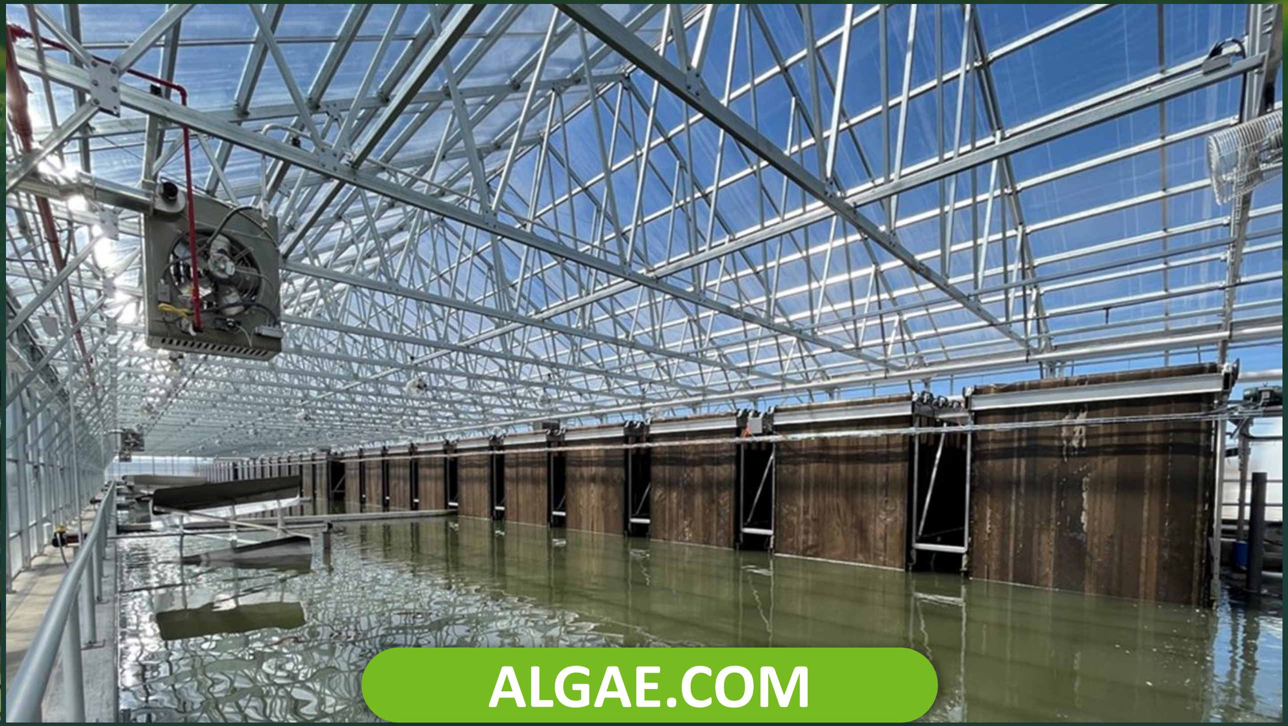
How Does the RAB Offset GHG Emissions?

Metropolitan Water Reclamation District of Greater Chicago

Iowa State University

Gross-Wen Technologies





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