Potable Water Recovery:
Integrated Algal-Membrane System

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Introduction

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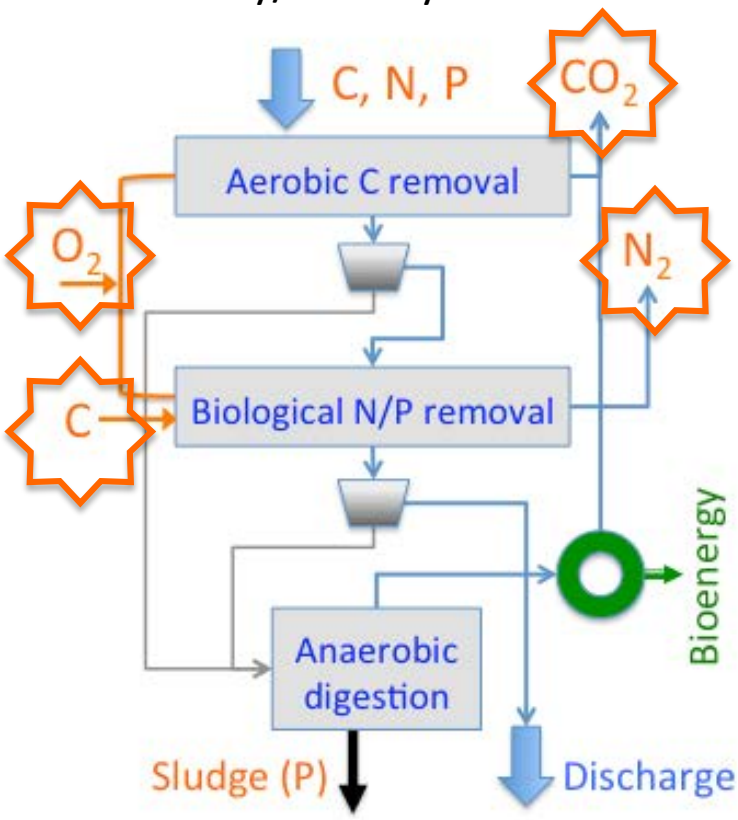
Wastewater Treatment (WWT)

Current practice

Secondary/Tertiary treatment:



Urban wastewaters contain organic carbon (C), nutrients (nitrogen, N; and phosphorous, P), and pathogens that are are required to be reduced to meet discharge permits.

- Current technologies for WWT are energy-intensive
  - C removal = 1.48 kW-hr/kg C
  - N & P removal = 19.8 kW-hr/kg N & P

* Total energy consumed by WWTPs in US
  = 1,200 kW-hr/day per 10,000 people
  = 3% of total energy consumed by US

Wastewater Treatment (WWT)

Current practice

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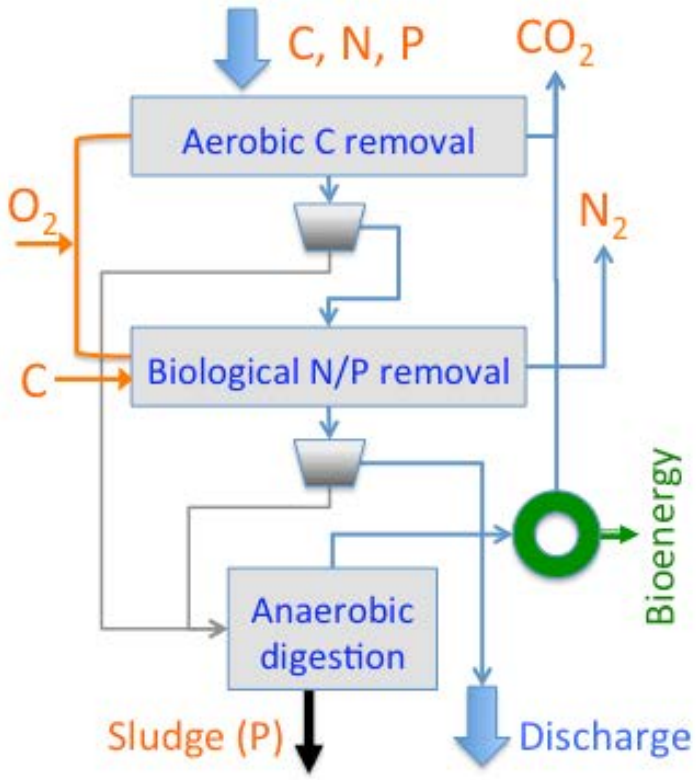


Environmental impacts of energy use in WWT plants

- total emissions = 15.5 Tg CO_2-equiv.
- acidification potential = 145 Gg SO_2
- eutrophication potential = 4 Gg PO_4^{3-}

Current technologies at WWT plants

- dissipate valuable organic-C
- dissipate valuable nutrients (N & P)
- energy-negative
- not sustainable or cost-effective.

Research Program at NMSU

Goal: Engineer an integrated algal-membrane system for sustainable wastewater treatment and recovering potable-quality water, fertilizers, and energy.

History of algal wastewater treatment:

- Originally proposed in UC Berkeley in the 1950s
- Symbiotic functioning of bacteria-algae
- Polishing of secondary effluent
- Treating nutrient-rich wastewaters
- Utilizing autotrophic metabolism (CO_2 + sunlight)

Algal Wastewater Treatment

Traditional algal cultivation systems have relied on open raceways

Limitations of raceways for algal wastewater treatment:

- Evaporative loss and odor emissions
- Invasion by predators
- Low biomass density to allow light penetration: *< 1 g/L*
- Low culture depth to allow light penetration: *0.4 m*
- Need for CO_2 supply: *sparging with CO_2-enriched air*
- Poor gas-culture CO_2 transfer: *short CO_2 contact time*
- Diurnal/seasonal temperature fluctuations
- Inability to meet discharge limits for BOD, N, P, coliform, SS

NMSU Algal System- WWT

Overcoming limitations of algal wastewater treatment systems:

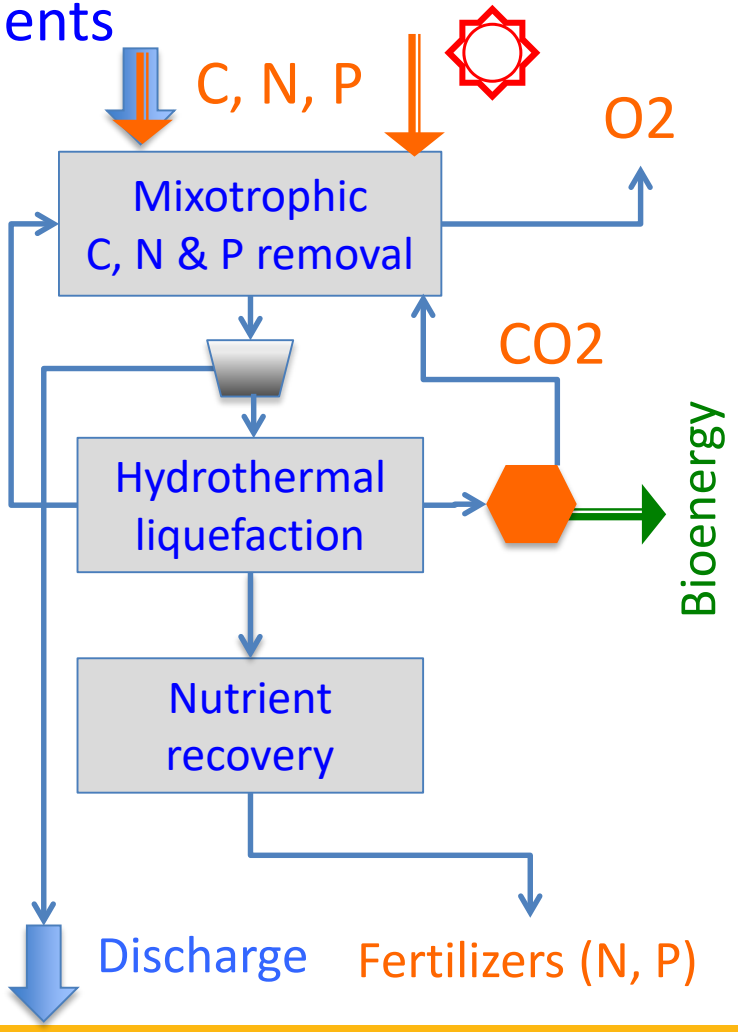
- ✓ Using enclosed algal bioreactors for
  - minimizing invasion by predators
  - better temperature control
  - controlling evaporation and odor emissions
- ✓ Using light-independent mixotrophy for high biomass density
- ✓ Using acidophiles to minimize invaders/control pathogens

***Galdieria sulphuraria*:**

- *mixotrophic*: uptake of dissolved organic-C, N, and P
- *acidophilic*: pH of 4 and thermophilic: 25ºC to 50ºC.
- single-step process to meet discharge standards for BOD, N, and P

NMSU Algal System- WWT

Proposed algal system for UWWT and recovery of energy and nutrients

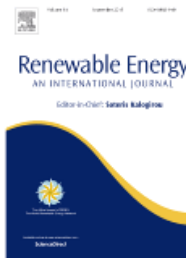


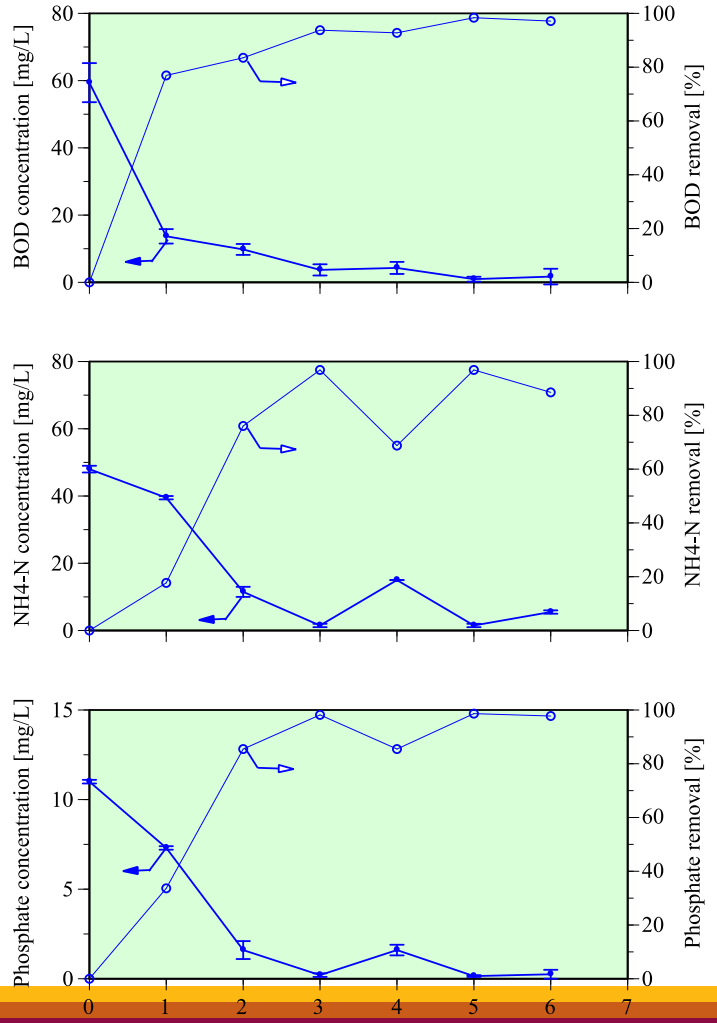
* Eliminates aeration
* Eliminates external C
* Eliminates sludge
* Generates net energy
* Recovers nutrients

NMSU Algal System- WWT

- Laboratory validation w/primary effluent
  - § BOD- removal = 18.6 mg L^{-1} day^{-1}
  - § N-removal = 15.5 mg L^{-1} day^{-1}
  - § P-removal = 3.6 mg L^{-1} day^{-1}

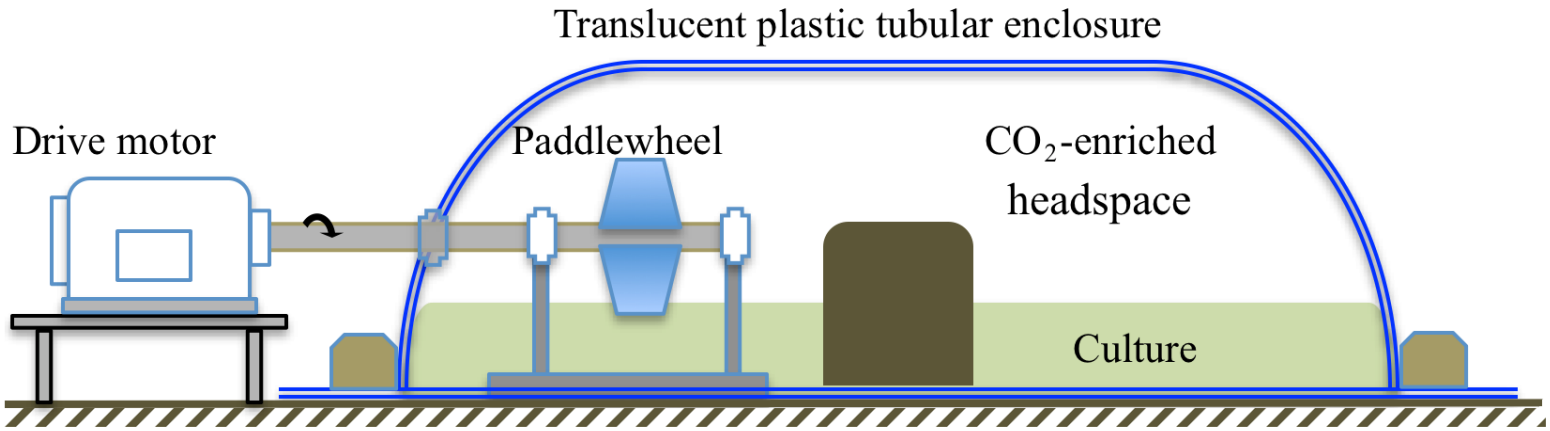
1. Biores. Technol., 156, 395-399, 2014
2. Renewable Energy, 82, 71-76, 2015
3. Biores. Technol., 182, 232-238, 2015
4. Biores. Technol., 189, 273-278, 2015





NMSU Algal System- WWT

- Field demonstration
  - § Prototype scale study from Jan 2015
  - § Batch operation to fed-batch operation



NMSU Algal System- WWT

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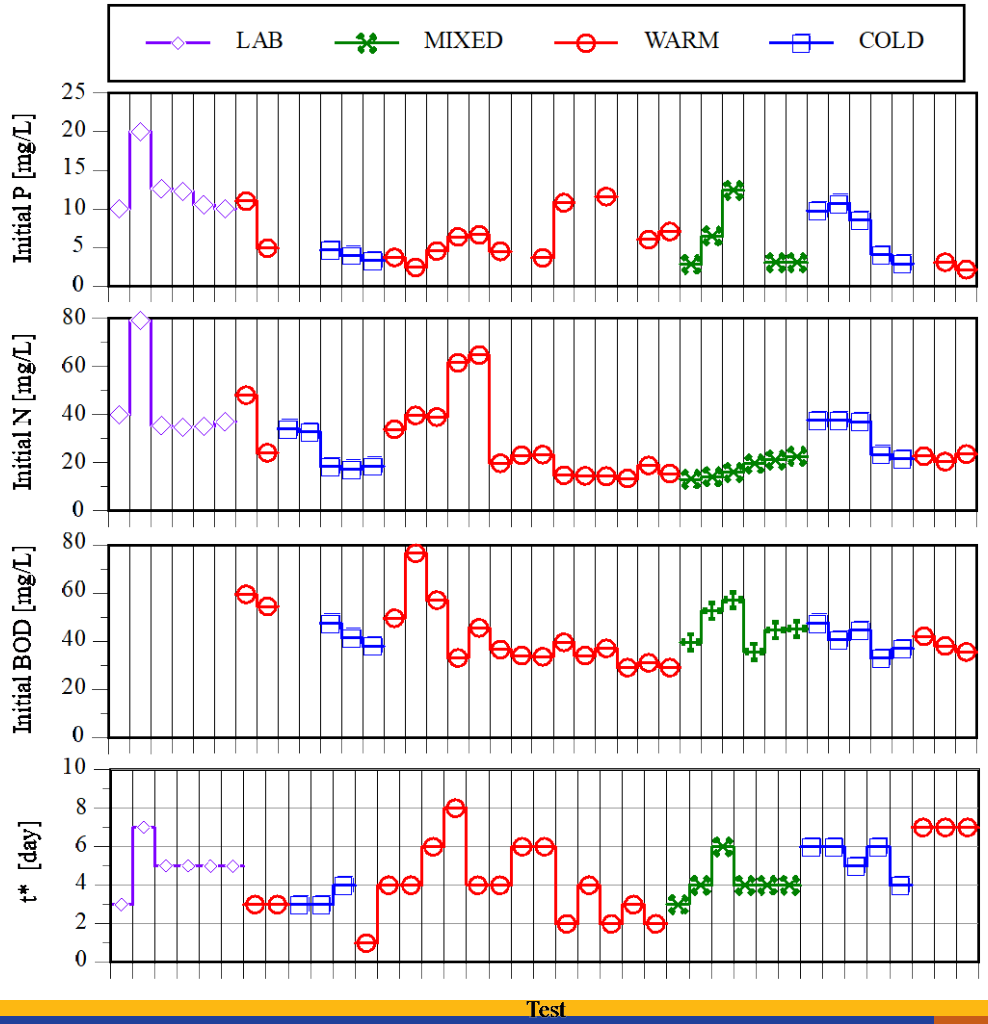
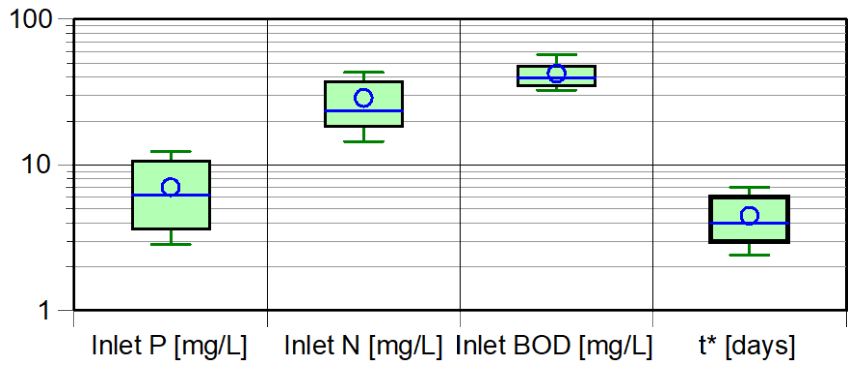


Long-term testing:

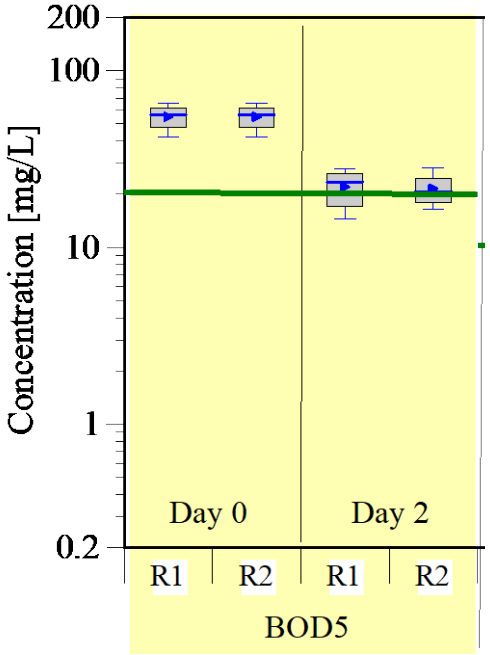
Results from lab and outdoor batch tests (up to 60 different configurations) on "warm", "cold", and "mixed" cultures of *G. sulphuraria* cultivated in primary effluent,
Jan 2015 - Dec 2016

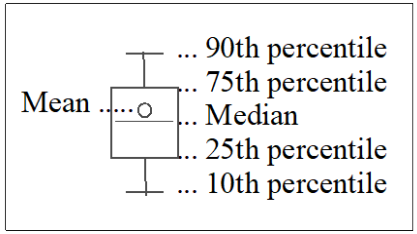


NMSU Algal System- WWT

Batch ➡ Fed-batch

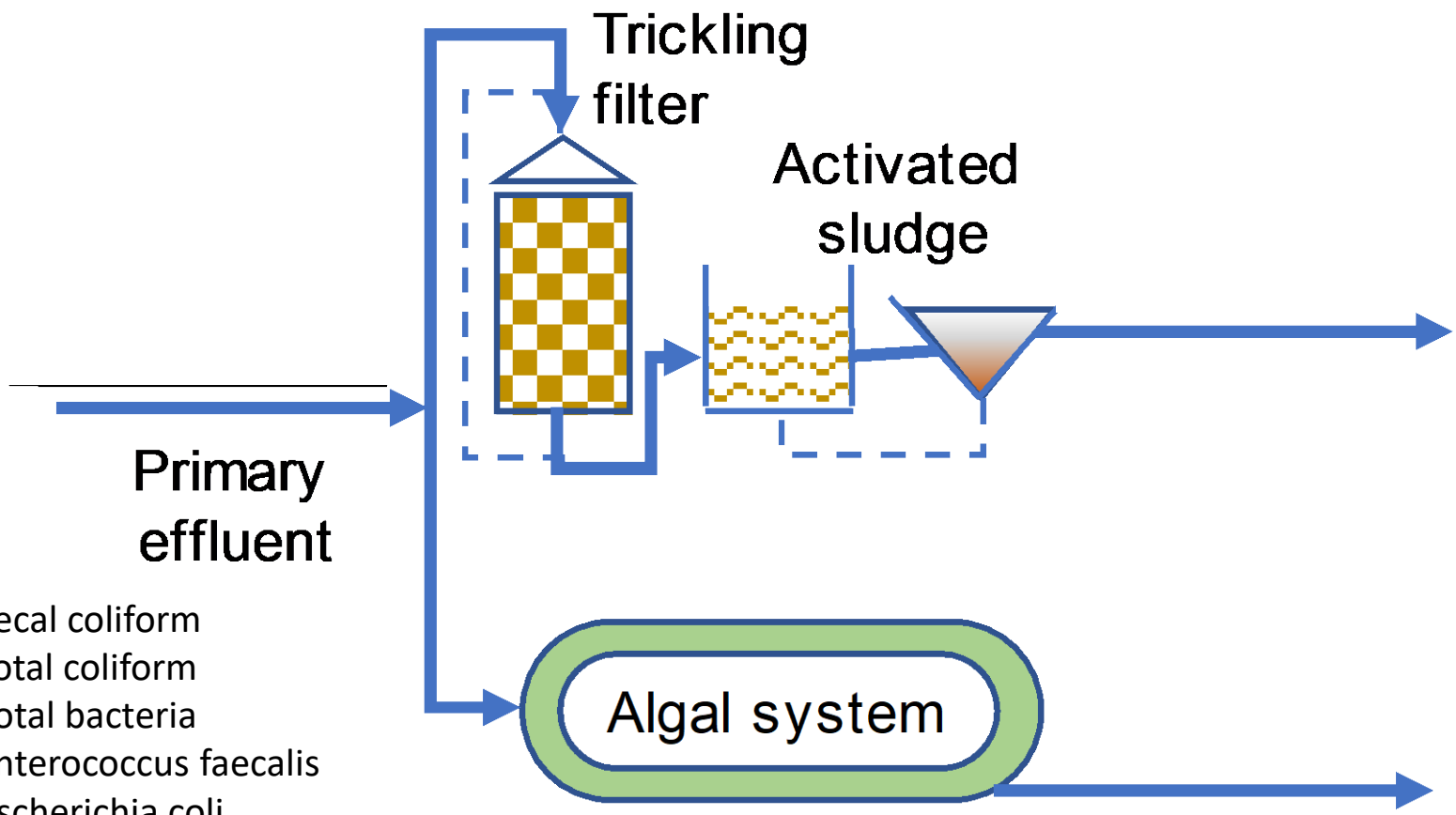
- Fed-batch testing initiated in 2016
- Long-term fed-batch testing from 2017
- Optimized cultivation system to reduce process time to 2 days
- Consistent, reproducible performance under varying influent loading and climate conditions





NMSU Algal System- WWT

Pathogen removal: Traditional vs. Algal technologies



FC- Fecal coliform
TC- Total coliform
TB- Total bacteria
EF- Enterococcus faecalis
EC- Escherichia coli

NMSU Algal System- Water Recovery

Algal effluent

Forward Osmosis Membrane

Dilute draw solution (brine)

Reverse Osmosis Membrane

Water

Water

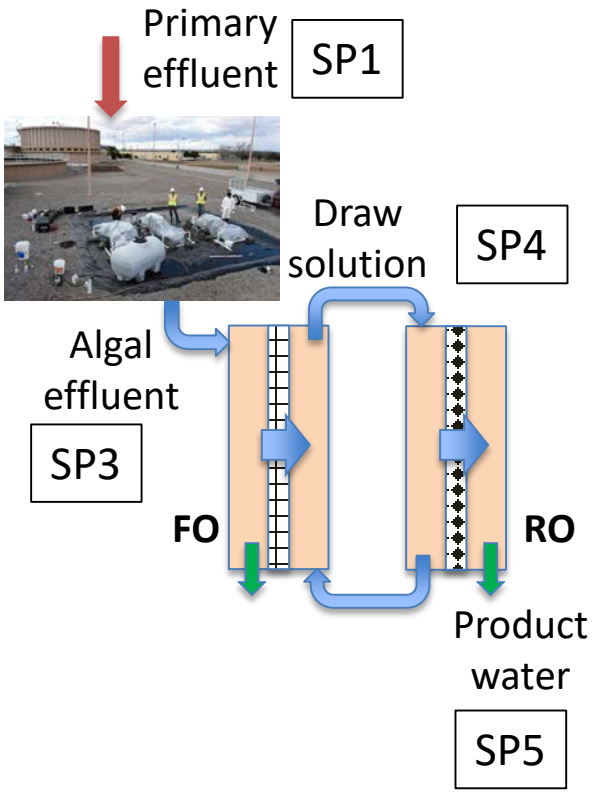
* Zero discharge
* Low energy input
* Low energy harvesting
* High quality effluent

Conc. draw solution (brine)

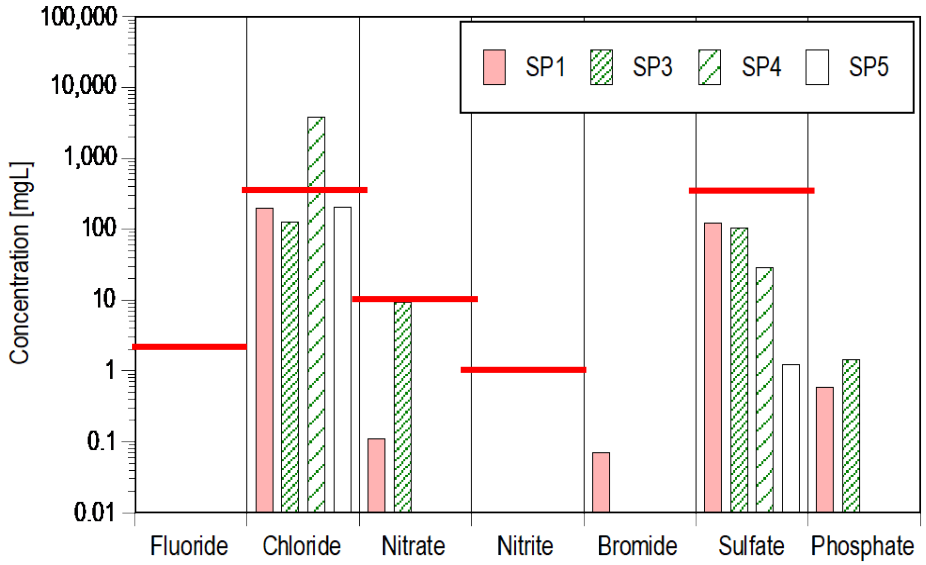
Concentrated algal biomass

Potable-quality water

NMSU Algal System- Water Recovery



Removal of anions



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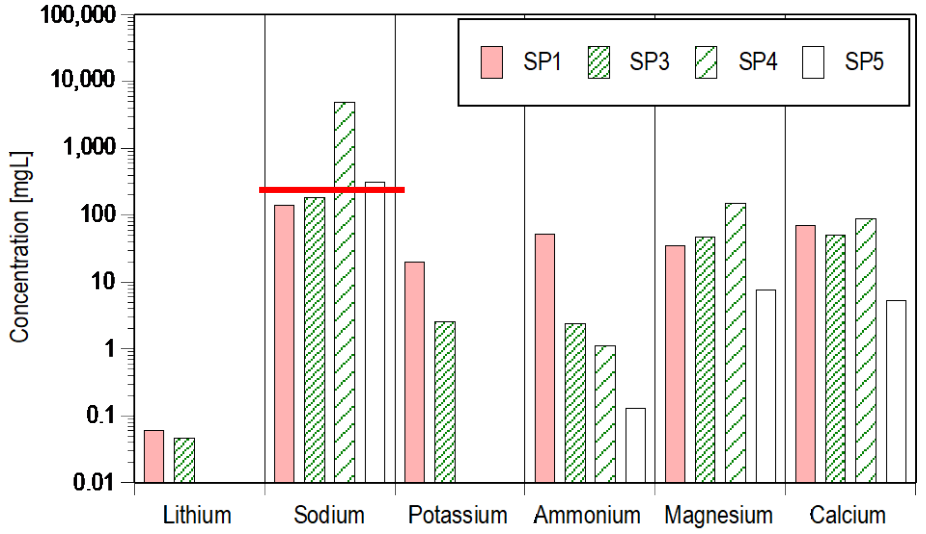
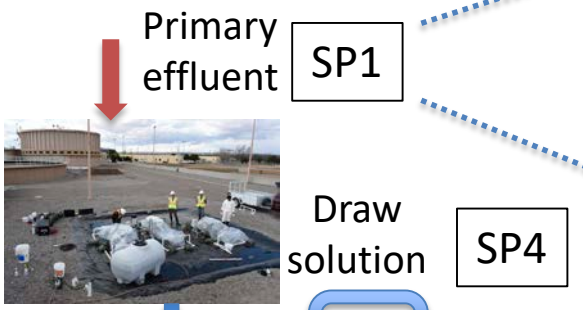


NMSU Algal System- Water Recovery

Removal of Trace organics
Fluorescence Excitation Emission Matrix (FEEM)



Primary effluent

SP1

Draw solution

SP4

Algal effluent

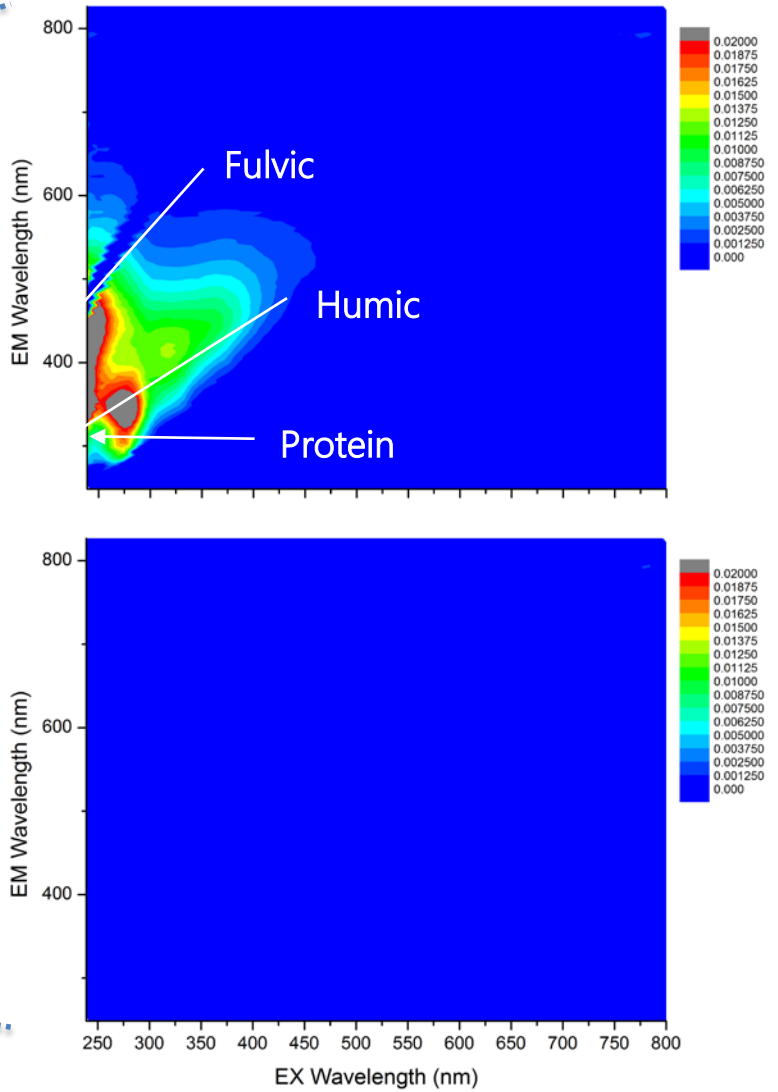
SP3

FO

RO

Product water

SP5



NMSU Algal System- Water Recovery

Product Water Quality vs.
Primary/Secondary Drinking Water Standards

Parameter	Primary effluent	Product water	Standard
TOC [mg/L]	42.0	nd	
Cr [µg/L]	16.7	nd	100
Fe [µg/L]	1048.7	nd	300
As [µg/L]	4.8	1.4	10
Se [µg/L]	3.5	nd	50
Cd [µg/L]	0.03	nd	5
Ba [µg/L}	17.1	nd	2000
Pb [µg/L]	nd	nd	15

Conclusions/Future studies

- Mixotrophic algal systems can be engineered for removal of dissolved BOD, N, P, and pathogens from urban wastewaters to meet mandated discharge standards
- Algal system can conserve energy input for BOD-removal, Org-C input for N-removal, and minimize disinfectant demand for pathogen control
- Algal system integrated with FO/RO membrane has potential for energy-harvesting of algal biomass and recovering potable-quality water from urban wastewaters
- Current pilot scale algal-membrane system deployed at the Las Cruces Wastewater Treatment Plant will provide detailed water quality analysis and demonstrate long-term performance and techno-economic feasibility.

Acknowledgement

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